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Conversion of poultry wastes into energy feedstocks

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ABSTRACT

In this study, conversion of wastes from poultry farming and industry into biochar and bio-oil via thermochemical processes was investigated. Fuel characteristics and chemical structure of biochars and bio-oils have been investigated using standard fuel analysis and spectroscopic methods. Biochars were produced from poultry litter through both hydrothermal carbonization (sub-critical water, 175–250 °C) and pyrolysis over a temperature range between 250 and 500 °C. In comparison to hydrothermal carbonization, pyrolysis at lower temperatures produced biochar with greater energy yield due to the higher mass yield. Biochars obtained by both processes were comparable to coal. Hydrothermal liquefaction of poultry meal at different temperatures (200–325 °C) was conducted and compared to optimize its process conditions. Higher temperatures favored the formation of bio-crude oil, with a maximum yield of 35 wt.% at 300 °C. The higher heating values of bio-oils showed that bio-oil could be a potential source of synthetic fuels. However, elemental analysis demonstrated the high nitrogen content of bio-oils. Therefore, bio-oils obtained from hydrothermal liquefaction of poultry meal should be upgraded for utilization as a transport and heating fuel.

1. Introduction

According to the Food and Agriculture Organization of the United Nations (FAO), poultry now account for over 80% of all livestock (FAO, 2015a). The poultry industry produced approximately 23 billion poultry in 2013 all over the world (FAO, 2015b). Today, poultry are mostly raised in large farms. Due to the intensive poultry farming, poultry litter raise serious concerns about treatment and disposal. It is traditionally used as fertilizer, but potential environmental problems such as spread of pathogens (Gerba and Smith, 2005) and emission of greenhouse gases and odorous compounds are reported due to its overuse as fertilizer (Font-Palma, 2012). The other waste produced in a huge amount by the poultry industry is poultry meal. It consists of ground, rendered, clean parts of poultry carcasses and can contain bones, offal, undeveloped eggs, and in a few cases, feathers, that are unavoidable parts in the poultry meat processing (El-Boushi and van der Poel, 2000). It was used in formulated animal feed, but today it can be only used in formulated pet feed according to EU Regulation 1774/2002 (European Community, 2002). Therefore, the poultry industry is facing difficulties in the proper treatment of surplus poultry litter and meal and seeking an alternative technology for the utilization of these wastes.

Existing technologies such as combustion, anaerobic digestion, gasification, pyrolysis and hydrothermal conversion may be an alternative way for proper management of the wastes from poultry industry. Direct combustion would not be suitable due to the high water and nitrogen contents of these wastes. Also, anaerobic digestion may not be a good alternative due to the high nitrogen content of poultry wastes which would inhibit microbial activities (Yanagida et al., 2007). The use of these wastes as feedstock in energy production may be of great interest both economically and environmentally. Hydrothermal conversion has received increasing attention due to the possibility of processing wet biomass feedstock by eliminating the energy-intensive step of drying biomass (Libra et al., 2011). It involves the application of heat to biomass in a closed aqueous medium under autogenic pressure. Depending on the temperature range, either solid, liquid or gaseous products are formed predominately by hydrothermal conversion (Kruse et al., 2009). If hydrothermal conversion is applied in the temperature range between 160 and 250 °C, mainly a carbon-rich solid product, named biochar, is formed (Kruse et al., 2013). The process is referred to as hydrothermal carbonization (HTC) and was verified as an effective way to densify the energy content of biomass with high water content (Zhao et al., 2014). Biochar

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produced during HTC is characterized with enhanced fuel properties such as increased carbon content, higher homogeneity, better grindability, and hydrophobic behavior (Sermyagina et al., 2015). If hydrothermal conversion is applied in the temperature range of 225–350 °C, a high-viscous oil, named bio-oil, is formed. In this case, the process is referred to as hydrothermal liquefaction (HTL) (Elliott et al., 2015; Kruse et al., 2013). Bio-oil can be converted into liquid petroleum fuels, such as diesel and gasoline by upgrading (Tekin et al., 2014). On the other hand, gasification reactions are dominant under near- and supercritical-water conditions. Hydrothermal gasification is mostly preferred for methane and hydrogen production (Savage et al., 2010).

In the literature, the application of hydrothermal processes to different types of biomass such as woody biomass (Nanda et al., 2016a; Lynam et al., 2015; Chan et al., 2014; Hoekman et al., 2011; Liu et al., 2013; Qu et al., 2003; Sevilla et al., 2011; Xiao et al., 2012; Wiedner et al., 2013), agricultural wastes (Lynam et al., 2015; Sevilla et al., 2011; Xiao et al., 2012; Román et al., 2012; Pala et al., 2014), food wastes (Nanda et al., 2016b; Li et al., 2013; Lu et al., 2012), algal biomass (Elsayed et al., 2016; Eboibi et al., 2014; Jena et al., 2011; Heilmann et al., 2010), aquatic plant (Poerschmann et al., 2015), sewage sludge (He et al., 2013; Parshetti et al., 2013; Chen et al., 2013; Zhang et al., 2010), paper waste sludge (Louw et al., 2016) and manure of different livestock (Cao et al., 2011; Xiu et al., 2010; Yin et al., 2010) has been discussed by many authors. However, there are few studies on hydrothermal conversion of poultry wastes in the literature. These studies include the hydrothermal gasification and carbonization. For instance, Nakamura et al. (2008) and Yanagida et al. (2007) studied the hydrothermal gasification of poultry litter in the presence of activated carbon catalyst and obtained gas products consisting mainly of H_2, CO_2 and CH_4, besides NH_3. Similarly, in the hydrothermal gasification of poultry litter in the presence of wood, the organic matter in the poultry litter was converted into gases mainly H_2, CO_2, and CH_4 (Yong and Matsumura, 2012). In another study, Oliveira et al. (2013) carried out the HTC of poultry litter at 180 °C for 4 h. The resultant biochar had a calorific value of 24 MJ/kg which was similar to that of bitumen-rich brown coal. In contrast to hydrothermal processes, a number of studies relating to pyrolysis of poultry litter exist in the literature (Chan et al., 2008; Song and Guo, 2012; Azargohar et al., 2014; Novak et al., 2014; Van Zwieten et al., 2013; Ameloot et al., 2015; Rombolá et al., 2015). These studies focused on the physical and chemical characteristics of the biochars obtained from poultry litter for use as soil amendment.

In this study, conversion of poultry wastes, poultry meal and poultry litter, into biochar and/or bio-oil was investigated in order to find a feasible approach for their disposal and to obtain suitable energy feedstocks. In this context, hydrothermal carbonization of and comparatively pyrolysis of poultry litter were performed to produce biochar. Hydrothermal liquefaction of poultry meal was performed to produce bio-oil. Fuel characteristics and chemical structure of biochars and bio-oils were investigated using standard fuel analysis and spectroscopic methods. To the best of our knowledge, no study on hydrothermal conversion of poultry meal exists in the literature.

2. Methods

2.1. Materials

Poultry wastes were kindly provided by CP Group, Izmir, Turkey. Poultry meal (<1 mm) was used as received, whereas poultry litter was previously dried at room temperature and ground to <1.5 mm, then dried in a drying oven at 105 °C overnight. The characteristics of feedstocks are given in Table 1.

Table 1
Characteristics of poultry wastes.

	Poultry meal	Poultry litter
Proximate analysis, (wt.%)		
Moisture	6.6	8.2
Volatile matter	78.4	60.2
Ash	12.9	15.4
Ultimate analysis,(dry basis, wt.%)		
C	52.1	40.0
H	7.4	5.4
N	11.6	5.6
S	0.5	0.1
O*	15.5	33.5
Protein	65.0	33.1
Oil	16	N.D.
HHV (MJ/kg)	24.7	16.0

N.D.: not determined.
* Calculated by difference.

2.2. Hydrothermal conversion experiments

Hydrothermal conversion experiments were carried out in a 100 mL stainless steel shaking autoclave under autogenic pressure. For a typical run, a mixture of poultry meal or poultry litter and deionized water (waste/water ratio of 20:80) was loaded into the autoclave. The autoclave was sealed and purged with nitrogen. It was heated to the desired temperature at a rate of 5 °C min^{-1} and was held at this temperature for the required duration. In the case of HTC experiments, different reaction times (0–60 min) and temperatures (175–250 °C) were tested. HTL experiments were conducted at different temperatures (200–325 °C) for a reaction time of 30 min. At the end of the hydrothermal process, the reactor was rapidly cooled down to room temperature. In HTC, after gaseous products were vented into the atmosphere, the solid residue (biochar) was separated from reactor content by filtration and washed with 100 ml distilled water and then dried at 105 °C for 24 h and weighed. The filtrates (aqueous phase) were bottled for further analysis. In HTL, gaseous products were collected in a volumetric flask for measuring their volume and GC analysis. The reactor content was washed with dichloromethane and filtered to separate the solid residue (char). The filtrate was separated into dichloromethane phase and aqueous phase by a separatory funnel. After evaporation of dichloromethane at 30 °C using a rotary vacuum evaporator, the residue was weighed as bio-oil. Char was weighed after being dried at 105 °C for 24 h. The gas yield was calculated depending on its volume and GC analysis. The water soluble product yield was calculated by following equation:

$$\text{water soluble product yield (wt.\%)} = \text{100-char yield (wt.\%)-bio-oil yield (wt.\%)-gas yield (wt.\%)}.$$

2.3. Pyrolysis experiments

The pyrolysis experiments were carried out in a vertical fixed bed design reactor. In a typical run, 50 g of poultry litter was placed into the reactor. The system was heated to the desired temperature (250–500 °C) at a heating rate of 5 °C min^{-1}, and held at this temperature for 1 h. The volatile products were swept by nitrogen gas with a flow rate of 25 mL min^{-1} from reactor to collection flasks cooled with ice where the liquid products were condensed in the traps. The non-condensable volatiles (gases) were vented to the atmosphere. The solid residue (biochar) was weighed in order to calculate the biochar yield.