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Energy Valorisation of Wastewater Treatment Plant Sludge through Thermal Gasification: An Economic Perspective †

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Abstract: The technical-economic analysis was carried out for the production of sludge-derived fuel from a municipal wastewater treatment plant (WWTP). The baseline for the analysis consists of a sludge drying plant, processing 6 m^3 of sludge per day and producing a total of about 1 m^3 of combustible material with 8% of moisture and a higher calorific power of 18.702 MJ/kg. The transformation of biofuel into energy translates into an electricity production of about 108 kW per 100 kg of sludge. The project in the baseline scenario demonstrated feasibility with a payback time of about six years.

Keywords: sludge; gasification; drying and economic evaluation

1. Introduction

Enormous amounts of sludge with high organic content are produced at different stages of the wastewater treatment plant (WWTP) treatment. The sludge production rate varies according to the country and region, and is directly related to the characteristics of wastewater and the processes applied in the treatment [1]. By 2020, Europe is expected to be responsible for generating 12 million tons per year, with an estimated sludge production rate being around 0.1 to 30.8 kg per population equivalent per year (kg/PE/year) [2].

In Portugal, in 2016, 700,000 tons of these "wastes" were generated, where this fraction is sent to landfill and represents a significant quantitative value, ranging between 50% and 60% of the material processed in the installation [3].

Several technologies are being developed to convert sewage sludge into usable energy, with anaerobic digestion and incineration dominating the practical application of these processes [4]. The thermochemical conversion of the sludges into energy and fuel, has been widely studied and has been considered as one of the most attractive technologies to deal with cumulative amounts of production due to the increased number of WWTPs. The thermochemical process not only offers a massive reduction in volume, but also becomes effective in destroying pathogens agents [5].

The present study demonstrate a process model and technical-economic analysis for the production of centrifugal sludge-derived fuel from a municipal wastewater treatment plant (WWTP) and subsequent biofuel improvement and subsequent energy recovery.

2. Recovery Process

The sludge recovery process took place in a chair process, where it entered through a rotary dryer to remove a large percentage of the moisture, after, the dried sludge is sent to a pelletizing system which, after being turned into pellets, is ready for energy recovery by thermal gasification. This study aims to demonstrate the economic viability for drying and subsequent energy recovery of WWTP sludge from a population of about 15,000 habitants, with a monthly production of 180 tons of sludge, which amounts to about 0.4 kg/hab per day. This required a qualitative characterization of the sludge produced (mass, volume, thermogravimetric and elemental analysis), as well as technical and economic evaluation of the drying system and the recovery system (gasification).

From the above, several tests were performed to characterize the collected sludge, whose characteristics are represented in the following Table 1.

Table 1. Characterization of the sludge from the wastewater treatment plant.

Properties	Parameters	Values
Apparent density (kg/m^3)		1048
Ultimate analysis	Moisture (wt% ar) [1]	86.7
	Volatile matter (wt% db) [2]	69.1
	Ashes (wt% db)	23
	Fixed carbon (wt% db)	7.9
Chlorine content (wt% db)		0.1
Higher Heating Value (HHV) (MJ/kg db)		18.7

[1] Weight percent, as received basis. [2] Weight percent, dry basis.

Based on the process, the mass balance was defined, accounting for all the inputs and outputs that involves the process. After the sludge storage process, where there is a preheat to remove 6% moisture (from 86% to 80%), the sludge goes through a chain aiming at the optimization (drying and pelletizing) of raw material that will later enter in the gasifier. Said chain is composed of a rotary dryer (3 m^3/h) that reduces the sludge humidity up to about 26%, followed by a pelletizing system (100 kg/h), where the sludge finally attains a humidity of 8%.

The sludge pellets are gasified in an updraft fluidized bed thermal gasification reactor (100 kg/h) where it becomes a combustible gas called syngas. After cleaning in a filter and a condenser system, this syngas will be burned in an internal combustion engine for power generation. In this type of gasifier, the fuel is processed at temperatures between 700 °C and 900 °C. Fluidization of the bed is achieved by introducing air from the bottom of the reactor and a layer of sand into the reactor, usually dolomite, to keep the biomass in suspension. The most important features of this type of gasification are: flexibility for changes in fuel properties, sizes and shapes; moisture up to 60%; and higher ash content.

3. Results and Discussion

The unit will be designed for the power to be injected at the receiving point be 150 kW, considering a power factor of 0.93. The values used in the calculations are shown in Table 2.

Table 2. Important data for the feasibility calculations of the installation project.

Total Power to Install	
Gross Power (generator terminal power)	110 kW
Elevator Transformer Yield	99.20%
Line Losses	1.80%
Receiving Point	
Maximum power to be injected at the receiving point	0.110 MW
Power Factor	0.93

The project inputs include the dryer and oven, pelletizer, and gasifier, with 65.38, 126.5 and 270 kWh, respectively. The output involved in the process is related to the motor, with a production of 1,296,288 kWh.

3.1. Consumption and Production Indicators

The sum of all unit consumptions per day are shown below in Table 3.

Table 3. Consumptions per day of all units of the system.

Unit	Dryer	Pelletizer	Gasifier	Total
Electric Energy (kWh/day)	65.38	126.5	270	461.88

Regarding the indicators for the electricity produced, the gasification unit, as mentioned above, has a consumption capacity of 100 kg/h of sludge and 90 m^3/h of air, which corresponds to about 90 m^3/h of syngas produced. During experiments carried out at the Portalegre Polytechnic Institute, an average of 5 MJ/m^3 of lower calorific value syngas produced was obtained.

Knowing the efficiency of the internal combustion engine (30%) and the power generator (80%), we can use Formula (1).

$$Pe = Qsyngás\ .\ LHVsyngas\ .\ \eta Engine\ .\eta Generator;\ Pe = 90.02\ .5\ .0.3\ .0.8;\ Pe = 108{,}024\ \text{kW} \quad (1)$$

As planned in the project, the gasification unit will work for 12 h a day, 330 days a year, which translates into a total energy of 427.78 MWh/year.

3.2. Economic Feasibility Analysis

The added value will be energy and sludge reception (treatment). Actually, the cost for sludge final destination is approximately 35 €/ton, produced and dehydrated, so the energy recovery and drying unit would be left with dehydrated sludge for a total cost of €30, which would save about 14.3% of total cost currently charged.

3.2.1. Energy

The total annual production, which corresponds to 12 h per day, 27.5 days per month and 330 days per year, corresponds to a total of 427.78 MWh per year. Formula (2) was used in the calculation.

$$Pe = Eday\ .330;\ Pe = 1296{,}288\ .\ 330;\ Pe = 427{,}75\ \text{MWh/year} \quad (2)$$

As the unit foresees self-consumption, it has to account for the electricity consumed annually, which corresponds approximately to 152.42 MWh/year. For this calculation, Formula (3) was used.

$$Econsumed = Eday\ .330 \quad (3)$$

The difference between the produced energy and the consumed energy results in the sale of energy to the electricity grid at a total of 275.36 MWh/year which, after losses in the line (1.8%), corresponds to a total of 270.4 MWh/year, with a sale price of about 0.2 € [6]. With respect to economic indicators, the project has a net present value (NPV) of €134.619, an internal rate pf return (IRR) of 12.55% and a payback period of approximately six years. As the project is quite viable, no external funding is required for its implementation.

3.2.2. Justification of Equipment Costs

The costs involved for the acquisition/maintenance of the equipment are presented in Table 4.

Table 4. Costs involved in the acquisition and maintenance of the sludge energy recovery unit.

Unit	Rotary Dryer	Pelletizer	Gasifier	Operation	Investment
Price (€)	150,000	5000	140,431.2	21600	295,431.2
Maintenance/year (€)	7500	250	7021.56		36,371.56

Table 5 gives a summary of the parameters considered in the economic evaluation and the results calculated for annual cash flows, NPV and payback period (PP) for the unit proposed.

Table 5. Parameters for economic analysis and corresponding results for the construction of a gasification plant.

System Parameters		**Economic Evaluation Results**	
Type of gasifier	Bubbling fluidized bed	Profits (annual, k€)	70.947
Thermal power (MW)	Own consumption	Electric energy (k€)	54.08
Electrical power (MW)	0.108	Sludge (k€) (3% inflation rate year)	59.4
Feedstock	WWTP Sludge	Costs (annual, k€)	11.348
Quantity (ton/year)	363	Operating cost (k€)	31.185
Biomass HHV (MJ/kg)	18	Economic evaluation results	
Economic parameters		Annual cash flow (k€)	77.3
Investment (€/kW)	1300	IRR (%)	12.55
Price of electricity (€/kWh)	0.086	NPV (M€)	134.619
Operative costs (% investment)	12.311	PP (years)	6
Lifetime (years)	15		

4. Conclusions

The present study aimed to test the use of thermal gasification process as a way to valorize waste residues into a useful gas for energy production purposes, as well as to evaluate the economic feasibility of the construction of a plant able to process residues produced in a municipality waste water treatment plant. The justification for the investment is related to the current costs of landfill sludge deposition, 78,120 €/year, as well as the environmental policy governing of this co-product. Based on the economic assessment, the entity would save about 10,936 €/year (14.3%) and have an energy profit of 70,947 €/year.

Centered on the study and on the presented results, the feasibility of transforming sludge, high polluting waste into valuable, hydrogen-rich gas and other products that are highly relevant in terms of heating power and are of interest to the chemical industry was demonstrated.

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