BUBBLING FLUIDIZED BED GASIFICATION OF A POULTRY FARM WASTE

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Abstract
A bubbling fluidized bed air-blown gasifier, having an internal diameter of 102mm and a maximum feeding capacity of 3kg/h, was operated with a waste manure coming from an Italian chicken farm. The experimental runs have been carried out by keeping fixed the fluidized bed velocity (0.4m/s), the reactor bed temperature (between 750 and 800°C) and the type and size range of bed material (quartz sand, 0.2-0.4mm) and by varying the equivalence ratio between 0.27 and 0.40. The main components of the obtained syngas (CO, CO_2, H_2, CH_4, C_2H_m, C_3H_m, BTX, N_2) were measured by means of on-line analysers and a gas-chromatograph. The process performance was assessed on the basis of different parameters, such as carbon conversion efficiency (CCE), cold gas efficiency (CGE), specific energy production, syngas low heating value and yield of undesired by-products (tar, fly ash, ammonia, hydrogen chloride and sulphide). The results indicate that the air-blown gasification process of chicken manure is technically feasible and the best results in terms of CGE and CCE were obtained at a temperature of 750°C with an ER of 0.34.

Introduction
In the last years, the intensive population growth and the following increase of the meat demand, determined a proliferation of the food industry. In particular, the Italian poultry industry is one of the Europe's largest producer and exporter of poultry meat (12% of the overall market) with a turnover of 5,300 million euro, mainly due to the continuous national growing meat consumption (18kg/cap/y), with a production of a large quantity of manure by-products [1]. Landfilling of chicken manure was the traditional disposal solution until the beginning of 2000. The necessity of an adequate treatment of pathogens and heavy metals as well as that of avoiding potential eutrophication effects have driven to restrictive environmental regulations [2, 3]. Consequently, bio-chemical (composting and anaerobic digestion) and thermo-chemical (combustion and gasification) conversion processes were recently identified as possible better management options.
The bio-chemical units allow to obtain weight and volume reduction together with the elimination of pathogens but they have additional equipment and handling costs and do not solve the problems of nutrient losses and heavy metals contamination [4]. The thermo-chemical units can instead obtain the destruction of pathogen

agents together with a remarkable weight reduction and energy generation: they can then appear as an economical and environmental viable solution [5]. The gasification process, in particular, can be used to convert the poultry farm waste in a fuel gas (syngas), mainly made of carbon monoxide and hydrogen, which can significantly contribute to the sustainability of chicken manure management [6].

Problems associated with the formation and release of different contaminants (tar, ashes, heavy metals, halogens and alkaline compounds) could cause environmental and operational troubles, such as clogged or blockage in fuel lines, filters, heat exchangers and energy conversion devices, material corrosion, wastewater pollution, and still are today a crucial obstacle to be overcome.

This study aims to evaluate the performances of the air gasification process of a chicken manure by utilizing a bubbling fluidized bed reactor. Fluidization is in fact the most promising among all biomass gasification technologies, due to its peculiar characteristics and, in particular, for the possibility to utilize different fluidizing agents, reactor temperatures and gas residence times, to inject reagents at different reactor heights and to operate with or without a specific catalyst [7, 8]. An appropriate utilization of these features could therefore be the key to define an efficient and sustainable management of this kind of waste.

Experimental apparatus

The experimental work was carried out in an atmospheric bubbling fluidized bed gasifier (BFBG) with a feeding capacity of approximately 3kg/h. The sketch of the experimental apparatus is schematically given in Fig. 1.

The BFBG is a 102mmID cylindrical column, made of AISI 316L and electrically heated by five shell furnaces. Each furnace is controlled by a data acquisition system connected to five thermocouples, located in the reactor internal wall, which allow to independently set the temperature of each reactor section (blast feeding, pre-heater, bed and freeboard). The air utilized as fluidizing agent was injected at the bed bottom through a distributor plate composed of three nozzles. These have a truncate pyramidal shape and were specifically designed in order to ensure a homogeneous distribution of the fluidizing gas in the bed cross-section. The total height is 2.5m from the metal distributor plate to the product gas outlet. The feedstock was over-bed fed in continuous by means of a screw-feeder device. A nitrogen flow was used to help the fuel feeding and to avoid the back flow of the produced gas. At the syngas outlet a high efficiency cyclone allows dust removal. Downstream of it there are two alternative symmetric syngas conditioning lines, each one consisting of a bubbler and a filter for tar, residual fly ash, acid and basic gases.

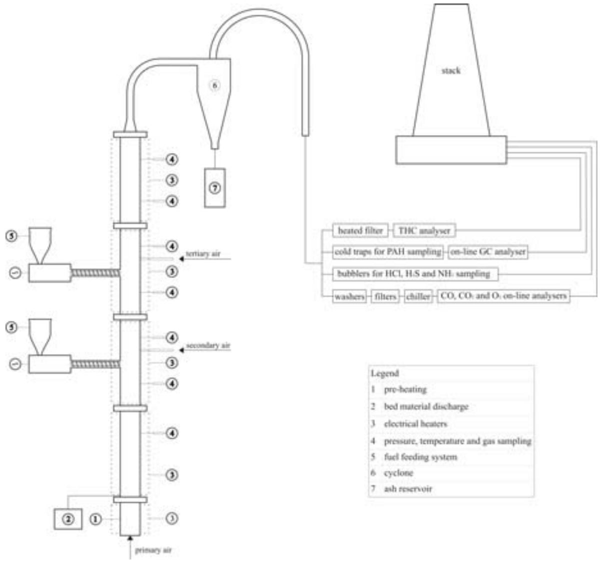

Figure 1. Sketch of the bubbling fluidized bed gasifier and its conditioning lines.

The main syngas compounds (CO, H_2, CH_4, CO_2, N_2, O_2, C_2H_m, C_3H_m and BTX) were measured by using an Agilent Micro-GC 3000 located downstream of the tar sampling line. The syngas is further sampled by means of tedlar bags to off-line analyses in other two points along the reactor height (0.9m and 1.8m).

Operating conditions

The experimental tests were carried out by keeping fixed the fluidized bed velocity (0.4m/s), the reactor bed temperature (between 750 and 800°C) and the bed material (a quartz sand having a SiO_2 content of 96% and a size range of 0.2-0.4mm) and by varying the equivalence ratio between 0.27 and 0.40. Preliminary tests as well as specific measurements of softening and melting temperatures of manure ash indicated that the maximum reaction temperature has not to overcome 800°C, in order to avoid ash-to-bed particles interactions that can cause agglomerate segregation at the bed bottom and the consequent worsening of fluidization quality or, eventually, a complete bed defluidization.

The feedstock used was a chicken manure coming from an Italian poultry farm. Proximate and ultimate analyses reported in Table 1 were performed using a Perkin-Elmer Pyris Diamond Thermogravimetric Differential Thermal Analyzer (TG/DTA), a muffle furnace, and a Leco TruSpec automatic elemental analyser.

Gas and solids sampling procedures were activated when the values of pressure, temperature and gas composition were at steady state conditions for not less than 1h. For the sampling of condensable species, a system consisted of four in-series cooling coils plugged in an ice bath, a suction pump and a flow meter, was installed and operated with a syngas flow rate of about $3dm^3_N$/min for 30min to obtain tar and water phase. Water was separated from tar in order to evaluate its content in the syngas and the condensed hydrocarbons were off-line analysed, with a specific pre-treatment, in a Perkin-Elmer Clarus 500 gas chromatograph coupled with a mass spectrometer (GC-MS). This procedure allows to recognize tar belonging to the classes between 2 and 5 of the classification system proposed by ECN (Energy research Centre of the Netherlands) in 2004 [9]. Hydrogen chloride, hydrogen sulphide and ammonia were collected by bubbling the product gas through a pair of gas stripping bubblers, connected in series and containing basic and acid solutions respectively, and subsequently analysed by means of a Dionex DX-120 ion chromatograph.

Table 1. Main chemical properties of the chicken manure utilized for the gasification tests.

	chicken manure
Ultimate analysis, % on weight basis ±SD	
C	33.0±3.1
H	4.4±0.5
N	5.6±0.1
S	0.3±0.1
O (by difference)	29.6±2.9
Moisture	9.9±1.9
Ashes	17.2±0.4
C/N ratio	5.90
Proximate analysis, % on weight basis	
Volatile matter	69.9
Fixed carbon	3.0
Heating value[a], kJ/kg	
HHV	13,010
LHV	11,940

a) evaluated by means of a specific biomass relationship proposed by Sheng and Azevedo (2005) [10].

Data obtained from on-line and off-line gas measurements and from chemical analyses of solid samples were processed to develop mass balance on atomic species and the related energy balance for each chicken manure gasification test. The bed carbon loading, i.e. the amount of carbon present in the bed as char particles at steady-state condition, was experimentally determined at the end of each test by switching from reducing to oxidizing conditions and by recording and integrating the CO_2 and CO contents produced by oxidation. Finally, the flow rate of produced syngas was determined by the “tie-component” method applied to the value of nitrogen content in the dry syngas, as obtained by (on-line and off-line) GC measurements, and adequately corrected to take into account the nitrogen fed into the gasifier with the waste and that leaving it as ammonia.

Experimental results and discussion

Syngas composition

Table 2 lists the data of the main operating and process performance parameters for the chicken manure gasification tests.

Table 2. Main operating parameters and experimental results of chicken manure gasification tests.

Test	T_{bed}	ER	A/F	CO_2	CO	H_2	CH_4	C_nH_m	BTX	Q_{syngas}	LHV_{syngas}	Specific energy	Dust	Tar	CGE	CCE
#	°C	-	kg_{air}/kg_{fuel}	%	%	%	%	%	%	m^3_N/h	kJ/m^3_N	kWh/kg_{fuel}	g/m^3_N	g/m^3_N	-	-
1	753	0.27	1.09	17.8	10.6	11.6	3.1	1.5	0.3	5.38	4,930	2.10	80.8	1.34	0.60	0.92
2	755	0.30	1.22	18.4	10.2	10.2	2.3	1.4	0.2	5.47	4,310	1.89	56.2	2.41	0.57	0.90
3	755	0.34	1.37	18.2	9.6	9.7	2.8	1.3	0.2	5.06	4,350	2.09	52.2	2.11	0.63	0.92
4	800	0.34	1.37	18.4	7.7	6.9	2.9	1.1	0.2	4.49	3,650	1.61	147.2	3.05	0.49	0.96
5	800	0.40	1.59	18.8	7.8	6.5	2.5	0.9	0.2	4.48	3,420	1.75	43.79	1.37	0.53	0.98

Fig. 2 shows that, as expected, the contents of hydrogen, carbon monoxide, methane and C_nH_m (i.e. the hydrocarbons with two or three C atoms) in the obtained syngas decrease as ER increases from 0.27 to 0.40.

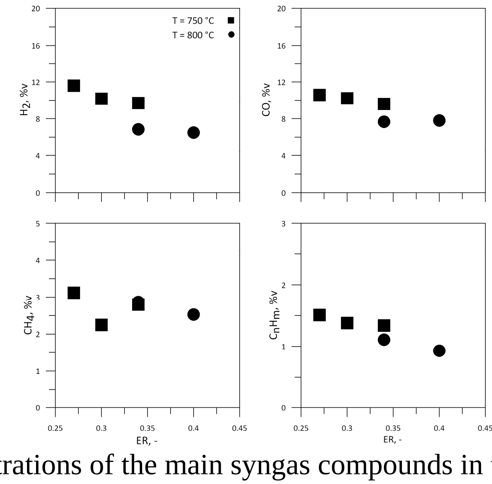

Figure 2. Concentrations of the main syngas compounds in the chicken manure gasification tests.

This necessarily implies (Fig. 3) a reduction of syngas lower heating value (from about 4.9 to 3.4MJ/m^3_N) and an increase in the specific syngas yield (from 1.5 to 1.8m^3_N/kg_{fuel}). These opposite effects balance to each other producing no remarkable variations in the specific energy production (from 2 to 1.8 kWh/kg_{fuel}). The chemical energy transferred to the syngas (CGE) changes from 0.63 to 0.49. In particular, at ER=0.34, the gasification performances in terms of LHV, specific energy and CGE clearly decreases if the temperature increases from 750 to 800 °C, as a consequence of the less amount of CO and H_2 in the syngas and the three times larger entrained fines flow rate.

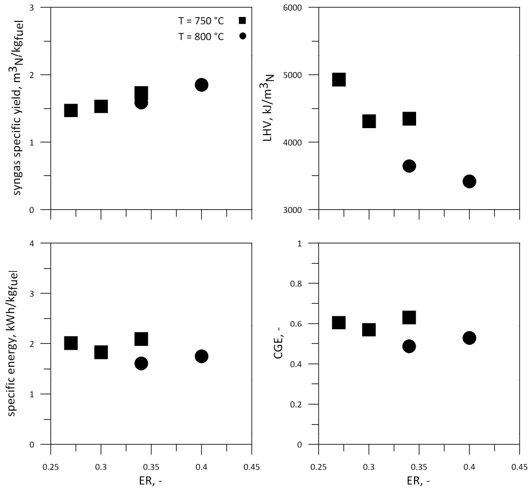

Figure 3. Main performance parameters of the chicken manure gasification tests.

With reference to this latter aspect, Fig. 4 reports the total flow rate of carbon leaving the reactor as elutriated fines or tar. An increase of ER has a positive effect on these carbon losses, which reduce from about 39 to $8g_C/h$, mainly as a consequence of the larger oxygen amount that can react with volatile compounds in the pyrolysis zone [11].

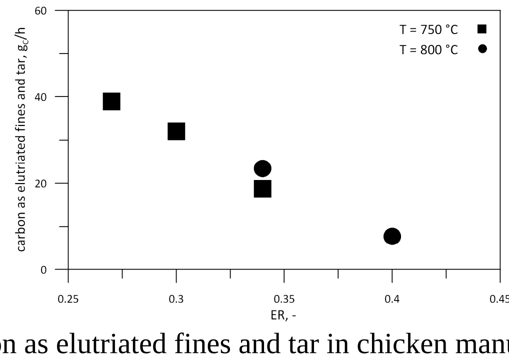

Figure 4. Carbon as elutriated fines and tar in chicken manure gasification tests.

The obtained syngas also contains small amounts of hydrogen chloride and sulphide (which in all the gasification tests are in the order of few mg/m^3_N), but higher ammonia concentrations (between 2.2 and $5.7 g/m^3_N$), as a consequence of the high nitrogen content of the chicken manure (see Table 1). The ammonia concentrations resulted to reduce when ER is increased and/or the reactor temperature is reduced.

Tar content and composition

The syngas organic impurities range from low molecular weight hydrocarbons to heavy PAHs (usually collectively known as tar). Tars tend to condense or polymerize into more complex structures in pipes, heat exchangers or on particulate filters, leading to high risks of plant stop and larger maintenance costs and, above all, to impede the utilization of high efficiency energy conversion devices [8, 11]. It is generally recognized that tar control is a key issue for a successful application of biomass derived producer gas [12]. The reliable evaluation of their concentration and composition it is then a pre-requisite to define and adopt a suitable combination of primary and secondary methods (i.e. inside the reactor and downstream of it) to control its content below the limit imposed by the specific syngas end-use device [13].

Fig. 5 reports the content and composition of these heavy PAHs for two test carried out at the same ER but different reactor temperatures (a) and at the same reactor temperature but different ER (b).

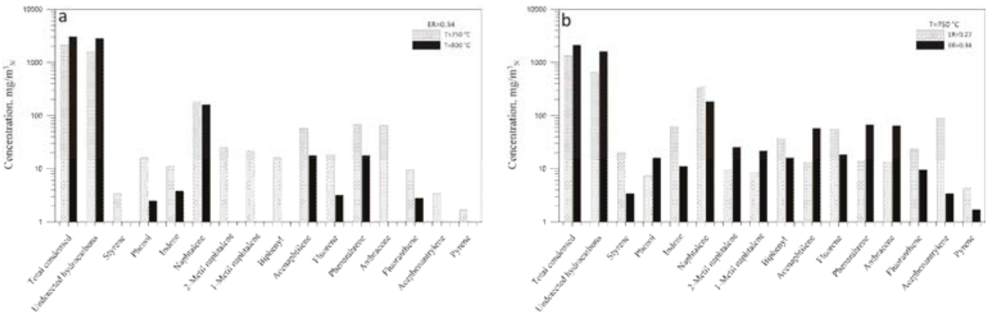

Figure 5. Tar content and composition for two values of reactor temperatures (a) and two values of ER (b).

Fig. 5a reveals an increase in total tar concentration from 2.1 to 3.0g/m^3_N (i.e. +45%) when the gasification temperature increases from 750 to 800°C. Although both the tests exhibit the large concentration in tar class 4, i.e. that of light PAHs with 2 or 3 rings, and naphthalene is in both the tests the main compound, undetected tars (class 1) increase in concentration with increasing gasification temperature (76.3% vs 93.1%) while all the detected compound concentrations decrease. Fig. 5b shows an increase in total tar concentration from 1.3 to 2.1g/m^3_N (i.e. +57%) when the gasification ER is switched from 0.27 to 0.34. As previously, for both the tests the main concentration is tar class 4, and naphthalene is the leader compound. Moreover, it is observed a growth of undetected tars concentration with increasing ER (47.4% vs 76.3%) while the concentrations of tar classes 3, 4 and 5 decrease. A possible explanation of the observed increase of undetected tar compound assumes that the PAH growth reactions involve compounds of tar classes 2-5 or unsaturated hydrocarbons in the formation of heavier tars [9].

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