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Biochar production through hydrothermal carbonization: Energy efficiency and cost analysis of an industrial-scale plant

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Biochar production through Hydrothermal Carbonization (HTC): Energy efficiency and cost analysis of an industrial-scale plant

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Introduction

HYDROTHERMAL CARBONIZATION: → Coalification process that converts raw wet biomass into a coal like product → High carbon content; High calorific value

OPERATIVE CONDITIONS: →

- Substrates: organic waste (OFMSW, sewage sludge, wet agricultural residues, algae, etc)
- Moisture: > 75%
- Temperature: 180 – 250 °C
- Pressure: 10 -50 bar (autogenous)
- Residence time: 0.5 – 8 h

APPLICATIONS OF OBTAINED BIOCHAR: →

- Biofuels: co-firing in coal handling infrastructure
- Feedstock for supercritical water gasification
- Soil amendment
- Production of advanced materials (activated carbon)

AIM OF THE WORK: →

- Modelling of a semi-continuous industrial-scale process on the basis of experimental data of grape marc (GM) and off-specification compost (OSC);
- The model estimates: thermal energy and power consumption of the HTC plant; thermal and plant energy efficiencies; biochar production costs.

Material and methods

The model is based on HTC experimental results
performed in a stainless steel batch reactor (V = 50 mL)

EXPERIMENTAL DATA: →

Experimental parameters used in the model:

- Ultimate analysis and experimental HHV of feedstock and biochar.
- Yields of biochar and gas.
- Total organic content (TOC) of the liquid phase.
- Gaseous composition (CO2, CO, H_2, and CH_4).

FEEDSTOCK USED: →

Off-specification compost (OSC): published data
Grape marc (GM): published data

OPERATIVE CONDITIONS: →

- Dry biomass to water ratio DB/W = 0.07 for OSC, DB/W = 0.19 for GM
- Temperature: T = 180, 220, 250 °C
- Residence time: θ = 1, 3, 8 h

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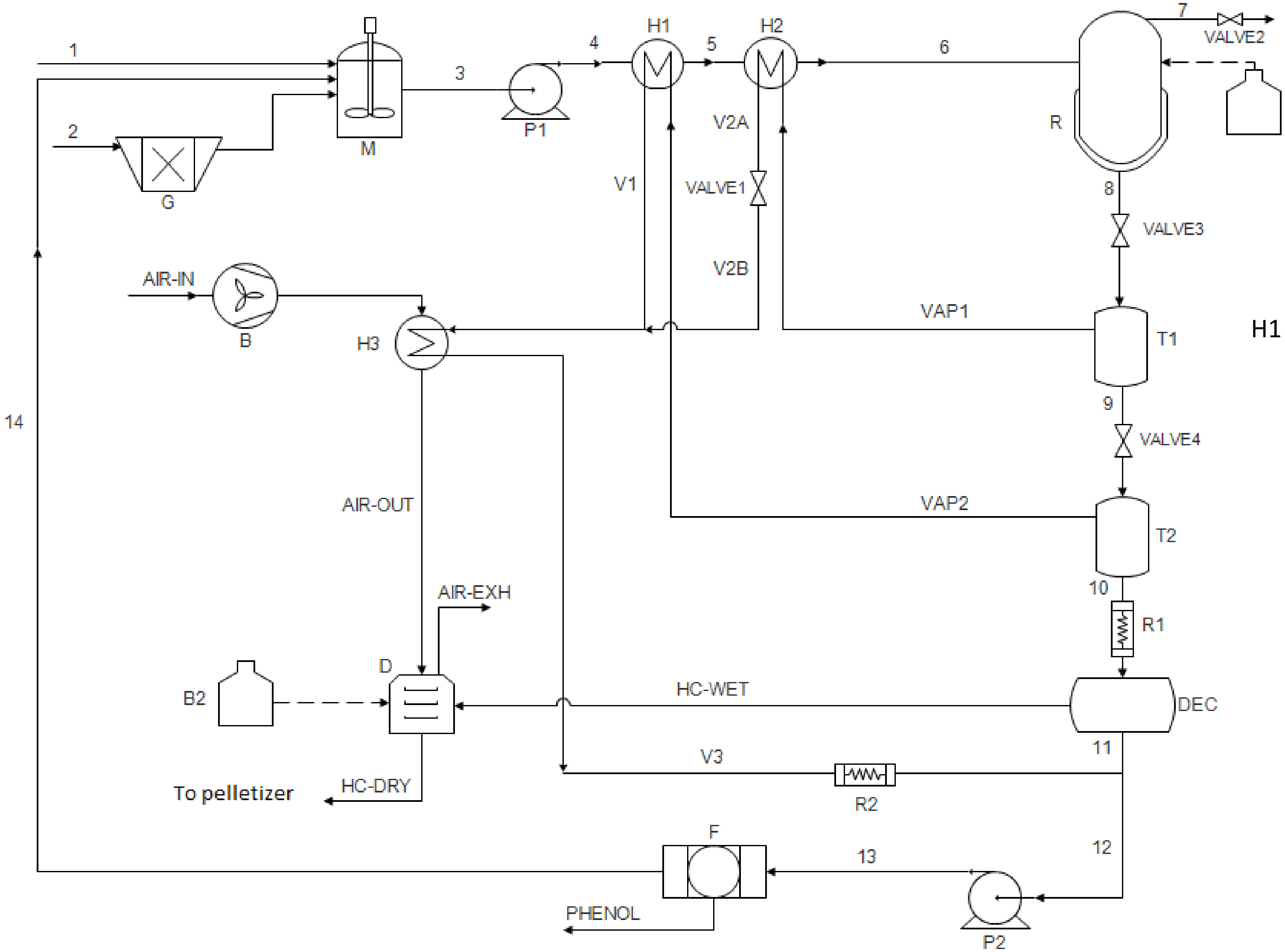
Material and methods: plant scheme



LEGEND:
G - grinder
M - mixer
P1 P2 - pumps
H1 H2 H3 - heat exchangers
R – HTC reactor
B1 B2 – burners
T1 T2 – flash tanks
DEC – decanter
D – air dryer
B – air blower
F – filter
R1 R2 – heat losses

Material and methods

PROCESS PARAMETERS:

- 8000 h/year of operating time
- 20000 ton/year of treatment capacity (2500kg/h)

	OSC	GM
Biomass as received (ton/y)	20,000	20,000
DB = Biomass db (ton/y)	14,000	7,000
Water added (ton/y)	200,000	23,840
W = Total water (ton/y)	206,000	36,840
Total flow rate (ton/y)	220,000	43,840
DB/W (-)	0.07	0.19
Biomass moisture content (%)	30	65

MODEL ASSUMPTIONS:

- Each piece of equipment stationary and adiabatic
- Heat losses simplified with 2 heat exchangers
- No material losses
- Pressure drops concentrated in the equipment

EFFICIENCY PARAMETERS:

$$Thermal\ efficiency = \frac{Energy_{HC,HHV}}{Energy_{th}}$$

$$Plant\ efficiency = \frac{Energy_{HC,HHV}}{Energy_{biomass,HHV} + Energy_{e} + Energy_{th}}$$

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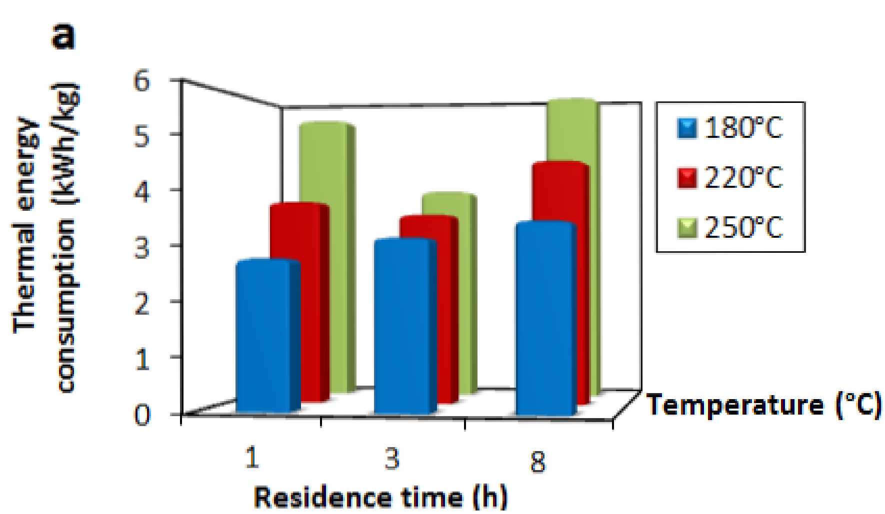
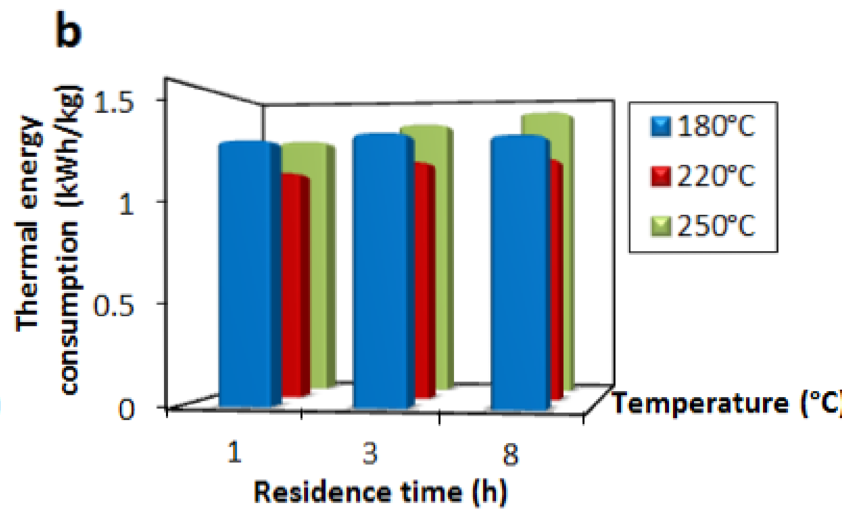
Results: thermal energy consumption

OFF SPECIFICATION COMPOST **GRAPE MARC**





Thermal energy:

OSC: 2.79-6.28 $kWh/kg_{biochar}$

Most of thermal energy (81.1%-91.7%) is required by burner B1

GM:1.17-1.50 $kWh/kg_{biochar}$

. No trend is evident. The lowest thermal energy is recorded at 220 °C.

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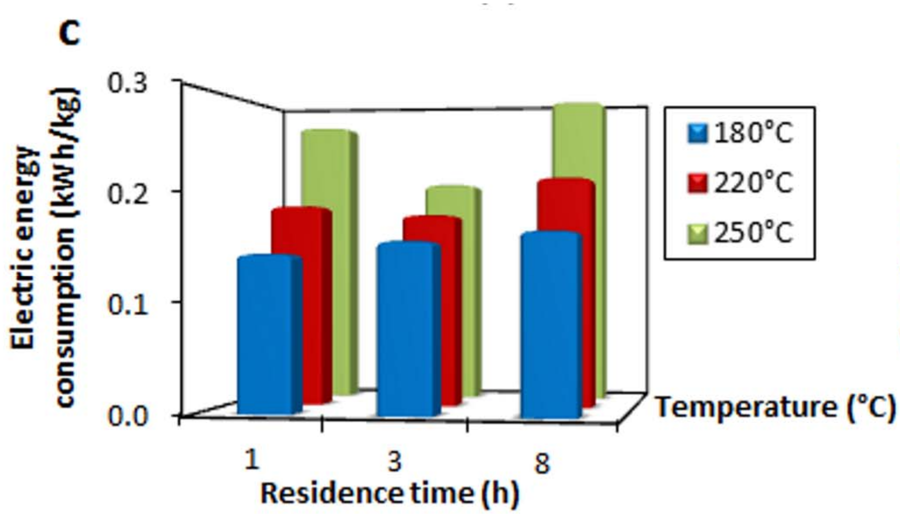
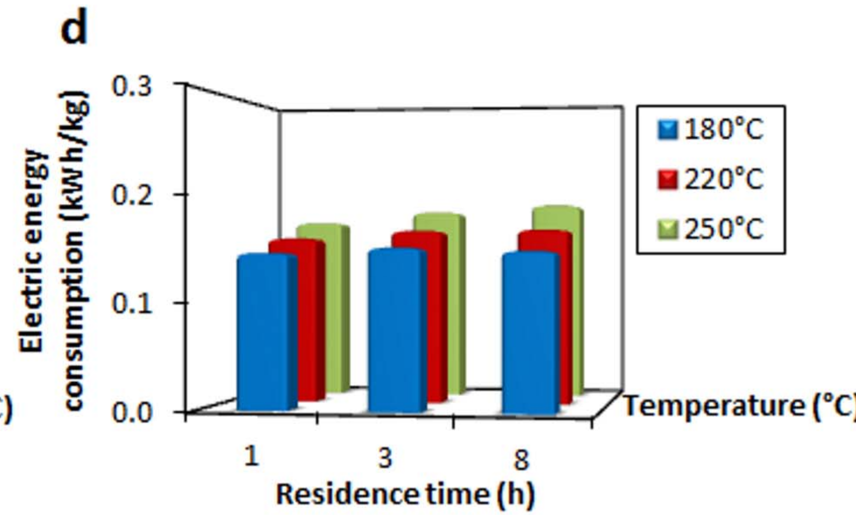
Results: electric energy consumption

OFF SPECIFICATION COMPOST



GRAPE MARC



Electrical energy:

< 0.30 $kWh/kg_{biochar}$ for GM and OSC.

Results:
thermal efficiency

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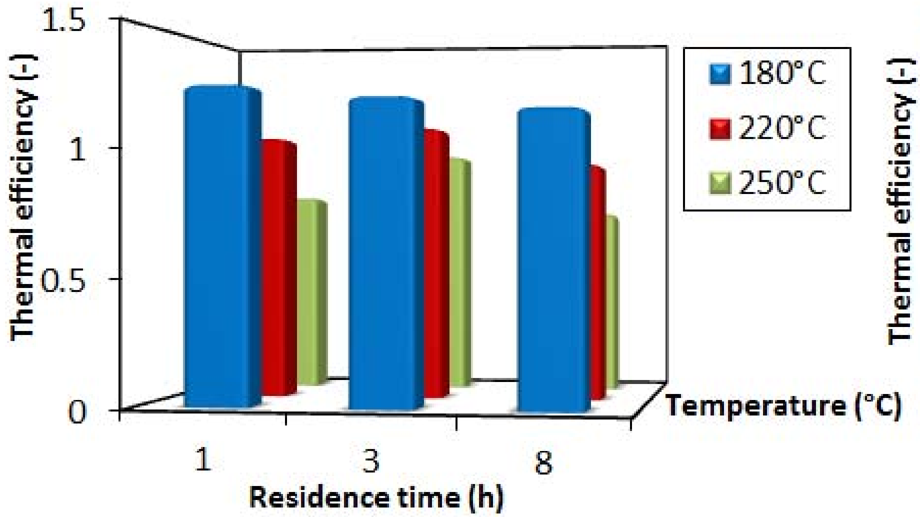

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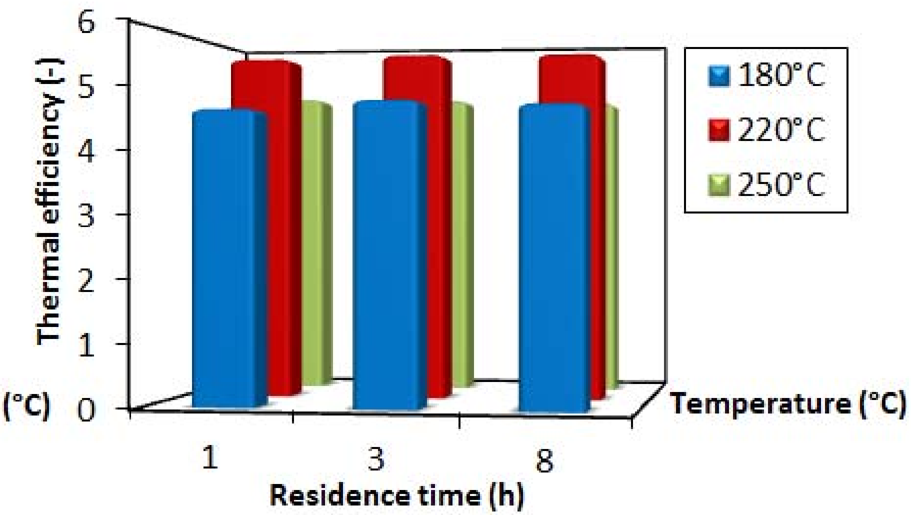

b

- Values are lower when using OSC with respect to GM due to the different DB/W (DB/W=0.07 for OSC and DB/W=0.19 for GM).
- At T>180 °C, the energy content of OSC-derived biochar cannot provide sufficient thermal energy to compensate for the thermal energy of the process.
- Thermal efficiency for GM ranges between 4.67 and 5.64: the relatively high DB/W chosen (=0.19) allows for significantly improved HTC thermal performance

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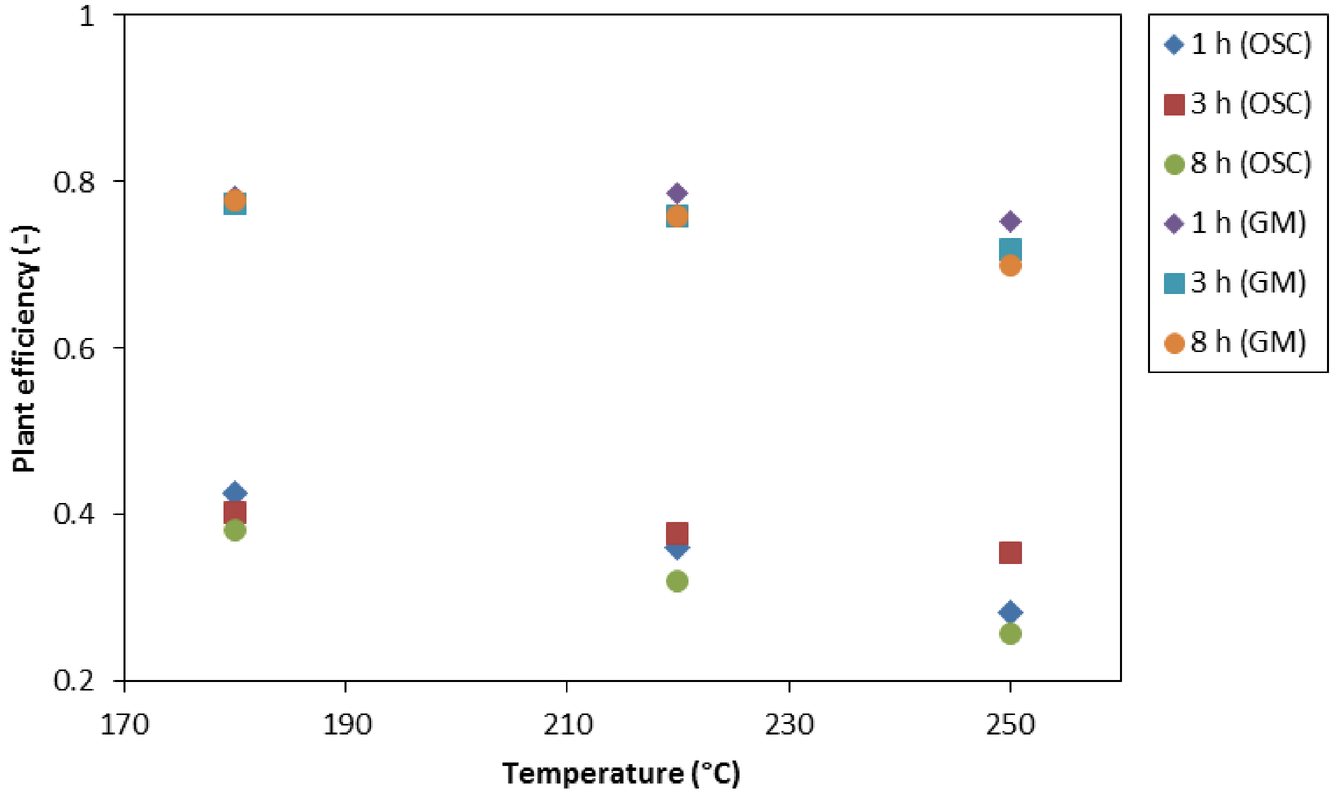
Results: plant efficiency



Plant efficiency decreases with temperature.

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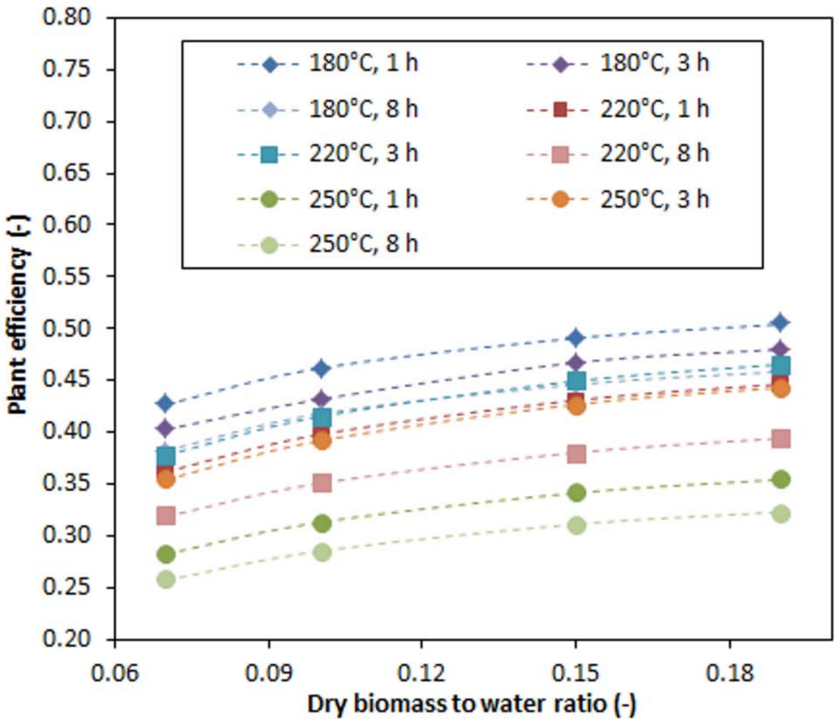
Results: plant efficiency

OFF SPECIFICATION COMPOST



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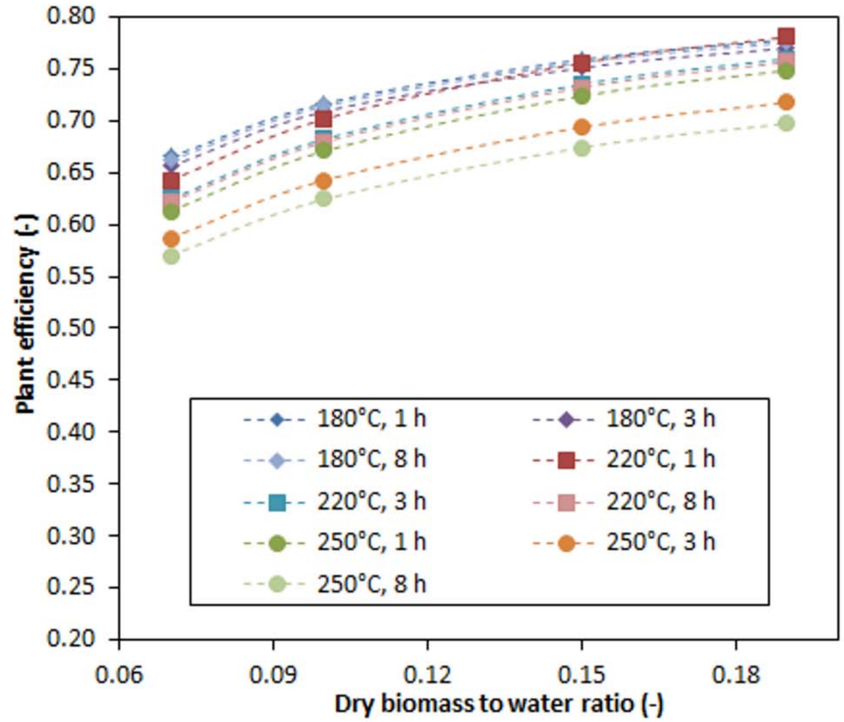
GRAPE MARC



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GM: plant efficiency is notably higher than for OSC values. This is due to the highest value of HHV of GM and also to the higher DB/W value used.

Results: economic feasibility

Best results from GM at T=220 °C, θ=1h and DB/W=0.19

Type of Unit	Cost (€)
Heat exchangers (H1, H2, H3)	32,983
Agitator	5110
Direct fired heaters	354,063
Reactor	436,051
Flash tanks	145,276
Pumps	57,237
Centrifuge	55,028
Crusher	10,739
Dryer	131,535
Filter	1359
Pelletizer	30,907
Total cost for on-site equipment	**1,260,288**

Cost linked to the capital	Annual Cost (€)
Average loan interest rate 5% (10 years)	229,717

Type of Unit	Cost (€)
Total depreciable capital (TDC)	1,260,288
On-site equipment	21,526
Utility plants	230,727
Contractor's fee and contingencies	30,251
Land	30,251
Plant start up	151,254
Working capital	79,765
Total capital investment (TCI)	**1,773,811**

Operating costs	Annual Cost (€)
Electricity	1,260,288
Methane	21,526
Labor related operations	230,727
Maintenance	30,251
Property taxes and insurance	30,251
General expenses	151,254
Waste water treatment	79,765
Total production costs	**832,984**

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Results: economic feasibility

Best results from GM at T=220 °C, θ=1h and DB/W=0.19

↓

Biochar production of 5317 ton/years

↓

Break-even point is 200€/ton

↓

Break-even point of wood pellets is 150 - 200€/ton: biochar is competitive

Conclusions:

In the most favorable conditions, i.e. GM at DB/W = 0.19, T = 220 °C and Θ = 1 h:

- plant efficiency : 78%
- specific thermal energy consumption: 1.17 $kWh/kg_{biochar}$ (0.31 $kWh/kg_{feedstock}$);
- specific electric energy consumption: 0.16 $kWh/kg_{biochar}$ (0.04 $kWh/kg_{feedstock}$);
- the production cost of pelletized biochar: 157 $€/ton_{biochar}$;
- the biochar break-even value for a plant repayment period of 10 years: 200 $€/ton_{biochar}$, (competitive with price of wood pellets, 150-200 $€/ton_{wood}$).