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ScienceDirect

Energy Procedia 45 (2014) 315 – 322

Energy Procedia

68th Conference of the Italian Thermal Machines Engineering Association, ATI2013

Energy valorization of poultry manure in a thermal power plant: experimental campaign

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Abstract

According with EU Directives, waste management is a major task with respect to the industrial productive cycles. Getting energy from residues can be possible by means of several technologies, to be chosen as a function of the waste main properties. The present paper will present an example of energetic valorization of poultry manure in an innovative gasification thermal power plant (300 kWt). Such experience has been developed by CRB (Biomass Research Center – University of Perugia) during the implementation of a national funded research project. Physical and chemical characterization of the litter will be shown, together with both the monitoring of the demo plant performances and the relevant features of the exhaust gases at the chimney.

Selection and peer-review under responsibility of ATI NAZIONALE

Keywords: poultry manure, gasification, biomass characterization

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Nomenclature

CRB	Biomass Research Centre
PA	Proximate analysis
UA	Ultimate analysis
U	Relative humidity
Pt	Thermal power
T_{MAN}	Temperature of the water flow out from the boiler
T_{RIT}	Temperature of the water flow in to the boiler
Q_{H2O}	Water flow circulating for thermal exchange

Selection and peer-review under responsibility of ATI NAZIONALE
doi:10.1016/j.egypro.2014.01.034

ΔT	Thermal gradient
Tf	Flue gas temperature measured in a orthogonal section to the flow of the exhaust gases
Ta	External air temperature
Ea	Air excess

1. Introduction

Residues from poultry farms include a mixture of manure, litter materials (e.g. wood sawdust or rice straw), dead chickens and more. Since the mixed litter and manure has an high nutritive potential for land cultivation, the most common use of such residues is the spreading of fields of rural area in order to achieve soil restoration [1, 2]. The 91/676/CEE Directive fixed the maxima nitrogen contents releasable into the soil and after these constraints [3] , alternative uses (preferably energetic valorization) had to be applied. The use of this waste product has been historically limited to the surroundings of the place of generation because of its inherent low density. Compaction is one possible way to enhance the storage and transportation of the litter [4].

Several technological options can be used in order both to recover energy and to ensure the correct disposal of such farm by-product [5]; anaerobic digestion is a diffuse possible solution: indeed, some literary works demonstrated the possibility to improve in lab the digestion yields 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 [6, 7]. Biogas plant using both waste and animal manure as input matter are diffused in European rural lands [8]. Another chance for the disposal of poultry manure is the aerobic treatment prior to spreading in the fields; it has been shown that composting of poultry litter converted the soluble nutrients to more stable organic forms, thereby reducing their bioavailability and susceptibility to loss when applied to crop fields [9,10]; in addiction, the aerobic phase allows the reduction of the litter moisture content [11].

A relevant part of the literature reports experimental experiences of thermo-chemical employment of chicken manure i. e. gasification and pyrolysis [12, 13, 14]; under specific conditions, the gasification process can be able to enhance the production of a hydrogen pure flue gas useful for energy [15]; also evidence of direct combustion are available worldwide [16]. From the analysis of the state of the art it appears that the gasification of poultry waste is today mainly related to small-scale and laboratory applications [14]; however a small farm based gasification plant is operative in Netherlands [17]. In order to consider animal waste (e.g. poultry litter) as an alternative energy source, both the energetic 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 2,600 kJ/kg) due to the high moisture content of poultry manure [18].

The purpose of the work is the description of both the installation and monitoring start up phases of a small sized experimental gasification plant, arranged into the property of a central Italy chicken farm; coherently, at first the characterization stage of the matrix, storage method and energy requirements for the breedings are briefly described.

2. Experimentation

2.1 Site survey – energy requirements

The case study is a poultry farm located in the rural context of central Italy. The farm is structured in n. 7 grounded sheds, inside which the animals (about 80.000 chickens) are stowed; it is expected an upcoming company growth. Currently, the emptying and disinfection cycles are carried out each 9 month and the total poultry litter produced is up to 1.200 tonnes/year.

Such litter is stored into closed big bags in order to accomplish regional regulation constraints. Particular temperature and humidity conditions are required into the breedings in order to ensure 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 conditions is carried out by 4the use of heaters powered by electric water heaters placed in each shed. Summer conditioning is controlled by water mist sprayed into the indoor environment, together with the action of mechanical ventilators. The thermal and electrical energy requirements for the 7 breedings both for winter and summer period are showed in Table 1.

Table 1. Thermal and electrical energy requirements for the 7 breedings both for winter and summer period[1]

Energy use[1]	Electrical requirement (kWhe/y)	Thermal requirement (kWht/y)
Lighting	9.000	-
cleaning eggs	-	50.000
Summer air conditioning (including humidity control)	32.000	-
Winter heating	16.000	64.000
TOT.	57.000	114.000

[1] the energy requirements computation is referred to the heating, cooling lighting and cleaning system currently used by the farmer

2.2 Poultry manure characterization

CRB lab is equipped with various instruments for both the chemical and physical characterization of biomass [19] [20]. For the characterization of the poultry manure the following instrumentations have been used:

- 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%);
- 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%);
- LECO AC350 calorimeter for the measurement of the higher heating value (with measurement uncertainty of ± 0.05%).

Ultimate analysis is carried out in compliance with the directive procedural indicated in ASTM D-5373. For the proximate analysis we follow the Italian legislation: indeed, for the determination of moisture and ash content in the sample, the reference procedure is the regulations CEN TS 14744 and 14745, for the determination of solid volatiles we refer to Italian normative UNI 9903 - 3.

The higher heating value is measured in compliance with UNI 9017 and, by analytical formula, the lower calorific value is calculated. The first sampling procedure concerned two manure specimens (named in the following manure 1 and manure 2 collected in two different sheds. The collected materials appeared inconsistent, consisting in compact blocks and apparently heterogeneous; it is composed of manure and sawdust shavings used as litter. Using sampler a quantity of manure enough for the laboratory analysis was collected. The results of the proximate and ultimate analysis (PA, UA) are reported in Table 2.

Table 2: Proximate and ultimate analysis of two manure samples

Sample description	Proximate analysis (PA)			Ultimate analysis (UA)		
	Moisture (%)	Volatile matter (%)	Ash yield (%)	C (%)	H (%)	N (%)
Manure 1	62,50	26,56	10,60	14,81	8,16	2,39
Manure 2	12,83	64,43	15,41	36,02	5,73	1,85

It is observed that the chemical-physical characteristics of the two manures, coming from two different sheds are very different, especially with respect to the volatile matter and moisture content. One possible explanation is due to different poultry farming conditions carried out: indeed, both are farms with livestock buildings at the ground, with wood shavings used as litter and animals free to move inside to the sheds, but while manure 1 is collected from poultry meat breeding, manure 2 belongs to breeding used for the production of biological eggs.

The living conditions in the second shed should either ensure maximum comfort for the animal: it is equipped with an air conditioning system that allows control of temperature and humidity. Therefore, the air flow from the unit heaters and its forced extraction partially dry the manure, reducing the moisture content.

The thermo-hygrometric conditions inside the barn are kept as constant as possible during the whole period of the year while varying the external environmental conditions.

Afterwards, the calorimetric analysis for the energetic characterization of the manures was performed and the Higher Heating Values were measured. Results are shown in Table 3.

Table 3: Energetic properties (LHV, HHV) of manure 1 and manure 2

Sample description	LHV (J/g)	HHV (J/g)
Manure 1	12.828	14.587
Manure 2	10.351	11.552

2.3 Set up of the plant - mass energy flows

Gasification technology has been so long experienced to get energy from several kind of biomass such as wood [21, 22, 23] and solid waste [24, 25, 26]; the use of animal sludge is instead not so developed and it is considered as innovative [27]. The presented case study provides the application of a 300 kWt thermal power plant with gasification section. With respect to the energy consumption the company (see par. 1.1), the rated power of the plant was deliberately oversized, according to the future further development of the company.

The experimental plant is composed of the following sections: the loading system for the input of poultry manure supply, the gasifier, the burner heat output of 300 kW, and finally the output section of the flue gas, with cyclone dust collector [28]. The calculation of the maximum thermal energy achievable from the farm are referred to the ordinary production rate of waste of the breedings; as already mentioned a relevant company expansion up to 1/3 (i.e. 40.000 new animals) is programmed for the next year.

The poultry manure yearly produced is about 1.200 t with moisture content varying between 12% and 60%. However, as a precautionary measure, we use the upper value for the energetic calculation. The expected production of ashes is around 25 – 30 % of the introduced matrix. The expected yearly energy production is of about 700 MWht. Fig. 1 shows a schematic representation of the process.

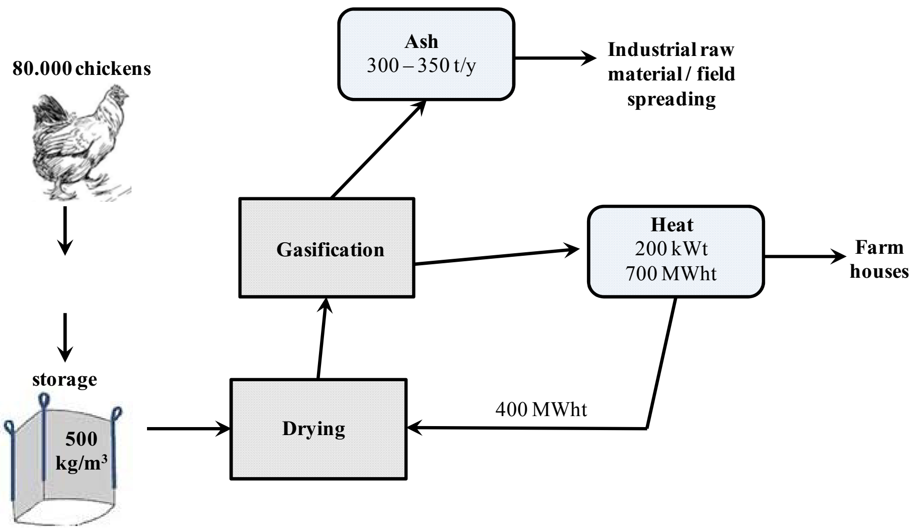

Fig. 1: Process for the small-scale farm based gasification system: maximum energy production achievable from the available poultry manure (1.200 t/y).

2.4 Monitoring of the start up phase

The start-up phase of the plant was carried out by taking starting power of the gasifier with dry material (mixture of sawdust bedding and manure with a moisture content of about 15%) and therefore with a high HHV.

This choice was dictated by the need to speed up and facilitate the thermal processes and minimize set-up times regime. The initial temperature inside the gasifier was measured and is equal to the outside air temperature (about 25 ° C). The monitoring phase starts when a heat exchange between the fluid (water) inside the boiler and the secondary circuit used for the heat dissipation is observed. During the testing phase, the final heat exchange fluid is circulating in a closed circuit which includes a swimming pool and a tank connected to it. The large availability of water allows the dissipation of the heat produced. The monitored parameters are: thermal power produced, temperature of water leaving the boiler, the return temperature of water from the secondary circuit to the boiler, the fluid flow rate of heat exchange water, delta heat exchange (temperature difference between the termo-carrier fluids of the primary and secondary circuit).

From the experimentation conducted in powering up the plant is observed the passing of temperature inside the gasifier from 25 ° C up to about 800 ° C in a time interval equal to about 7 hours.

The thermal power produced by the boiler was detected oscillating in a range between about 150 kWt and 380 kWt. The temperature of the heat transfer fluid exiting the boiler was observed variable between 70 and 82 °C, while the temperature of the heat transfer fluid returning to the boiler is maintained between the values of 51 and 69 ° C. The flow rate of the circulating fluid used for heat exchange is equal to about 16 m^3/h.

Fig. 2 reports the data resulting from the monitoring of the plant start-up phase. At regular time intervals we proceeded to the acquisition of the temperature values of the flow of gas exhausted from the exhaust, the ambient temperature and the percentage of oxygen O_2 and carbon dioxide CO_2 present (measurement uncertainty of ± 0.5%), and excess air.

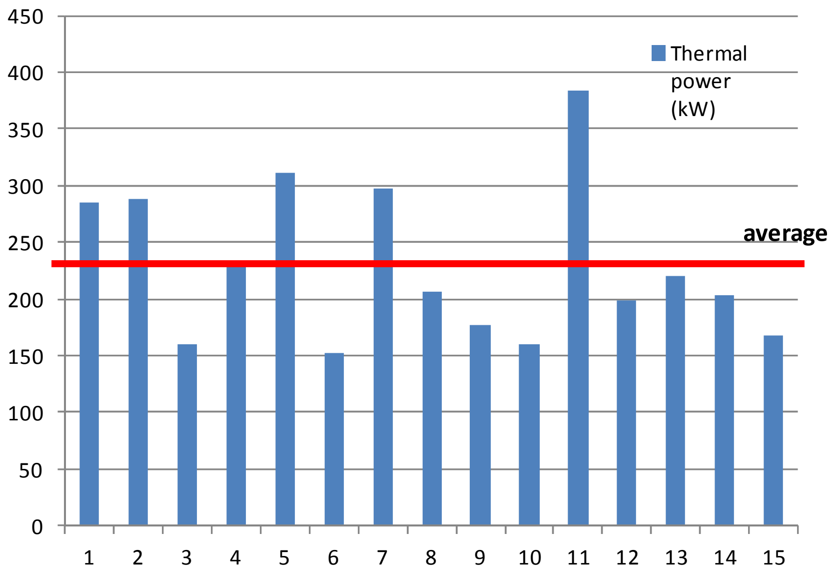

Fig.2: Produced thermal power during a 7 hours functioning cycle (two registered values each hour)

Sampling of the gas mixture coming out of the chimney were performed with fumes analyzer TEXT 350XL, this instrument has an uncertainty on the measure that is assumed to be equal to ± 0.01% Vol% CO_2, ± 1 ppm for NO, ± 0.1 ppm for NO_2). The observed data showed that the temperature of the combustion fumes from the exhaust the plant was kept between 88 and 127 °C, placed in direct contact with the ambient air at temperatures ranging from 23 and 29 º C approximately. The percentage of molecular oxygen present in the mixture of combustion exhaust gas stood in percentages ranging from 17 to about 15%, while the percentage of residual carbon dioxide was observed approximately constant and with values of the order of 2-3%.

Fig. 3 shows the trend of the temperature measured by the fumes from the exhaust. It is observed a peak temperature of the gaseous flow exiting the fireplace in correspondence of the intermediate monitored temporal phases.

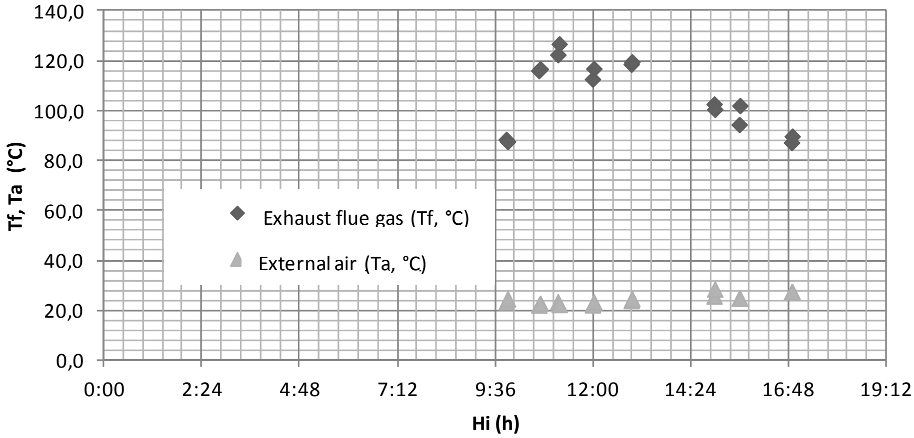

Fig.3: Temporal trend of the temperature of the flue gas flow from the exhaust (Tf) with respect to the outside air temperature (Ta).

Fig.4 shows the results of the monitoring of the flow of gas leaving the combustion chamber with reference to concentrations, measured in ppm, of the molecules of NO, NO_2 and NO_x.

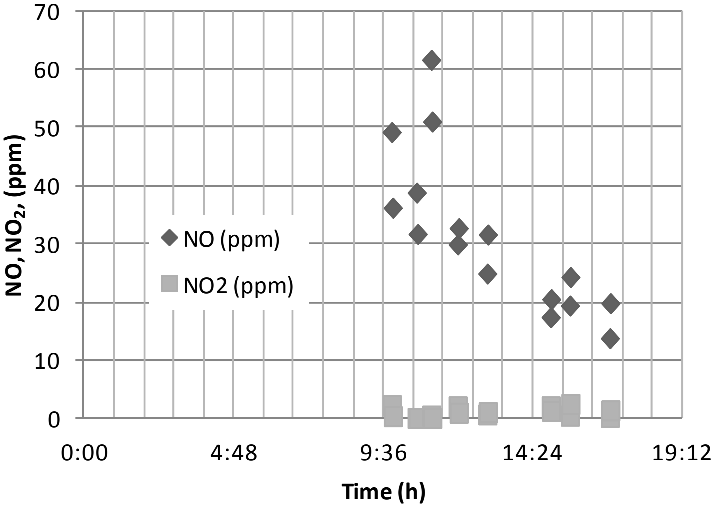

Fig.4: Monitoring of the NO, NO_2 concentrations.

The concentrations of nitrogen monoxide (NO) observed in output from the chimney in the gaseous mixture were maintained between 17 and about 39 ppm, while the nitrogen dioxide (NO_2) has never exceeded concentrations above 2 ppm. In conclusion, we show below the results for the determination of the carbon content of the ashes of the combustion chamber and burner and from the combustion of manure from the farm of San Venanzo (Table 4).

Table 4: Ultimate analysis of ashes

Sample tipology	C
Crucible ash	5,80%
Burner ash	4,35%
Crucible – burner ash variation	- 25%

The thermal process at high temperature inside the burner allows the oxidation of the organic substance, as demonstrated by the reduction of the carbon content.

2.5 FUTURE PROSPECTS

With respect to the experimental campaigns, are described below the main objectives to be pursued yet. The first objective is to optimize thermal and chemical processes inside the boiler and gasification section the plant, fueled by poultry manure; monitoring the physical and chemical parameters of the incoming material is used to determine the optimal conditions for the realization of the maximum energy efficiency.

The second objective consists in the study of the formation processes of siliceous deposits inside the combustion chamber and around the heat exchangers, since it is a significant problem in thermal processes that affect the droppings. The formation of these deposits may impair the functionality of the system.

With regard to plant design, is ending the market investigation aimed at identifying the best system of break-bags and load the raw material, which is very uneven and can contain elements which would militate against the flow of the animal carcasses and parts of the plumage. The modification and adaptation of machinery for the production and mobilization of the components of the concrete is pre-exist, while on the other hand, we are evaluating the performance of machines chippers here adapted for the manure.

Finally will conduct a recognition of air conditioning units and heaters in the company, in order to retrieve them and feed them with the new heat engine. The end result will be to achieve energy independence for the breeding host experimentation and offer a model of energy production system replicated for poultry farms of small and medium size, size is very common in Italy. [29].

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