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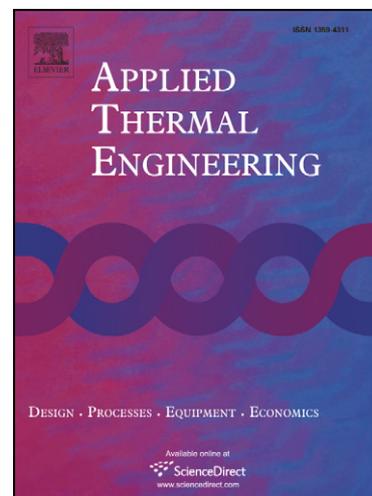
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COGENERATION PLANT IN AN OLIVE SLUDGE INDUSTRY

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Spain is the world's main producer of olive oil, with an annual production approaching one million tons. A great amount of wet residues are generated –mainly sludge–, thus favouring the development of energy plants for their treatment and/or elimination. Such installations require a simultaneous electric and thermal energy demand, and combined heat and power (CHP) systems might be the most adequate in certain cases. The economic viability of a CHP system in a sludge processing plant (sludge obtained from olive oil extraction industry) is analysed in the present work. Special attention is paid to the analysis and discussion of energy savings and environmental benefits.

Keywords: Combined heat and power (CHP); Sludge; Olive husk; Economic analysis.

Nomenclature

CHP	combined heat and power
E	electric energy (TJ)
F_k	annual cash flow at k th year (€)
IRR	internal rate of return (%/year)
NPV	net present value (€)
OH	olive husk
OMW	olive mill wastewater
PBT	payback time (months)
PE	purchased equipment cost (€)
PI	profitability index
Q	primary energy consumption, with respect to LHV (TJ)
EEE	equivalent electric efficiency (%)
R_{ee}	revenues from sale of electric energy (€/year)
R_{co}	revenues from sale of concentrated OMW (€/year)
R_{oh}	revenues from sale of olive husk (€/year)
R_{oo}	revenues from sale of olive oil (€/year)
TCI	total capital investment (€)
TOC	total operating cost (€/year)
V	useful thermal energy demand (TJ)

1. Introduction

Kyoto Protocol came into force on February 16th 2005, after ratification by at least 55 countries that represent 55% of the world's greenhouse gas emissions, in order to achieve a 5.2% reduction (from 1990 levels) in such global emissions by 2008-2012.

According to the Directive 2004/8/CE [1] of the European Parliament, the promotion of cogeneration on the basis of useful heat demand is priority, provided their benefits. Some of the most relevant among these are: (i) primary energy savings, (ii) elimination of energy loss in the electrical network and (iii) reduction of greenhouse gas emissions. Also, positive contribution to safe energy supply is also favoured.

Non-cogeneration systems involve heat produced in the boiler and electricity purchased from a utility, whereas cogeneration combines heat and electricity production from a single energy source. Overall cogeneration efficiencies (based on both the electrical and thermal energy products) of over 80% are achievable [2]. Besides, energy savings may reach 15-40% of the primary energy needs, if compared to the separate production of electric and thermal energy. The main limitation of the combined heat and power (CHP) scheme lies in its economic viability, since a high simultaneous utilisation of heat and power is required in most applications [3].

According to the statistics of the International Olive Council, Spain is the world's main olive oil producer, followed by Italy and Greece. The combined production of these three countries exceeds 70% of the world's total. Fig.1 shows the percentage contributions of the main producer countries for the season 2006-2007. The average annual virgin olive oil production in Spain approaches one million tons, which

corresponds to approximately 5.5 million tons of olives processed in extraction plants. The most currently used extraction system in Spain is the two-phase centrifugation, which is characterised by a relevant generation of sludge as a semi-solid residue. It is composed of olive husk (OH), of remaining oil in a proportion between 2.5% and 3.5% by weight, and of olive mill wastewater (OMW). The strong seasonality of olive oil production –mainly from November to February–, the high rates of sludge generation–approaching 80% by weight from the total olive mass processed in industry–, its high moisture content –normally 70% by weight (wet basis)–, as well as the presence of polyphenols and other organic compounds, make the treatment of this residue to be actually problematic.

Mechanical separation by centrifugation is commonly one of the first operations in the processing of sludge. This way, solid (OH) and liquid (OMW) phases, as well as oil, are obtained, and then specific actions are performed for each product. OH is composed of pulp, olive stones, residual oil and water in variable quantities within the range 50-55% [4, 5]. Once the added moisture content is reduced, OH is characterised by an average heating value in the range 18-22 MJ kg⁻¹ [6], which is sold on the market as solid fuel for small boilers. Taralas and Kontominas [7] analysed some other potential applications for OH, like hydrogen production by pyrolysis. OMW comes from the vegetable water of the fruit and the fresh water used during the process, and it contains olive pulp, mucilage, pectin, certain dissolved mineral salts, etc. The typical weight composition of OMW is [8]: 83-96 % water, 3.5-15 % organics and 0.5-2 % mineral salts. Vitolo, Petarca and Bresci [9] proposed different ways to treat OMW, such as evaporation, ultra filtration/reverse osmosis, anaerobic and aerobic digestion, specific chemical and biochemical treatments, manufacture of animal foods and incineration. In practice, the most common method to eliminate OMW is that of evaporation pools, provided low cost and favourable climate in the Mediterranean area. However, this procedure presents a series of objections such as bad smell, increase of insect population, flooding, filtration, need of vast areas and strong visual impact.

Caputo, Scacchia and Pelagagge [10] proposed a simultaneous energetic use of OH and OMW in centralised-combined scenarios, in order to achieve an integral management of this kind of sub-products. In particular, those authors described gasification, combustion (after mixing) and drying processes, followed by vapour cycles.

The direct drying process of high moisture content residues like sludge is subject to high energy costs. For this reason, small- and mid-sized cogeneration plants appear as an excellent alternative, using heat engines (internal combustion engines or gas turbines) to generate electric power apart from the thermal power required in the drying process. The use of a cogeneration plant for the processing of the sludge from olive oil industry is analysed in the present work. Primary energy savings in the production process, environmental benefits, as well as the most relevant economic magnitudes involved are pointed out, according to the new legislative framework set in the Spanish Royal Decree 661/2007 May 25th [11] which regulates the activities for electric power production subject to special regime.

2. Configuration of the cogeneration plant

One of the optional operations for the treatment of sludge are the extraction of the remaining olive oil and the drying of OH, so that it can be used as fuel. The OMW generated in these processes must be reduced in order to lessen the environmental impact. However, among some other disadvantages, their main limitation lies in their poor profitability.

A cogeneration scheme based on internal combustion engines was integrated to the previous technology with the aim of overcoming the economic limitations of the treatment of sludge. Fig.2 shows a scheme of the olive sludge industry under study. The process described here was structured in three main steps: three-phase centrifugation, thermal drying of OH and concentration of OMW.

The thermomixer was the first device in the centrifugation line, and it was fed with sludge from the reception basin, after an olive pulp/pit separation process. The sludge was then mixed and heated in order to maximise enzyme activity and the anti-emulsifying power of temperature. This way, further oil extraction was favoured. The thermal energy needed to raise the temperature of the sludge into the thermomixer was supplied by the cooling circuit of the internal combustion engines.

Once the sludge had been warmed up to about 35°C, it was taken to the three-phase decanter, where the components were separated according to their densities (1.2, 1.05 and 0.91 g/cm³ for OH, OMW and oil [4], respectively) by centrifugal action. Water supply into the decanter might be necessary in order to achieve an appropriate separation, in a rate of about 0.03 to 0.06 litre water per kilogram sludge, although the recirculation of OMW might allow a reduction of such value. Finally, the depletion of OMW took place in a vertical centrifuge.

The olive oil obtained after centrifugation was stored for further sale. OH was then taken to the drying unit, so that moisture content was reduced down to an approximate value of 15% by weight (wet basis). Provided efficiency and economic advantages, the selected setup was a direct contact rotary dryer. The biomass and the drying airflow were arranged in equiflow, in order to minimise volatility and to prevent fire risk. A gas-to-air heat exchanger allowed to reach an inlet-air temperature of about 400°C. Exhaust gases from the engines (at temperatures over 500°C) acted as hot fluid in the heat exchanger, and were channelled towards the chimney after cooling. The cold fluid was set to be an airflow pre-warmed to about 75°C in the air-coolers of the engine water circuit. Finally, the wet airflow was channelled across the cyclones, leaving the drying unit towards the OMW concentration tower.

Moreover, OMW was stored in an intermediate basin to feed the concentration tower, where a recirculation process until OMW got a final moisture content of about 60% by weight (wet basis) was performed. The drying agent in the concentration tower was on the one hand the wet airflow from the rotary dryer (at about 110°C), and on the other hand a 75°C hot airflow from the water-to-air heat exchanger of the engine jackets. The outlet of the OMW concentration tower was connected to the chimney so that wet air was emitted to the surroundings. The power of the plant's engines was maximized as stipulated by the Spanish Royal Decree 661/2007, with the corresponding bonus to the annual electric energy production. The thermal energy supplied by such engines exceeds the energy needs of the OMW drying process, which regards this simple OMW

dehydration device as being an economically favourable alternative if compared with other ones –like, for instance, the use of heat pumps-.

The power plant consisted of three internal combustion engines, powered by natural gas. In particular, two TBG620V16K model by Deutz (1355 kW unitary power according to DIN ISO 3046 code, 3393 kW ISO fuel consumption and 2.04 kg/s exhaust gas flow at 542°C) and one QSV81G model by Cummins Power Generation Ltd. (1639 kW unitary power, 4051 kW fuel consumption and 2.49 kg/s exhaust gas flow at 503°C).

3. Mass-energy balance and legislative framework

Plants operating in cogeneration mode during determined periods and as a strict electric power production plant during the rest of time are regulated by the European Directive 2004/8/CE, as well as by the Spanish Royal Decree 661/2007. In order to receive the corresponding subvention, 9.35 c€/kWh for all programming periods in this particular case, the plant should show a mean annual equivalent electric efficiency (EEE) equal or greater than that of table 1. In this situation, the minimum EEE (EEE_{min}) of the plant under study should be 55%. The EEE associated to the installation was calculated as:

$$EEE = \frac{E}{Q - \frac{V}{\eta_{ref}}} \quad (1)$$

where E represents the electric energy generated –measured at the alternator terminals–, Q the primary energy consumption with respect to the low heating value (LHV) of the fuel, V the useful thermal energy demand during the process and η_{ref} the reference value for the efficiency in separated heat production published by the Commission of European Communities on December 21st 2006 [12].

The analysis of the annual operation of the plant was based on mass and energy balances, assuming an annual reception of 25000 t sludge to be the reference value for dimensioning. However, it must be brought into mind that olive production -and hence sludge generation- generally presents significant annual variations. This is mainly caused by crop rotation: an abundant harvest is usually followed by a low flowering period. The storing pool capacity was then dimensioned as 22962 m³.

The criterion considered in the programming of the cogeneration plant operation was that of satisfying the thermal energy demand at EEE_{min} . The operation process was divided in two well-defined periods: cogeneration mode (in which all the sludge was processed) and strict electric power production (until EEE_{min} was reached). The initial values for the mass balance analysis were obtained either from previous experiments or from equipment manufacturers:

(i) Sludge reception basin: 70% by weight (wet basis) initial moisture content of sludge; 3.5% by weight (wet basis) remaining oil in sludge.

- (ii) Pit/pulp wet separation: pit separation 12% by weight from pit content of sludge (around 15%); 22% by weight (wet basis) moisture content of pit.
- (iii) Centrifugation phase: 5.66 t/h operating rate; 3% by weight (wet basis) fresh water added into the decanter (referenced to total sludge weight); recovered oil 45% by weight (referenced to total oil in sludge); non-recovered oil was retained in WOH (65%) and in OMW (35%); 60% by weight (wet basis) moisture content of WOH.
- (iv) Thermal drying phase: 15% by weight (web basis) final moisture content of dried olive husk (DOH).
- (v) OMW concentration tower: 60% by weight (wet basis) final moisture content of concentrated OMW.

The mass balance analysis was carried out for annual values of the main variables, according to a specific model developed by the authors. The most relevant results are shown in table 2.

Electric energy was used for:

- Wet husk/pulp separator.
- Internal transport of sludge.
- Centrifugation section (including thermomixer, horizontal and vertical centrifuges, vibrofilters and racking pumps).
- Thermal drying section (including rotary drier, fans, worm gears and pneumatic transport systems).
- OMW concentration tower (including pumps and fans).
- Internal combustion engine section (including pumps and fans).
- Lighting and general administration facilities.

The total electric power of the plant was 615 kW. In order to estimate the electric power demand for the different sections of the plant, a utilisation coefficient was associated to each installed electric power, which was defined as direct function of the daily working time and of the operating regime of each device (values determined experimentally). The electric power demand for each section is shown in Fig. 3.

Thermal energy was used for:

- Thermomixer; as hot water flow.
- Drier; as high temperature (400°C) airflow.
- OMW concentration tower; as low temperature (100°C) air/gas flow.

A detailed analysis of the electric and thermal energy demand of the system under study is a crucial task for further calculations [3]. Energy demand profiles can be estimated hourly, monthly or yearly, depending on accuracy needs for each particular system. In this sense, no fluctuations of the energy charge were observed for the installation reported here; instead, seasonal energy demand profiles followed an almost constant pattern. Therefore, according to the results of the energy analysis performed for an annual period, Table 3 shows the electric and thermal energy demanded/produced by the different sections of the process. The total electric energy demand of the plant reached about 8.68 TJ/year, 54.28% of which was consumed in the processing of the sludge, and the rest by the internal combustion engine auxiliaries.

The total thermal energy demand for the sludge treatment reached 60.61 TJ/year, and additional consumption of natural gas ($5.394 \cdot 10^6 \text{ Nm}^3/\text{year}$) by the internal combustion engines should also be considered. Therefore, the average energy supply rate required for the treatment of sludge was found to be 0.188 MJ/kg electric energy and 2.424 MJ/kg thermal energy.

The thermal energy required for the treatment of sludge represented 77% of the useful thermal energy supplied by the cogeneration plant (excluding the periods of strict electric power generation), while the electric power demand represented only 11.77% - thus favouring the marketing of the excess energy-

4. Energy-environmental analysis

The energy and environmental benefits derived from the use of cogeneration systems in the processing of sludge from the olive oil industry were analysed in order to evaluate the primary energy savings and the reduction of CO₂ equivalent emission.

If the thermal and electric energy separated production was considered, the primary energy needed to generate the electric energy equivalent to that of the producing process demand was found to be 9.95 TJ, assuming the sludge annual reception as 25000 t and reference value for the efficiency in separated electric production as $\eta_{el \text{ ref}} = 0.4733$, according to the guidelines published by the Commission of European Communities [12]. Such value for the electric efficiency was determined in terms of: (i) the type of fuel, natural gas; (ii) the date (year) of construction of the plant, 2002; (iii) the correction factor to account for the mean values of the weather parameters, which leads to a 0.3% reduction in the electric efficiency for the particular location of the plant referred to in the present work (Extremadura, Spain); (iv) the correction factor to account for the avoided loss to the electric network, based on the generation voltage (380 V) as well as on the electricity percentage consumed *in situ* (11.77%) and that transferred to the electric network (88.23%).

A primary energy of 73.91 TJ was required to generate the thermal energy equivalent to that needed in the process, provided that the harmonised thermal energy reference for separated production was $\eta_{th \text{ ref}} = 0.82$ [12]. As a consequence, the total primary energy need for separated production of electric and thermal energy for the industry was 83.86 TJ.

The total primary energy demand in cogeneration mode corresponds to natural gas consumption (LHV 38.52 MJ/Nm^3), and reached a value of 207.79 TJ. The electric energy to be transferred to the electric network –after the thermal and electric energy demands of the plant were satisfied- reached 65.04 TJ. If such electric energy had been generated under ordinary energy production regime conditions ($\eta_{th \text{ ref}} = 0.4733$), an equivalent 137.43 TJ primary energy consumption would have been achieved. Consequently, the net primary energy needs associated to the cogeneration mode could be evaluated as 70.36 TJ, thus achieving a significant energy saving (16%) if compared to the separated-production mode.

The CO₂ emission saving will depend on the base case scenario. According to the specifications of the Spanish Renewable Energies Plan for 2005-2010 [13], the CO₂ emission factor associated to the thermal use of natural gas is 55.80 kg CO₂/GJ. Similarly, the CO₂ emission factor for electric energy production was determined according to the technologies involved in the electricity production process from the same energy source –natural gas- (372 t CO₂/GWh indicated value for combined-cycle power plants and 54% electric efficiency). In the particular case reported here, the value for the CO₂ emission factor of the electric energy production process was estimated as 117.90 t CO₂/GJ).

The CO₂ emission factor for power and thermal use is applied, respectively, to the amount of electric energy considered at end-use and to the amount of gas burned. This way, the CO₂ equivalent emission of greenhouse gases were estimated according to the energy use in the plant. The reduction of CO₂ emission achieved by the cogeneration system in the plant was found to be about 753 annual tons. See results in Table 4 for further details.

5. Economic feasibility of cogeneration

A comparative economic analysis of a conventional sludge processing installation (separated production of thermal and electric energies) versus an installation incorporating the cogeneration system under study is carried out in the present section. Two possible scenarios were considered:

Scenario-1: additional cost of 12 €/t incoming sludge, according to the average price for 2006 campaign.

Scenario-2: no additional cost for incoming sludge, provided that transport costs are covered by olive oil industries.

This analysis was based on the following parameters: total capital investment (TCI, M€), total operating cost (TOC, M€/year), revenues from electric energy sale (R_{ee} , M€/year), revenues from olive oil sale (R_{oo} , M€/year) and revenues from dried OH (R_{oh} , M€/year). The TCI was evaluated as the sum of all direct and indirect costs of the plant. The former include purchased equipment cost (PE, M€), equipment installation cost (10% PE), control equipment cost (5% PE), pipes and tubes (5% PE), auxiliary facilities (7% PE), and civil work and buildings (15% PE), whereas the latter cover engineering, setting up of equipment and contractor fee (10% PE) (all percentages derived from the specific literature [14, 15]). The TOC including maintenance, insurance and personnel vary for different technologies, and annual costs range from 3% to 6% of TCI [16]. In particular, a value of 4% was used in this study.

The following values were considered for the cogeneration installation under study: direct costs 3.544 M€ (main and secondary basins 0.375 M€, centrifugation phase 0.270 M€, thermal drying phase 0.127 M€, OMW concentration tower 0.170 M€, engines 1.553 M€) and TCI 3.793 M€.

A value of 1.837 M€ was obtained for TOC, including natural gas and incoming sludge costs (only in scenario-1, as explained before). The reference price for natural gas was taken as 6.666 €/GJ.

The revenues from sale of electric energy (R_{ee} , M€/year), were calculated as the product of the net electric power transferred to the main supply (kW) times the annual operating hours (h/year) times the estimated sale price of the electric power (€/kWh). Two alternatives for the sale of net electric energy are allowed by Spanish legislation: (i) to transfer the electric power to a distributing company (in this case, the price will be set by means of a unique rate valid for all the programming periods); (ii) to sell the electric power in the free market (price will be that arising from the free market complemented by an incentive and/or an extra payment). In this situation, a price of 9.35 c€/kWh for all programming periods is established by the Royal Decree 661/2007, which regulates the installations for the treatment and reduction of sludge from olive oil industry.

Direct costs reached 1.289 M€ for the conventional plant, and only 1.432 M€ were devoted to the TCI. The value for the TOC was 0.7861 M€, which included: cost of natural gas to satisfy the thermal energy demand (6.666 €/GJ), cost of the electric energy demand (7.00 c€/kWh), and cost of incoming sludge (only in scenario-1).

The marketing of the olive oil obtained from a second centrifugation is not so relevant as that of the virgin oil. In fact, it has been subjected to significant price fluctuations for certain reasons along the years: from more than 0.78 €/kg before the 2001 crisis of the sector down to 0.42 €/kg in 2003. The price considered in the present analysis was approximated as 1€/kg (as for the last two years).

Dried OH are usually sold in bulk for thermal use at domestic and industrial scales, or even for animal feed production. A sale price of 0.0576 €/kg was considered here for wet husk, and 0.048 €/kg for OH. Finally, the concentrated OMW obtained in the process is sold as organic fertilizer, at a very reduced sale price (0.0060 €/kg).

The parameters used for the economic evaluation [17] of the proposal are the following:

(i) Net present value (NPV), defined as:

$$NPV = \sum_{k=1}^N F_k / (1+i)^k - TCI, \quad (2)$$

where N is the economic life (in years) of the plant, i the annual interest percentage rate and F_k the annual cash flow in the year k evaluated as follows:

$$F_k = R_{ee} + R_{oo} + R_{oh} + R_{co} - TOC \quad (3)$$

(ii) Profitability index (PI), obtained through the equation:

$$PI = \sum_{k=1}^N F_k / (1+i)^k / TCI \quad (4)$$

(iii) Internal rate of return (IRR), defined as the value of the interest rate that cancels the NPV.

(iv) Payback time (PBT), the period of time after which the investment is recovered.

The results obtained for the economic parameters relating to the comparison of the conventional plant versus that including the cogeneration system are shown in Table 5 for the two possible above-mentioned scenarios.

In scenario-1, the NPV associated to the conventional plant showed a negative value, which indicates a poor profitability for the traditional second-centrifugation oil extraction operation. The TCI showed a 164.87% increase for the cogeneration plant; however, a low –positive– NPV was found. Therefore, cogeneration appears as an efficient energy technique for the integral management of by-products. A negative NPV was also found for the conventional plant in scenario-2, although a 660% increase with respect to that of scenario-1 was observed. In this case, a 4.5-year period for the PBT was achieved, with a 17.7% generated interest rate.

The economics of CHP are very sensitive to fuel and electricity prices. Provided that price fluctuations are quite unpredictable, a specific parameter should be included to test the sensitivity of such changes. Therefore, an additional sensitivity analysis was carried out in order to evaluate possible fluctuations in the economic and operating variables from the results achieved in the present study. The variation range for each of the parameters involved as well as their influence on the NPV values are shown in Table 6.

6. Conclusions

The feasibility of CHP system for the industrial sludge treatment was studied from technical, environmental and economic points of view. Reductions in the primary energy demand (over 16%) as well as in the CO₂ equivalent greenhouse gases emission were achieved. Moreover, this kind of energy recovery system allows a profitable integral treatment of by-products from olive oil industry in small- and mid-sized plants.

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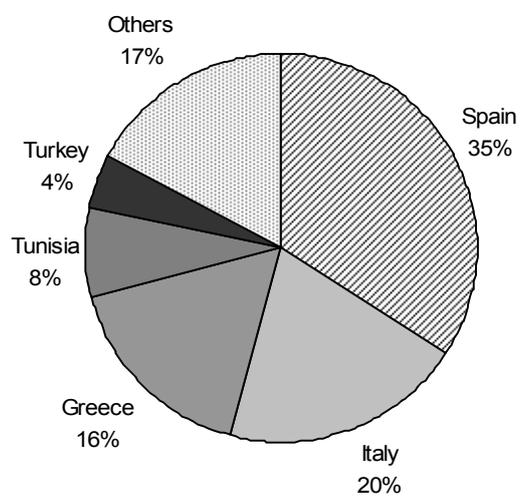
FIGURE CAPTIONS

Figure 1. Olive oil world production (2006-2007).

Figure 2. Cogeneration plant for the treatment of sludge from olive oil industry.

Figure 3. Sharing of the electric power demand (kW).

FIGURE 1



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FIGURE 2

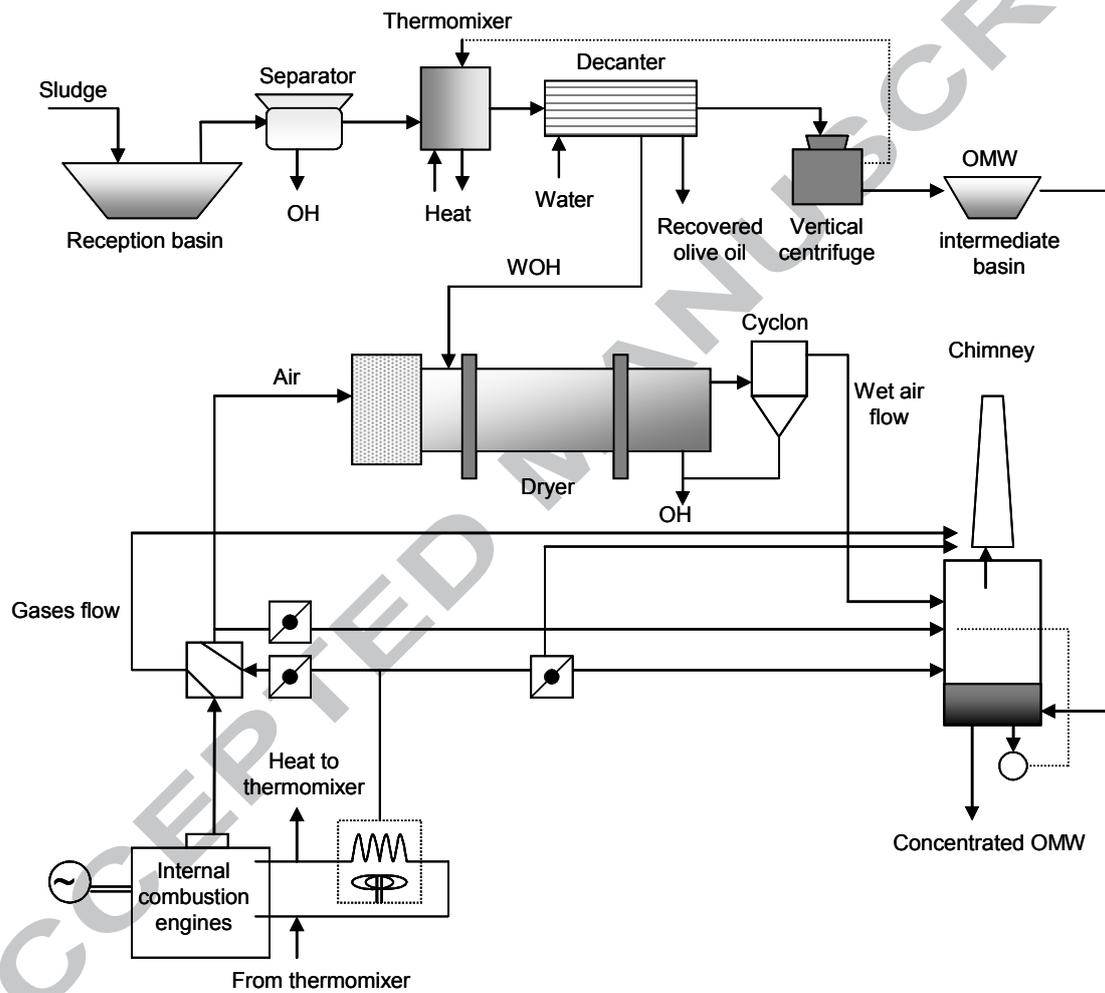


FIGURE 3

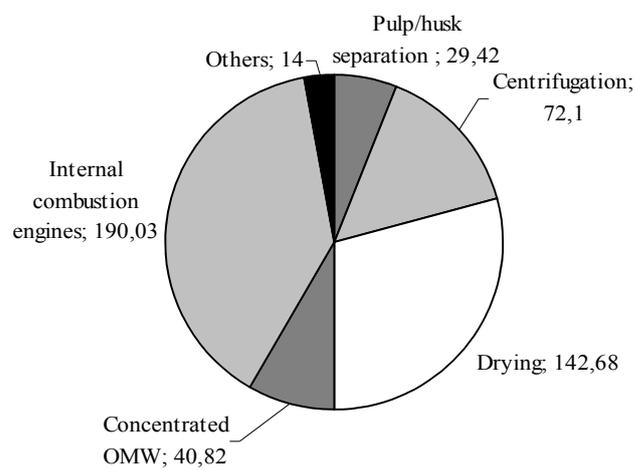


TABLE CAPTIONS

Table 1. Minimum values of EEE for different fuels and technologies.

Table 2. Results for annual mass balance of the plant.

Table 3. Results for annual energy balance of the cogeneration plant.

Table 4. Primary energy demand and CO₂ equivalent emission of greenhouse gases.

Table 5. Economic indexes for the plant under study.

Table 6. Values of the sensitivity analysis parameters.

TABLE 1

Type of fuel	EEE (%)
Liquid fuel in plants with boilers	49
Liquid fuel in thermal engines	56
Solid fuel	49
Natural gas and petroleum liquefied gas in thermal engines	55
Natural gas and petroleum liquefied gas in gas turbines	59
Other technologies and/or fuels	59
Biomass from energy cultures and from agricultural/forestry activities	30
Biomass from industrial installations	30
Biomass and/or biogas from anaerobic digestion of agricultural wastes, from industrial biodegradable residues and from wastewater treatment plant sludge	50

TABLE 2

Equipment	Input	Mass flow rate (t/h)	Amount of input (t)	Output	Mass flow rate (t/h)	Amount of output (t)
Basin	Sludge	-	25000	Sludge	8.39	25000
Wet husk separator	Sludge	8.39	25000	Wet husk	0.15	450
				Sludge	8.24	24550
Three-phase decanter	Sludge	5.50	24550	Olive oil	0.09	400
	Fresh water	0.16	715	Olive husk	2.19	9820
				OMW	3.37	15045
Dryer	Olive husk	2.20	9820	Dry olive husk	1.03	4604
Concentration tower	OMW	3.38	15045	Concentrated OMW	1.58	7062

TABLE 3

Equipment (including auxiliars)	Operating time (h/year)	Electric energy demanded/produced (TJ/year)	Thermal energy demanded/produced (TJ/year)
Basin-Wet husk separator	2980	0.31/-	-/-
Three-phase decanter	4470	1.16/-	4.66/-
Dryer	4470	2.29/-	18.70/-
Concentration tower	4470	0.65/-	37.23/-
Internal combustion engine	5800	3.96/73.72	207.79/101.72
Others	8640	0.28/-	-/-

TABLE 4

Separate production		Cogeneration	
<i>Energy</i>			
Electric energy (TJ)	9.95	Electric energy transferred to the network (TJ)	137.43
Thermal energy (TJ)	73.91	Natural gas burned (TJ)	207.79
Total (TJ)	83.86	Net (TJ)	70.36
		Annual saving (TJ)	13.50
<i>Greenhouse gases emissions</i>			
Electric energy (t CO ₂ /year)	556	Associated to electric energy transferred to the network (t CO ₂ /year)	7669
Thermal energy (t CO ₂ /year)	4124	Natural gas burned (t CO ₂ /year)	11595
Total (t CO ₂ /year)	4680	Net (t CO ₂ /year)	3926
		Annual saving (t CO ₂ /year)	754

TABLE 5

System	TCI (M€)	NPV (M€)	PI	IRR (%)	PBT (months)
<i>Scenario-1</i>					
Conventional	1.432	-2.57	-	-	-
Cogeneration	3.793	0.35	1.09	6.85	85
<i>Scenario-2</i>					
Conventional	1.432	-0.25	-	-	-
Cogeneration	3.793	2.66	1.70	17.7	54

TABLE 6

Parameter	Pessimistic value	Modal value	Optimistic value	% variation respect modal NPV value			
				Scenario-1		Scenario-2	
				Conventional	Cogeneration	Conventional	Cogeneration
Amount of sludge (x10 ³ t)	17.5	25	32.5	+7.39/-8.17	-462.88/+451.43	-204/+192	-86.84/+85.71
Sludge cost (€/t)	15	12	9	-22.57/+22.57	-165.71/+165.71	-	-
Gas price (€/GJ)	8.33	6.66	4.99	-25.29/+25.29	-765.71/+762.86	-260/+260	-100.37/+100.75
Interest rate (%)	6.25	5	3.75	-2.72/+2.72	-68.57/+74.28	-28/+28	-13.91/+15.41
Cost electricity purchased (c€/kWh)	7.48	9.35	11.22	-	-745.71/+745.71	-	-97.74/+98.12
Cost electricity sold (c€/kWh)	8.05	7	5.95	-3.89/+4.28	-	-44/+40	-
Recovered olive oil price (€/kg)	0.75	1.00	1.25	-29.57/+29.57	-220/+214.28	-304/+304	-28.57/+28.57