Project Number	862834
Project acronym	AQUACOMBINE
Project title	Integrated on-farm Aquaponics systems for co-production of fish, halophyte vegetables, bioactive compounds, and bioenergy
Contract type	H2020-RUR-2019-1

Deliverable number	D9.7
Deliverable title	Draft report on the scale-up of the transformation of lignin into pelletized biochar
Work package	WP9
Due date of deliverable	M36
Actual submission date	M38 – 30/11/2022
Start date of project	01.10.2019
Duration	48 months
Reviewers	Leonidas Matsakas (LTU), Axel Gottschalk (BHV)
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Contributing partners	ENVIROHEMP (ENV)
Dissemination level	PU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862834. Any results of this project reflect only this consortium's view and the European Commission is not responsible for any use that may be made of the information it contains.

Document history

Version no.	Date	Authors	Changed chapters
0.1	03-11-2022	Carlos Sanchis	First document version
0.2	08-11-2022	Leonidas Matsakas	Internal review
0.3	24-11-2022	Axel Gottschalk	Internal review
1.0	30-11-2022	Carlos Sanchis	Final version for submission

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Table of Contents

1 Introduction

The production of activated carbon, AC, from lignin is not an industrially exploited process nowadays. Lignin due to the abundance of aromatic rings in its backbone has higher C/H and C/O ratios than other bio-based sources conventionally used in the production of activated carbon. For that reason, it has been often suggested as a suitable raw material for the production of carbon materials, including AC. In most of the literature, lignin obtained from the pulping industry (mainly black liquors) has been used, with little attention addressed to organosolv lignin which are typically characterized by a lower molecular weight and a higher degree of purity (especially when it comes to ashes and particularly sulphur) than pulping side-streams. Altogether, little evidence is available about the technoeconomic feasibility of the production of AC from organosolv lignin, however organosolv lignin consist of a very promising feedstock for high quality AC preparation.

The goal of the present deliverable is to explain how the scale-up of the production of AC from organosolv lignin, sourced from *Salicornia ramosissima*, will be carried out: the equipment proposed, opportunities and ambition of the study.

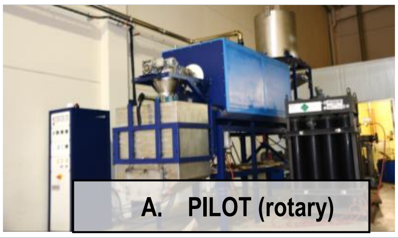
2 Materials and methods

Envirohemp owns different furnaces that enable the replication of industrial process at pilot and pre-industrial scale.

The furnaces available are described below, classified in 2 major types:

1. Furnaces for continuous pyrolysis
2. Furnaces for batch pyrolysis
3. The characteristics of the 4 types of furnaces available are described in Figure 1 and Figure 2.

CONTINOUS PYROLYSIS (Rotary furnaces)



APPLICATIONS

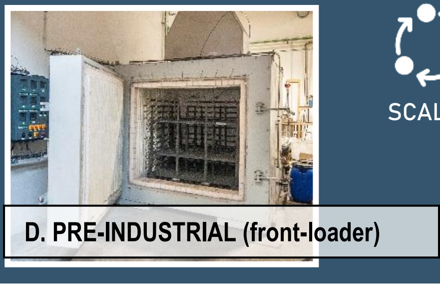
- ✓ Biochar | Char | Activated Carbon for vehicle & industrial filters
- ✓ Condensation of tars

SCALE

	A. PILOT	B. PRE-INDUSTRIAL
FEED RATE	5 kg/h	100-200 kg/h
MAX. TEMPERATURE	900ºC	600ºC
RESIDENCE TIME	1h	2h
HEATING	Electric	Gas
BIOMASS MOISTURE	>40%	>20%

Figure 1: Description of Rotary furnaces at Envirohemp's facilities

BATCH PYROLYSIS (Top and front loader furnaces)



APPLICATIONS

- ✓ Activated Carbon | Supercarbons | AC cloths for energy and hydrogen storage
- ✓ Recovery of chemical agents

SCALE

	C. PILOT	D. PRE-INDUSTRIAL
BATCH SIZE	1 kg	20 kg
MAX. TEMPERATURE	1300ºC	900ºC
RESIDENCE TIME	∞	∞
HEATING	Electric	Electric
BIOMASS MOISTURE	<40%	<40%

Figure 2: Description of batch furnaces at Envirohemp's facilities

For raw materials of several grams up to 1 kg, the production of ACs shall be conducted in furnace "C" (pilot top-loader). Then, depending on the type of activation method selected (acidic or alkaline) the scale-up can proceed via different furnaces.

- For the acidic type, the scale-up can be performed via production in continuous furnaces. For such purpose furnace "A" (5 kg/h; requires at least 10-20 kg) can be used and eventually also furnace "B" (100-200 kg/h; requires from 100 kg to several tons)
- For the alkaline type, furnace "D" (up to 20 kg per batch) would be the best option as this process is not compatible with processing in continuous

In the case of the project AQUACOMBINE, the furnace "C" is in all cases the best option as it enables to optimize the conditions of production of AC up to a scale of hundreds of grams. Then it is possible to establish a reliable inventory of process data (mainly the mass and energy balances) of the process and to elaborate a solid business case.

3 Results

3.1 Optimization study and ambition of the scale-up

So far, type "C" furnaces have been used in the optimization of the production of ACs from Salicornia lignin to study several lignin samples produced during the optimization of the organosolv process, to understand which lignin characteristics are beneficial for the process. This was typically done at a scale of 4-5 grams of lignin per each experimental run.

The conclusion from this study is that by selecting the optimum lignin characteristics (typically low molecular weight and low sugar content) the acidic type can be used, reaching a BET surface area as high as 730 m^2/g. Furthermore, this method enables yields in the range of 65-75%, closer to yield initially intended in the project (80% yield). The use of alkaline activation can produce higher values in the range of 980 – 1530 m^2/g, however, this has a larger cost due to a combination of several factors: higher temperature required, higher input of reagents and lower yield of final product (typically in the order of 25-35%).

Since 900 m^2/g is already a market entry value for the application of ACs in water treatment, the goal will be to try to optimize the acidic activation during the scale-up to gain some more surface area. Ideally an increase of 25-30% would result in an appealing material for commercial use.

A priori, this could be naturally achieved by increasing the load of the activation mixture for the same volume of the hot chamber. This is known to result in a higher concentration of reactive gases in the chamber and a larger residence time, producing a more thorough gasification of the material for a given ratio of activating agents. Therefore, the main goal of the scale-up will be to study the quality of the AC produced

As such, scale-up of the process will be conducted in type "C" furnace, in which the amount of lignin tested will be >400g (>90-fold increase compared with the previous study), to understand the impact of process scale-up and eventually to identify how this could improve char surface area. In the scale-up, the amount of activation mixture will be increased from about 13-14 g (used in the optimization) to > 1200 g in the scale-up test. The volume of the hot chamber is kept constant at around 50 L, enabling a higher gasification with a similar overall yield.

This will: i) establish the impact of a high load of mater in the hot chamber, and ii) produce a complete data sheet of the product.

Additionally, we will study ball milling of the carbon (as an alternative to carbon pelletisation), which will allow to reduce the particle size under 100 micron (potentially under 20 micron if required) to study its application as super-fine powdered activated carbon (SPAC) that has been recently proposed as a filtering solution for the efficient removal of micropollutants. Nevertheless, the pore size distribution of the carbon will be compared to the one of conventional granular activated carbons, GACs, used in the water treatment sector. This will allow to predict the efficiency of the AC produced in AQUACOMBINE and market value for typical water treatment applications.

4 Conclusions

The possibilities of different furnaces owned by Envirohemp have been revised.

Towards scaling-up the process, the behaviour of the process operating at batch mode will be investigated at a higher scale of feedstock (at least 90-fold higher than what was studied so far). This scale-up, by using >400g lignin, is expected to have the desired property of introducing a higher load of the activation mixture in the hot chamber. As a result, an increase of the degree of activation (BET surface area) is expected.

The scale-up study will be completed with an investigation of the micronisation of the activated carbon to explore its use as a SPAC filter.