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Pyrolysis treatment of poultry processing industry waste for energy potential recovery as quality derived fuels

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HIGHLIGHTS

- External heat atmospheric pressure pyrolysis is applied to chicken feathers.
- The influence of process temperature on mass variation rate is investigated.
- Parameters influence on product formation, distribution and properties is analyzed.
- Process cold gas efficiency is calculated.
- Conditions for maximum net energy content as pyrolysis products are identified.

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ABSTRACT

The paper presents the thermal–chemical treatment of residues from poultry slaughterhouses using the pyrolysis process for derived fuel production with high energy density properties, as alternative solution for waste to energy conversion. The residue consists of chicken feathers with traces of blood and offal, sampled directly from the industrial processing line. A specially designed tubular batch reactor was used for the externally heated atmospheric pressure pyrolysis. Experimental campaign reliability was ensured by using raw waste products and industrial operating parameters with temperatures in the range of 350–800 °C.

The experiments were developed with respect to sample mass reduction rate, thermal degradation process kinetics, reaction products distribution, physical–chemical properties and specific energy content. The influence of process parameters on char, tar and gas formation was quantified along with the mechanisms involved. The experiments revealed that minimum treatment periods for complete volatile fraction release vary between 35 min and 3 min depending on process temperature. The char mass fraction represents 40% to 10% of the pyrolysis products. The minimum tar fraction is generated at 350 °C and increases continuously to the maximum reached at 600 °C. The pyrolysis gas yield is quasi-constant between 350 °C and 450 °C and decreases with temperature rising. The energy content of pyrolysis products was determined based on their low heating value and mass fractions. The study aimed at minimum energy consumption and quality derived fuels production using the pyrolysis process as pretreatment stage applied to a potential renewable fuel with high specific energy density (HHV-26 MJ/kg) but low combustible properties due to high water content (up to 70%).

1. Introduction

The poultry processing industry is the largest and fastest growing sector in the food industry chain, producing important amounts of poultry meat and noticeable quantities of organic residues such as feather, bone meal, blood and offal, rising problems related to their disposal [1,2]. The feathers represent 5%–7% of the body weight of a mature chicken, being the main waste product of the poultry industry due to high specific volume and hygroscopic properties that combined with hot water from the meat processing line, increase its mass up to three times [3]. Consequently, the feathers based waste represents 30% of the total waste produced by an industrial processing line, 4 million tons being produced every year world-wide [4]. The difference is represented by bones, blood, offal, skin, claws etc. Currently the feathers from poultry slaughterhouses are disposed of by incineration or in landfills [5,6]. Due to the negative environmental impact and high removal/neutralization costs of such residue, the special interest in the development of alternative disposal methods occurs [7].

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In the past an effective economic solution was represented by hydrolyzed derived products like Feather Meal (FM) and Meat and Bone Meal (MBM) used as feed supplement for animals, but concerns about Bovine Spongiform Encephalopathy (BSE), commonly known as mad cow disease, has resulted in banning this application [8,9].

Studies have revealed certain methods of poultry industry waste disposal, including composting (aerobic digestion) [10], anaerobic digestion [11], and direct combustion [12,13]. However, the major disadvantages of compositing are loss of nitrogen and other nutrients, equipment and labor cost, unpleasant odor, and land availability [14]. In general Poultry slaughterhouse wastes are regarded as difficult substrates for any biologic treatment method because of their high protein and lipid content resulting in the production of some by-products which are toxic and inhibitory to the microorganisms involved in biologic treatments [15]. Chicken feathers contain approximately 91% protein (keratin), small amounts of lipids (1%) and water (8%) [16]. Such impediments restrict the biologic treatment of feathers and other solid poultry slaughterhouse wastes.

Currently there is one industrial application for waste to energy recovery using thermal treatment applied to this type of product [17]. Due to its high water content (up to 70% in weight) any thermal processing requires important amounts of support fuel and the interest for this waste valorization for power generation is low. The existing application operates in a slaughterhouse in Olsztyn, Poland and produces only thermal energy delivered as industrial steam used for the poultry processing line. Our study focused on complete pyrolysis treatment characterization for further combined pyro-gasification processing to produce high quality syngas as advanced modalities of waste to power generation. The major problem raised by a gasification conversion solution is represented by the product high water content and physical structure with respect to: process run, product feed-in and advancement in installation, as well as the gasification agent and product mixing. The first stage treatment by pyrolysis process can solve all these problems and deliver high quality products that can be used in other thermal-chemical process as homogenous carbon and hydrocarbon based fuels.

The pyrolysis pre-treatment could be a promising waste management solution when combined either with classical combustion or gasification. The interest for energy generation from renewable sources and the more stringent environmental legislation could recommend processes like pyro-combustion and pyro-gasification as economically viable options for waste with high energy potential but low combustible properties induced by high water content or heterogeneous structure. The paper presents the results of the pyrolysis process applied to poultry feathers with respect to sample mass reduction rate, thermal degradation process kinetics, products distribution, characterization and specific energy content. The study is based on the assumption that pyrolysis represents a stage within the waste to energy conversion chain. Consequently the overall approach of the study aimed for minimum energy consumption and quality derived fuels production.

2. Experimental setup

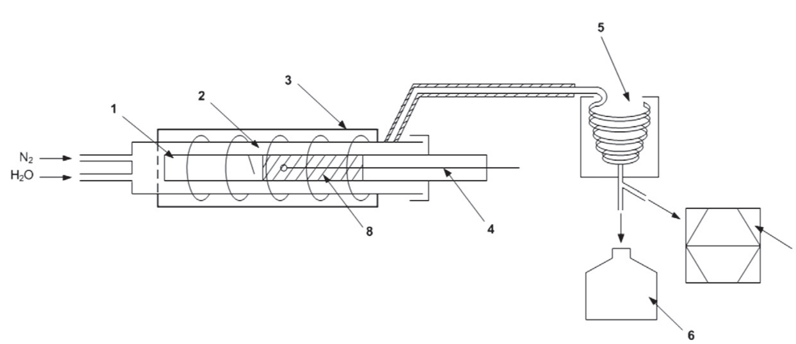
2.1. Installation

The laboratory scale batch reactor used for the pyrolysis experimental campaign was specially designed using an electric tubular reactor platform (model Nabetherm 60/750/13). The reactor was modified according to the experiment set-up to meet the requirements for the atmospheric pressure pyrolysis process with an external heat source and is equipped with a phase separation unit for reaction products (Fig. 1). The reactor consisted of a refractory stainless steel tube, electrically heated, with an inner diameter of 60 mm. The active heating zone was 750 mm long (an isothermal temperature profile was ensured in this zone). The installation was equipped with a control unit for the adjustment of process temperature (between 20 °C and 1300 °C) and heating rate.

To ensure an inert atmosphere in the reactor during the pyrolysis process, nitrogen was blasted and the flow was controlled by a flow meter. The gas was injected into the active zone through one inlet situated on the left of the reactor. This configuration enabled the complete control of the treatment atmosphere. The process gases were evacuated to the phase separation unit where the heavy hydrocarbons were condensed. After separation, the non-condensable fraction (pyrolysis gas) was analyzed using a GC–MS system (model Shimadzu QP2010 Plus). The analyzed gaseous compounds were CO_2, CO, CH_4, H_2, C_2H_4, C_2H_6, C_2H_2 and H_2S. Pyrolysis char and tar were submitted to physical–chemical analysis.

The sample to be subjected to the pyrolysis process was introduced into the reactor in a tubular parallelepiped crucible of refractory steel equipped with a thermocouple. The thermocouple enabled the direct observation of the temperature rise inside the sample, providing information on the sample heating rate.

To assess the influence of the treatment temperature and residence time on the sample mass variation under pyrolysis conditions, another series of experiments were conducted using a calcination oven (model Nabertherm L9/11/SW) with integrated precision balance, presented in the authors' previous works [18]. The results enabled setting the pyrolysis temperature range with respect to the volatile release sequence and the minimum required treatment period for complete volatile release.



1. Refractory steel crucible; 2. Refractory steel reactor; 3.Heated case; 4.Thermocouple; 5.Gas-liquid fraction separation unit; 6. Tar collector; 7. GC-MS analysis; 8. Sample

Fig. 1. Tubular batch reactor configuration.