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Energy from poultry waste: An Aspen Plus-based approach to the thermo-chemical processes

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ABSTRACT

A particular approach to the task of energy conversion of a residual waste material was properly experienced during the implementation of the national funded Enerpoll project. This project is a case study developed in the estate of a poultry farm that is located in a rural area of central Italy (Umbria Region); such a farm was chosen for the research project since it is almost representative of many similar small-sized breeding realties of the Italian regional context. The purpose of the case study was the disposal of a waste material (i.e. poultry manure) and its energy recovery; this task is in agreement with the main objectives of the new Energy Union policy. Considering this background, an innovative gasification plant (300 KW thermal power) was chosen and installed for the experimentation.

The novelty of the investigated technology is the possibility to achieve the production of thermal energy burning just the produced syngas and not directly the solid residues. This aspect allows to reduce the quantity of nitrogen released in the atmosphere by the exhaust flue gases and conveying it into the solid residues (ashes). A critical aspect of the research program was the optimization of the pretreatment (reduction of the water content) and the dimensional homogenization of the poultry waste before its energy recovery. This physical pretreatment allowed the reduction of the complexity of the matrix to be energy enhanced.

Further to the real scale plant monitoring, a complete Aspen Plus v.8.0 model was also elaborated for the prediction of the quality of the produced synthesis gas as a function of both the gasification temperature and the equivalence ratio (ER).

The model is an ideal flowchart using as input material just the homogenized and dried material.

On the basis of the real monitored thermal power (equal to about 200 kW average value in an hour) the model was used for the estimation of the syngas energy content (i.e. LHV) that resulted in the range of 3–5 MJ/m^3 for an equivalence ratio (ER) equal to 0.2.

1. Introduction

Animal wastes (e.g. poultry manure and litter) represent a very complex matrix to be treated for energy purposes because of their highly heterogeneous components, produced by different operative conditions of the farm breeding. However, some efforts in this sense have already available in the Literature applying thermo-chemical processes (Di Gregorio et al., 2014; Joseph et al., 2012; Taupe et al., 2016; Pandey et al., 2016; Priyadarsan et al., 2004). In many more cases, the mixture resulting as waste from the farms operative cycles of poultry batteries is characterized by having an high nutritive potential for land cultivation and then a common use of such residual matrices is their spreading in the fields of rural areas for soil restoration (Delgado et al., 2012; Gaind and Nain, 2010). However, the 91/676/CEE Directive indicates the maxima nitrogen contents releasable into the soil and implicitly suggested alternative uses (i.e. energy enhancement). It is known that the major contribution to the non-fossil energy recovery is generally mainly achieved by renewable energies e.g. wind, solar, hydrogen and biomass (Cotana et al., 2011; Kullander, 2009; Rossi and Nicolini, 2009, 2011; Sesto, 1996) and not by animal residues.

Moreover, the gasification of poultry waste is today mainly related to small-scale and laboratory applications (Font-Palma, 2012); however a small farm based gasification plant is operative in Netherlands (Buffinga and Knoef, 2005).

A relevant part of the Literature reports experimental experiences of thermo-chemical employment of chicken manure i.e. gasi-

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fication and pyrolysis (Cantrell et al., 2012; Florin et al., 2009; Mante and Agblevor, 2010); under specific conditions, the gasification process can be able to enhance the production of a hydrogen pure flue gas useful for energy (Midilli et al., 2002); also evidence of direct combustion are available worldwide (Abelha et al., 2003).

In order to consider animal waste (e.g. poultry litter) as an alternative energy source, both the energy and physicochemical characterization of manure assume a relevant role; typical values for the Higher Heating Values (HHVs) on a dry basis (experimental) varies between about 12,000 and 14,000 kJ/kg while Lower Heating Values (LHVs) on a wet basis range are much lower (mean values of about 2600 kJ/kg) due to the high moisture content of poultry manure (Quiroga et al., 2010).

More in general, the use of such a waste product has been historically limited to the surroundings of farms because of its low density, producing expensive costs for transportation; in this context, some users considered the compaction as an opportunity allowing to reduce volumes (Bernhart et al., 2010).

Further to gasification, different technologies have been already experienced to energy enhance such a farm by-product, ensuring a proper disposal procedure and the energy recovery (Kelleher et al., 2002); some anaerobic digestion experiments demonstrated the possibility to improve in lab the digestion yields of poultry manure by using self mixed anaerobic digester (SMAD) and by enhancing hydrolysis and methane production from poultry litter by means of thermo-chemical pre- and biological co-treatments (Costa et al., 2012; Gangagni et al., 2011). Biogas plant using both waste and animal manure as input matter are in fact diffused in European rural lands (Iglinski et al., 2012). Also the aerobic treatment prior to spreading in the fields can be considered as a disposal solution since composting of poultry litter converts the soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields (Tiquia and Tam, 2002); in addiction, the aerobic phase allows the reduction of the litter moisture content (Petric et al., 2009).

The case study of this work is a poultry farm located in the rural context of central Italy. The farm is structured in n. 7 grounded sheds hosting about 80,000 chickens; even though an upcoming company growth is expected. Currently, the emptying and disinfection cycles are carried out each 9 month and the total poultry litter produced is up to 1200 tons/year.

Such animal byproduct is currently stored into closed big bags in order to accomplish regional regulation constraints and avoid odor emissions. Particular temperature and humidity conditions are required into the breeding ensuring safety and comfort to the animals; such optimal indoor conditions are relative humidity equal to 60% and indoor air temperature between 20 and 27 °C.

Winter climate conditioning is carried out by electric water heaters placed in each shed. Summer conditioning is controlled by water mist sprayed into the indoor environment, together with mechanical ventilation. The project began with recognition of both the energy requirements of the farm and of the availability of poultry manure, then the more appropriate technology for the waste-to-energy conversion was chosen. A market analysis was carried out about the conventional available technologies allowing the direct combustion, the anaerobic digestion, and the gasification processes. As a result of such a preliminary evaluations, a 300 kW thermal power plant was chosen, over-sizing it with respect to the farm requirements, expecting to expand its properties in the near feature.

The experimental results obtained from both the Lab characterization and start-up phase of the pilot plant will be presented and discussed in the following sections, also including some results obtained from an Aspen Plus v. 8.0-based simplified model.

2. Materials and methods

2.1. The case study

The experimental plant is composed of the following sections: a loading system for the input of poultry manure supply; a tank where biomass can be homogenized; a gasifier; a 300 kW powered thermal boiler; a final section for the heat recovery and exchange through a 300 kW plate heat-exchanger (Cotana et al., 2012). The thermal efficiency are the followings: gasifier 46% (evaluated by experimental tests), thermal boiler 88% (reported in the machine datasheet), heat exchanger 89% (reported in the device datasheet). An additional efficiency of the pipeline has to be considered when the district heating will be built.

The calculation of the maximum thermal energy achievable from the farm has been quantified considering the current operative conditions production rate of waste of the breeding; but as already mentioned, a relevant company expansion up to 1/3 (i.e. 40,000 new animals) has been planned for the nearest future.

The yearly produced poultry manure is about 1200 t with a moisture content varying between 12% and 60%. The expected yearly thermal energy production is of about 700 MWht.

2.2. The plant monitoring system

The start-up phase of the plant was carried out by taking starting power of the gasifier with dry material and therefore with a high LHV. This choice was dictated by the need to speed up and facilitate the thermal processes and minimize set-up time regime. A monitoring system provided with a data collector has been implemented. According to the following picture (Fig. 1) it was composed of six thermocouples and a flow meter, installed in different components of the experimental plant. The first sensor was installed outdoor to monitoring the external temperature. The second sensor was set at the core of the gasifier. Two sensors were installed at the primary water circuit connecting the boiler to an external metal plate heat-exchanger; two other sensors were placed at the secondary circuit used as heat sink, connecting a water tank and a swimming pool. During the testing phase, the heat from the primary circuit was transferred to the secondary circuit: the large availability of water allows the dissipation of the produced heat.

2.3. Characterization of poultry manure

CRB Lab is equipped with various instruments for both the chemical and physical characterization of biomass (Buratti et al., 2005; Cotana et al., 2006). For the characterization of the poultry manure the following instrumentations have been used: (i) TruSpec CHN LECO analyzer to perform the ultimate analysis of the samples, or for the determination of the content of elements such as carbon (C with measurement uncertainty of ±0.5%), Hydrogen (H with measurement uncertainty of ±1%) and Nitrogen (N with measurement uncertainty of ±0.5%); (ii) TGA 701 thermo-gravimetric analyzer LECO for the proximate analysis, for the measurement of total solids (TS), volatile solids (SV), moisture and ash content (with measurement uncertainty of ±0.02%); (iii) LECO AC350 calorimeter for the measurement of the higher heating value (with measurement uncertainty of ±0.05%).

The Ultimate analysis has been carried out in compliance with the procedures indicated in ASTM D-5373. For the proximate analysis the Italian legislation was followed: indeed, for the determination of moisture and ash content in the sample, the reference procedure is the regulations CEN TS 14744 and 14745, and for