TORREFACTION OF FOREST RESIDUES USING A LAB-SCALE REACTOR

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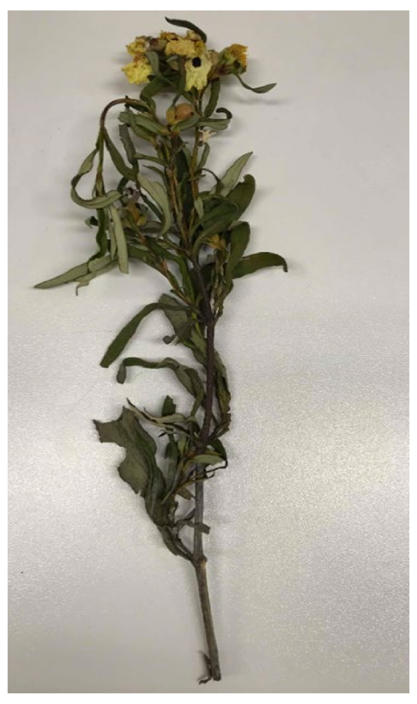
Motivation

Biomass as a energy source is known to have many advantages such as being a renewable resource, low cost, being carbon dioxide neutral, reducing the dependence on fossil fuels, and having high availability. However, this resource, like any other fuel, has limitations, such as the collection of the material and its transportation to a processing site, since biomass has a relatively low bulk density. Moreover, the costs of exploiting this resource may be relatively high. [1]

Processing biomass by mild thermal treatment, i.e., torrefaction, at 200-350ºC in an inert atmosphere can be a solution. This process convert raw biomass into charcoal and have some advantages, for instance, reduces moisture content, improves heating value, improves grindability and harmonizes feedstock properties. The most common torrefaction reactions comprise devolatilization and carbonization of hemicelluloses, depolymerization and devolatilization of lignin and cellulose. [2,3]

In this work , shrubs that occur widely in the Portuguese forest, e.g ***Cistus ladanifer*** (Esteva) were studied, as a possible energy source. A laboratory scale reactor was built for the torrefaction process, with a Schlenk-type glass vessel placed in an oven for which the temperature was controlled at predefined levels.

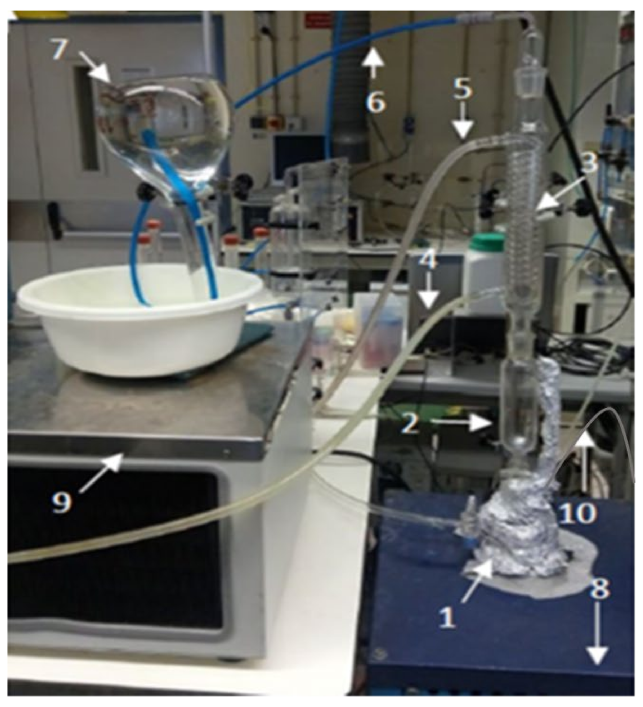
Experimental setup



Cistus ladanifer branches

2, 4 , 6 g

Initially flushing with N_2



T= 250 and 350 ºC at 30 min

Legend:

1 - Reactor with isolation material
2 - Liquid collector
3 - Condenser
4,5 - Cooling water lines
6 - Gases exit line
7 - Gas collection system
8 - Furnace
9 - Thermostatic bath
10 - Thermocouple

Solid — *DSC/ TG experiments*; *SEM analysis*; *FTIR*

Liquid — *MS spectroscopy*

Gas — *GC chromatography*; *Multi-Gas analyzer*

Results

➢ THERMAL ANALYSIS (TG/DSC)

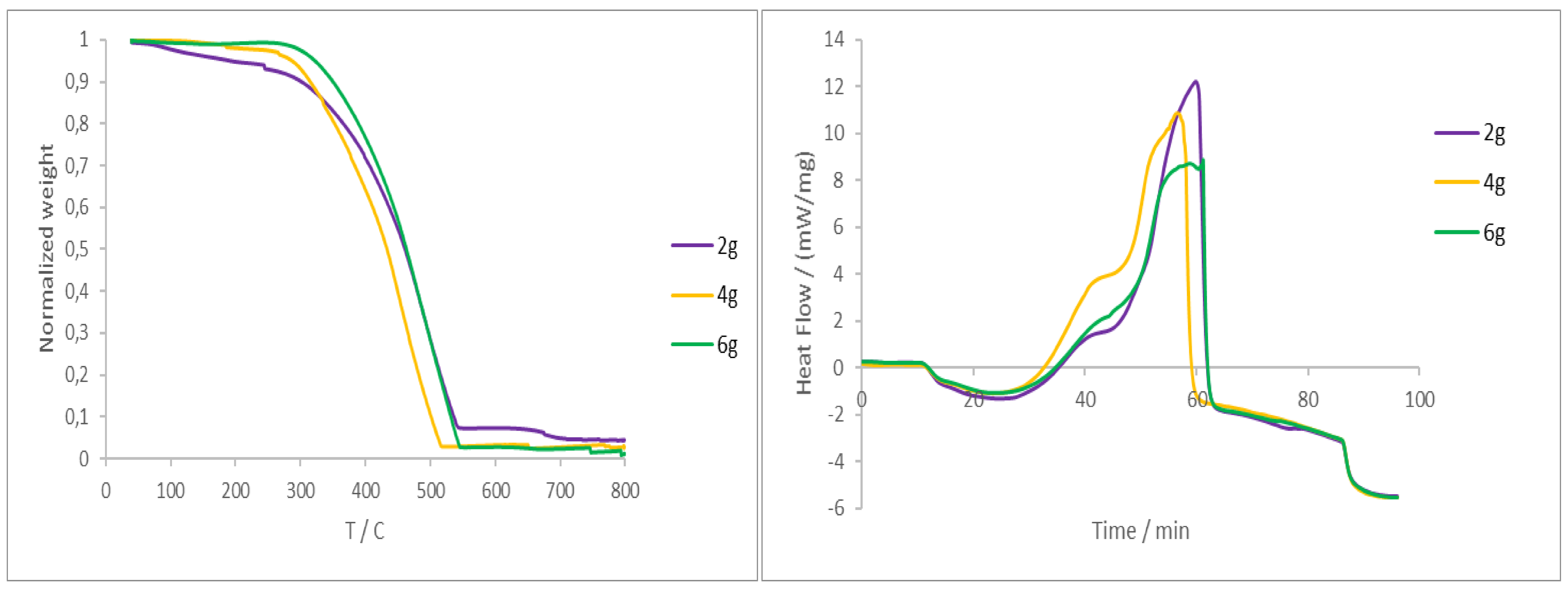


Fig. 1: TG and DSC profile for the combustion of Esteva at 800ºC with heating rate 10°C/min of torrified material obtained at 350ºC during 30 min.

➢ MASS AND ENERGY YIELDS

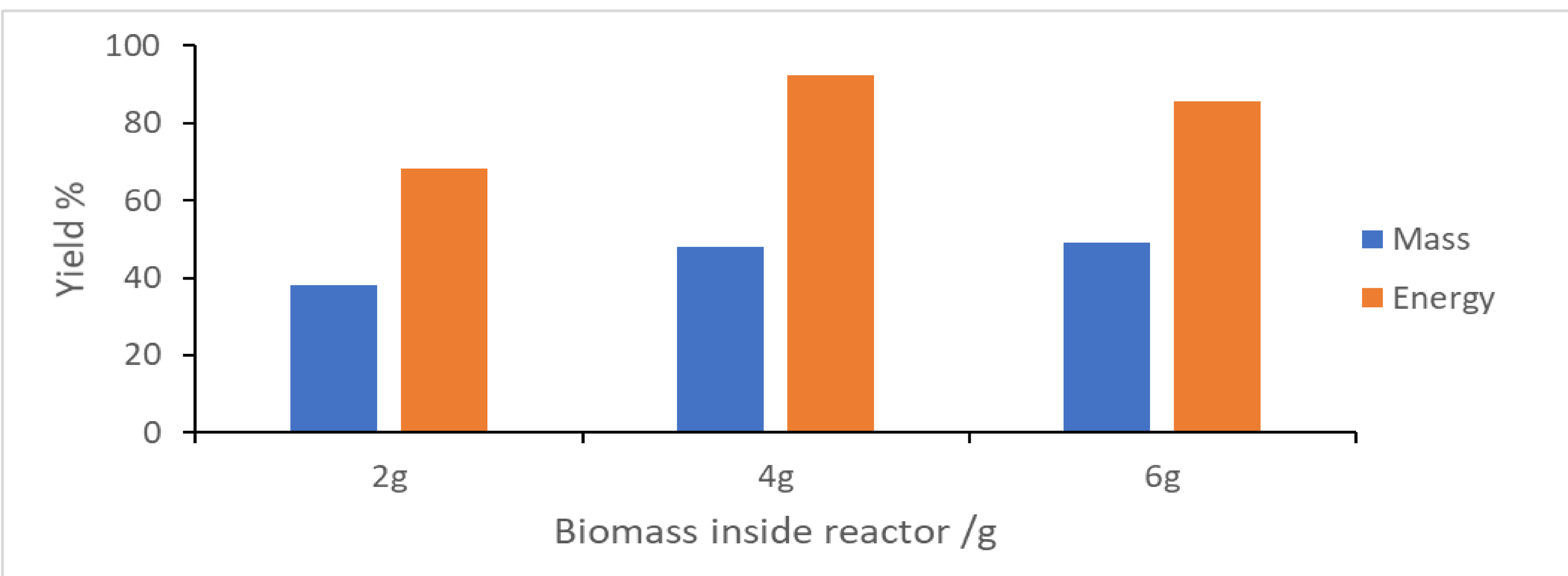


Fig. 2: Effect of biomass quantity on energy and mass yields for torrefaction of Esteva at 350ºC during 30min.

➢ ENERGY BALANCE ON LAB-SCALE REACTOR

$$\left(M_{empty\,reator}\overline{C_{p(empty\,reator)}} + M_{sample}\overline{C_{p(sample)}}\right)\frac{dT_{reactor}}{dt} = UA(T_{oven} - T_{reactor}) + (-\Delta_r H)r - L(T_{reactor} - T_{room})$$

Note : L - coefficient of thermal losses (kJ / K / min)
M - mass (Kg)
Cp - calorific value (KJ/kg/K)
ΔH_r - amount of heat released in the reaction (kJ/kg)
UA - heat transfer coefficient (kJ/K/min)

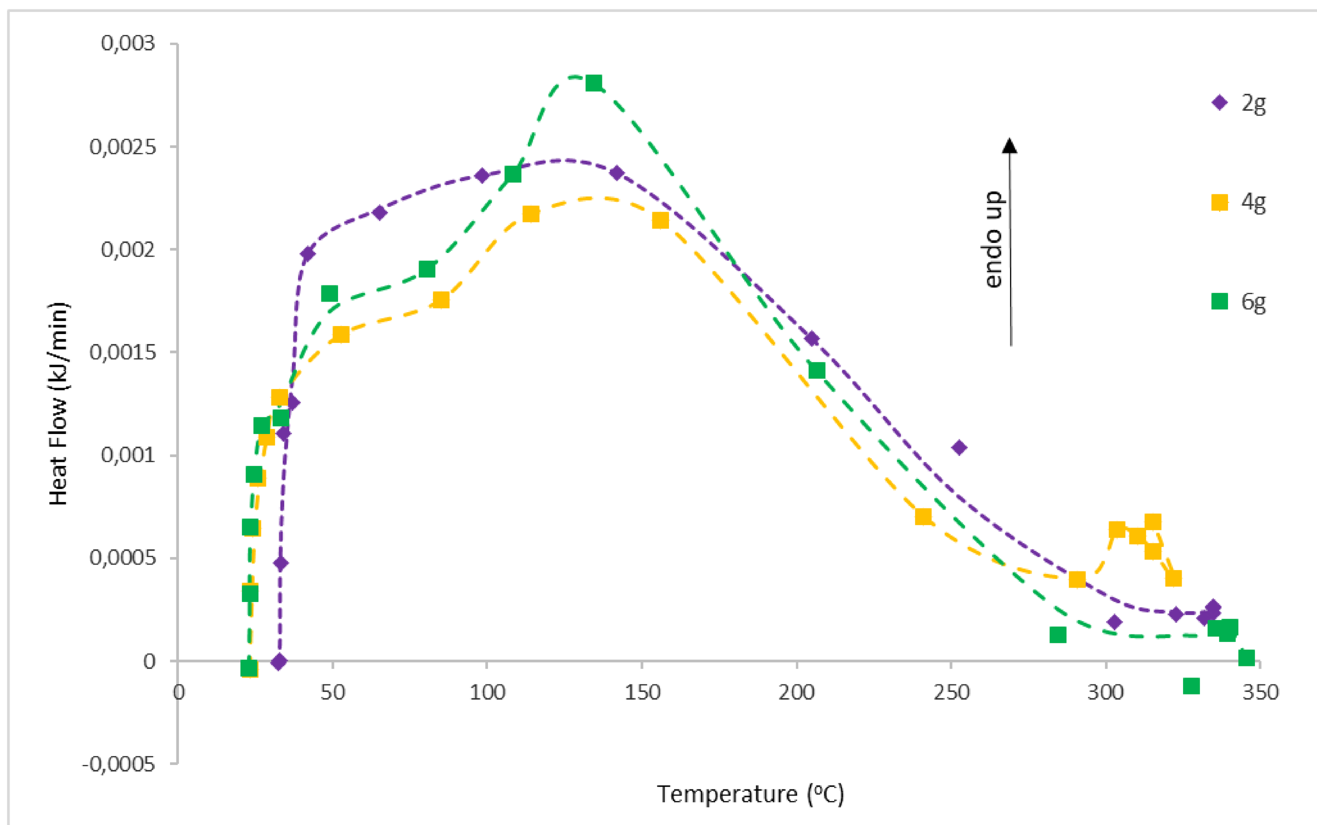


Fig. 3: Heat flow obtained on lab-scale reactor for torrefaction of Esteva at 350ºC during 30min (symbols - experimental results , dashed line – tendency line) .

Table 1 - Mass and energy yields and LHV obtained for torrefaction of Esteva at 250 and 350ºC during 30 min.

250ºC		mass yield %	energy yield %	LHV (MJ/kg)
30 min	2g	76.7	92.3	6.9
	4g	79.8	99.2	7.2
	6g	83.1	83.7	5.8

350ºC		mass yield %	energy yield %	LHV (MJ/kg)
30 min	2g	38.0	68.4	10.4
	4g	48.0	92.2	11.1
	6g	49.2	85.6	10.1
	11g	54.3	91.9	9.8
	19g	66.4	110.1	9.6
	26g	70.9	111.0	9.0

LHV of raw material= 5.8 MJ/kg

Conclusions

- ❑ Increasing the mass in the reactor has a positive effect on the energy yield.
- ❑ Torryfying 26g of biomass at 350ºC for 30 min leads to the production of 70.9 % of char that contains 111% of the initial energy content.
- ❑ Lower heating value (LHV) of 9 MJ/kg was obtained for torrified material compared with 5.8 MJ/kg of original biomass.
- ❑ At higher torrefaction temperature, there is a significantly decrease in the mass of the material with an increase in the heat content.

References

[1] S. Ferreira , E. Monteiro, P. Brito, C. Vilarinho, Renew. Sust Energ Rev 78 (2017) 1221–1235.
[2] J.S. Tumuluru,S. Sokhansanj,J. R. Hess, C. T. Wright, R. D. Boardman, Ind. Biotechnol. 7 (2011) 384–401.
[3] P. Basu, Biomass Gasification, Pyrolysis and Torrefaction Practical Design and Theory (2nd Edition), Academic Press, Amsterdam, 2013.

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