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Exploitation of Digestate in a Fully Integrated Biowaste Treatment Facility: A Case Study

Maria Laura Mastellone

Abstract

The increase of biowaste generation has reached critical levels in many countries. The European legislation introduced the biowaste treatment and the organic recycling as central theme of its political agenda with the aim to promote the sustainable exploitation of this peculiar waste. The most utilized technologies applied to the biowaste treatment are based on the biological processes targeting to produce biogas or, more recently, biomethane to be used as fuel. The production of biomethane allows to produce a substitute of the fossil methane with a yield of about $0.07\text{g}_{\text{CH}_4}/\text{g}_{\text{biowaste}}$; the remaining fractions are waste coming from the pretreatment/refining steps, solid digestate or stabilized compost, and leachate. The sustainable treatment of these fractions is a mandatory issue to treat the biowaste in a reliable and sustainable integrated process since their amount is more than 85% and the impact of their treatment on environment and economy of the overall treatment process can be quite relevant. This chapter focused on the so-called smart facility that integrates processes based on thermochemical processes with the biological one targeting to increase the overall sustainability, the flexibility regarding the input biowaste composition, and the independency by the external factors affecting the waste trading.

Keywords: anaerobic digestion, biomethane, hydrochar, carbonization, gasification, smart facility, sustainable waste management

1. Introduction

Biowaste can be defined as a mixture of vegetal and animal biomasses that are residues of human activities. It contains large carbon-based macromolecules that can be used as a renewable material for energy production, carbon sequestration, and soil conditioner and fertilizer. Nevertheless, biowaste management requires a specific attention in order to increase the overall sustainability of the treatment and to define guidelines to increase its effective recovery. In Europe, more than 118 millions of tons of biodegradable waste are produced each year; only 25% of this amount is collected and sent to the given recovery option [1]. The recovery treatments are mainly based on biological processes: the most used is the composting (low capital and operating cost, low value of products) followed by the integrated anaerobic/aerobic digestion (medium–high capital cost, low operating cost,

medium value of products, depending of country incentives program). Although the composting is widely used, its sustainability is not always guaranteed because of long process time, large areas needed for storage and processing, environmental impact due to annoying odors released by diffuse and fugitive emissions other than a not favorable ratio between the value of the product (compost), and the cost of the process. The recourse to an anaerobic digestion as preliminary stage allows to improve the overall process by permitting the production of biogas in addition to the compost. The main limitation of biological process is the low economic value of the compost obtained from biowaste coming from separate collection of municipal waste. This important source of biodegradable matter is often contaminated by other waste with a fraction between 10 and 25%, depending on the waste collection system adopted for the separate collection [2–4]. The presence of this fraction, generally represented by plastics and metals, can further decrease the economic value of the compost that is sold at a price between 0 and 3 €/Mg [5].

An alternative to compost production is the transformation of the biowaste, including digestate, into different products, either solid, liquid, or gaseous obtained by means of thermochemical treatments. Depending on the specific production process and feedstock, the obtained products are different: thermal decomposition of wood, peat, or some related natural organic materials produces charcoal [6, 7]; the torrefaction produces biocoal [8]; if the charred organic matter is applied to soil with the intent to improve soil properties, it is called biochar [9]; moreover, the product of hydrothermal pyrolysis, is called hydrochar [10].

The hydrothermal pyrolysis (HTC) converts all substrates containing carbohydrates and molecules, including biowaste, into hydrochar, gas, and leachate by means of extraction of nitrogen and oxygen in a subcritical water environment [11]. The HTC stage can be applied to the fresh biowaste or to the digestate produced by the anaerobic digestion plants. In this latter case, the integration is able to avoid the aerobic treatment that is time- and space-consuming and obtain a high-added value product, in a limited footprint. The other waste stream that needs to be exploited is the not biodegradable waste; the fate of this waste is the landfilling or the energy recovery by combustion [12], and the gate fee for its disposal strongly increased in the last years. The thermochemical processes applicable to this kind of waste are pyrolysis and gasification: the latter is preferable since it is energetically self-sustainable and allows to produce both heat and electricity [13–15]. The main advantage of gasification is the limited size of the plant and the possibility to install it with capacities starting from few hundreds of kilograms in an hour.

The present chapter aimed to demonstrate the feasibility of integration between small-scale thermochemical processes and the biowaste biological treatment facility with the target to reduce the waste production, increase the energy recovery, and, more in general, increase the sustainability of the plant.

2. Configuration of the base case anaerobic digestion facility

2.1 Description of the unit processes

The standard configuration of anaerobic digestion facility consists of the following sections:

- a. Acceptance, weight, and discharge of biowaste from the lorries
- b. Preliminary mechanical treatment and sorting

- c. Mixing between substrates having different moisture content and structure (e.g., lignin-based biowaste is added to food biowaste to increase permeability, moderate moisture content, and modify the C/H ratio)
- d. Pulping (only in case of wet digestion processes)
- e. Anaerobic digestion into one (unique bioreactor) or two stages (two in series reactors for hydrolysis and acetogenesis/methanation steps)
- f. Leachate recirculation and storage before treatment or delivery to the water treatment plant
- g. Aerobic stabilization of digestate (composting)
- h. Mechanical refining and foreign matter removal

The data and the information utilized in this work are based on a full-scale facility that utilizes a dry-batch technology to perform the anaerobic digestion, and it is integrated with the composting plant to obtain the mineralization of the digestate. The facility is located in the industrial area of Naples, Italy [5], and treat biowaste from household separate collection and restaurants.

The block diagram of the integrated processes is reported in **Figure 1**.

With reference to the unit processes labels reported in **Figure 1**, a short description is reported in the following paragraphs.

2.1.1 Pretreatment and sorting

The organic fraction of municipal solid waste contains a certain amount of foreign matter constituted by inorganic and organic nonbiodegradable materials such as glass, ceramic, metals, plastic bags, plastic closures, wires, etc. The size distribution of this fraction ranges from few millimeters up to several centimeters, allowing the removal of large objects by means of manual sorting and sieving in a trommel. Generally, the minimum size of the holes installed to remove the foreign matter is 5 cm. A photo of the waste removed by using the mechanical sorting after the bag opener (light-intensity shredding) is reported in **Figure 2**.

2.1.2 Anaerobic digestion

The anaerobic digestion is then carried out by using eight batch reactors operated by recurring to an operation mode by including the following phases: emptying (a), filling and mixing (b), and reaction (c). The reactors are sequentially operated in order to have a semicontinuous operation. Steps (a) and (b) require a couple of days to be carried out, that is why each bioreactor starts the reaction phase with a delay of two days; the reaction phase has a duration of 28 days. Each reactor is filled with about 200 t of fresh biowaste after the removal of a part of the digestate formed by the preceding cycle. The digestate remaining in the batch reactor (about 50%) is mixed with the fresh one, acting as an inoculum for the microbial growing kinetics.

The process is a dry-batchwise since the solids fraction in the reacting mass is larger than 30%. The level of moisture that ensures the microbial activity inside the reactors is maintained by feeding the leachate collected from the bottom of each reactor at the top of it. It is important to highlight that the reactors are not stirred and that heat transfer and water percolation are limiting factors for the process:

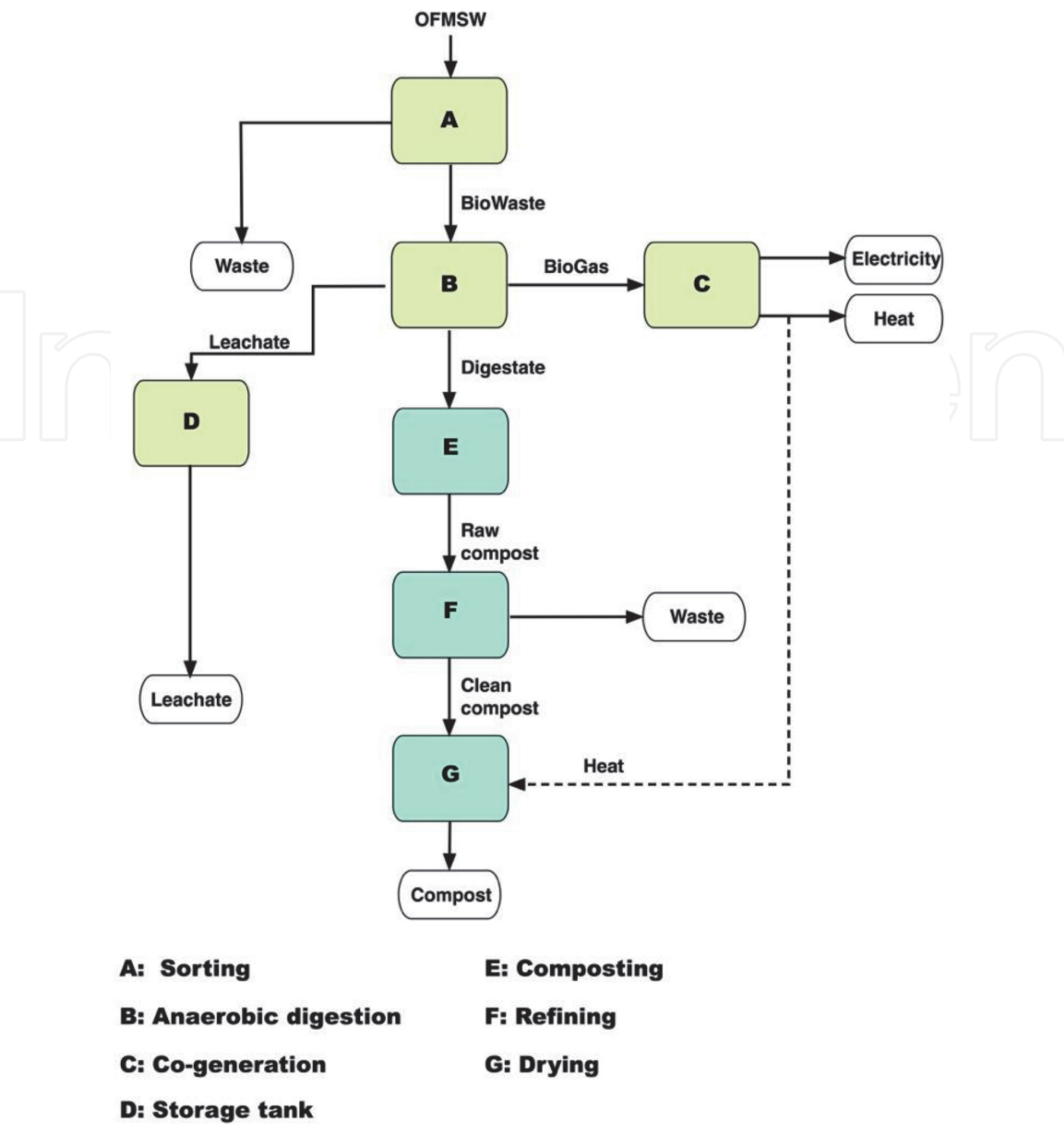


Figure 1.
Block diagram and unit processes included in the reference case.

without the recirculation of preheated leachate and the mixing with activated digestate, the process shall not occur in an appreciable way.

2.1.3 Cogeneration

The biogas generated by the anaerobic bioreactors resulted to be 5,040,000 Nm³ per year, corresponding to a production yield of 140 Nm³/t. This biogas is conditioned in order to remove hydrogen sulfide, ammonia, and moisture that results to be 5% in the final gas. The composition of biogas is variable, but the mean values are 60%_v of methane and 40%_v of carbon dioxide. The combustion of biogas is carried out in two 500 kWe Jenbacher engines that produce the electricity introduced in the public grid. The corresponding produced heat is recovered and used to enhance the composting process rate and drying the final compost.

2.1.4 Leachate storage tank

The leachate is produced during the anaerobic digestion thanks to the percolation of interstitial water from the substrate; a part of leachate is heated and



Figure 2.
Waste removed by the biowaste in the pretreatment stage.

recirculated inside the anaerobic bioreactors in order to keep the substrate humidified. The rest of the leachate is stored in a tank having a volume of 1000 m³ and sent to the external facility to be treated and disposed. The leachate corresponds to about 30–40% of the initial biowaste.

2.1.5 Composting

The aerobic stabilization of the unconverted volatile solids occurs in order to mineralize the substrate for a period of 90 days. The composting process requires air not only for chemical oxidation of volatile solids but also for the heat removal and odor dilution in the indoor environment. The aerobic treatment requires 16,000 Nm³ of air each Mg of digestate; that means that, in this specific case, 29,000 Nm³/h need to be continuously extracted from the warehouse and sent to the air treatment modules in order to be cleaned up. The air treatment system receives this stream containing odorigenous molecules including organics, acids, and ammonia; it is composed of a scrubbing unit followed by two biofilters; this system is designed in order to remove odor molecules from the conveyed air stream before the diffusion in the outdoor environment. Electricity consumption for air recirculation, biofilter replacement, and wastewater treatment are expenses for this stage of the overall process.

The aerobic stabilization is followed by the maturation and refining phases (F + G). The refining process aims to remove the foreign materials and obtain a homogenized size distribution. The moisture level in the compost is lowered at 5% by using the heat recovered by section C. This phase is required in order to produce a compost that can be sold on the market of fertilizers.

2.2 The critical issues of the present configuration

The mass balance of the plant in the present configuration is reported in **Table 1**. Data are in agreement with those obtained by other anaerobic facilities assessed in the scientific and technical literature [16–18].

	Input	Intermediate	Output			
	Biowaste	Digestate	Waste	Leachate	Biogas	Compost
Mass rate, Mg/day	35,000	15,600	4200	13,278	12.34	4471
Specific indicator, Mg/Mg	—	0.45	0.12	0.38	0.13	0.13

Table 1.
Mass balance of the reference facility.

The amount of produced waste, whose amount is depending on the separate collection performance, and that of leachate both represent a negative feature as well as for environmental and economic reasons: the delivery and disposal of leachate at external facilities requires about 50 €/Mg, while the tipping fee of the waste is more than 150 €/Mg. The impact of transportation should also be included in the environmental impact assessment and in the cost evaluation since the distance between treatment plant for waste and leachate can be quite large.

Moreover, the present configuration is economically sustainable only if electricity and/or biomethane is sustained by incentives. The value of green certificates for biogas is variable, but for 1 MW biogas facilities, an indicative value of 104 €/MWh can be used [19].

Despite the incentives for the obtained products (electricity/methane), and considering that the compost has a very low value, the cost of waste disposal and that of composting (aeration) result in the increase of biowaste tipping fee that, in Italy, leads the cost of the management of separate collected waste over 190 €/t [20]. Other countries in Europe have lower tipping fees for biowaste treatment due to less restrictions about digestate use (e.g., it is not mandatory to mineralize the digestate prior to the soil scattering) and a lower cost of waste disposal due to an efficient network of waste treatment facilities. This latter cost is anyway continuously increased in the last years due to the difficulty to process inside the Europe borders the plastic waste [12].

Based on these considerations and on the European guidelines about the proximity criterion, an improvement of the industrial layout of the facility can be proposed in order to reduce the impact and the cost of the whole system. This improvement is based on the integration inside the facility boundary of the processes that allow to:

- a. Treat the digestate in a more efficient way.
- b. Exploit the not biodegradable waste by avoiding disposing it outside the facility boundary.
- c. Treat the wastewater by using the heat produced by the integrated processes.

3. Configuration of the integrated anaerobic digestion facility

3.1 Description of the unit processes of the alternative configuration

The configuration of anaerobic digestion facility presented in **Figure 1** has been integrated with unit processes allowing:

- A sustainable production of a stable product (hydrochar) useful for agriculture purposes in place of compost

- The energy and heat production from the waste by minimizing the amount of waste to be disposed outside the facility boundary and its economic cost
- The treatment of leachate by using an effective evaporation method carried out by using the accumulated sensible heat and the recovered heat from the waste conversion

The unit processes able to reach the abovementioned targets have been reported in the integrated block diagram in **Figure 3** and described in detail in the following paragraphs.

3.1.1 Pulping and filtering

The digestate contains about 70% of moisture, as resulted from the mean values of the proximate and ultimate analyses reported in **Table 2** [21].

In this stage, it is conditioned in order to be suitable to undergo a thermal process aimed to hydrochar production, instead of the aerobic biological process aimed to compost production.

The hydrochar production process (F) occurs with very good efficiency if the organic fraction of digestate is in a pulping state, well mixed with water, and with a given water/dry matter ratio; this means that the mixing and pulping preprocessing has to be realized.

The pulping process allows to deal with another negative feature of digestate composition: the presence of foreign matter (inorganic or not reactive organics). In fact, a critical characteristic of digestate is the content of foreign matter such as glass, stones, and plastics that cannot be removed by the sorting made in the pretreatment stage where only the coarser fraction of foreign matter having a mean size larger than 5 mm is removed during the presorting; the remaining amount is not negligible and can be responsible of a dramatic decrease of the value of the final product if not removed. The pulping process between the digestate and the added water allows to separate the foreign matter by filtering the mixture following standard techniques applied in well-known wet anaerobic processes pretreatment. In this specific case, the digestate is mixed with the leachate produced by the anaerobic digestion in such a way to prepare a homogeneous pulp by respecting a given value of the parameter R (Eq. 1). In Eq. 1, $w_{digestate}$ is the weight of the digestate and $x_{H_2O,digestate}$ is the mass fraction of the moisture in the digestate.

$$R = (w_{digestate} \cdot x_{H_2O,digestate} + w_{H_2O,added}) / [w_{digestate} \cdot (1 - x_{H_2O,digestate})] \quad (1)$$

The pulping process can be favored by the preheating of leachate at about 70–80°C and by an intense shredding of the pulp itself. In this way, the foreign matter can be removed with very high efficacy (**Figure 4**, right) by floating (low-density fraction), by sedimentation (high-density fraction), and by sieving. The pulping creates the best conditions for this filtering/cleaning process and for the following reacting process reported in step F.

3.1.2 Hydrothermal carbonization

The hydrothermal carbonization (HTC) is a thermochemical process occurring in the presence of subcritical, liquid water: the target of this “wet or hydrous pyrolysis” is making products with higher carbon content, that are biologically inert, and with physical characteristics that make them suitable for agricultural or

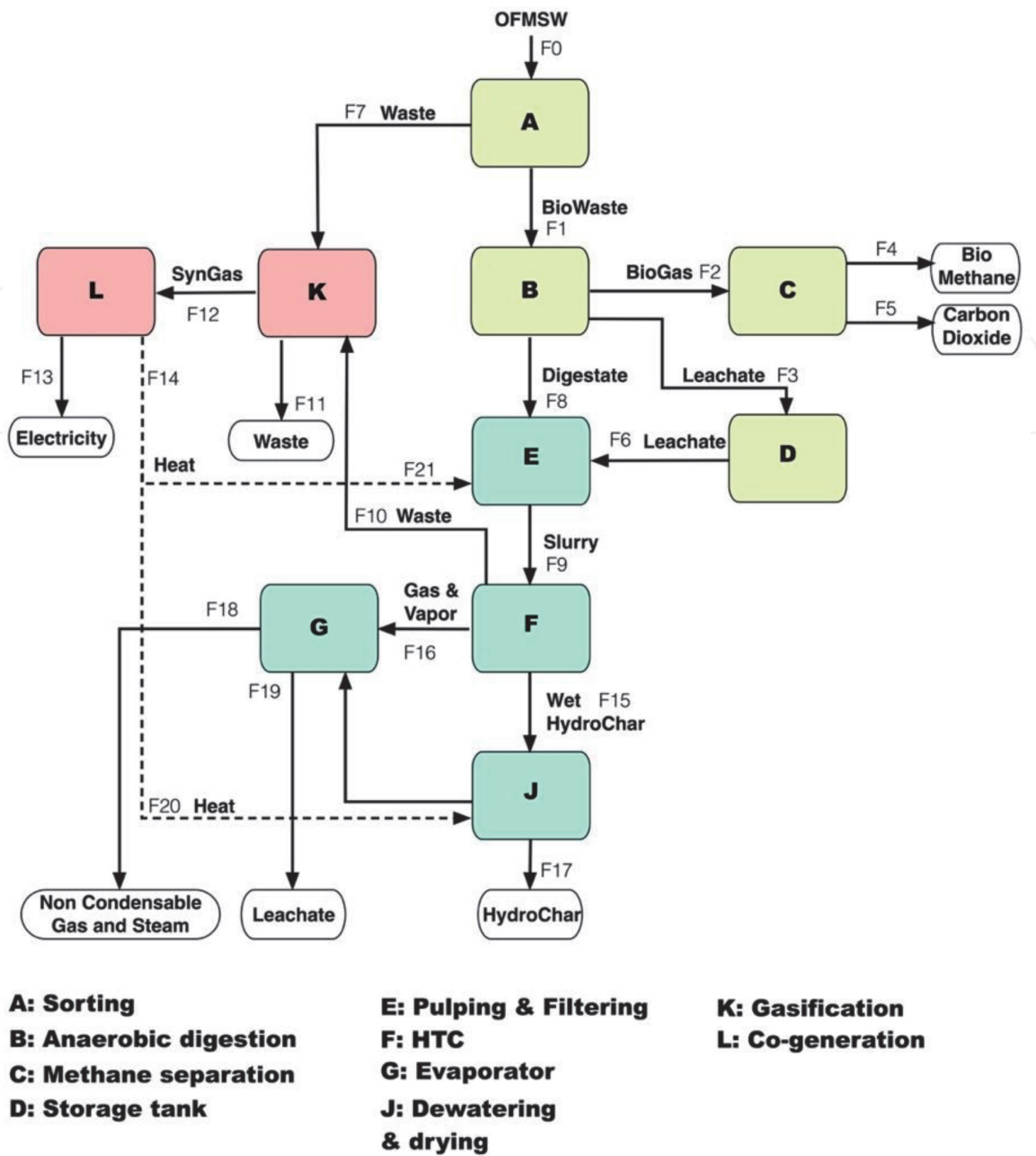


Figure 3.
Block diagram and unit processes of the proposed integrated facility.

Carbon, %	Hydrogen, %	Nitrogen, %	Oxygen, %	Ash, %	Moisture, %
32.82 ± 1.2%	4.25 ± 0.2%	2.11 ± 0.08%	33.93 ± 3.2%	26.89 ± 3.6%	69.85 ± 2.4%

Table 2.
Proximate and ultimate analyses of digestate (dry basis).

industrial purposes. The product obtained from the hydrous pyrolysis is called hydrochar to distinguish it from the biochar that is obtained by dry pyrolysis [22, 23]. During the hydrothermal process, the volatile solids contained in the digestate are surrounded by water which is kept at liquid state by allowing the pressure to rise until the endogenous value reached at the reactor temperature. The production of gases is very limited (1–5%), while dissolution of elements in the water can have a certain extent such as 5–20% [24]. The carbonization requires a reaction time of hours (1–12 h), depending on the reaction’s temperature utilized, and occurs in a closed reactor by allowing the elimination of diffuse release of odors.



Figure 4.
Photos of digestate (left) and pulp (right).

Moreover, the high temperature destroys pathogens and active organic molecules. The resulted hydrochar may contribute to climate change mitigation and soil amelioration [24]. The HTC process is basically a decomposition process where chemical reactions such as hydrolysis, dehydration, decarboxylation, aromatization, and condensation occur [25]. The hydrolysis's activation energy is lower than the other reactions; this lowers the decomposition temperature of the main constituents of biomasses: cellulose and lignin, for example, decompose between 180 and 220°C.

The reactor where the HTC is carried out is a batch reactor, filled with the pulp obtained by mixing, stirring, and filtering digestate and leachate and heated up to the reaction temperature in a given heating time. A schematic process flow diagram of the HTC section is reported in **Figure 5**.

The pressure inside the reactor is determined by the temperature setup for the reaction; the temperature vs. pressure correlation can be obtained by the Antoine equation.

In the specific case of this simulation, the HTC operating conditions are reported in **Table 3**.

3.1.3 Evaporator

This stage realizes the evaporation of water under the form of steam by using the pressure difference between the reactor and the evaporator and the sensible heat of the liquid water. The evaporation allows to realize the separation of the pure water under the form of vapor from a concentrated flow, having a higher boiling temperature. The concentrated flow is rich in nitrogen and carbon; it is sterile and could be used as fertilizer, in case the regulations allow this application. The worst case is to consider it as leachate, as in the case of **Figure 3**. The steam can be condensed or lost in the atmosphere, depending on specific cases.

3.1.4 Dewatering and drying

The wet hydrochar is sent to dewatering, which is quite efficient due to its hydrophobia [26], and finally dried.

3.1.5 Gasification

The waste produced by the anaerobic digestion facility consists mainly of plastic bags and dishes, foils, and a limited amount of metals. It is basically a combustible

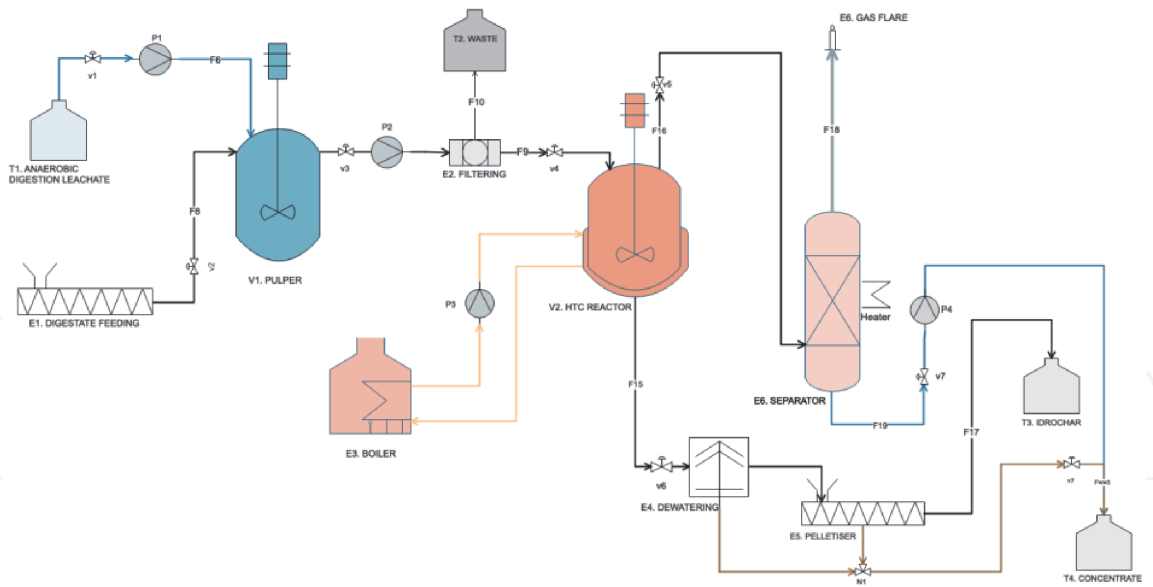


Figure 5.
Process flow diagram of HTC section.

Temperature of reaction	°C	220
Pressure	Bar	19
Water/digestate ratio	Mg/Mg	0.90
Reaction time	h	6.0
Reactor heating time	h	0.4
Reactor charge-discharge time	h	1.0
Total treatment time	h	7.4

Table 3.
HTC reactor and process parameters.

material having a moisture content until 20% and it is very dirty. Its fate is the landfilling or energy recovery in large incineration plants.

The integration of the AD plant with a small-scale gasifier allows to reduce the disposal costs and the production of electricity and heat necessary for the other processes.

The gasification unit basically consists of a downdraft reactor equipped with a fixed bed as support for the primary reactions of the combustible material with water and air, three plasma torches aligned with the bed surface, a secondary zone where homogeneous reactions take place, and a secondary stream of air that is added to favor the reactions' completion. The gasification reactions occurring on the plastic-based waste are responsible of a large production of hydrocarbons and aromatics (PAHs), partly transformed into tar, that need to be minimized in the syngas than the primary and secondary methods [13, 15, 27, 28]. In this specific case, the minimization of tar content is guaranteed by a mechanism of thermal cracking coupled with the saturation of produced radicals promoted in a secondary cracking reactor, located at syngas exit. The thermal cracking is realized by obligating the syngas by passing throughout a plasma plume composed of oxygen and hydroxyl radicals.

3.1.6 Energy production

The syngas is then sent to a cogeneration system to produce electricity and heat. Data related to the production of energy are reported in the following paragraphs.

A possible alternative is to convert the syngas into heat and use it to feed the leachate treatment process and increase the evaporation yield.

3.2 Assessment of the unit processes of the alternative configuration

3.2.1 HTC mass and energy balance

With reference to the section of the plant reported in **Figure 3** and destined to the hydrochar production and thickening of leachate, the mass balance is reported in **Table 4**. The flow ID are referred to in **Figure 3**.

The yield of hydrochar referred to the initial biowaste results to be 7%. The amount is quite similar to the compost yield, obtained by using the aerobic stabilization instead of the HTC process. The main differences are the following:

- a. The HTC process requires three cycles by day, each as long as 6 hours, and two closed batch reactors to reach the given yield.
- b. The HTC process does not emit odors and fugitive/diffuse emissions.
- c. The HTC process requires an area quite lower than that necessary for composting.
- d. The HTC can be conveniently coupled to a leachate treatment plant based on the evaporation/thickening standard processes available in the industrial market by using the heat content of liquid/vapor at the reactor outlet.

The energy balance of the HTC section is proposed in **Table 5**.

The heat necessary for the heating of the slurry from the input temperature (exit of filter) up to 220°C is 866 MJ/Mg (at 42.6 bar); once the reaction temperature is reached, the carbonization begins by absorbing heat from the environment until exothermic reactions begin. The heating time has been fixed in 0.4 h (1440 sec), so an installed heating power of about 10 MW is necessary to provide the heat in the specified time interval.

The thermal energy necessary to provide for the evaporation of water has been obtained by subtracting that requested to bring the water into vapor phase at 100°C and 1 bar to the thermal energy of the water medium present in the reactor. The amount of heat to carry out this process is 1366 MJ/Mg that corresponds to a thermal power of 9.7 MW, by assuming an evaporation time equal to that necessary for slurry’s heating. By using the energy content of water after the reactions are completed, it is possible to obtain the evaporation for about 78% of water

Flow ID	From	To	Mg/year	Description
F8	B	E	15,600	Digestate
F6	D	E	14,278	Leachate
F9	E	F	29,878	Slurry
F17	J	out	2526	Hydrochar (4.3% impurities)
F18	G	out	19,437	Gas and vapor
F19	G	out	6281	Leachate (concentrate)

Table 4.
HTC mass balance.

	F (slurry heating)		F (slurry reaction)	Evaporation	
From	E	F	F	F	F
To	F	F	F	J	F
ID	F9	F9		F18	F18
Mass amount (for each cycle and reactor)	16.06	16.06	16.06	13.01 (liquid)	10.19 (steam)
Physical state	l	l	l	l	g
P, bar	1.5	42.6	42.6	42.6	1.0
T, °C	43.8	220.0	220.0	220.0	105.0
Flow enthalpy, MJ	1242	15,162	1213	11,661	25,581
Reaction enthalpy, MJ			−1886		
Enthalpy to be provided, MJ	13,920		Negligible	13,920	

Table 5.
Evaluation of enthalpy flows for the unit processes E and F.

(10.19/13.01); the remaining fraction remains in the liquid form by forming a thick leachate with solute.

The hydrochar can be separated by water, by centrifugation, or by other standard dewatering systems.

The most important feature is that the leachate produced by the facility is reduced at 44% of that produced by anaerobic digestion sector, without increase of thermal heat, but that used for HTC reaction.

Further evaporation is technically possible and can be also economically feasible if heat demand is fulfilled by the third section of the plant: the gasification with energy recovery.

The overall feedstock energy balance is reported in **Table 6**.

The energy balance shows in brief that:

- The biogas contains 42% of the initial feedstock energy content
- The removed waste contains 37% of the initial feedstock energy content
- The hydrochar contains 20% of the initial feedstock energy content

The energy content of waste corresponds to about 3800 MW of chemical energy that can be used to produce energy by means of a gasification process, described in the following paragraph.

3.2.2 Gasification mass and energy balance

With reference to the section of the plant reported in **Figure 3** and destined to the conversion of waste into energy and heat, the data in **Table 7** are the basis for calculation. Data refer to the the typical waste resulting from the sorting of biowaste treated in the reference facility, just before being fed to digestors. These data are the starting point for calculation of calorific value, stoichiometric oxygen demand, bottom ash production rate, and other process parameters.

	Mass flow, Mg/year	Energy content, HHV, MJ/Mg	Energy flow, MJ/day
Raw biowaste	36,000.0	7437	892,392
Waste	4320.0	18,658	268,673
Biowaste	31,680.0	5906	623,719
Of which biodegradable	30,600.0	5456	556,551
Of which foreign matter	1080.0	18,658	67,168
<i>TOTAL IN (AD)</i>	<i>31,680.0</i>		
Biogas	6122.4	18,380	375,100
Leachate	14,277.6		
Digestate	11,280.0	6612	248,619
Of which foreign fraction in digestate (nonbiodegradable)	1080.0	18,658	67,168
<i>TOTAL IN (pulper)</i>	<i>28,218.2</i>		
Digestate	11,280.0	6612	248,619
Added water/leachate	16,938.2		
Removed foreign matter	972.0	18,658	60,451
Mixture	27,246.2	2072	188,168
Of which water	24,044.6		
Of which organic	3093.6	17,596	181,451
Of which foreign matter	108.0	18,658	6717
<i>TOTAL IN (HTC)</i>	<i>27,246.2</i>		
Gas	624.2		
Liquid	24,096.4		
Hydrochar (dry)	2525.6	20,766	174,817
Of which foreign fraction	108.0	18,658	6717
<i>TOTAL OUT (HTC)</i>	<i>27,246.2</i>		

Table 6.
Energy balance.

The gasification process is carried out in a plant that is composed of two sections:

- a. Thermal conversion under partial oxidation conditions
- b. Energy recovery (with two options: electricity and heat or only heat)

The conversion section is composed of the gasifier itself and the thermal cracking reactor where the tar undergoes cracking and upgrading. The gasifier is fed with the waste once shredded and compacted in order to increase the bulk density at a suitable value to guarantee a constant mechanical feeding. The waste is then converted into syngas by recurring to a thermal cracking at high temperature, sustained by plasma torches, providing a thermal load of 125 kW.

The gasifier temperature as obtained by the energy balance results to be 1350°C in the homogeneous phase. The air-to-waste ratio has been fixed at 2.13 and corresponds to an equivalence ratio of 0.25.

The main input and output parameters are reported in **Table 8**.

Commodity item, #	Weight fraction, %	Ultimate analysis	Weight fraction, %
Metals	0.5%	C	51.71%
Biowaste	15%	H	9.25%
Plastics	68%	O	12.41%
Paper and cardboard	10%	N	0.85%
Glass and inerts	2%	Cl	2.42%
Wood	5%	S	0.28%
		Moisture	17.06%
		Ash	5.56%

Table 7.
Waste characterization.

Waste flow rate	0.668	Mg/h
Air flow rate	1425	Nm ³ /h
Bottom ash	34.15	kg/h
Syngas flow rate (humid)	2059	kg/h
Syngas yield (dry)	1832	Nm ³ /t
Syngas calorific value (dry)	5.71	MJ/Nm ³
Engine electricity generated power	832.2	kWe
Cogenerated heat	1058	kWe
Plasma torch absorption	75	kWe
Plasma torch installed power	150	kWe
Cold gas efficiency (CGE)	0.70	—

Table 8.
Gasification parameters and calculated data.

4. Conclusions

The integration between the anaerobic digestion plant of biowaste with thermo-chemical processes such as hydrothermal carbonization coupled with the evaporation/thickening process and gasification of nonbiodegradable waste has been proposed and described.

The mass and energy balances have been reported in order to evaluate the feasibility of the proposed integrated “smart” facility.

The advantages obtained by using the smart facility design can be briefly summarized as follows:

- The waste production destined to disposal decreased by 95%.
- The leachate to be disposed decreased by more than 66%.
- The electricity produced is 5370 MWh/year.
- The hydrochar can be sold in the market or used as fuel in the gasifier.

By an economic point of view, the capital cost of the smart facility increases by a factor of 3. Anyway, the operating costs strongly decreased by considering the savings connected to the above listed advantages.

The strong reduction of transportation of waste and leachate by trucks, the minimization of air pollution and odor emission, the possibility to cover the electricity cost by self-producing itself without grid losses, the reduction of waste volume of more 95%, and the production of clean biofuel (biomethane) and a high-added value char (hydrochar), all these positive features allow to consider the smart facility and even a green facility.

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Conflict of interest


The author declares no conflict of interest.

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