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Alkaline hydrothermal liquefaction of swine carcasses to bio-oil

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ABSTRACT

It is imperative that swine carcasses are disposed of safely, practically and economically. Alkaline hydrothermal liquefaction of swine carcasses to bio-oil was performed. Firstly, the effects of temperature, reaction time and pH value on the yield of each liquefaction product were determined. Secondly, liquefaction products, including bio-oil and solid residue, were characterized. Finally, the energy recovery ratio (ERR), which was defined as the energy of the resultant products compared to the energy input of the material, was investigated. Our experiment shows that reaction time had certain influence on the yield of liquefaction products, but temperature and pH value had bigger influence on the yield of liquefaction products. Yields of 62.2 wt% bio-oil, having a high heating value of 32.35 MJ/kg and a viscosity of 305cp, and 22 wt% solid residue were realized at a liquefaction temperature of 250 °C, a reaction time of 60 min and a pH value of 9.0. The bio-oil contained up to hundreds of different chemical components that may be classified according to functional groups. Typical compound classes in the bio-oil were hydrocarbons, organic acids, esters, ketones and heterocyclics. The energy recovery ratio (ERR) reached 93.63%. The bio-oil is expected to contribute to fossil fuel replacement in stationary applications, including boilers and furnaces, and upgrading processes for the bio-oil may be used to obtain liquid transport fuels.

1. Introduction

With the large increase of the swine industry in China, there are about 6.5×10^8 slaughtered fattened hogs every year in China. Routine mortality of pigs is an inevitable consequence, and a typical 5000 sow farrow-to-finish farming system (with mortality losses of 7%, 10%, 5%, 1%, and 1% in the sow, neonatal, nursery, growing, and finishing herd, respectively) will produce over 90 tonnes of dead pigs annually. In many farming systems in the China, actual losses may be much higher. Chinese farmers have difficulties in disposing of so many swine carcasses, which need to be disposed of safely, practically and economically (Liu and Hua, 2013).

Most swine mortality carcasses from company-owned or large contract farms can be delivered to a rendering plant, whereas smaller operations dispose of carcasses on the farm. On-farm disposal techniques include trench burial, disposal pit, burning, and composting. Landfill and rendering are the two main opportunities for off-farm carcass disposal (Morrow and Ferket, 2001).

The major disadvantage of burial is that the carcasses can contaminate groundwater supplies, particularly in areas with light soil and a high water table. Livestock burial has been banned in the EU due to fears that infectious agents may inadvertently enter both the human food and animal feed chains or lead to environmental pollution. Microorganisms anaerobically digest the carcass into substrates for bacteria that produce methane, carbon dioxide, and many other compounds in disposal pits. Unfortunately, anaerobic digestion can generate hydrogen sulphide in concentrations that can exceed human safety levels and some compounds which are malodorous. Although incineration eliminates all pathogens, but high operational costs and incineration's potential to contribute to air pollution (if not properly maintained and operated) decreases its usefulness for widespread use as a mortality carcass disposal option (Morrow and Ferket, 2001).

For routine use, or when supply exceeds disposal capacity, producers can sometimes take pig carcasses to a landfill. Landfills raise the same concerns of groundwater contamination and predators as on-farm burial. Rendering has been the best means for converting carcasses into a valued, biologically safe protein byproduct. Unfortunately, because world prices for fat, protein, and hides are depressed, fewer rendering facilities are in operation. Transporting carcasses can be prohibitively expensive if the rendering facility is too far away. Prices received for the carcasses also can vary considerably (Morrow and Ferket, 1993).

The above mentioned means either have the potential environment impacts or have biosecurity risks. It is therefore

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essential to find new disposal methods which may provide a more cost-effective, practical and biosecure mechanism for swine carcass disposal as well as having a lower environmental footprint (Gwyther et al., 2011).

Hydrothermal liquefaction of swine carcass to bio-oil may be a promising disposal method. Hydrothermal liquefaction is a medium-temperature, high-pressure thermochemical process and can produce a liquid product, often called bio-oil or bio-crude (Akhtar and Amin, 2011; Toor et al., 2011; Behrendt et al., 2008; Biller and Ross, 2011). At these conditions water is still kept in a liquid state, and has a range of exotic properties, such as low viscosity and high solubility of organic substances. Furthermore, water is an important reactant and catalyst, and thus the biomass can be directly converted without an energy consuming drying step, as in the case of pyrolysis (Bridgwater et al., 1999; Venderbosch and Prins, 2010). Because of the crude oil crisis the research activities in the field of hydrothermal liquefaction were performed. Within this scope all kinds of hydrothermal processes have been developed. This PERC process (Pittsburgh Energy Research Center, Pittsburgh, USA) worked with wood chips and prepared bio-oil. Wood chips were pumped through a tube reactor with a residence time of 10–30 min at temperatures of 330–370 °C and a pressure of 200 bar. The oil yield amounted to 45–55% of the employed dry matter of organic material (Behrendt et al., 2008). The DoS process was developed by the HAW (Hochschule für Angewandte Wissenschaften Hamburg, Germany). It is a direct one-step liquefaction process for lignocellulosic biomass (e.g. wood, straw) and worked under a pressure of about 80 bar and at temperatures between 350 and 500 °C. It is a bottom phase crack process based on a fast pyrolysis followed by the solvolysis into product oil and is claimed that the required hydrogen is also generated from the biomass (Behrendt et al., 2008). Heavy oils and plastic waste (PE, PP, PS) can also be converted by the CL500 process designed by Clyvia Technology GmbH (Wegberg-Wildenrath, Germany). After pre-heating and liquefaction of the raw material at 150–250 °C it was fed to a CSTR operating at 380–420 °C and ambient pressure. In the reactor the plastic waste was depolymerized and evaporated. Subsequently the reaction mixture was separated in a distillation column into a bituminous and a light oil fraction. A pilot plant (4000 t/y) has been running since mid 2006 in Wegberg-Wildenrath (Germany). (Behrendt et al., 2008; Bouvier et al., 1988).

Because of the strict process conditions, industrial application of hydrothermal liquefaction processes suffers from many challenges. Corrosion demands the use of expensive alloys, and the high operation pressures put hard requirements on process units such as feed pumps. The energy input for hydrothermal processes in the case of thermal and mechanical energy are considerable, and the high investment cost is a significant obstacle for commercialization. Therefore most work on hydrothermal liquefaction has so far been carried out in lab- or bench-scale.

But hydrothermal liquefaction is attractive from the viewpoint of energy consumption and process integration, making it a promising method for biomass conversion. In hydrothermal liquefaction, the energy recovery from biomass to fuel is often as high as 80%, which is excellent in comparison with other biomass conversion technologies. In comparison to pyrolysis hydrothermal liquefaction cannot compete in terms of yields, but it has other fundamental advantages such as a relatively stable oil product and an aqueous reaction environment, which does not require energy consuming drying of the biomass (Tian et al., 2014). The thermal and mechanical energy input for hydrothermal processes are considerable; however by applying energy recirculation such as preheating the substrate with the reactor effluent stream, the energy consumption can be reduced significantly (Toor et al., 2011).

Studies have shown that this technology can convert different types of biomass to bio-oil. The feedstock tested included wood chips, straw, animal manure, microalgae and municipal garbage (Biller and Ross, 2011; Cantrell et al., 2008; He et al., 2000; Wang et al., 2013; Xu and Lad, 2007; Yin et al., 2010, 2011). But so far hydrothermal liquefaction of swine carcasses to bio-oil has not been investigated yet. Hydrothermal liquefaction may be favoured by the farming community due to the perceived environmental, practical, economical and biosecurity benefits. The objective of the present work is to provide a new method for the disposal of swine carcasses and to evaluate of hydrothermal liquefaction characteristics of swine carcasses for production of bio-oil with lower oxygen content and higher nitrogen content.

2. Materials and methods

2.1. Materials

Swine carcasses were collected from Shaoyuan town in Henan Province, PR China. The race of the swine carcasses is Yunan black swine and contains 42 wt% lean meat content. The swine carcasses were cut using a knife. The size of the swine carcass material used in the experiments was less than 3 mesh. The proximate and element analysis results of the lean meat and the fat meat of the swine carcass material are listed in Table 1. The elemental composition (CHNS) was determined according to the ASTM D-5291 method using a Leco-CHNS932 elemental analyzer system. The oxygen content was calculated by difference. Trace phosphorus and other metal elements of the samples were ignored. The proximate analysis of the samples was measured using a Leco MAC-500 proximate analyzer. The fixed carbon content was calculated by difference. The higher heating value of the samples was determined by a E2K bomb calorimeter.

Deionized water was prepared in our laboratory for use in the experiments. All other chemicals (analytical pure) used in this study were obtained commercially and used as received. Alkaline aqueous solution was prepared by adding sodium hydroxide (NaOH), which is used widely in alkaline hydrothermal liquefaction studies (Liu and Zhang, 2009; Toor et al., 2011; Yin et al., 2011, 2010; Yin and Tan, 2012). During the preparation of the alkaline solution, the pH was monitored by a pH meter (PHS-3C) with an accuracy of 0.01.

2.2. Alkaline hydrothermal liquefaction

Alkaline hydrothermal liquefaction of the swine carcass material was performed in a 100 mL high pressure, jacket heated closed

Table 1
Proximate analysis and elemental analysis of the swine carcass materials.

	Fat meat	The standard deviation	Lean meat	The standard deviation
Proximate analysis				
Moisture	8.8 wt%	3.14E−03	70.3 wt%	3.44E−03
Volatile	65.9%	8.05E−04	67.6%	4.57E−03
Ash	0.002 wt%	4.56E−06	0.009 wt%	2.12E−06
Fixed carbon[a]	25.3 wt%	4.04E−03	3.9 wt%	3.68E−03
Higher heating value	39.3 MJ/kg	2.98E−01	8.80 MJ/kg	4.20E−01
Element analysis				
C	77.2 wt%	2.18E−03	17.4 wt%	2.44E−03
H	13.8 wt%	3.47E−03	10.2 wt%	6.16E−04
O[a]	8.6 wt%	2.28E−03	68.7 wt%	2.16E−03
N	0.4 wt%	4.43E−04	3.2 wt%	1.55E−04
S	0.05 wt%	2.14E−05	0.4 wt%	2.56E−05

[a] Determined by difference.

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