

# A comparative study for energetic valorisation of partially digested sewage sludge

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## Abstract

The common final disposition of the sewage sludge obtained after their anaerobic digestion, whose heating value is about a quarter of the coke or peat, is often used in agricultural soils or as substitute of fossil fuels in clinker kilns. In this paper, a comparative study between incineration and gasification with CO<sub>2</sub> as oxidant agent has been carried out. After the physical and chemical characterization of the sludge, the combustion and gasification properties have been studied by means of thermogravimetric analysis. According to the combustion profile, while the ignition temperature (200°C) and peak temperature (288°C) are of the order of any kind of plant biomass, the maximum combustion velocity is much lower, around 0.25 mg/min. Moreover, although gasification requires higher temperatures (around 790°C) for the complete transformation of the organic matter, the resulting gas, with a heating value much higher than the one contained in the dried sludge, may be used in the wastewater treatment plant, reducing both the gas natural requirements and the final sludge volume by 37%, and consequently the costs associated to the transport. The final inorganic matter may also be incorporated directly in construction materials, closing the whole loop.

*Keywords: biomass, waste, sludge, energetic valorisation, co-combustion, gasification.*

## 1 Introduction

The current global energy output based on the use of fossil fuels threatens an ecological catastrophe in the short term, on the one hand, due to their depletion through uncontrolled and irrational use today and, on the other, by exceeding the limits of the Earth's capacity to absorb its impact.



Another important source of pollution is industrial waste, which without a proper treatment is very harmful to the Earth's ecosystem. So, it is necessary to find alternative solutions that contribute to its minimization and finally its complete elimination, without endangering other social and economic factors. It is therefore imperative to find renewable sources of raw materials and to develop green technologies that address the current energy crisis and pollution problems.

The wastewater treatment is not left behind this issue. The progressive implementation of Directive 91/271/EEC, as well as the slow but steady growth of households connected to sewage treatment plants and the increased level of treated water quality has increased the amount of sludge to landfill (from 5.5 million tons of dry matter in 1992 to 9 million tons in 2005).

The use of waste to energy technologies allows the increase of flexibility of the national/regional energy systems, as well as the production of renewable energy. However, in general, the characteristics of most of these wastes are not suitable to replacing conventional fuels, so that the transformation into higher energy density fuel is necessary. The fuels thus obtained have the following advantages: lower emissions of sulfur, slag is not burning, low ash content, and contribute to improving the quality of the environment. So, biomass is converted to heat, fuels or electricity. These transformations can be divided into two groups:

- Thermo-chemical processes: Chemical transformation that takes place under high temperatures and excess oxygen (combustion) [1], limited amounts of oxidant agents, as  $O_2$ , water or  $CO_2$  (gasification) [2] or in lack of it (pyrolysis) [3].
- Biochemical processes: Degradation of complex molecules to simpler molecules with high energy density carried out by microorganisms, the most commonly used are alcoholic fermentation [4] and anaerobic digestion [5, 6], to produce ethanol and biogas, respectively.

The Wastewater Treatment Plant of Aguas del Añarbe, S.A. (Loyola, Spain), was designed for the treatment of urban wastewater by anaerobic digestion, so that partially recovers the energy content of sludge in the form of biogas, which is fed to a cogeneration system together with natural gas. Heat is used for the drying and dehydration phases in the sludge line and electricity for both consumption and for sale. Moreover, the final dried sludge shows low biological activity in very low volume.

However, the wastewater treatment plant produces 10 tons/day of final partially digested and dried sludge and it is expected that the production will increase to 30–40 tons/day in the near future. So, it is necessary to find alternative solutions for the biosolid whose production is expected to grow exponentially in the following years.

Among the thermochemical processes, co-combustion with fossil fuels offers economic and environmental benefits [7–9], contributing to reducing total pollutant emissions per unit of energy produced, as  $CO_2$  emissions from biomass are not counted in the overall calculation, and also reduces both  $NO_x$  and  $SO_x$  levels on existing coal plants. Thus, biomass is usually burned in conventional power plants with steam cycles, as it was some years ago in the sugar mills [10].

In contrast, gasification is applied in more advanced and efficient systems. The gases obtained in the gasification can be used in heating processes by direct combustion or in internal combustion engines or even in gas turbines, systems that are between 10 and 15% more efficient than direct combustion of any solids and also less polluting [11], or even in more efficient systems that integrate fuel cells [12, 13].

In this paper, after a previous physical and chemical characterization of the final dried and partially digested sludge, a comparative study between combustion and gasification using carbon dioxide has been carried out by means of thermogravimetric analysis in order to demonstrate the environmental, technical and economic advantages of their use as alternative fuel.

## 2 Experimental work

The characterization of the biosolid has been carried out in order to know the physico-chemical properties that determine its performance as fuel by energetic valorisation. For this purpose, the following analytical methods have been used: CEA 1424, CEA 1281 and CEA 1358 standard methods for elemental analysis; drying at 105°C, and gravimetry for immediate analysis; calorimetry, atomic absorption and atomic emission spectroscopy for the determination of heavy metal and inorganic content; granulometry has been measured according to Directive 87/94/CEE; and the higher heating value following the CEA 1235 standard method.

In order to analyse microscopic properties, reactivity studies were carried out by thermogravimetry using a SETARAM Setsys Evolution thermobalance. These tests were carried out by The General Research Services of the “Instituto de Carboquímica” (ICB) of Zaragoza. Samples were heated with a temperature ramp of 10°C/min under oxidant atmosphere (with air from room temperature up to 1200°C, and 5% CO<sub>2</sub> in Ar from room temperature up to 900°C), followed by isotherm during 10 min.

## 3 Results

In general, biomass is much less dense than coal (500 kg/m<sup>3</sup> vs 1300 kg/m<sup>3</sup>) [14]. It is also much more difficult to reduce to small sizes. Biomass with coal burning cannot have a particle size greater than 6.3 mm (carbon 0.1 mm) [14]. Table 1 shows the result of the fineness of the sludge, 99.9% is below 5 mm, thus ensuring its use as a supplement to coal.

Tables 2, 3 and 4 summarize the main results of the chemical characterization of the biosolid. The results of the analysis of metal content and elemental analysis are consistent with those found in the literature for this type of sludge [15, 16], with recorded values within an acceptable range to be a partially digested sludge. Thus, the content of C and H are low and its relationship (7.1) slightly lower compared to the initial (10.0) of undigested sludge. A low sulfur content (lower than in coal) translates to lower emissions of SO<sub>x</sub>, although the nitrogen content is substantially higher, and therefore, the NO<sub>x</sub> emissions.



Table 1: Granulometry of sludge.

Granulometry	%
> 5 mm	0.1
4–5 mm	1.0
3–4 mm	26.2
2–3 mm	60.9
1–2 mm	11.3
0.5–1 mm	0.1
< 0.5 mm	0.1
Stones and gravel in diameter > 5 mm	< 5
Impurities: metals, glass and plastic > 2 mm	< 3

In general, the biomass has a high oxygen content, even in the case of sludge despite its higher content of inorganic matter.

On the other hand, coal shows higher iron content, while plant biomass has higher potassium content than coal and sludge, but similar contents of iron, calcium, magnesium, phosphorus and chlorine as sludge. The moisture content of sludge (4.2%) is even lower than that of coal (4.8%).

Also, it is remarkable that the CaO content of sludge is higher than that of coal (5.5%). CaO is directly related to the ability of the ashes to adsorb sulfur and nitrogen by formation of the corresponding sulphates and nitrates, which is an advantage of the use of sludge as alternative fuel [17–19].

Table 2: Elemental analysis.

% dm	C	H	N	S	Cl	Ash	O(diff.)
Sludge	20.7	3.3	2.1	0.8	0.3	75.7	10.8

Table 3: Heavy metal content.

ppm	Pb	Ni	Cd	Cr	Zn	Cu	Hg
Sludge	60.1	26.5	0.8	59.0	256.5	103.9	0.4

Table 4: Analysis of the inorganic matter.

% dm	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	SO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>
Sludge	6.6	13.7	0.9	0.3	0.9	2.1	2.3

The higher heating value of sludge is 8.8 MJ/kg, above the crust (HHV = 5.9 MJ/kg), the order of sawdust or straw (HHV = 8.4 and 12.5 MJ/kg), half those of wood or sunflower husk and about a quarter that of coke or peat.

Figs. 1 and 2 show the results of the thermogravimetric analysis with air and carbon dioxide (5% in Ar), respectively, and tables 5 and 6 show the results of the deconvolution of the previous graphs.

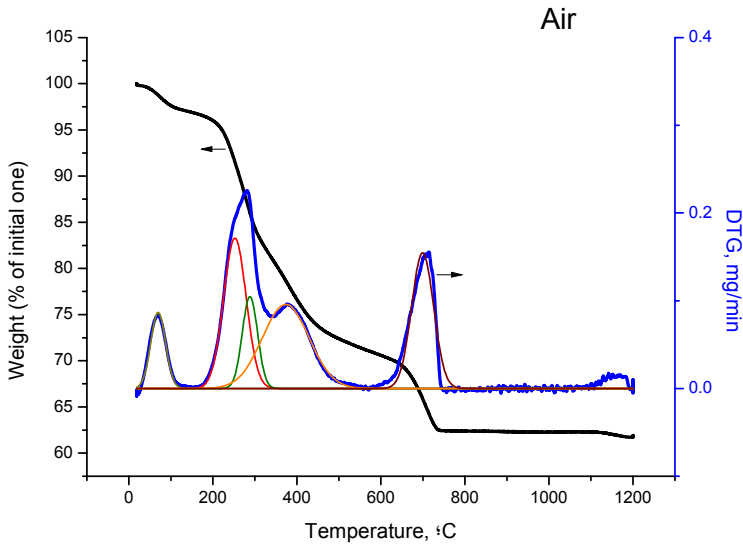


Figure 1: Thermogravimetric analysis of the combustion of the sludge.

The first peak in the profile corresponds to combustion of the sludge moisture, about 3.3%. After removing the moisture, several peaks occur as a result of the desorption of adsorbed gases.

Between 200 and 500°C there is a sudden loss of mass: about 68% of the total loss experienced during the test, which represents the formation of volatile and their ignition.

Table 5: Results of the deconvolution of the combustion graph.

Peak	T max, °C	Area, %	Loss of weight (g/100g sludge)
1	70	8.8	3.4
2	252	26.5	10.1
3	288	11.0	4.2
4	373	30.6	11.7
5	699	23.2	8.8
<i>Total</i>	--	<i>100</i>	<i>38.1</i>

Another peak of smaller size but not the smallest appears at very high temperatures near 700°C, probably due to partially charred residue.

The ignition temperature is the point at which the profile of combustion shows a sudden increase, in this case at 200°C, the order of any plant biomass (203°C for

shells of sunflower and pine cone, 190°C for seeds rapeseed or 200°C for olive refuse [20]).

The point of combustion curve for the rate of weight loss is known as high temperature peak and is indicative of the reactivity of the sample. This temperature is 288°C, the order of the shells of sunflower (300°C), rapeseed (262°C), the pine cone (292°C), or olive refuse (264°C). The maximum combustion rate, is 0.25 mg/min, much lower than that of the aforementioned types of biomass (5.5, 2.8, 5.2, and 3.4 mg/min, respectively [20]).

As for the gasification analysis with carbon dioxide, as can be seen in fig. 2 and table 6, there are three regions or temperature ranges with loss of mass: 25–100°C (4.8%), 200–600°C (23.9%) and 700–850°C (11.6%). The first one corresponds to the loss of moisture by heating the sample. The other two are a direct consequence of the gasification, requiring at least a temperature of 790°C for a residence time long enough for the complete gasification, or 900°C and shorter times, which will affect the composition of the final synthesis gas.

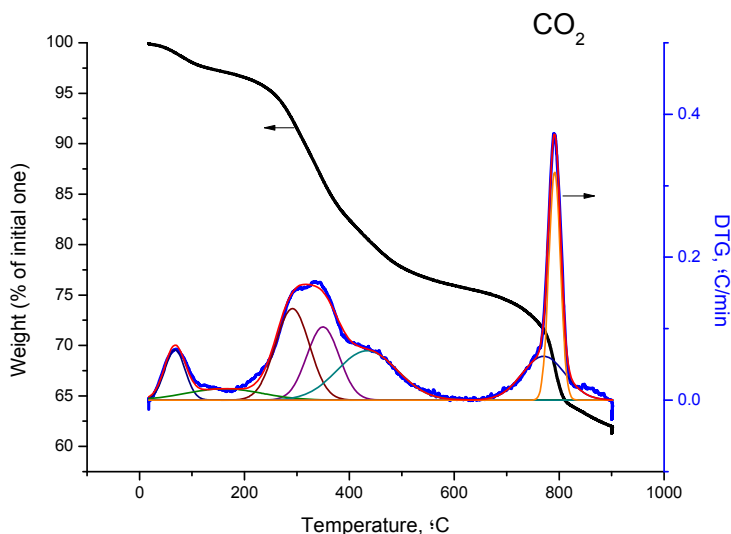


Figure 2: Thermogravimetric analysis of the activation of the sludge with CO<sub>2</sub>.

In fig. 2 also can be observed a loss of approximately 37% of mass after the test that coincides with the total organic content of the sludge obtained in the combustion tests. This means that the gasification of the sludge results from a practically complete transformation of the organic content of the sludge to medium power combustible gas (synthesis gas is composed primarily of methane, carbon monoxide and hydrogen) with a much higher heating value (39.9 and 120 MJ/kg, for natural gas and H<sub>2</sub>, respectively) than sludge (8.8 MJ/kg). Due to this, it would be interesting to consider it as an alternative route for energy recovery from sludge

in the wastewater treatment plant or otherwise use the gasification of fossil fuels, such as power plants integrated gasification combined cycle (IGCC) generating electricity from fossil fuels. This synthesis gas obtained after the gasification is cleanly burned later in a gas turbine to produce electricity.

Table 6: Results of the deconvolution of the gasification graph.

Peak	T max, °C	Area, %	Loss of weight (g/100g sludge)
1	68	6.8	2.6
2	161	5.7	2.2
3	291	21.1	8.0
4	350	16.0	6.1
5	434	20.0	7.6
6	770	12.7	4.8
7	791	17.7	6.8
<i>Total</i>	--	<i>100</i>	<i>38.1</i>

The heat required for gasification of the sludge in the wastewater treatment plant itself may be obtained by combustion of biogas and CO<sub>2</sub> (gasifier agent) coming from the flue gases from the engine generator, which would access hot to the gasifier, reducing energy requirements. The fuel gas obtained could feed back into the gasifier to supply the heat required and the remainder to the combustion chamber of the dryer reducing the need of natural gas or co-fed with biogas in biogas generator sets. This would reduce the cost derived from consumption of natural gas, which is currently around 100,000 €/month, a proposal for maximum economic performance of the facilities that makes them viable and attractive from the point of view of exploitation.

## 4 Conclusions

Regardless of the proposed solutions in the coming years, dependence on fossil fuels to sustain economic development will remain so, it is necessary to find technological solutions that reduce environmental pollution due to emission of gaseous pollutants, and to seek alternative fossil fuels.

However, to ensure energy sources are affordable, safe and friendly, the environment requires exactly the same actions: energy efficiency, so no matter which of them more focus is on. From this point of view, to give an energy value to a waste, which as such is annoying, must be positive from these three points of view.

The use of sludge as alternative fuel is a net saving in CO<sub>2</sub> emissions because the emissions from biomass are not accounted, whereas if it is deposited in landfills, emissions due to uncontrolled fermentation itself are counted. The use of biosolids in cement kilns is accepted, but it is necessary to control specific

parameters such as maximum allowable dose of sludge according to their characteristics, the range of temperature and types of fuel used, as well as the final properties of the cement. It is estimated that the use of 1 ton of sludge involves a reduction of 1.28 tons of CO<sub>2</sub>, without including the emissions associated with transport [16].

On the other hand, the transformation of dried and partially digested sludge into synthesis gas with a higher heat of combustion is an alternative to their use in cement kilns. Also, this technology would take the total energy contained in the sludge in the sewage itself, reducing the costs associated with transport by 38% (inorganic matter cannot be enhanced through the wastewater treatment plant). The disadvantage of this route is the need for investment of the filter in the right technology, but energy-wise (HHV of the gas is well above the sludge) and environmentally (would reduce emissions from transport and the gases would be used to combustion engines in the gasification) would be most advantageous.

In 2004 the emissions of CO<sub>2</sub>-e in Spain exceeded by 33% the expected value due, to a no real adjustment between emission reduction and economic benefit, among other factors. All the policies and advances in technology and management that lead to harmony between these two parameters will be beneficial. In particular, those that have major impact on the development of any way of recovering energy from waste and the development of sinks of CO<sub>2</sub>-e is being expected.

## Acknowledgement

This work has been possible thanks to the financial support of the BIOVALOR project (Euskadi 09 Programme – Basque Government).

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