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Evaluation of poultry litter as a feasible fuel

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Abstract

Caloric values (massic energy of combustion) of poultry litter coming from the chicken farm "Cantos Blancos" (Guadalajara–Spain) were determined by static bomb calorimetry. These values correspond to samples treated in different conditions of drying-up. The massic energy of combustion of the "dry samples" was 14 447 kJ/kg and for "wet samples" decreased linearly with increasing water content. The optimum conditions to use these waste product as an economic fuel were also established.

Keywords: Poultry litter; Renewable fuel; Biomass combustible; Electrical power; Calorimetry of combustion

1. Introduction

The size of poultry litter production in many countries shows a sustained and increasing trend (e.g. in UK the poultry farming industry produces 1.5 million tons per year [1]). The poultry concentration can present problems for the management disposal of litter. One possible solution is recycling litter through the age-old process of composting to be used as a traditional fertilizer of fields. However, in some regions this has caused environment problems, such as ground water run-off pollution by phosphorus [2,3].

Other possible, interesting novel solution, could be the use of poultry litter as an alternate primary fuel source. Previous studies have documented that it is feasible to use poultry litter as an alternative, natural fuel source power generation [3,4]. In this respect, there are many promising projects, both in USA and the European countries, researching the environmental effects and economic benefits of this waste biomass combustible [3,5–8]. As an example of power generation, the Fibrowatt has built in UK three power plants, consuming 800 000 t of litter per year to generate approximately 64 MW of electricity [1,9].

This paper is aimed to evaluate the energetics of the combustion of poultry litter. Thus, we will report on the parameter known as *caloric value* [10] or *massic energy*, *q*, that is the amount of energy (kJ) released by each unit of combustible mass (kg). The highest *q* value is related to the *complete combustion* of biomass (basically constituting C, H, O, N, S) at constant volume in an oxygen atmosphere, which implies the absence of C and CO in the final products of combustion. As a consequence, it is assumed that these final products consist basically of O_2, CO_2, N_2, SO_2 in gas phase together with water coming from sample burned.

2. Experimental

2.1. Waste sample

The initial poultry litter sample consisted of some kilograms of material coming from a chicken farm

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called "Cantos Blancos" (Guadalajara–Spain). It arrived at our laboratory, kept in closed bags. This will be denominated in the following as "wet-poultry litter". The water content, w (%), of this sample was determined as the weight loss of approximately 100 g of sample after heating in vacuum ($\sim 10^{-5}$ Torr) at 110 °C for 8 h. We assumed that the material evacuated was basically constituted by water, in agreement with the elemental analysis of the samples (see Section 3.1). Thus, it is found that wet-poultry litter has a water content of 70.4%. We will call to the products obtained after the treatment described above as "dry-poultry litter".

2.2. Drying-up process of waste samples

The wet-poultry litter was subjected to a drying-up process that consisted of exposing to outdoors during different times. Ten open recipients containing each one approximately 100 g of wet-poultry litter were exposed for several hours to a week. These days were hot ones in Madrid (reaching maximum temperature of 40 °C). The water content of these samples was determined as the weight loss of the sample according to the exposure time.

2.3. Preparation of samples

All the poultry litter samples to be burnt were conveniently mixed and grounded into an agate mortar. After that, compressing in pellet forms which had between 1 and 2 g of mass.

2.4. Calorimeter and procedure of measurements

The combustion experiments were performed in an *isoperibol* calorimeter equipped with a static bomb and an isothermal water jacket. The calorimeter system consists of a stainless-steel vessel of about 3.5 dm^3 capacity, containing a weighted amount of water. It provides a closely fitting cover and an arrangement for stirring, an electric heater, a static bomb of 0.380 dm^3 capacity made of a corrosion-resistant alloy (Illium, model 1002 from Parr Instrument), and a sensitive platinum-resistant thermometer (model 8160, Leeds and Northrup). The calorimeter system is completely enclosed within a jacket with an air-gap separation of 1 cm between all surfaces. The water jacket is maintained at a constant temperature of 25.430 ± 0.005 °C.

The temperature measurements (within $\pm 10^{-4}$ °C) were made at intervals of 15 s with a platinum thermometer and recorded by a resistance bridge (Model F26, Automatic System Laboratories) which is interfaced with a microcomputer programmed to compute the adiabatic temperature change [11].

The pellet samples were ignited in oxygen at 3.04 MPa with 1 cm^3 of water added to the bomb, following a procedure similar to that described by Prosen [12]. The initial temperature of the combustion experiments was approximately 23 °C and the energy of reaction was always referred to the final temperature of 25 °C. The electrical energy for ignition was supplied by a 4700 μF capacitor when discharged from 13.5 V through a platinum wire. Previously, the pellet sample was connected to the ignition system by means of a cotton thread fuse, whose empirical formula and massic energy of combustion, $CH_{1.74}O_{0.871}$ and $17\,410 \pm 17$ kJ/kg, were determined in our laboratory.

The samples, platinum crucible and cotton thread were all weighed using a Mettler H33AR balance (sensitivity ±0.1 mg). The energy equivalent of the calorimeter, ε, was determined from the combustion of benzoic acid, NIST standard reference sample 39j, having a massic energy of combustion under the conditions specified on the certificate of $-26\,434 \pm 3$ J/g. We obtained a value of $\varepsilon = 14\,273 \pm 6$ J/°C from six calibration experiments, where the uncertainty quoted is the standard deviation of the mean.

After disassembling the calorimeter, the bomb gases were allowed to release slowly. The presence of SO_2 and Cl_2 were quantitatively analyzed with Dragër tubes. These devices have a relative accuracy of measurement of ±10–15% for both gases. Finally, the liquid phase in the bomb was transferred to a flask with rinsing water. This solution was titrated with standard alkali, 0.1 N NaOH(aq), to determine the total acid.

3. Results and discussions

3.1. Elemental analysis of wet- and dry-poultry litter

The elemental analysis of wet- and dry-poultry litter is given in Table 1. In the case of dry-sample, the

Table 1
Elemental analysis of wet- and dry-poultry litter

	Elemental analysis (%)					
	C	H	N	S	Halogens	O + others
Wet-poultry litter	10.2 ± 0.7	9.1 ± 0.6	1.3 ± 0.1			79.4
Dry-poultry litter	34.7 ± 0.4	5.2 ± 0.2	5.6 ± 0.2	0.13 ± 0.12	0.35 ± 0.15	54.09

halogens correspond mainly to chlorine while the percentage of oxygen and other elements non-detected in the analysis amounts up to 54% of the total content. In the wet samples, this concentration is up to 79%.

If we considered the presence of most significant elements (C, H, O, N), the empirical formula of wet- and dry-poultry litter would be $CH_{10.7}O_{5.84}N_{0.11}$ and $CH_{1.8}O_{1.17}N_{0.14}$, respectively. The wet-poultry litter formula can also be expressed as $CH_{1.8}O_{1.39}N_{0.11}\cdot 4.45H_2O$, thus we can find that the water content of the wet sample is approximately 68%, comparable to that found by treatment described in Section 2.1.

3.2. Combustion experiments of dry-poultry litter

The combustion of dry-poultry litter was complete (without the presence of residual biomass and neither C soot). The results are given in Table 2.

The caloric value mean is $q_{dry} = 14\,447$ kJ/kg. This value is comparable to those reported by other authors [3]. According to the final products of combustion, we found the following results:

- The inorganic solid amounted to ca. 22% of the total mass burnt.
- The concentration of Cl_2 and SO_2 gases were approximately 5.6 and 3.7 mg/kg of poultry burnt, respectively.
- The normality of the residual solution was ∼0.47 N. This solution was constituted basically of an aqueous mixture of HNO_3, H_2SO_4 and HCl, originating from the gaseous NO_x, SO_x and Cl_2 produced during the combustion process.

3.3. Combustion experiments of wet-poultry litter ($w = 70.4\%$)

The wet-poultry litter did not burn completely. Therefore, it was necessary to add “extra-fuel” (benzoic acid in our case) in different proportions (Table 3) to reach a full combustion (complete combustion). The mean caloric value was $q_{wet} = 5084$ kJ/kg. Considering these samples water free, the percentage (in weight) of the inorganic solid final product of combustion was ∼20%. This result is similar to the obtained for dry-poultry litter.

3.4. Combustion experiments of poultry litter with different water contents

To assure complete combustion, the samples were burnt adding benzoic acid (extra-fuel) in a proportion (in mass) approximately of 1:1, except for the sample left outside for 1 week ($w = 8.5\%$). The results are given in Table 4.

Using the caloric values given in Table 4 and the ones corresponding to wet and dry-poultry litter, we

Table 2
Results of combustion experiments of dry-poultry litter

Mass (g)	ΔT (°C)	Final products of combustion				q_{dry} (kJ/kg)
		Solid inorganic (g)	Cl_2 gas (mg/kg)[a]	SO_2 gas (mg/kg)[a]	Normality of solution (N)	
1.9033	1.8831	0.4244	5.4	4.4	0.48	14269
1.8173	1.8753	0.3780	5.7	2.9	0.46	14630
Mean value						14447

[a] mg Cl_2 or SO_2 gas/kg of poultry litter burnt.

Table 3
Results of combustion experiments of wet-poultry litter

Mass (g)		ΔT (°C)	Final products of combustion		q_{wet} (kJ/kg)
Wet-poultry litter	Benzoic acid		Solid inorganic (g)	Normality of solution (N)	
2.0035	0	No burn			
1.5101	0.5033	Incomplete combustion			
1.2417	0.7611[a]	1.8624	0.0820	0.16	5105
0.9830	1.0029	2.2060	0.0521	0.21	5063
Mean value					5084

[a] Value related to the minimum amount of benzoic acid to get complete combustion.

Table 4
Results of combustion of poultry litter with different water contents

Poultry litter		Benzoic acid (g)	ΔT (°C)	Final products of combustion		q_w (kJ/kg)
Water content (%)	Mass (g)			Solid inorganic (g)	Normality of solution (N)	
8.5[a]	2.0603		1.8339	0.4945	0.41	13012
8.5[a]	2.0197		1.9852	0.4686	0.46	13991
20	1.0475	0.9553	2.8070	0.0943	0.38	12360
40	0.8271	0.8042	1.9984	0.0504	0.36	8795
58.2	0.8782	0.8782	2.0744	0.0476	0.17	6715

[a] Correspond to samples exposed outdoors during 1 week. The calorific value mean is $q_{week} = 13\,502$ kJ/kg.

represented in Fig. 1 the massic energy of poultry litter against its water content (q vs. w). From a linear fit, we found the following expression:

$$q_{w,\mathrm{fit}}\ (\mathrm{kJ/kg}) = 14636.5 - 136.6w\ (\%)$$

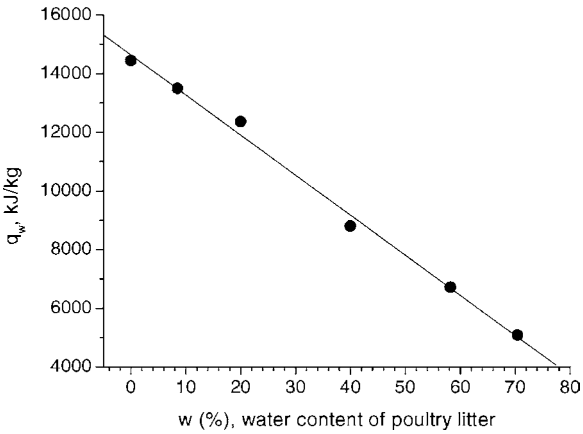

Fig. 1. Massic energy combustion vs. water content of poultry litter.

3.5. *Additional energy to get complete combustion of poultry with different water contents*

As it has been told above, both dry-poultry litter and poultry litter with 8.5% of water were burnt without adding extra benzoic acid. The other samples were burnt after adding benzoic acid as extra-fuel in different proportions, being an extreme case the wet-poultry litter sample, which needed a minimum amount of benzoic acid of ∼38% of total mass burnt (see Table 3). The minimal amounts of benzoic acid used for samples with different water contents were determined and expressed as energy, as shown in Table 5. These values permit us to define an useful parameter: "*minimum additional massic energy*", E_{min}, as the lowest quantity of additional energy, from any source, necessary to get a full or complete combustion of one unit of poultry litter mass. In Fig. 2, we present the percentages corresponding to E_{min} and q_w, respect to the total available energy obtained by full combustion of poultry litter, against its water content. This plot shows that for a water

Table 5
Combustion type of poultry litter with different water contents

Total mass (g)	Percentage (in mass) of poultry litter	Percentage (in mass) of benzoic acid	Energy of poultry (J)	Energy of benzoic acid (J)[a]	Combustion type
$w = 60.3\%$					
1.8600	50	50	5937	24564	Complete
2.1471	66	34	9050	19397[b]	Complete
2.4211	72	28	~628	17908	Incomplete
2.5000	100				No burnt
$w = 39.4\%$					
1.6313	51	49	4720	21112	Complete
2.0317	72	28	13535	15138[b]	Complete
2.1920	78	22	~12661	12736	Partially burnt
$w = 19\%$					
2.0980	52	48	13150	26598	Complete
2.0360	83	17	20372	9142[b]	Complete
2.1241	88	12	22531	6661	Incomplete
2.200	100		~9205		Partially burnt

[a] Evaluate, knowing that $q_{\text{benzoic acid}} = 26\,434\,\text{kJ/kg}$.
[b] Values used to calculate E_{min}.

content less than $w \approx 9\%$ is feasible to reach the total combustion of poultry litter ($E_{\text{min}} = 0$). However, the needs for extra-fuel increase strongly for samples with water contents higher than $w \approx 9\%$, to become approximately in 76% of the total available energy of wet-poultry litter samples. This corresponds to a $E_{\text{min}} \approx 16\,200\,\text{kJ}$ per each kilogram of wet-poultry litter burnt.

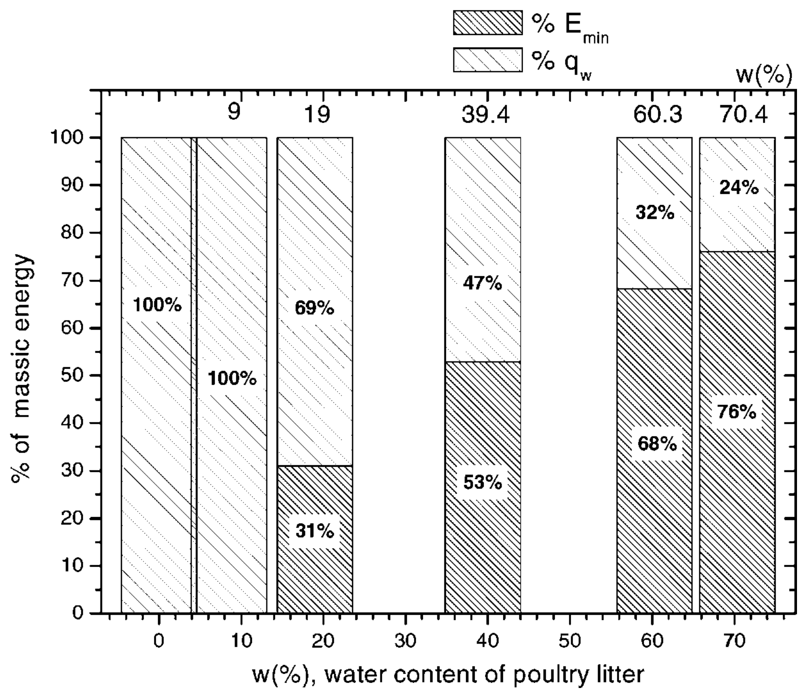

Fig. 2. Diagram of the percentage of E_{min} and q_w vs. water content of poultry litter.

4. Conclusions

The massic energy combustion of dry-poultry litter determined was 14 447 kJ/kg. This value decreases when the water content of the sample increases. We found for the final products obtained after combustion, that: (i) the mass of inorganic solid was approximately 20% of the mass of sample; (ii) the normality of the residual acid solution was less than 0.5 N; and (iii) the concentration of gases released such as Cl_2 and SO_2 were approximately 6 and 4 mg/kg of poultry burnt, respectively.

Finally, we found that poultry litter with water contents less than 9% can burn without extra-fuel. Therefore, these samples seem to be suitable for their use as fuel for generation of electrical power. At present, a prototype power plant, which intends to use the poultry litter studied here as a fuel, is under development [13].

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