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Supplementary Material

Optimization of Biochar Production by Co-Torrefaction of Microalgae and Lignocellulosic Biomass Using Response Surface Methodology

Catarina Viegas [1,*], Catarina Nobre [2], Ricardo Correia [1], Luísa Gouveia [3] and Margarida Gonçalves [1]

[1] MEtRICs, Mechanical Engineering and Resource Sustainability Center, Department of Science and Technology of Biomass, FCT-NOVA, Campus de Caparica, 2829-516 Caparica, Portugal; rjc07189@campus.fct.unl.pt (R.C.); mmpg@fct.unl.pt (M.G.)

[2] CoLAB BIOREF—Collaborative Laboratory for Biorefineries, Rua Amieira Apartado 1089, 4466-901 S. Mamede Infesta, Portugal; catarina-nobre@bioref-colab.pt

[3] LNEG—Laboratório Nacional de Energia e Geologia, I.P./Bioenergy Unit, Estrada do Paço do Lumiar 22, 1649-038 Lisbon, Portugal; luisa.gouveia@lneg.pt

* Correspondence: cv.sousa@campus.fct.unl.pt

Table S1. Experimental design matrix using the RSM modelling technique (Cv – Microalgae sludge, Lc – Lignocellulosic biomass) and corresponding masses of Cv, Lc and water introduced in the reactor.

Run	Temperature (°C)	Time (min)	Lc Incorporation rate (%)	Moisture content (%)	Cv (g)	Added water (g)	Lc (g)	Total water in feed* (g)	Total feed mass (g)
1	*300*	*60*	*50*	*30*	3.5	4.9	10.0	5.6	18.4
2	*300*	*60*	*25*	*15*	12.0	2.2	5.0	2.9	19.2
3	*300*	*60*	*25*	*15*	12.0	2.2	5.0	2.9	19.2
4	*300*	*45*	*0*	*45*	11.0	8.5	0.0	8.8	19.5
5	*300*	*45*	*100*	*5*	0.0	0.0	20.0	1.0	20.0
6	*300*	*45*	*50*	*5*	10.0	0.0	10.0	1.0	20.0
7	*300*	*45*	*0*	*5*	20.0	0.0	0.0	1.0	20.0
8	*300*	*30*	*50*	*30*	5.5	5.6	10.0	6.4	21.1
9	*300*	*15*	*25*	*45*	5.2	7.5	5.0	8.0	17.7
10	*300*	*15*	*0*	*45*	11.0	8.0	0.0	8.6	19.0
11	*300*	*15*	*50*	*5*	10.0	0.0	10.0	1.0	20.0
12	*275*	*60*	*0*	*70*	7.0	15.2	0.0	15.6	22.2
13	*275*	*45*	*25*	*30*	8.5	4.9	5.0	5.6	18.4
14	*250*	*60*	*0*	*15*	16.0	1.9	0.0	2.7	17.9
15	*250*	*60*	*50*	*5*	10.0	0.0	10.0	1.0	20.0
16	*250*	*45*	*50*	*30*	3.5	4.9	10.0	5.6	18.4
17	*250*	*45*	*25*	*30*	8.5	4.9	5.0	5.6	18.4
18	*250*	*45*	*25*	*30*	8.5	4.9	5.0	5.6	18.4
19	*250*	*45*	*25*	*15*	12.0	2.0	5.0	2.9	19.0
20	*250*	*45*	*25*	*15*	12.0	2.0	5.0	2.9	19.0
21	*250*	*30*	*25*	*45*	5.2	7.5	5.0	8.0	17.7
22	*250*	*30*	*25*	*45*	5.2	7.5	5.0	8.0	17.7
23	*250*	*30*	*50*	*15*	8.0	2.2	10.0	3.1	20.2
24	*250*	*30*	*25*	*5*	15.0	0.0	5.0	1.0	20.0
25	*250*	*15*	*50*	*30*	5.5	5.6	10.0	6.4	21.1
26	*250*	*15*	*0*	*5*	20.0	0.0	0.0	1.0	20.0
27	*250*	*15*	*0*	*5*	20.0	0.0	0.0	1.0	20.0
28	*225*	*60*	*25*	*5*	15.0	0.0	5.0	1.0	20.0
29	*225*	*45*	*0*	*45*	11.0	8.0	0.0	8.6	19.0
30	*225*	*15*	*25*	*15*	12.0	2.0	5.0	2.9	19.0
31	*200*	*60*	*25*	*45*	5.2	7.5	5.0	8.0	17.7
32	*200*	*60*	*50*	*30*	5.5	5.6	10.0	6.4	21.1
33	*200*	*60*	*0*	*5*	20.0	0.0	0.0	1.0	20.0
34	*200*	*30*	*25*	*15*	12.0	2.0	5.0	2.9	19.0
35	*200*	*30*	*25*	*15*	12.0	2.0	5.0	2.9	19.0
36	*200*	*30*	*50*	*5*	10.0	0.0	10.0	1.0	20.0
37	*200*	*15*	*0*	*70*	7.0	15.2	0.0	15.6	22.2
38	*200*	*15*	*50*	*30*	3.5	4.9	10.0	5.6	18.4
39	*200*	*15*	*25*	*30*	8.5	4.9	5.0	5.6	18.4

*Total water in feed corresponds to the sum of the added water and the residual moisture present in the Cv and Lc biomasses introduced in the reactor.

Table S2. Equations generated by RSM software, with R^2, Adjusted R^2, Predicted R^2 and Adequate Precision for product yields

Parameter	Equation **	Model F-value	R^2	Adjusted R^2	Predicted R^2	Adequate Precision
Char Yield	$86.52 + 0.40\ T - 0.62\ t - 2.10\ M + 0.14\ I + 3.97x10^{-3}\ (T \times M) - 1.53x10^{-3}\ (T \times I) - 1.26x10^{-3}\ (T^2) + 4.20x10^{-3}\ (t^2) + 5.34x10^{-3}\ (M^2) + 1.52x10^{-3}\ (I^2)$	130.00	0.980	0.973	0.950	40.754
Condensate Yield	$-1.10 + 0.01\ T - 0.30\ t + 0.10\ M + 9.70x10^{-5}\ I - 1.20x10^{-4}\ (T \times M) - 2.70x10^{-4}\ (t \times M) - 5.39x10^{-4}\ (M^2)$	26.19	0.859	0.827	0.698	16.900
Gas Yield	$-24.66 + 0.16\ T + 0.24\ t + 0.43\ M - 0.07\ I - 1.80x10^{-3}\ (T \times t) - 3.28x10^{-3}\ (T \times M) - 9.92x10^{-3}\ (t \times M) - 1.40x10^{-3}\ (M \times I)$	5.53	0.604[1]	0.595	0.340	9.911
Aqueous Phase Yield	$-1.87 + 3.05x10^{-3}\ T - 9.29x10^{-3}\ t + 0.05\ M + 0.08\ I + 7.50x10^{-5}\ (T \times t) - 2.20x10^{-5}\ (t \times I) - 1.30x10^{-5}\ (M \times I) - 4.42x10^{-4}\ (M^2) - 5.64x10^{-4}\ (I^2)$	30.58	0.908	0.878	0.611	27.606
Bio-oil Yield	$47.98 - 0.45\ T + 0.38\ t + 0.55\ M - 0.42\ I - 1.97x10^{-3}\ (T \times M) + 1.88x10^{-3}\ (T \times I) - 2.92\ (t \times M) + 8.98\ x10^{-4}\ (T^2) - 3.14x10^{-3}\ (t^2)$	18.98	0.864	0.818	0.700	18.463

Note: p-value model is always 0.01%, and it means that there is only a 0.01% chance that an F-value this large could occur due to noise.

The equations did not undergo any transformations except the Condensate and Aqueous phase equations with a natural log transformation.

The Lak of Fit is not significant (< 4), except for the parameter Bio-oil (Lak of Fit of 6.06)

** Where T, t, M and I means temperature, residence time, moisture and incorporation rate of lignocellulosic material, respectively.

1 – a low R^2 suggests a dispersion of values that decrease the predictability of the model [39].

Table S3. Equations generated by RSM software, with R^2, Adjusted R^2, Predicted R^2 and Adequate Precision for char characterization

Parameter	Equation **	Model F-value	R^2	Adjusted R^2	Predicted R^2	Adeq. Precision
Ash	$18.09 - 0.16\ T + 0.04\ t + 0.02\ M - 0.02\ I - 1.53x10^{-4}\ (T \times t) - 7.10x10^{-5}\ (T \times M) + 9.40x10^{-5}\ (T \times I) - 1.50x10^{-4}\ (t \times M) - 5.90x10^{-5}\ (M \times I) + 3.53x10^{-4}\ (T^2) - 3.03x10^{-4}\ (I^2)$	57.80	0.962	0.946	0.886	23.239
Volatile Matter	$-57.02 + 1.12\ T - 0.06\ t - 0.489\ M + 0.39\ I - 3.40x10^{-3}\ (T \times t) + 3.68x10^{-3}\ (t \times I) + 6.44x10^{-3}\ (M \times I) - 2.26x10^{-3}\ (T^2) + 5.52x10^{-3}\ (t^2) - 3.38\ x10^{-3}\ (I^2)$	41.07	0.943	0.920	0.874	27.313
Fixed carbon	$116.76 - 0.80\ T - 0.74\ t - 0.54\ M + 0.16\ I + 3.12x10^{-3}\ (T \times t) + 1.42x10^{-3}\ (T \times M) - 9.18x10^{-4}\ (T \times I) + 2.73x10^{-3}\ (t \times M) + 1.66x10^{-3}\ (T^2)$	80.69	0.964	0.952	0.920	39.412
O/C ratio	$0.88 - 1.67x10^{-3}\ T + 3.46x10^{-3}\ t + 9.30x10^{-3}\ M - 1.98x10^{-4}\ I - 2.60x10^{-5}\ (T \times t) - 9.50x10^{-5}\ (M \times I)$	60.89	0.921	0.910	0.871	26.910
H/C ratio	$2.48 - 3.74x10^{-3}\ T - 5.96x10^{-3}\ t + 1.14x10^{-3}\ M + 1.85x10^{-3}\ I - 3.10x10^{-5}\ (T \times t) + 1.13x10^{-4}\ (t^2)$	102.92	0.954	0.944	0.923	35.734
Char adsorption capacity	$273.18 - 0.80\ T - 0.66\ t - 2.74\ M + 0.20\ I + 9.55x10^{-3}\ (T \times M)$	38.40	0.857	0.835	0.786	19.010

Note: p-value model is always 0.01%, and it means that there is only a 0.01% chance that an F-value this large could occur due to noise. The equations did not undergo any transformations except Ash equation with a natural log transformation. The Lak of Fit is not significant (< 4), except for parameters Volatile Matter (Lak of Fit of 9.18) and Char adsorption capacity (Lak of Fit of 108.61).

** Where T, t, M and I means temperature, residence time, moisture and incorporation rate of lignocellulosic material, respectively.

Table S4. Equations generated by RSM software, with R^2, Adjusted R^2, Predicted R^2 and Adequate Precision for Q_{input} and Q_{output}.

Parameter	Equation **	Model F-value	R^2	Adjusted R^2	Predicted R^2	Adeq. Precision
$\mathbf{Q_{input}}$	$1.66 + 6.89x10^{-4}\ T - 4.70x10^{-3}\ t + 3.36x10^{-2}\ M + 6.367x10^{-3}\ I$	59.44	0.878	0.863	0.821	27.054
$\mathbf{Q_{output}}$	$0.38 + 8.30x10^{-5}\ T - 1.94x10^{-3}\ t - 8.35x10^{-3}\ M + 2.19x10^{-3}\ I + 1.3x10^{-5}\ (T \times M) - 1.20x10^{-5}\ (T \times I) - 2.10x10^{-5}\ (t \times M) + 1.50x10^{-5}\ (t \times I) + 4.80x10^{-5}\ (M^2)$	193.09	0.988	0.983	0.972	49.376

Note: p-value model is always 0.01%, and it means that there is only a 0.01% chance that an F-value this large could occur due to noise.
The Lak of Fit is not significant (< 4).
** Where T, t, M and I means temperature, residence time, moisture and incorporation rate of lignocellulosic material, respectively.