BIOCHAR BEYOND CARBON SEQUESTRATION: LIFE-CYCLE EMISSION REDUCTIONS, NUTRIENT RECYCLING AND FOOD SECURITY

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Carbon dioxide withdrawal from the atmosphere is increasingly seen as an indispensable approach to mitigate climate change in concert with emission reductions from fossil fuel use. Conversion of biomass into biochar decreases mineralizability by one to two orders of magnitude and typically constitutes half of life-cycle emission reductions of biochar systems focusing on crop or forestry residues. In addition, emission reductions related to changes in nitrous oxide emissions or photosynthesis may contribute to climate change mitigation. While impacts of pyrolyzing carbon-rich crop or forestry residues on greenhouse gas emissions have been widely investigated, less attention has been paid to nutrient-rich materials such as animal manures or human wastes. Nutrient recycling using pyrolysis not only reduces climate impacts by several tens of percent but also enables establishing new products in the market place and reducing environmental impacts beyond climate change. In comparison to other major carbon dioxide removal approaches such as crop management or restoration of wetlands, biochar systems may generate greater emission reductions at equivalent carbon dioxide removal. The reason may lie in a systemic reduction of soil-based emissions of non-carbon dioxide greenhouse gases and the greater control of the conversion process in what essentially is a hybrid engineered-biological sequestration. Due to biochar being an external carbon resource, it does typically not constitute an on-site competition for organic matter as observed with crop management and increasing carbon in soil with biochar may therefore not constitute a trade-off with food production. These features make biochar systems a complementary approach to other ways of reducing greenhouse gases with potentially large contributions to a global strategy to mitigate climate change.

EXPERIMENTAL DESIGN AND TESTING IN A PILOT-SCALE ROTARY KILN FOR THE TORREFACTION OF BEECH WOOD UNDER SYSTEM RESTRICTIONS

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Key Words: Torrefaction, beechwood, pilot-scale, simulation, rotary kiln

The torrefaction process increases the energy density of the torrefied feedstock through the loss of volatiles and moisture. The anhydrous weight loss (AWL) measures the loss of volatiles and it is easily correlated with the net calorific value (NCV) of the torrefied product.

This work has two different parts. The first part consists of the design of the experiments and the second includes the experiments with results. The system used in CENER, where the simulation and experiments were completed, is a rotary kiln with a maximum capacity of 500 kg/h and a range of operating temperatures between 220-310°C. The innovative design feature of this reactor is the extraction of the gases from the middle of the reactor, in such a way that the direction of the gases is co-current in half of the reactor (at the beginning) and countercurrent in the last half. Besides the reactor, there is a flare which combusts the gases from the reactor before releasing them to the atmosphere, and does not allow flows higher than 120 Nm^3/h. The two variables that can be modified to overcome the restrictions and achieve the target AWL are the temperature of the reactor (controlled by the temperature of the thermal fluid used to heat the reactor), and the input capacity to the reactor. The relationship of the gases produced to the temperature is straight, the higher the temperature the more gases are produced due to a higher devolatilisation of the feedstock. On the other hand, when the input capacity was modified, it is more difficult to estimate the gas production yield; with an increased feeding rate, the AWL is lower and the amount of volatiles released reduces but there is a higher release of the total amount of moisture content due to a higher feed rate. Given a lower input of feedstock, the total amount of water evaporated is lower but the AWL and the devolatilisation degree of the feedstock is higher and, consequently, more volatiles are produced.

To meet the system requirements, it is necessary to simulate the experiments before conducting them to complete the experimental plan, which is the first part of the work. The variables in this process are the type of feedstock, feed rate and the temperature of the reactor. The simulation tool in CENER follows the kinetic mechanism proposed by Di Blasi and Lanzetta in 1997 [1]. Also, there are other properties simulated in the model such as the calorific value, the density and the thermal conductivity of the bed of solids along the reactor. The experiments completed in the second part of the work are used as validation for the model created for the reactor and to see the behavior of the beechwood under certain torrefaction conditions. Table 1, shows a comparison between the predictions from the model and the actual results obtained from the torrefaction of the beechwood with an input capacity of 300 kg/h and temperatures of 260 and 280 °C in the experiments 1 and 2, respectively.

From the data obtained it is seen that there is some difference between the model and the real behavior of the reactor. In previous experiments it has been demonstrated that the model matches the real performance of the reactor for lower temperatures and AWL, although it is more inaccurate for conditions near its working range limit.

Experiment 1: 300 kg/h and 260 °C
Experiment 2: 300 kg/h and 280 °C

		Experiment number			
		1		2	
		Model	Experimental	Model	Experimental
Thermal fluid	Outlet T [°C]	260	260	280	279.5
	Thermal fluid heat (kW)	66	58	70	73
Biomass	Type	Beech wood		Beech wood	
	Mass flow [kg/h]	300	300	300	300
	Density [kg/m3]	310	310	310	310
	Moisture content [wt.%]	9.9	9.9	9.9	9.9
Torrefied product	Mass flow [kg/h]	218	227	199	198
	Density [kg/m3]	325	330	345	355
	Exit T [°C]	243	234	252	251
	AWL [wt.%] (d.a.f.)	19.4	15.9	26.8	26.6
Gases	Exit T [°C]	219	224	229	225
	Flow [Nm^3/h]	92	91	111	99

Table 1 – Comparison model-experimental work

[1] Di Blasi, C. and M. Lanzetta (1997). "Intrinsic kinetics of isothermal xylan degradation in inert atmosphere." Journal of Analytical and Applied Pyrolysis 40-41: 287-303.

FARM AND LABORATORY SIZE BIOCHAR & HEAT COPRODUCTION IN REDUCING ATMOSPHERE COMPACT AUTOTHERMAL PYROLYSIS REACTOR/BOILER

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Key Words: Biochar and heat, reducing atmosphere, compact pyrolysis, boiler

Local production of the biochar (BC) at the farm level remains unresolved regarding technology and operation/business model. A new patented technical solution of coproduction BC and heat in a Reducing Atmosphere (BC&H-RA) [1] as a compact autothermal pyrolysis reactor/boiler enters the market. The device covers a niche market of smaller size (5-50 kg/h of BC) [2, 4] production units offering fully automatic all day (24 h) operation with all ecological features of flue/exhaust gases. Fully automatic operation provides BC acc. to EBC quality standard from standard wood chips (BS-EN-ISO 17225) of wide particle sizes up to 45 mm of diameter. Under presented conditions, farm size reactor/boiler use 20 kg/h of BM (wood chips) or 1.7 m^3 per day and produce 5 kg/h of BC or approx. 0.8 m^3 per day at 26 kW continuous thermal output.
A possible implementation of alternative biomasses (BM) needs to be tested to assure BC - EBC quality with some corrections of process parameters. Compact pyrolysis unit can be installed as a domestic boiler producing hot water (max 90/70 ºC regime) and BC in big bags.
Laboratory compact BC&H-RA compact pyrolizer exactly follows the process in a large unit but in smaller proportions. Continuous production of BC with integrated dryer and automatic operation targets 5 h of operation per day. With 1kg/h of BC capacity from 4 kg/h BM at input approx. 70 l of BM need to be provided per day. At output a 5 kg or approx. 33 l of BC can be produced. The unit generates 5.2 kW of heat output continuously and can be recorded and used as a heat source or blown to exhaust. Computer controlled process provides 24 h operation of the unit (drying 1 day before running test) and enables continuous data monitoring and logging during the whole period of testing. One experiment last, according to the operation cycle, three days. The first day only drying, second-day pyrolysis and third day cooling down, mass balance and cleaning. Two experiments can be provided in a week.
Economic indicators regarding CAPEX and OPEX accordingly follow small production scale or only domestic applications of BC, heat is always a side product.
Basic CAPEX assumptions stick to provide investment price of the presented process unit in a range less than 15 k€ per 1 kg/h of BC plant capacity (<15 k€ / kg/h BC plant capacity). OPEX assume two to three cleanings and one general service per year in a range of domestic boiler maintenance costs.
A presented technological solution is comparable only with larger pyrolysis process units and not with simple batch stove technologies. Simple, manual stoves can produce batches of BC in an environmental controversial manner [3] and only for a limited quantity of BC. A modern automatic continuous production of BC and heat on demand in an environmentally friendly manner can rise BC application to a new level. Changes of business model to new “modus of operandi” of BC production on small scale becomes possible.
Presented thematic cover the biochar reactor technologies area.

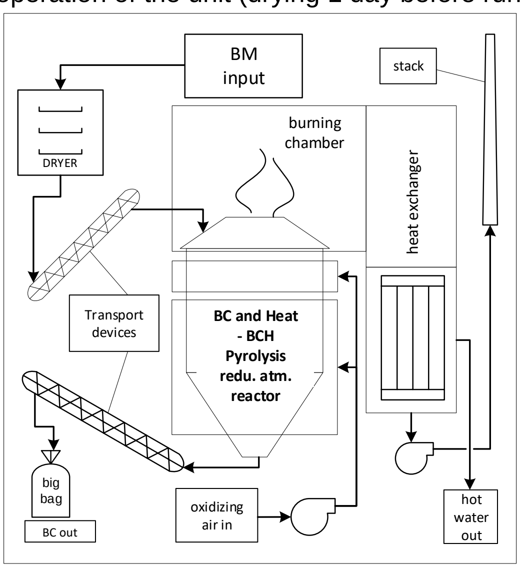

Figure 2 – Biochar & Heat (BCH) Reducing Atmosphere (RA) pyrolysis reactor/boiler

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SMALL-SCALE BIOCHAR PRODUCTION ON SWEDISH FARMS

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Key Words: biochar, on-farm production, optimization, life cycle assessment, climate change

Several small-scale pyrolysis plants have been installed on Swedish farms and the trend is also expanding in the Nordic countries. These projects are driven by ambitions of achieving carbon dioxide removal, reducing environmental impacts and improving farmers' economy and resilience. The pyrolysis plants are fuelled with either commercial pellets or agricultural residues. The pyrolysis plants co-produce heat for the farm's buildings, biochar for non-oxidative applications, mostly agricultural ones, and electricity in some cases. In the Nordic context, on-farm biochar production potential is thus linked to energy consumption. The main research question investigated is whether farms producing biochar can meet their own biochar needs in an energy-efficient way. The research also provides insights on how biochar production at various scales, centralized and decentralized, can be integrated in a given landscape.

In this study, we developed a general model to estimate the amount of biochar that can be produced as a by-product of an energy-optimized farm. We then investigated how the biochar production potential is affected by different scenarios and under different climatic conditions. The model is applied to one Swedish case study and compared with preliminary data from this case. The environmental impacts and energy efficiency of the farm's energy consumption are evaluated through life cycle assessment, including soil carbon stock changes. We also develop a framework to describe, qualitatively and quantitatively, how biochar is used on the example farm for different applications: feed, manure and compost additive; orchard and perennial root-zone amendments; vegetable production; greenhouse cultivation; and sale to other farms in the region. This framework provides an estimate of farm biochar demand and serves as a basis for future environmental evaluation of biochar practices in Sweden.

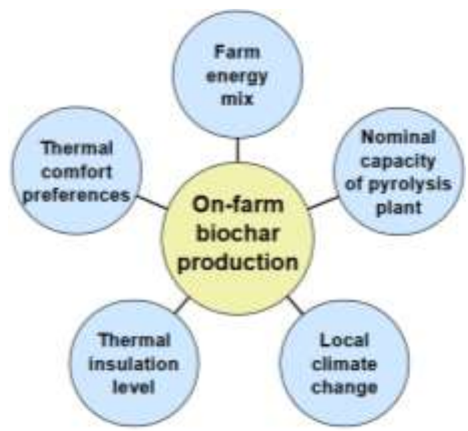

Figure 1 – Dimensions investigated in the scenario analysis

For an average year, with heat supplied to a 400 m^2 residential building, by a heat pump and a pyrolysis plant, the biochar production is estimated to be 10 Mg yr^{-1}. At full scale, the case studied is expected to produce 19 Mg yr^{-1}. Detailed life cycle, energy and scenario analyses are under preparation. These analyses will enable estimation of biochar production variability and comparison of different environmental performance indicators. Applying the model to other cases may support farmers and advisors in their evaluation of on-farm energy supply and biochar production alternatives.

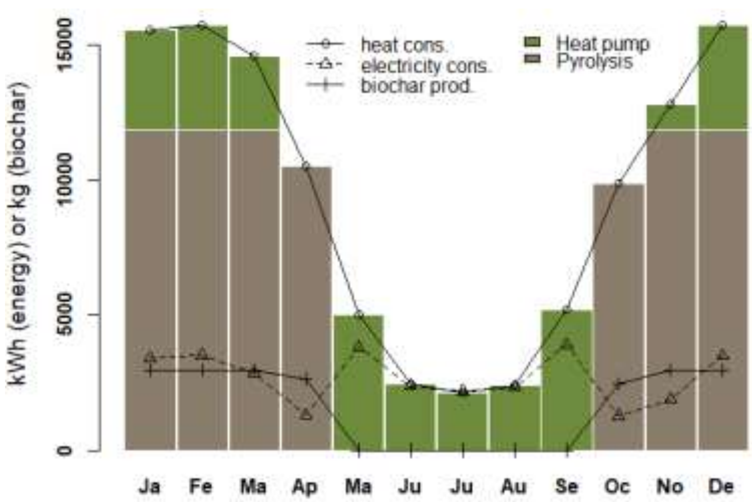

Figure 2 – Monthly heat supply, electricity consumption and biochar co-production in current standard operation

OPTIMUM BIOCHAR APPLICATION RATE FOR IMPROVING SOIL MOISTURE CHARACTERISTICS

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Key Words: optimum rate, particle size, available water content, soil moisture, biochar.

Water movement and storage in soils are crucial for successful intensification of agriculture and maintaining productivity in the face of changing climate. Previous studies have shown biochar to be a natural porous material with potential to be used in maintaining soil moisture. Its application, especially in sandy soils can improve total soil porosity, pore size distribution and soil aggregation thereby increasing total water retained as well as maintain this water in the soil for a long time. However, there is little known about the optimum rate of biochar application in sandy soils for moisture improvement. The cost of biochar production varies from US$300 to $7000 per tonne and most studies to date used relatively high application rates of biochar. At such high application rates, the cost may not lead to a return on investment. This study aims to assess the optimum rate of biochar application as well as to evaluate the potential of biochar particle size in affecting this rate. An extensive meta-analysis was performed on published literature data to quantify the relationship between biochar characteristics and soil moisture properties. The literature data spans across a wide range of feedstock, pyrolysis condition, soil texture and experimental conditions. Out of a total of 150 published studies, 42 articles providing sufficient amount of reliable data on biochar-soil moisture effects were selected. These studies covered; 51 feedstock, 16 pyrolysis temperatures, 20 particle size ranges, 12 soil textural classes and 45 rates of biochar application. The meta-analysis results confirmed that biochar particle size, surface area, feedstock, porosity and carbon content are important factors to consider when using biochar as a material for improving soil moisture content and identified relative importance of different parameters.

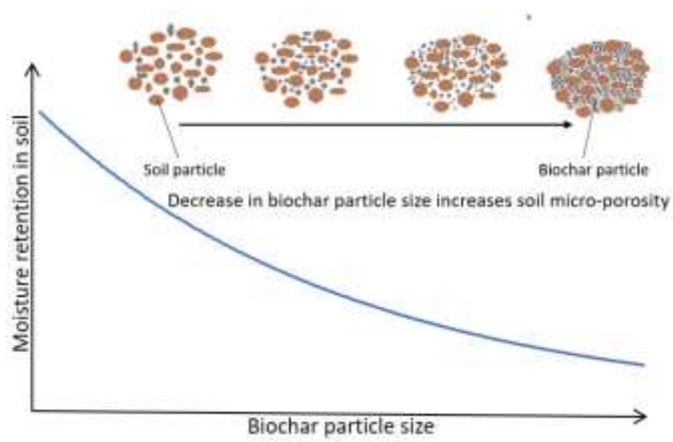

Figure 3 – Schematic diagram of the effect of biochar particle size on soil moisture retention

Based on the outputs of the meta-analysis we designed a laboratory study aimed at providing further insights on the role of biochar type and range of biochar particle sizes (PS) on water content at saturation, field capacity, and permanent wilting point, available water content, saturated and unsaturated hydraulic conductivity. Standard biochar – softwood pellet and wheat straw both produced at 700 ^{0}C – were selected because of their high carbon content and the fact that they represent both woody and crop residue-based feedstock. Biochar particle sizes of 2 – 0.5 mm, 0.5 – 0.25 mm, 0.25 – 0.063 mm and <0.063mm were used. The study hypothesis was that smaller PS will have large surface area, can easily fit into the large pores of sandy soils and increase micro-porosity probably giving rise to higher benefits at lower rates of application (Fig 1). Different rates of biochar (1, 2, 4 and 8wt%) were tested using 3 standard LUFA soil (sandy loam, loam and clay textures). Soil moisture characteristics/curve, water content at saturation, field capacity, permanent wilting point, and available water content were determined using Wp4 and Hyprop. Saturated hydraulic conductivity was also determined using KSAT device. Findings from this study will be important in developing engineered biochar tailored for enhancing water use efficiency and provide low-dose, high efficiency benefits.

FLAME CAP KILNS FOR HAZARDOUS FUELS REDUCTION AND BIOCHAR APPLICATION IN THE WESTERN UNITED STATES

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Key Words: kiln, production, fuels, wildfire, sheep.

Forest managers use hazardous fuels treatments to reduce the severity and intensity of wildland fire. Forest managers commonly pile and burn forest residues, an inexpensive approach to treating hazardous fuels. Fire danger and air quality restrictions increasingly limit the ability of forest managers to burn piles of forest residue. Further, pile burning often consumes organic soils and reduces future productivity of forest stands. A novel approach to this challenge is the use of low cost flame-cap biochar kilns to reduce hazardous fuels while making biochar in forest settings from excess woody biomass. A primary benefit of this approach is accessibility; almost anyone can do it, often with materials and equipment on hand. This method allows for small-scale biochar production across a wide variety of uses and users. Instead of open pile burning of forest residues, we put the fire in a box, or a flame-cap kiln, which reduces damage to the soil and protects air quality. We apply a fraction of the biochar on-site while a portion is available for application on nearby agricultural lands. This reduces wildland fire hazard by converting forest residues into biochar, and the addition of biochar to the soil can increase the drought tolerance of remaining vegetation.

The Utah Biomass Resources Group (UBRG) conducted seven hands-on kiln workshops in Utah with more than 200 attendees. We have successfully pyrolyzed five different forest feedstock types including two invasive tree species. By creating methods for biochar production that land managers can easily access, the use of biochar can grow, which may lead to increased carbon sequestration, increased soil productivity, and improved air quality.

While these small-scale kilns have reduced hazardous fuels by approximately 20 semi-truck loads, the UBRG is scaling-up this approach to increase the pace and scale of hazardous fuels reduction by these methods. The UBRG recently received a Public Lands Initiative Grant to scale up this approach from kilns that measure 1.5 meters across, to kilns that are six meters across. Parallel efforts are ongoing in Oregon, Nevada, and North Dakota using a variety of kiln designs that depend on repurposed local materials; this is an important regional development in biochar production.

Other important benefits of this approach include the cost reduction of feedstock preparation by avoiding the expense and energy necessary for chipping and/or grinding feedstock material. We safely deployed these kilns in close proximity to heavy fuels loads, urban infrastructure, homes, and ecologically sensitive locations such as within Stream Management Zones.

Meanwhile, the UBRG is testing the efficacy of using locally produced biochars as an animal feed amendment by investigating the behavioral and physiological response of sheep when given access to biochar. Humans use activated carbon to ease ingestion and as a poisoning antidote. Biochar can enhance the efficiency of nutrient utilization, reduce environmental impacts, increase rates of detoxification, and reduce the presence of xenobiotics to promote animal health, welfare, and productivity. This research fills a knowledge gap regarding how locally produced biochars influence animal performance.

INFLUENCE OF FEEDSTOCK AND OPERATIONAL CONDITIONS ON BIO-CHARS DERIVED FROM THE PYROLYSIS OF SELECTED BIOMASSES

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Key Words: Biochar, Pyrolysis, TGA, Surface area, BET

The proprieties of bio-char, the solid product from biomass pyrolysis, depends on both the feedstock and process conditions during thermochemical conversion[1]. As regards the interaction of the char with soil (i.e. as soil amendment), surface areas, size and shape of pores are among the most important factors to be considered.

Nine bio-chars were produced by pyrolysis of three different types of biomass, representative of softwood-conifer (black pine) and hardwood-deciduous (black poplar and willow) wood. Pyrolysis was carried out in a macro TGA at 400, 550 and 650 °C on each biomass, following decorticatication and chopping. Porosity of these bio-chars was studied by means of BET analysis, Hg porosimeter and electron microscopy, while the retention and release capacity of ions was quantified via the cation exchange capacity (CEC) that is usually determined for the soils. It has been observed that the adsorption properties of the chars increase with pyrolysis temperatures, with a more pronounced effect on softwood than hardwood species.

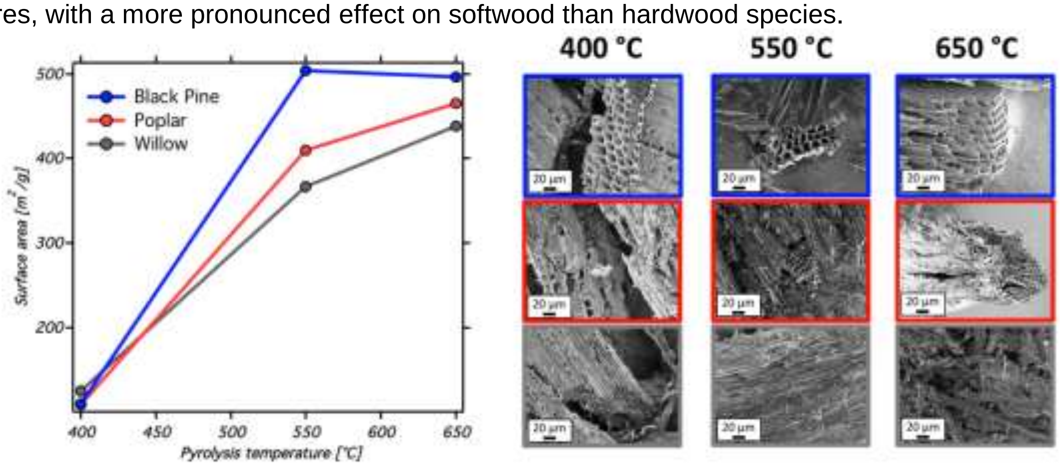

Figure – Left: surface area of all bio-chars. Right: scanning electron micrographs at the same magnification (1 kX) of Black Pine (blue frame), Poplar (red frame) and Willow Biochar (grey frame) at different pyrolysis temperatures (heating rate 20 °C / min with a 2-hour plateau).

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INFLUENCE OF HEATING RATE ON THE SOLID YIELD OF BIOMASS PYROLYSIS

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Key Words: biochar, pyrolysis, char yield, heating rate, cellulose

The use of biochar has become increasingly popular over the last decade. The possible applications are vast and range from renewable carbon carrier in industrial and energetic applications to soil amendment and fodder additive. The various applications have different demands on the properties of biochar. These can be influenced by the choice of feedstock, reactor and production conditions. Regardless of production process and application however, achieving a high yield of the solid product is desirable from an economic point of view. The higher the treatment temperature, the more material is devolatilized and the lower is the amount of biochar that remains after pyrolysis [1]. Nevertheless, some properties such as a very high relative carbon content can only be achieved at high temperatures and therefore at the cost of the char yield. Furthermore, it is generally accepted that a higher heating rate leads to a lower char yield and vice versa. Despite this common believe, there is not a large amount of systematic data available, which shows these correlations. Investigations using rapeseed straw as an example show that the heating rate of up to about 5 K/min initially increases the char yield [2]. As the heating rate continues to rise, the mass yield of biochar decreases. Similar results have already been observed in [3] and [4]. Nevertheless, systematic studies that would allow quantifying the influence of the heating rate on the solid char yield have not been conducted. This study aims to fill this gap.

Using systematic experiments with a thermogravimetric analyzer (TGA), the effects of the heating rate on the solid yield of biomass during slow pyrolysis are investigated. Biomass is a very inhomogeneous feedstock and the influence of the various components not clearly distinguishable from each other. Furthermore, reproducibility is poor, especially given the small amounts typically used in thermogravimetric analyses. Therefore, the experiments are carried out using not only wood as a feedstock, but also pure cellulose and lignin. The latter is often associated with a higher achievable char yield.

During the investigations, the starting materials are pyrolyzed in an inert atmosphere and at different heating rates, all within the regime of slow pyrolysis. The heat treatment temperature is varied between 450 and 700 °C, corresponding to typical conditions in practical biochar production processes. A sufficient holding time helps to minimize the effect of different carbonization degrees on the measurable char yield. Combining the different feedstocks with the pyrolysis conditions creates a broad data basis. This aids the quantification of the change in solid yield that can be achieved by varying the heating rate. After the experiments in the TGA, the resulting biochar is examined under the microscope for optical differences in pore structure and size in order to gain further insights into the influence of the heating rate. The results will further improve the understanding of biomass pyrolysis and optimize the process parameters for biochar production.

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EFFECT OF PYROLYSIS CONDITIONS ON SEWAGE SLUDGE DERIVED BIOCHARS FOR HIGH VALUE COMPOSITES APPLICATIONS

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Key Words: Sewage sludge, pyrolysis, biochar, electrical conductive polymers, composites

The economy of the whole wastewater treatment system is significantly burdened by the increasing amounts of sewage sludge due to the progressive implementation of the Urban Waste Water Treatment Directive 91/271/EEC and by the complexity of the treatments required for guaranteeing a safe handling and a proper end-of-life of the sludge. For this reason, thermal treatments of sewage sludge have been studied in the past for their efficient valorization in terms of energy and/or matter recovery. Among them, pyrolysis represents a viable route aiming at the recycling of resources without production of harmful substances to the humans or the environment. A lot of work has been done on the use of sludge-derived char as a fertilizer and soil conditioner showing its safer application with respect to the untreated sludge. The nutrients were intensified with the temperature rising (except nitrogen) and the bioavailability and the leaching of heavy metals was reduced [1]. However, the physical and chemical characteristics of biochar can be exploited also for the production of high value-added materials. Carbon materials such as nanotubes received a great attention due to their ability to enhance mechanical, electrical and thermal properties of polymer composites [2], but high costs and low reproducibility have discouraged their use. In this study sludge-derived char (SCHAR) is studied as a possible alternative to other high cost carbon fillers. Sewage sludge from a civil wastewater treatment plant was pyrolyzed both in slow [3] and fast [4] pyrolysis conditions at three different temperatures, 500, 600 and 700 °C. A lignocellulosic biomass was also processed in the same experimental conditions for comparing the SCHARs with typical biochars (BCHARs).

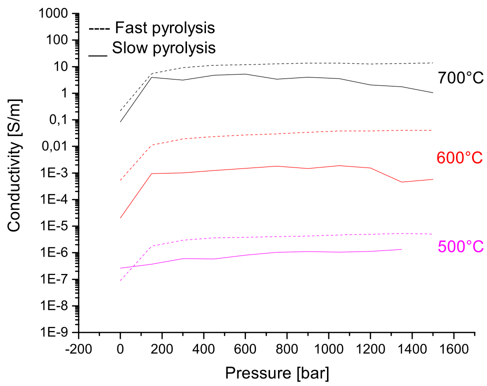

Figure 4 –Electrical conductivity of compressed powder of SCHARs and BCHARs produced at different temperatures.

The influence of the temperature and the heating rate on the char yields and properties was evaluated with a particular attention to those physico-chemical characteristics relevant for the determination of the electrical and mechanical properties of the polymer composite. The produced chars were characterized in terms of elemental analysis, ash content and speciation and electrical conductivity. Morphology of the chars was studied through Scanning Electron Microscopy and adsorption porosimetry. The retention of the heavy metals in the chars during pyrolysis was also monitored. Chars having the highest values of electrical conductivity were used for preparing composites based on epoxy resins [5]. The complex permittivity and the mechanical properties of the composites were measured and an attempt to correlate the obtained values to the physical and chemical characteristics of the chars was made.

As expected, the pyrolysis temperature affected positively the electrical conductivity of chars (c.f. Fig. 1), but in the case of SCHARs this is not trivially correlated to the increase of the BET surface that is significantly lower than the values obtained for the BCHARs.

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INFLUENCE OF HYDROTHERMAL PRETREATMENT ON THE PYROLYSIS OF SPENT GRAINS

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Key Words: hydrothermal carbonization, pyrolysis, biochar, FTIR, SEM

Hydrothermal carbonization process (HTC) is a thermochemical process which operates at elevated temperature and pressure, where liquid water is used as a reaction medium [1]. The biomass is converted into a lignite-like solid product called hydrochar [2]. The advantage of hydrothermal treatment is a possibility to convert high moist bio-waste streams without thermal drying. A two-step carbonization process (Figure 5) consisting of HTC and pyrolysis may improve the properties of final biochar (e.g., carbon content, surface area, and electrical conductivity). Hydrothermal conversion occurs using different mechanisms (e.g., hydrolysis and polymerization of intermediates) compared to pyrolysis, due to the liquid water environment, which also improves the heat transfer across the particles [1,3]. Hydrochar can be easily mechanically dewatered, due to higher hydrophobicity than the initial feedstock [2]. The mass of initial biomass is also reduced according to the HTC yield, which results in a lower mass flow of material for pyrolysis reactor and previous drying step. The two-step carbonization concept may spread the range of feedstocks used for biochar production and improve the overall energy efficiency as well as economic feasibility of pyrolysis, using wet biomass streams.
The aim of this study was to investigate the influence of hydrothermal pretreatment on the properties of biochar produced from pyrolysis of brewer's spent grains (BSG). BSG was selected as a feedstock for the research due to high water content 70-90% wt. moreover, huge worldwide production. Two pathways (Figure 5) were compared: two-step HTC + pyrolysis and one-step pyrolysis. The hydrothermal carbonization experiments were carried out in a batch stainless steel reactor (250 cm^3) coupled with temperature and pressure sensor. The hydrochars were produced at three different temperatures: 180, 220, and 260 °C. The reactor was kept for four hours at the desired temperature. Three hydrochars and biomass were pyrolyzed for two hours in muffle oven in an inert atmosphere provided by the nitrogen gas. The pyrolysis experiments were performed at 400, 600 and 800 °C to analyze the changes in the materials properties caused by hydrothermal treatment. The obtained biochars, hydrochars, and biomass were characterized by proximate and ultimate analysis. The nitrogen adsorption isotherms were measured to determine the surface area of biochars. Fourier-transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM) were used to characterize the structural properties of biochars produced in one-step and the two-step process. Moreover, the effect of HTC temperature on the final biochar yield and biochar properties was analyzed.

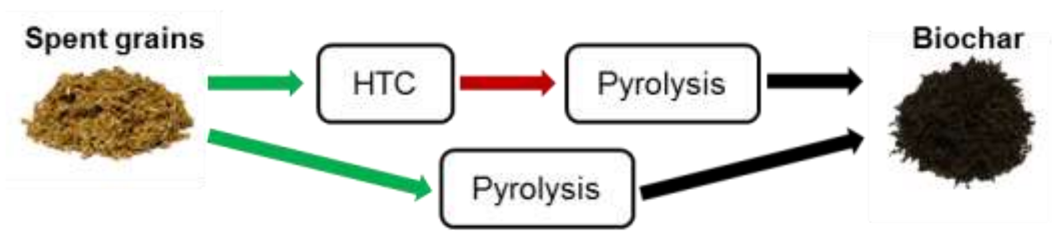

Figure 5 - The overview of two-step and one-step biochar production process.

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WHAT IF ELECTRICITY FROM WOOD COSTS 2 EURO CENTS / kWh AND PRODUCES HIGH QUALITY CHARCOAL?

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Key Words: charcoal, levelized cost of electricity, waste wood, activated carbon

Among the renewable energy sources to generate electricity, the combustion or gasification of biomass could play an extremely important role in the future. A major reason for its importance is the independence between the time of availability of the energy source and power generation. However, to maintain their importance in the long run, correspondingly low levelized cost of electricity (LCOE) are necessary; the technology used must also be able to operate profitably without subsidized renewable energy feed-in tariffs.
The aim of this work is to reduce the LCOE of biomass combined heat and power-plants with a gasification reactor –wood gasification plants in particular – by utilizing or increasing the value of the gasification residue and a favorable input material. Essentially, the gasification residue is refined into a higher quality product so that the charcoal has the properties of an activated carbon (AC). Furthermore, waste wood (untreated pallets and packaging wood) should be treated in such a way that the resulting fractions can be processed in an existing reactor with the floating fixed-bed gasification (FFBG) technology. Therefore, a "Functionalization Unit" (Green Carbon Unit (GCU)) and treatment processes for waste wood are to be developed.
In addition to the possibility to process waste wood in FFBG systems ecologically and economically, the GCU makes it possible to adjust the quantity and product quality of the resulting charcoal to a different market requirement. This allows, for example, a partial load operation with increased and a full load operation with lower charcoal production in order to meet regional needs and demanded load profiles.
As you can see in Table 1, the fuel costs account for more than 50 % of LCOE, the processing of waste wood chips reduces production costs by approx. 50 %. In addition, by refining the charcoal into activated charcoal, a further reduction of approx. 50 % (trading price AC approx. € 1 kg^{-1}) can be achieved.
Framework conditions for the calculation of the LCOE:

- The calculation is based on a 500 kW_{el} plant.
- All costs and revenues are calculated on € cents / kWh_{el}.
- The district heating or local heating grid is not included in the investments.
- "Only" the high temperature heat (HTH) is calculated as revenue.
- Low-temperature heat is used as a drying heat.
- Ratio kW_{el} / kW_{HTH} is about 40 / 60.
- For the heat revenue 4 € cents / kWh_{HTH} be calculated, representing 6 € cents / kWh_{el}.
- The charcoal revenues will be charged at 200 € / ton_{DM} (Table 1) and 1000 € / ton_{DM} (Table 2).
- The fuel costs are set at 85 € / ton_{DM} (Table 1) and 25 € / ton_{DM} (Table 2).

Table 1: LCOE of a standard FFBG

invest	+ 5 € cent/kWh
financing	+ 1 € cent/kWh
operation & maintenance	+ 3 € cent/kWh
fuel	+ 7 € cent/kWh
heat revenue	- 6 € cent/kWh
charcoal revenue	- 1 € cent/kWh
electricity costs	+ 9 € cent/kWh

Table 2: LCOE of the FFBG with waste wood and GCU

invest	+ 5 € cent/kWh
financing	+ 1 € cent/kWh
operation & maintenance	+ 3 € cent/kWh
fuel	+ 2 € cent/kWh
heat revenue	- 6 € cent/kWh
charcoal revenue	- 4 € cent/kWh
electricity costs	+ 2 € cent/kWh

The pre-treatment of waste wood and the post-treatment of the charcoal reduce the LCOE of gasification plants – of a FFBG system in particular – from currently € 0.09 kWh^{-1} by approx. 75 % (here commercial activated carbon as a by-product) to € 0.02 kWh^{-1} (Calculation shown in Table 2).
According to the current state of the art, the use and appreciation of gasification residue is an under-explored area. In particular, to date, no systems are known which perform an "inline/in-situ" decentralized activation of the gasification residue and used as input material waste wood.

CRAB BODY PYROLYSIS: CHARACTERIZATION AND APPLICATIONS OF CRAB BIOCHAR "A CRABBY SOLUTION"

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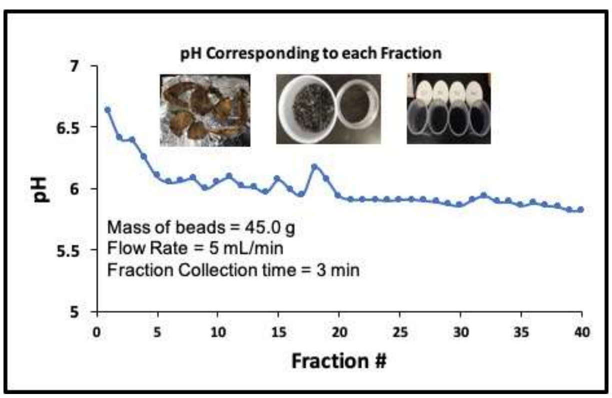
Key Words: Crab waste, Calcium carbonate, acid mine neutralization, biochar.

Nova Scotia crab harvesters sell over 5 million lbs of Snow Crab (*Chionoecetes opilio*) annually. The commercially desired product are the legs and shoulders generating resultant waste streams from bodies of the snow crabs (approximately 1/3 of the crab). Currently this waste is landfilled which is costly and fossil fuel intensive. There is a desire to find a more environmentally sustainable practice to divert this organic animal waste from NS landfills. In a landfill, snow crab residues will decompose and generate some small amount of fixed carbon, however much of the carbon is released into the environment as CO_2 during decomposition and aside from some microbial benefits none of the remaining interesting chemicals are utilized during landfill decomposition. The chemical composition of the snow crab includes a high content of protein (34.2% dw) and essential amino acids; they also have fat (17.1% dw), with a high proportion of ω3 polyunsaturated fatty acids and approximately 28.5% dw minerals (calcium, phosphorous, and magnesium) making this waste stream very intriguing as a starting biomass for the generation of biochar. In this paper we have determined the optimal pyrolysis conditions and highest yield for the char generated from the crab body waste stream. The chars have been fully characterized and we have investigated several applications ranging from neutralization material for acidic waters to concrete additives and catalysis.



BIOCHAR PRODUCTION THROUGH COMBINED SOLAR DRYING & SINGLE CHAMBER PYROLYSIS

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Key Words: Biochar, Pyrolysis, Solar Drying, Sewage Sludge, Fibrous Organic Waste

In this study, the challenging management of fibrous organic wastes (FOW) and dewatered municipal sewage sludge (MSS) in urban areas of Asia's newly industrialised countries is presented with high energy efficiency, negative CO_2 balance and biochar generation. This study investigates the feasibility and benefits of a combined treatment approach for both of the substrates, comprising solar drying (SD) and pyrolysis process (PYR). Based on material investigations, a calculation model is developed to project the material and energy flows of this process combination on the example of Chennai, India.
The original samples FOW (i.e. banana peduncle) and MSS are also used to estimate the thermogravimetric characteristics of substrate mixtures, which are validated against the measured characteristics, in order to identify synergistic effects and interdependent reactions. The calculate values represent thermogravimetric characteristics without any interdependent reactions. Based on the TGA results, calculated process temperature of the pyrolysis process is set to 600 °C. The thermal conversion characteristics are further utilized for estimating the biomass to biochar conversion degree as well as the amounts of biochar and sequestrated carbon. In addition, ventilation types for solar drying (forced and natural ventilation) are investigated. The lab scale results will be compared against a pilot plant in 2019 for further analysis.Through the SD process the selected initial input amount of $m_{wet,d}$ = 1,600 kg fresh matter per day is reduced to 335 kg dried substrate per day containing 20 wt.-% water content.

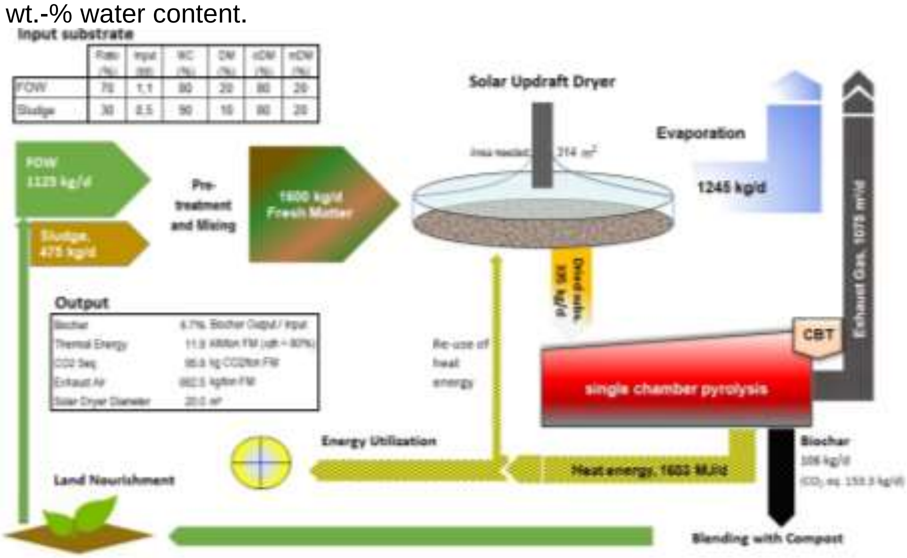

Figure 1- Material flows of combined system for 1.6 tons/day fresh matter input in a ratio of FOW/MSS 70:30

Based on the input waste generation and the treatment requirements the model was calculated with 1,600 kg/d of mixed organic waste with FOW/MSS ratio of 70/30. The combined process (SD and PYR) converts this 1.6 ton/d into 106 kg of biochar per day, equivalent to $m_{CO2,d}$ = 151 kg/d of sequestrated CO_2, and $E_{th,d}$ = 18.9 kW/d thermal energy. Thus, 66.3 kg biochar and 11.8 kW heat energy per ton of substrate can be provided as marketable products. The heat energy generated could be used to operate an absorption chiller and provide a cold storage facility for vegetables and fruit in order to reduce its spoilage and FOW generation.
While investigating substrate mixtures, the highest biochar production of 0.052 kg/kg input is observed for a mixing ratio of FOW/MSS 90/10, while it gradually reduces to 0.026 kg/kg input for an input ratio of 10/90. CO_2 sequestration through the use of biochar to increase the organic content of the soil and to improve soil resilience, e.g. through increased water retention capacity, are yet to be investigated.

THE HAMMENHÖG BIOCHAR PLANT – RESIDUES AND BY-PRODUCTS TO PRODUCE BIOCHAR AND RESIDENTIAL HEATING

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Key Words: Pyrolysis plant, biochar applications, feed-stock, holistic biochar system

In the small community of Hammenhög in Sweden, one of the largest biochar plants in Europe have been built as part of two projects supported by the Swedish government. Rest till Bäst is a Vinnova-funded project whose purpose is to develop solutions for managing organic residues (park- and garden waste, sludge, algae's and seaweed) and create a valuable product (biochar), while minimizing environmental and climate impact and a carbon sink is established. The other project is a climate initiative, Klimatklivet, which supports activities that act to mitigate climate change. The pyrolysis plant consists of two clines, were one is constructed to be run at high temperatures in order to separate Cd and other metals in the process. This capacity makes pyrolysis of polluted materials like sludge, algae and garden wastes a viable alternative and tests are being run. The main feed-stock in the other cline is residues from seed production on site that is pelleted. The plant is expected to produce xx W and produce 6500 tons of biochar per year. The nearby community will get distant heating from the plant making it a carbon negative community. The biochar characteristics as well as the growth potential in different applications like raingardens, urban tree plantations, green roofs and green walls, are tested in the project.

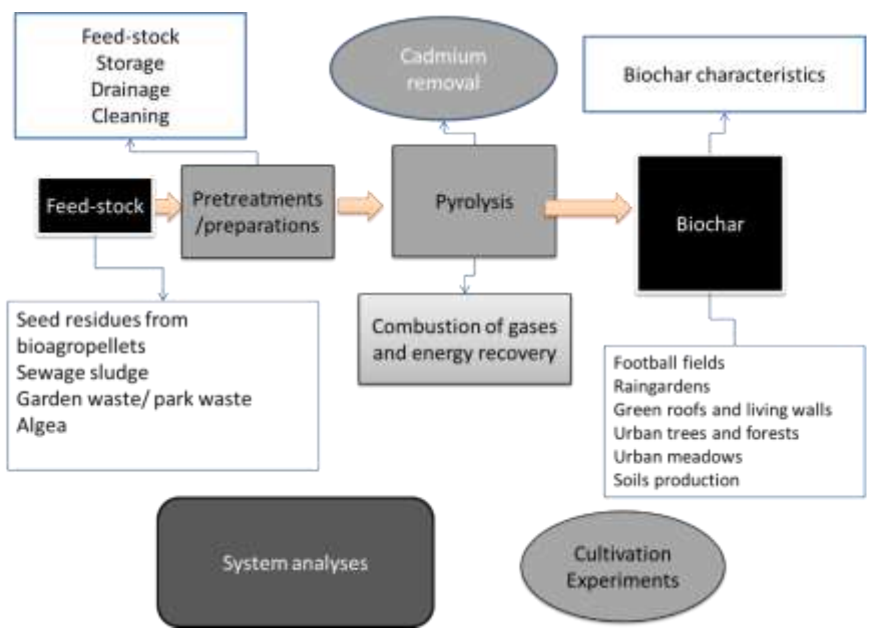

Figure 6 – Schematic description of the Hammenhög case and the adjacent studies in the project Rest till Bäst Biokol.org

WET AIR OXIDATION USING NITROGEN DOPED BIOCHAR CATALYST

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Key Words: Wet oxidation, Nitrogen doped bio-char, treatment of liquid effluents

Significant efforts in development of wood and algae HTL processes for fuel production, have been made by both government and private sector industry. However, little research has been focused on the treatment, recycle or disposal of the aqueous phase byproducts. Often the aqueous phase product is collected and stored for analysis but not for re-use in future conversion. The product is highly diluted by process water and can contain 1 – 2 wt. % carbon. Carbon content, although very dilute, is primarily comprised of organic compounds such as acids and alcohols. Due to such dilute contamination with organic compounds treatment, recycle, or disposal of such aqueous products has not been standardized in new bioprocessing plant design. The resulting impact on the technical viability of the processes is therefore unknown. In this research wet air oxidation (WAO) is used as a technique to treat water effluent with highly dilute concentration of organics, specifically phenol. WAO is often used in water treatment processes where organic contaminants are overly toxic to standard wastewater treatments such as biological treatments. Oxygen is transferred from the gas to the liquid followed by the reaction of activated free radical species, formed by the oxygen at moderate temperatures and high pressures, and the organic compounds in the water. In the interest of understanding the reaction mechanism, a model compound aqueous phase was used. All experiments have been conducted with phenol dissolved in water at initial concentrations of 1000 mg/L (1000 ppm). Batch processing in stainless-steel tube reactors with an 0.5 in OD and a length of 12 in, was conducted at temperature range of 190 – 260 ^{o}C and an isobaric oxygen partial pressure of 1 MPa. These data sets were used to develop baseline global reaction rate kinetics as well as energy of activation for phenol oxidation reaction. Initial results were favorable with complete phenol removal from the model water effluent. However, HPLC analysis indicated that secondary oxidation products such as hydroquinone were present and complete oxidation did not occur. In our quest to achieve full oxidation of phenol, a nitrogen doped biochar catalyst was developed. Global kinetic analysis was once again completed on this set of data and the result was an overall reduction in the activation energy of the phenol oxidation reaction.

MINERALS-CARBON INTERACTION DURING BIOMASS PYROLYSIS: IMPLICATIONS TO BIOCHAR CARBON SEQUESTRATION AND BIOENERGY

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Key Words: Inherent minerals, Doped minerals, Thermochemical decomposition, Surface oxygen-containing functional groups, Small molecule compounds.

Biomass carbon could be sequestrated in form of biochar, an aromatized carbon structure produced by pyrolysis. Minerals are reactive constituents, which could transform species and interact with organic fractions during pyrolysis, significantly affecting the products, biochar and bio-oil. This study reviewed researches by authors recent years related to removing inherent minerals from biomass and doping alkaline and alkaline earth metal (K, Na, Ca and Mg), as well as phosphorus (P) into biomass to understand their influences on carbon (C) retention and C stability in biochar during pyrolysis; How this minerals-doping induces the alteration of primary products in bio-oil? Some conclusions have been drawn by other researchers. It is of great importance that this should be analyzed synthetically with C sequestration in biochar. Some of our key conclusions are as follows:

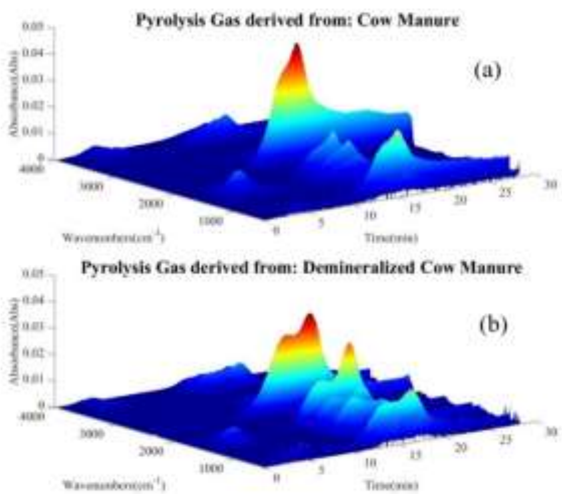

Figure 7 – TG-FTIR curves of the pyrolysis gas for the original (a) and demineralized (b) cow manure

The presence of all types of minerals could catalyze the thermal decomposition of C lowering its initial decomposition temperature due to they could decrease the activation energy and promote the cleavage of hydrogen bond, glycosidic linkage [1, 2]. Removal of inherent minerals reduced emissions of low molecular weight organic compounds (CO_2, CH_4, C_3H_6O, etc.), and promoted more C retention (3.5-30.1%) in biochar. The ordered structure and stability of biochar-C were increased.
Significant influences of inherent minerals on the pyrolytic bio-gas appeared from the beginning of pyrolysis to the end, resulting in more release of C as aromatized molecules (Figure 1a). More O-containing substances (wavenumber around 1000 cm^{-1}) released as large molecular substances for the demineralized cow manure (Figure 1b), which was consistent with the result that less O-containing functional groups retained on the demineralized biochar surface.

It was attractive to study the influences of each mineral on the pyrolysis process concerning C behavior. When we tried to dope common minerals into the biomass, it was found surprisingly that these added substances induced a significant increase of C retention. Doping $MgCl_2$ and $CaCl_2$ at dose of 20% (w/w) increased the C retention in biochar after pyrolysis by 31.5% and 29.1%, respectively. Mašek et al. also proved K doping increases biochar C sequestration potential by 45% [3]. Mg and Ca could form surface compounds (MgO, $MgO_3(CO_3)_2$, $CaCO_3$) as physical barriers and adsorbent to resist volatilization of small molecule compounds. Similarly, adding phosphate with main component $Ca(H_2PO_4)_2$ would react with biomass-C to form C–O–PO_3 or C–P, leading to greater C retention.

This study elaborated the different interactions of inherent and doped minerals with C in pyrolysis and suggested a potential strategy of regulating biochar-C sequestration by minerals-doping to build a physical barrier and chemical adsorbing layer.

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SLUDGE TRANSFORMS INTO BIOCHAR: DOPING CALCIUM INDUCES PHOSPHORUS TRANSFORMING INTO A PLANT-AVAILABLE SPECIATION

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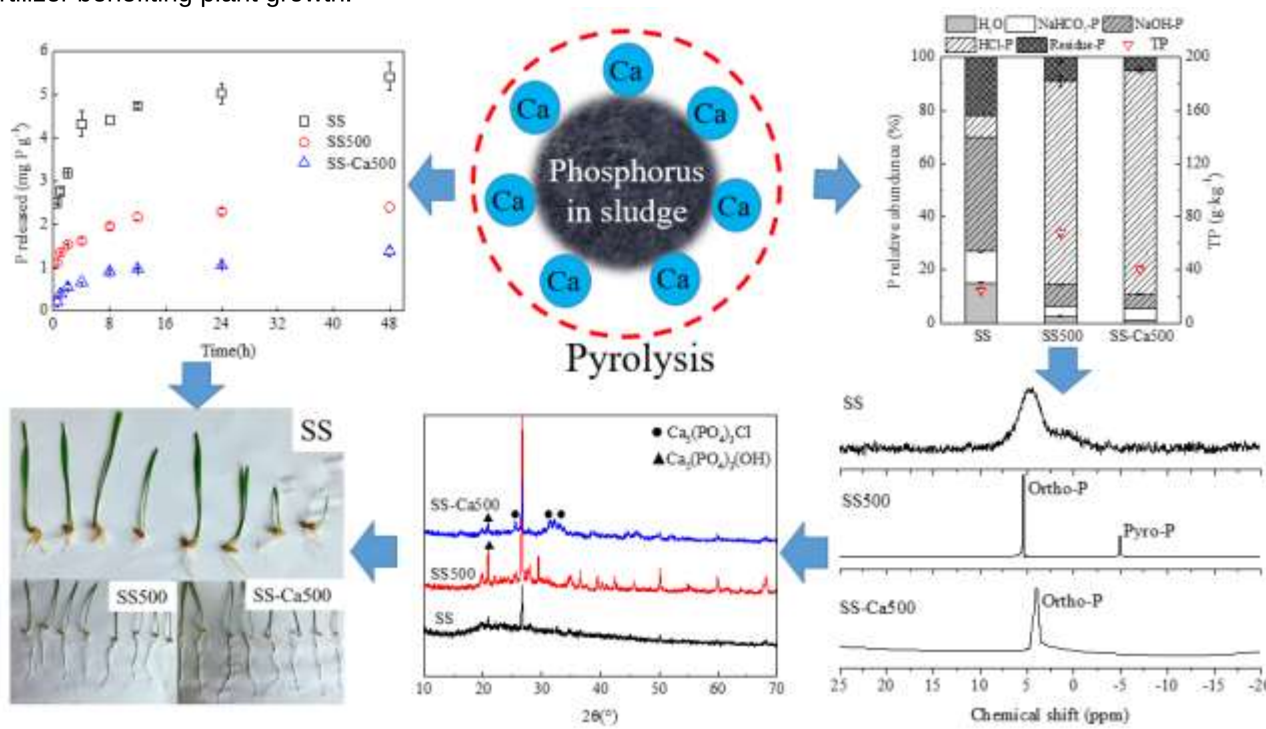
Key Words: Sludge, Composite biochar, Calcium-phosphorus crystalline, Slow-release, Plant root length.

The mass-produced sewage sludge (SS) worldwide is regarded as an important phosphorus (P) pool with a P-content of 2-3% (dry basis). Pyrolytic conversion of SS into P-rich biochar has multiple environmental benefits: toxicity elimination, carbon sequestration and soil fertilization. It has been proved that P transforms into insoluble speciation such as $Ca_2P_2O_7$ during pyrolysis, and this would be influenced significantly by inherent minerals such as Ca, Mg, Fe, Al, etc [1, 2]. With a purpose of enhancing biochar's fertilizer efficiency to plant, we selected calcium (Ca) as an additive to SS and expected their thermal-chemical interaction would induce P transforming into a plant-available speciation. The sequential extraction experiments showed that after pyrolysis (biochar: SS500) the percent of the insoluble phosphates (HCl-extracted P) increased significantly from 8.28% to 76.6%, while the readily soluble P species being extracted by water, $NaHCO_3$ and NaOH decreased sharply. Doping $CaCl_2$ strengthened this transformation and the produced biochars at pyrolysis temperature of 500°C with 20% (w/w) Ca-doping (biochar: SS-Ca500) contained 84.1% insoluble phosphates and 5.28% Fe/Al mineral adsorbed P (NaOH-extracted P). It indicated that Ca could compete for more P than Fe/Al during pyrolysis. Instrumental analysis (XRD, NMR) showed that Ca promoted more formation of pyrophosphate and short-chain polyphosphates such as $Ca_5(PO_4)_3(OH)$, $Ca_5(PO_4)_3Cl$, which are species facilitating plant-uptake while avoiding dissolution loss. This study gave an insight into P speciation transformation during biochar formation and suggested that P availability in biochars are controllable by doping minerals to structure a safe slow-release P fertilizer benefiting plant growth.



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MECHANISM OF HYDROCHAR FORMATION FROM BLACK LIQUOR

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Key Words: hydrochar, black liquor, carbon microparticles.

Hydrothermal carbonization is gaining increasing attention, since hydrochar demonstrates benefits for a large range of applications (biofuel, energy storage, electrodes…) [1]. The generation of solid is basically performed from solid materials (biomass or waste) making difficult the understanding of the phenomena involved. The aim of this study is to better understand the generation of hydrochar in subcritical conditions using black liquor. Black liquor (BL) is an alkaline liquid residue of paper industry containing high concentration of dissolved organics (lignin, partially hydrolyzed cellulose), and a high inorganics content (K, Na, Ca, S…). that makes it a high-value biomass. BL was chosen for its high water, organic and inorganic contents of respectively 80, 14 and 6 wt%. The study has been performed in batch reactor at 350°C, under autogenous pressure for various reaction times (0.5 to 24h).

Analysis of the reaction residue shows that for short reaction times (< 2h), carbonaceous microparticles are formed. At longer reaction time the size of the particles increased and then decreased (Figure 1). Their size is influenced by reaction time, and the heating and cooling rates as well. Available theories of carbonization were suitable to explain the particle generation up to 1.5h and above 6h. For instance, up to 90 min, the particles are formed due to the sursaturation of phenols and aldehydes in the droplets of oily phase dispersed in the aqueous phase [1]; above 6h, nucleation occurs in the transition media forming new microparticles due to phase equilibria [2]. In the mean time, the composition in the liquid does not vary significantly while the particle size increased. To account for the particle size and composition evolving, an hypothesis has been formulated involving the physical reorganization of the solid phase (coalescence of the transition layer) resulting in a coalescence of carbon particles.

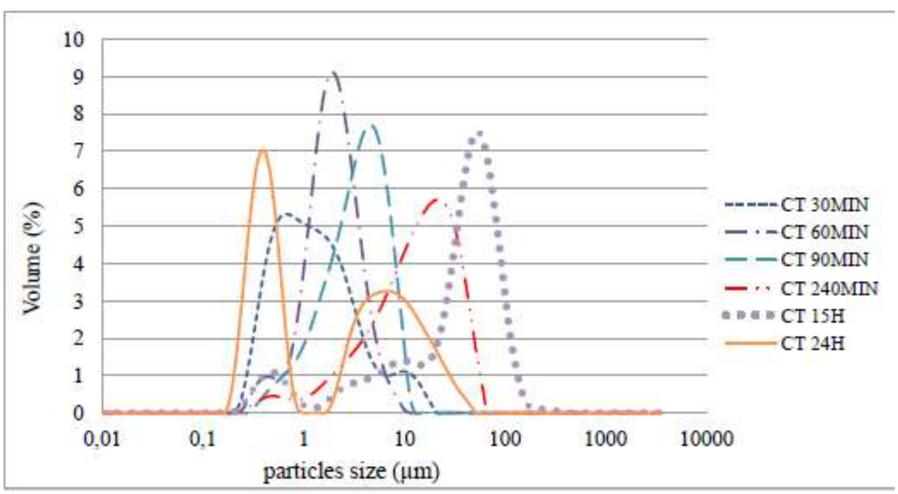

Figure 8 – particle size distribution (in volume) versus reaction time at 350°C

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CHARACTERISTIC STUDIES ON THE BIOCHARS PRODUCED BY HYDRO-THERMAL AND STEAM GASIFICATION OF CANOLA HULL AND CANOLA MEAL FUEL PELLETS

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Key Words: biochar, characterization, steam gasification, hydro-thermal gasification, fuel pellet

Biochars, based on their production process and biomass precursor, can have a broad range of structural, compositional, chemical, and physical properties. These properties are important for identifying the biochar performance and stability in further applications. Non-food biomass has a great potential to produce biochars. Two inherent agricultural biomasses from Canadian prairies including canola hull and canola meal were used for the production of fuel pellets. This study provides information on the specific features of biochars produced by steam and hydro-thermal gasification of these fuel pellets compared with those of well-known pyrolysis biochars. For steam gasification, the steam to biomass ratio (SBR=0.31, 0.47, and 0.62) and gasification temperature (T=650, 750 and 850 ^oC) were used as the main process parameters. In contrast, for hydro-thermal (supercritical water) gasification, the effects of gasification temperature (T= 350, 450, 550, and 650 ^oC) were studied on the biochar properties at a constant pressure, feed concentration and reaction time. Different characterization techniques were used to study the physical, chemical, and structural characteristics of biochar products.

Characterization results, for steam-gasified biochars confirmed development of aromatic carbon structure and formation of composite char. XRD spectra for biochars produced through steam gasification showed no retention of biochemical features from the parent precursors in the biochars prepared in different levels of operating conditions. FTIR spectra confirmed the rearrangement of biomass structure at the early stages of steam gasification for all used operating conditions. Elemental analysis and Van Krevelen plot showed that for pellets, the H/C and O/C atomic ratios were in the range of biomass material. However, after gasification, the these atomic ratios for biochars were in the range of them for coal material, especially lignite coal. SEM analysis showed that steam-gasified biochars had much more cracked surface as compared with hydro-thermally prepared biochars. This observation was consistent with the results of porous characteristics for biochars which showed low BET surface area (<11 m^2/g) for hydro-thermally produced biochars but it was much larger (> 400 m^2/g) for steam-gasified biochars. XRD results for hydro-thermally prepared biochars at 350 ^oC showed the presence of cellulose I and cellulose II in the material structure, but the related peaks were not observed for the biochar prepared at hydro-thermal gasification temperature of 650 ^oC. For prepared biochars prepared at the highest temperature of hydro-thermal gasification, Raman analysis showed a large change in I_D/I_G ratio compared with that for biochar prepared at temperature of 350 ^oC confirming a drastic structural change in biochar structure. Results from other characterization techniques such as XRD, ICP-MS, and thermogravimetric analysis will be also discussed in the presentation.

The degradation of biochars was progressive with the rise in hydro-thermal gasification temperature from 350 to 650°C. Hydro-thermally produced biochars showed characteristics of transition char at low temperature (350 ^oC as gasification temperature) and properties of amorphous char at high temperature (≥550 ^oC). For steam-gasified biochars, higher BET surface area indicated the development of composite char. It is noteworthy that characterization results showed that the steam-gasified biochars did not have the compact aromatic structure of turbostratic char and their aromatic structure is not developed as biochars produced via pyrolysis. However, properties of steam-gasified biochars showed their great potential for industrial applications such as adsorptive and/or catalytic applications. In addition, both types of biochars due to their mineral contents can be tested for agricultural applications(soil amendment and productivity).

PRELIMINARY STUDY ON THE INFLUENCE OF PYROLYSIS PROCESS CONDITIONS ON THE TEXTURAL PROPERTIES OF ACTIVATED CARBONS FROM WHEAT STRAW-DERIVED BIOCHARS

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Key Words: Activated biochar, slow pyrolysis, wheat straw, CO_2 activation

It is widely known that biochar can be used in a wide range of applications including —but not limited to— soil amendment, energy production, adsorption and catalysis [1]. For the last two final uses, however, the pristine biochar produced through pyrolysis processes does not have an appropriate porosity development. In fact, the porosity of biochar is mainly due to narrow micropores [2]. Therefore, an activation process is needed to develop a more hierarchical porous structure in order to facilitate the diffusion path of the corresponding adsorbates and/or reactants. To date, there is almost no research on how the pyrolysis process conditions, at which the biochar precursors are produced, can affect the porosity of the subsequent activated biochars.

The aim of this work is to evaluate how the slow pyrolysis process conditions adopted for the production of biochars from wheat straw pellets can affect the textural properties of the final activated carbons, which are obtained via physical activation with CO_2 at 800 °C of the raw biochars. For this purpose, the following operating parameters were selected: the absolute pressure (from 0.2 to 0.9 MPa), the pyrolysis peak temperature (from 400 to 550 °C), and the type of gas atmosphere during pyrolysis (pure N_2 or a binary mixture of CO_2 and N_2 60:40 v/v). Not only the main effect of these parameters individually but also the possible effects derived from the interactions between them have been considered. To this aim, an unreplicated 2-level factorial design has been adopted to objectively analyze the influence of these parameters on the response variables (i.e., the BET specific surface area, pore volumes, and pore size distribution of the physically activated biochars).

The wheat straw-derived biochars were produced through slow pyrolysis in a bench-scale fixed-bed reactor, made of stainless steel and electrically heated. More details regarding the reactor configuration are available in a previous publication [3]. Then, the produced raw pellet-shaped biochars were crushed and sieved to obtain particle sizes within the range of 0.212–1.41 mm. For the subsequent physical activation, around 20 g of pristine biochar was heated up to 800 °C in a fixed-bed reactor placed within a tubular furnace (model EVA 12/300 from Carbolite Gero, UK) under pure N_2 atmosphere and at atmospheric pressure. Once this temperature was reached, the inlet gas stream was switched from N_2 to pure CO_2. During the reaction step, both the soaking time and gas-hourly space velocity were kept constant at 1 h and 7000 h^{-1}, respectively. Under these conditions, the degree of burn-off of the produced activated biochar could be dependent on the intrinsic reactivity and porous structure of the precursor. The textural properties of both raw and activated biochars have been determined from the adsorption isotherms of N_2 at –196 °C and CO_2 at 0° C. The activation tests are almost finished and the results obtained will be presented during the course of the conference.

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CULTIVATING CAMELINA FOR SUSTAINABLE AVIATION FUELS IN EU MED MARGINAL LAND RECOVERED WITH CO-COMPOSTED BIOCHAR AND DIGESTATE: PRELIMINARY RESULTS

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Key Words: Biochar; co-composting; soil amendment; biofuel: marginal land

The H2020 BIO4A project aims at producing and deploying Sustainable Aviation Fuels (SAF) at large scale in Europe. A major oil refinery, owned and operated by Total based on Axen's technology, will run in non-segregated full jet-mode, targeting the production of 5 kt of ASTM-certified bio-based HEFA jet fuel. The produced SAF will then be used in commercial passenger flights: the demonstration activities will be complemented by market and policy analysis. While this part of BIO4A represent the industrial component of the project, the issue of developing additional alternative routes for supplying sustainable lipids to the HVO process represents the key R&D part: this addresses the production of Camelina in EU MED marginal land, recovered by biochar or COMBI addition.

The production of a novel soil amendment, here named COMBI (COMpost + BIochar), and the evaluation of its performances to increase soil resilience in marginal lands prone to desertification in Spain, are therefore the main R&D actions. Co-composted biochar and digestate obtained from biomass anaerobic digestion has been produced and characterized. The use of Biochar and COMBI in marginal land mostly aims at increasing organic matter to the soil, favouring nutrient recycling and availability, increasing soil water holding capacity, and sequestering fixed carbon, thus contributing to the Paris Climate agreement (Climate Change mitigation) and the UN Sustainable Development Goals. In particular, the carbon removed from the atmosphere, differently from most of the CCS routes, where C is stored, is employed to support the adaptation of difficult agricultural lands and regions to climate change, improving soil and agriculture resilience (Climate Change adaptation).

Biochar was produced from chestnut woodchips, thermo-chemically converted through the 50 kg/h oxidative slow pyrolysis unit developed at RE-CORD lab, while digestate was obtained from a mesophilic anaerobic digestion plant mostly fed with animal manure.

Co-composting was carried out in two different periods: the first one, during the Summer season in Tuscany (IT) in a greenhouse using static windrows, equipped with temperature and moisture sensors, and turned manually twice per week; the second campaign was conducted in the same location, but during the winter season.

The characteristics of different types of co-composted biochar-digestate-straw blends (COMBI) were assessed. Main physical and chemical properties were analyzed with respect to the European Biochar Certificate (EBC) standard and the European Compost Network specifications, that developed the European Quality Assurance Scheme (ECN-QAS), for the solid fraction of digestate. The potential dynamic respiration index (PDRI) test was carried out to investigate the biological stability of the solid digestate. The Brunauer–Emmett–Teller (BET) analysis was also performed on the biochar component, so to characterize the biochar in terms of total porosity and pore diameters distribution using the density functional theory (DFT) method.

The test compared the composting process of the digestate only with the co-composting process of the same organic matter with the addition of increasing rates of biochar, up to 15% w/w d.b. Results were compared in terms of duration of the bio-oxidative phase and the maximum temperature reached. Products obtained were characterized and compared as regards yield (in terms of organic matter), Humic and Fulvic Acid content, Nitrate and Ammonium-N content.

The products were then applied to two sites in Spain, before seeding Camelina crop: each site comprised 7 different microplots of 10 m^2 each, and 4 repetitions. The microplots included soil without fertilization (control), soil with NPK fertilization, soil with three different blends of COMBI, soil with only biochar, soil with composted digestate alone. The test sites were located in two different areas of Spain, one South and the other North of Madrid. The same site will continue to be tested in normal rotation with barley over the following two years.

The present works report the results of the on-going test campaign, assessing and discussing the benefits of the soil restructuring.

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ACTIVATION OF BIOCHAR FROM OLIVE RESIDUES: A PREDICTIVE MODEL FOR YIELD AND SURFACE AREA

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Key Words: Biochar, Activation, Olive residues, Modelling

A great amount of work in the literature is dedicated to the kinetic modelling of gasification reactions, while a limited number of authors have paid attention to the evolution of physical parameters, which are very important in the case in which the reaction is applied to the production of activated carbons. The Volume reaction model (VRM) [1], the Shrinking core model (SCM) [2], and the Random pore model (RPM) [3] are unable to provide a relationship between kinetics and the physical properties of the activated carbon and, particularly, between yield and surface area.

Experimental CO2 activation of pyrolytic bio-char produced from olive residues has demonstrated that both yield and surface area vary linearly with time. Moreover, a unique relationship between increases in surface area and reduction of yield is observed.

A simple model is proposed and validated, able to predict the relationship between yield and surface area of bio-char from olive residues, activated with carbon dioxide. The model is based on the following assumptions: (i) no external mass transfer limitations; (ii) formation of cylindrical pores; (iii) particle shrinking rate negligible with respect to the pore evolution rate; (iv) increase in pore diameter with time is negligible compared to the increase in pore length (the reaction is stopped before pores start to collapse); (v) the activation rate is independent of the CO2 partial pressure.

The experimental and predicted yields and specific surface areas are successfully compared as illustrated in Figures 1 and 2.

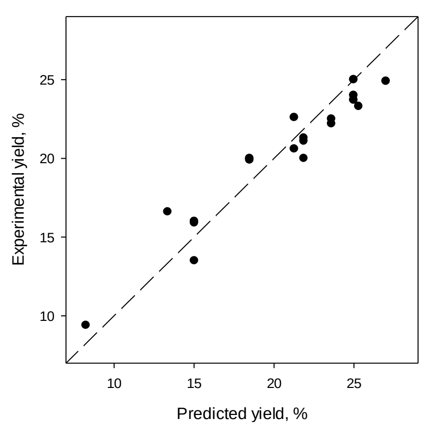

Figure 1. Yield model predictions

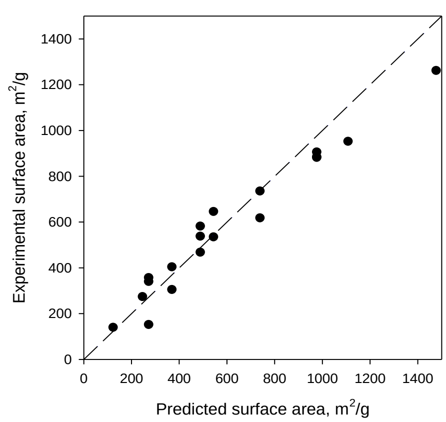

Figure 2. Specific surface area model predictions

VALIDATION AND APPLICATION OF A MULTIPARAMETER MODEL FOR THE DENSIFICATION OF BIOCHAR

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Key Words: biochar, densification, pelletization, modeling, pyrolysis

Densification is generally addressed to improve both the mechanical properties and the energy density of biomass feedstock. For such reason, it can also be used for biochar. However, the investigation of larger scales production by smaller academic equipment is not straightforward. It is therefore relevant to have access to models to facilitate a reliable comparison between the two different scales. In 2011, Holm et al. provided and validated a multiparameter model for analyzing industrial wood pelleting by a lab-scale single pellet press[1]. In 2017, the model was further verified for torrefied wood pelleting by Puig-Arnavat et al[2]. The intention of the authors of the present study was to prove the suitability of this model for pyrolyzed wood. It may help to understand how the densification process can be optimized at larger scales, especially regarding the forces that act through the pelleting channel, which are often cause of damages. Theoretically the model links the pelleting pressure P_x, that the pellets undergo when ejected out of the channel, to the compression ratio $c = x / 2r$ (where x is the length of the channel and r is its radius) [1]. This is described by the equation:

$$P_x(c) = \frac{U}{J}\,(e^{4Jc} - 1) \qquad \text{Eq. 1}$$

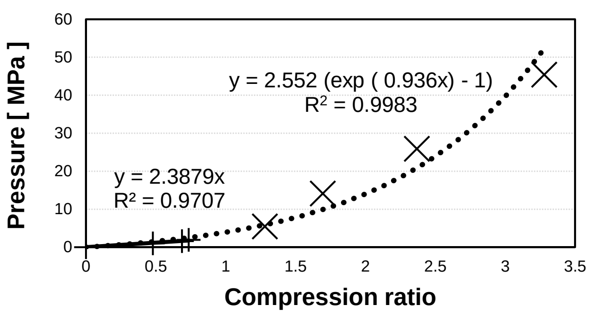

Figure 9 Comparison between experimental data and model equations at 20°C

Where U and J are constant parameters related to the Poisson's coefficient, the friction coefficient and the constant prestressing term[1]. The two constants can be easily computed by a limited amount of experiments. For $c \ll 1$, Eq. 1 can be simplified as:

$$P_x(c) = 4Uc \qquad \text{Eq. 2}$$

By measuring the pressure for a sufficient number of samples at different compression ratios (in this case with *c < 0.75*), *U* can hence be obtained by linear regression. Then, it is enough to measure the pelleting pressure for other pellets with $c > 1$, to compute by non-linear interpolation the value of J and define all the parameters of Eq. 1. In the present work, the model was validated by commercial charcoal. The moisture content was corrected to 10% of the total weight by addition of water. Pelletization underwent at 20°C and for each compression ratio value, a triplet was produced, and pressure computed as average. The result is shown in Figure 1. Afterwards the pressure curve was computed at three different other pelleting temperatures and the behavior of the constants *U* and *J* was observed. Finally, the model was further used to understand how pelletization is affected by the pyrolysis temperature and the water content. First, biochar from Norway Spruce produced at 400°C, 600°C and 800°C was pelletized. Then, Norway spruce pyrolyzed at 600 °C was pelletized with an adjusted moisture content of 10%, 20% and 30%. This sensitive study led to get an insight of the main parameters which strictly affect the pelletization of biochar. Higher pyrolysis temperatures and higher moisture contents make pelletization easier since the pressure the channel experience decreases at fixed compression ratio. As result, the forces acting through the pelleting channel become more acceptable at larger scales.

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NEWCARBON INNOVATION FOR THE PRODUCTION AND APPLICATION OF BIOCHAR, WOOD VINEGAR AND ENERGY

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Key Words: Innovative, Technology, Biochar, Wood Vinegar, Energy.

NewCarbon (Pty) Ltd is a South African company developing innovative technological solutions for the African and global markets. Due to world-wide transformational trends, such as population growth, economic development and climate change, energy shortages, water pollution and land degradation, resources are increasingly under pressure to support societal development and to maintain necessary services[2] NewCarbon's technology provides an integrated solution approach to address key aspects of the world's food-water-energy-crisis.

NewCarbon has developed a novel and innovative three-stage thermal pyrolysis-based technology to transform various forms of waste biomass into biochar, activated bio-carbon, wood vinegar, energy and other valuable products. Our technology is designed to be transportable and placed in a 20-50km radius from the biomass source[3], transporting raw products to regional facilities that process raw products into final packaged products for market distribution.

Our uniquely produced biochar and activated bio-carbon has been extensively tested in various markets including water purification, livestock farming and soil remediation. The demand for a consistent and high quality locally produced biochar and activated bio-carbon is growing daily, with municipality of the City of Cape Town utilizing 500 tons per annum in their water purification works at 4 different sites. The value of high-grade biochar in livestock farming and soil remediation is also gaining momentum with universities and farmers alike.

A unique selling point and value add of our technology innovation is the extraction of high purity wood vinegar (liquid wood smoke), wood tar and bio-oils from the biomass before being transformed to a high-grade biochar and activated bio-carbon product in our pyrolysis activation unit. Our superior wood vinegar product is used in boosting seed germination, organic fertilizer production to stimulate root and leaf growth in plants and applied elsewhere on a large scale as an organic pest repellent while improving crop growth.

The NewCarbon Innovation will advance the Southern African strategy to move towards lower-carbon economies, create growth and jobs, promote science and innovation partnerships and expertise, provide focused opportunities for environment and food security, enhance science and technology capacity building and address the challenges of climate change.

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[2] Waste biomass sources include forestry waste, alien invasive plants, municipal green waste, saw mill waste and agricultural farms that produce biomass wastes such as macadamia nut and maroela farms.

BIOCHAR IN RESIDUAL ASH FROM GASIFIER COOKSTOVES

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Key Words: TLUD, ash, water boiling test, PAH.

Biomass based cooking with open fire is still used by more than three billion people worldwide [1]. Open fires normally produce ash, which contains both pure ash and some unburned carbon or biochar. The possible agricultural advantages by biochar as a soil amendment, has increasingly been discussed the last decade [2]. There exist many different types of cookstoves suited for simultaneously cooking and biochar production. Top Lit Up Draft (TLUD) – Natural Draft stoves are tested in several countries but represent a risk for condensation of pyrolysis gases on the charcoal during the combustion phases. In the present study two different TLUD stoves were tested according to the laboratory-based Water Boiling Test (WBT) with two different fuels: wood chips of oak, *Quercus petrea*, and standard 6 mm wood pellets. Two of the main goals were to evaluate cooking efficiency and biochar production including suitability as a soil amendment. After the WBT, the combustion continued until the flames disappeared and the remaining biochar was then quenched, cooled and put into plastic bags and sealed for later analysis. The biochar yield and corresponding cooking efficiency are shown in figure 1. The biochar yield is lower for higher efficiencies and in general around 19-23 % based on the biomass input. The biochar was analyzed and some of the major findings are shown in table 1. PCB and heavy metal content were in all cases low.

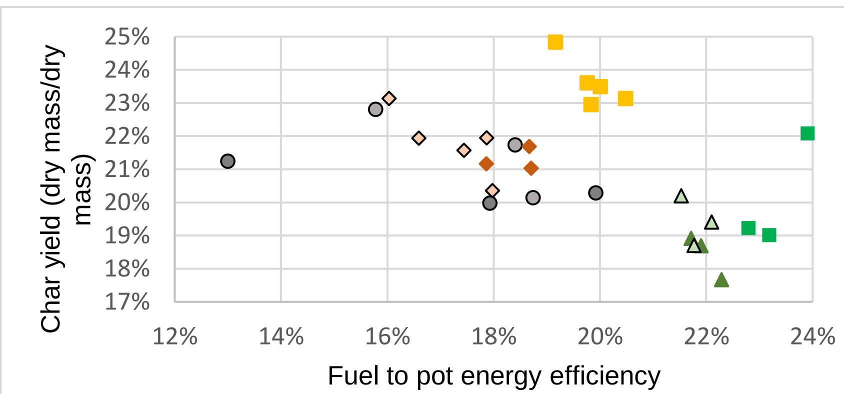

Figure 1. Cooking efficiency and biochar yield with different combinations of fuel and cookstove. Same type data point means equal combination.

Table 1. Selected characteristics of biochar from wood pellets and wood chips. Dry basis, db and molar ratio, $_{mr}$. HHV is Higher Heating Value.

Feed stock	C	H/C_{org}	O/C	HHV	Furans	16 EPA-PAH
Unit	$[\%]_{db}$	$[-]_{mr}$	$[-]_{mr}$	$[MJ/kg]_{db}$	$[ng/kg]_{db}$	$[mg/kg]_{db}$
Wood chips	84.5	0.33	0.063	31.0	1.45	10.9
Wood pellets	87.2	0.39	0.053	32.7	<0.92	9.8
Limit value	>50	<0.7	<0.4	-		<12
Standard	EBC	EBC	EBC	-	WHO(2005) PCDD/F TEQ	EBC Basic

EBC: European Biochar Certificate [3]

The two wood-based fuels resulted in a biochar yield of about 20 $\%_{db}$. The biochar quality is fulfilling the requirements of EBC except for PAH, which in two of in total six samples exceeded the limitation for EBC basic grade biochar.

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PRODUCTION AND CHARACTERIZATION OF HTC SOLIDS FROM LIGNIN-RICE BIOMASS AND DOWNSTREAM APPLICATION IN ANAEROBIC DIGESTION

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Key Words: lignin; Hydrothermal carbonization; Surface functional groups; Hydrochar; Anaerobic digestion.

Lignocellulosic biomass is mainly composed of three pseudo components, namely hemicellulose, cellulose, and lignin. Of these three, lignin as a cross-linked network hydrophobic polymer has a strong resistance to biodegradation such as anaerobic digestion (Hatfield and Fukushima 2005, Fernandes, Klaasse Bos et al. 2009), but can be decomposed thermally. Hydrothermal carbonization is a promising method of processing biomass with high moisture content for value-added products. This study evaluates and compares the physicochemical characteristics of hydrochar derived from rice husk, wheat straw pellets, oil rape straw pellets and reference alkali lignin. The results indicated wide variation in the physicochemical properties and quality of hydrochar depending on biomass feedstock composition. Mass yields of lignocelluosic biomass increased with the increase of lignin content, however, higher lignin content biomass exhibited lower hydrogen/carbon ratio. The results of this study also identified that hydrochar were more acidic than biochar produced from same feedstocks, however, Kraft lignin hydrochar exhibited higher pH 9.52. The study also seeks to explain the role of biomass composition on surface functional groups of hydrochar via attenuated total reflection - Fourier transform infrared spectroscopy (ATR-FTIR). The ATR-FTIR spectra were used to identify the functional groups qualitatively. It would give further insight into surface functional groups of hydrochars and the changes in the chemical composition of lignin and biomass during the conversion process.

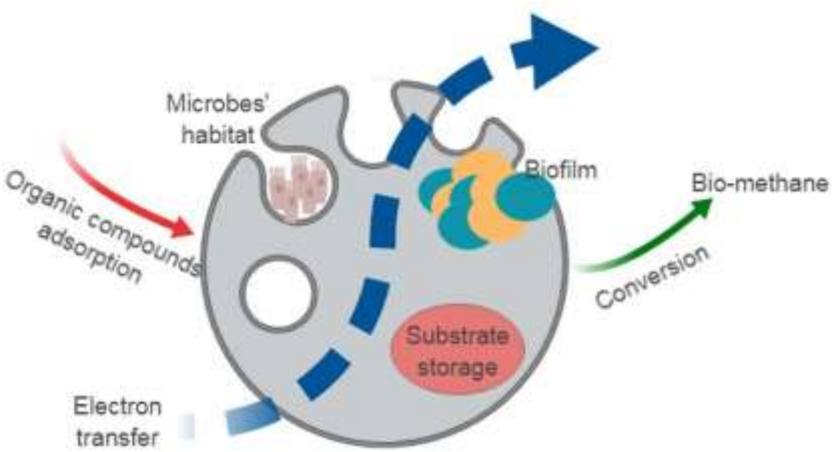

Figure 1 – propose functions of hydrochar in anaerobic digestion

We then further studied the effects of these hydrochars additions on the anaerobic digestion of sewage sludge. AD batch experiments were performed at an inoculum:substrate ratio of 1:2, at 37±1ºC and under agitating conditions. The hydrochar to inoculum ratio in each treatment condition was 2% weight basis. Graphene was used as reference material. The preliminary results showed that only the biogas volume produced by bioreactor supplied with Kraft lignin hydrochar was higher than the positive control with only sewage sludge as substrate. It had the highest biogas yield of 64.2±5.25 mL with 73% of methane at day 29. In contrast, the syringe bioreactor with treatment of rice husk, wheat straw pellets, oil seed rape pellets hydrochars and graphene generated less biogas volume compared to the positive control groups. These study results clearly indicated that the type of hydrochar and surface functional groups in hydrochar play a key role in determining the effectiveness of the hydrochar in enhancing biogas production from sewage sludge. Thus, a combined HTC-AD treatment provides a seemingly effective method for valorizing lignin-rice biomass.

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NANOINDENTATION CHARACTERIZATION OF MICROWAVE-PYROLYSIS BIOCHAR

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Key Words: Microwave pyrolysis, Biochar, Nanoindentation, Biocomposite materials,

This study investigates the nanoindentation hardness and Young's modulus of microwave pyrolysis biochar developed from hemp and softwood feedstocks. Recent studies have produced encouraging results on the potential for biochar as a reinforcing filler in composite materials, owing to the high porosity and hardness of the carbonous material. In order to further the understanding of the effect of biochar as an additive, and to develop predictive models for the composites, mechanical properties of the chars are needed.

The biochar was synthesized from both hemp and softwood feedstocks, in-house through a microwave-pyrolysis process at 2700 watts, for one hour, with heating rates reaching 50 °C/min and residence temperatures of up to 660°C. Proximate and ultimate analysis were performed as well as physiosorption analysis in order to relate the nanoindentation results to the biochar characteristics. Proximate analysis indicated larger fixed carbon content of softwood (71 wt%), and hemp (72 wt%) with inverse trend for volatile matter. Biochar samples of both softwood and hemp showed an H:C ratio of <1.2 showing a graphite like structure in the biochar. The elemental composition was similar due to the lignocellulosic nature of both biomasses. Porosity results favored hemp biochar which had 12.18 m^2/g BET surface area and 2.58 m^2/g micropore area, compared to 9.96 m^2/g and 1.63 m^2/g BET surface area and micropore area of softwood.

Prior to nanoindentation, biochar samples from each feedstock were cold-mounted, then polished with decreasing grit sizes from 500 to 1200 microns. The Young's modulus and hardness values of the biochar samples were obtained from an iMicro Nanoindentor using a 1mN load. An average of ten indentations were performed on the mounted biochar samples. Nanoindentation results indicated Young's modulus of 5.98 and 5.64 GPa as well as hardness of 0.26 and 0.51 GPa for hemp and softwood char respectively. Considering the nanoindentation results it was observed that heating rates/residence temperatures of pyrolysis and porosity of the biochar are the main factors in overall hardness and modulus. High pyrolysis temperatures allow the char to carbonize to a hardened glass-like state, while faster heating rates aid in the release of softer pyrolytic tars and residue. Furthermore the higher development of healthy micropores at faster heating rates leads to a stronger porous structure, increasing the Young's modulus.

Overall the findings from this study are important indicators of the factors influencing the potential of biochar as a reinforcing filler in biocomposite materials. Knowing the Young's modulus and hardness of biochar is highly useful in the development of analytical predictive models describing the behavior of biochar reinforced biocomposites under various loading conditions.

CHANGES IN PORE SIZE DISTRIBUTION WITH PYROLYSIS TEMPERATURE, PARTICLE ASPECT RATIO AND PRETREATMENT BY LEACHING OF LARGE BEECH WOOD PARTICLES

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Key Words: pore size distribution, specific surface area, pyrolysis, beech wood, porous carbonaceous materials

When assessing the usefulness of pyrolysis chars as porous materials for the application as adsorbents, catalysts or catalyst supports, one of the most important parameters of the assessment, besides the specific surface area, is their pore size distribution [1, 2]. The aforementioned processes are highly pore size selective, hence inappropriate pores sizes of the applied material can lead to the material's uselessness for a given application. In terms of the application of pyrolysis char as a soil amendment (i.e., biochar), pore size also plays a major role. For example, in case of a too large share of micropores, even though the water capacity is relatively high, water is only partially available for plants due to strong capillary forces in the micropores pores [3]. Besides their beneficial environmental applications, porous materials of biomass origin, like pyrolysis chars, are characterized by the possibility to change their porous structure with production parameters. Therefore, the possibility exists to set production process parameters in a way that allows obtaining a material with a desired pore size distribution. It makes pyro-chars more advantageous materials in comparison to its current, strongest market rival - silica-alumina materials. Even if the desired structure of the carbonaceous porous material is not obtained in the primary production process (pyrolysis), it is possible that specifically pre-processed materials will behave better in upgrading/activation processes (e.g., steam activation) and in the end, a tailor-made material, with tailor-made pore size distribution will be obtained.

The strongest inhibitor of the implementation of the mentioned approach is the large inhomogeneity within biomass feedstocks, in terms of both biological and inorganic composition as well as in the initial structure. Due to the significant amount of parameters playing a role in the process of surface and pore development of biomass-derived carbonaceous materials, detailed knowledge about their individual and shared influence is relatively low. Hence, at the present day, biobased materials obtained through thermal conversion are burdened with strong randomization of results in terms of pore size distribution.

The presented study had been performed to fill the existing gap and meet the increasing need for tailor-made, functional carbonaceous materials, for instance for environmental applications (absorbents). The study aimed at investigating the changes in the internal structure of large beech wood particles in relation to the production (pyrolysis) and initial biomass parameters. Large particles instead of fine powders were selected in order to bring the study closer to the conditions that are more likely to occur in large scale processing. As investigated parameters were chosen five different temperatures (300, 400, 500, 700 and 900 ^oC) and as the initial biomass parameters: two particle size (ø8x10mm and ø8x16mm) and initial inorganic concentration (samples with and without acidic leaching pre-treatment to demineralize the biomass beforehand). Each particle's pore size distribution was analyzed through three analysis methods, most suitable for specific pore size: helium pycnometry (total porosity) and N_2 adsorption (meso-porosity) and CO_2 adsorption (micro-porosity) [3]. Such approach allowed for proper and detailed assessment of changes in overall porosity, specific surface area, and pore size distribution.
The results obtained in this study allowed for the identification of the influence of investigated parameters on pore size distribution. Moreover, the applied data matrix will allow to form correlations between the investigated parameters and pore size distribution, resulting in basic formulations of the phenomena and therefore giving the foundations for initial modeling and possibility of process optimization.

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COMMERCIAL BIOCARBON PRODUCTS – A CASE STUDY

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Key Words: Biochar, charcoal, biocarbon, pyrolysis, climate.

The technologies of pyrolysis and gasification offer a unique opportunity to recover carbon from the atmosphere resulting in negative emissions. The International Panel on Climate Change has recently identified Pyrogenic Capture and Storage as a negative emission technology that is ready for scale-up world-wide. Pyrogenic capture and storage is economically favourable, and has positive effects on ecosystems, agriculture, and food security.

Although the environmental benefits of biochar are clear, it is only through commercial markets that the technology will provide value for both business and the environment and meet the standard of sustainable development.

This presentation will outline how autothermal slow pyrolysis recovers carbon from the atmosphere using only renewable energy while cleaning the atmosphere of carbon dioxide. The presentation will provide a case study of four commercial products that are removing carbon from the atmosphere every day.

Black Kitty's Odour Eliminator

firefly Activated Charcoal

CARBON 2M™ Animal Nutrition

MAYAN GOLD Biochar Soil Enhancer

Figure 10 – Commercial Biocarbon Products

PYROLYSIS OF ORGANIC SIDE STREAM MATERIALS FOR THE PRODUCTION OF BIOCHAR AS AN AMENDMENT IN GREEN ROOFS: CHARACTERIZATION AND FIELD EXPERIMENTS

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Key words: pyrolysis, biochar, green roofs, side-streams, valorization

Green roofs offer a solution to worldwide problems in cities like: the urban heat island effect, floods and the loss of rural regions. Nevertheless, the widespread application of green roofs still faces some serious challenges, e.g. an excessive amount of drainage water, an excess of nutrients in this water, and plant mortality in periods of severe drought. Also, the production process of the components of these substrates, such as expanded clay, is not environmentally and energy-friendly. Biochar amendment in green roof substrates can help to overcome these problems because of its valuable properties like a high nutrient content, high waterholding capacity (WHC), low density and its self-sustaining production process.

In this research, biochar is produced from six different side streams in a pilot-scale rotating kiln carbonization reactor (kg/hour input). These side streams consists out of: MDF, date palm, coffee skins, tree bark, olive stones and a waste wood mix. The produced biochars are characterized with multiple physico-chemical analyses like biochar yield, elemental composition, surface functional groups, morphology, WHC, cation exchange capacity and polyaromatic hydrocarbons (PAH's). Furthermore, a techno-economical analysis is performed on the large-scale production of these biochars.

Small scale (0,25 m2) and field experiments (2.5 m^2) with biochar incorporated in commercially available green roof substrates in the temperate climate of the Netherlands and Belgium examine whether biochar can offer a solution to the described problems. Based on the analyses of the biochar, in particular the PAH's and elemental composition, and the small scale growth experiments, two different biochars made from the waste wood mix and tree bark in concentrations of 1 and 5 % are selected for the field experiments.

Growth of Sedum plants is monitored with digital imaging processing over a period of several months, starting from November 2018. Several chemical and physical parameters are monitored and linked to the properties of the biochar incorporated substrate like pH, conductivity, nutrient leaching and waterholding capacity.

CORE LEVEL BINDING ENERGY FOR NITROGEN DOPED CHAR: XPS DECONVOLUTION ANALYSIS FROM FIRST PRINCIPLES

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Keywords: N-Doped, Char, X-ray photoelectron spectroscopy, Deconvolution, Density functional theory.

Amorphous carbon produced from lignocellulosic materials has received much attention in recent years because of its applications in environmental and agricultural management with potential to sequester carbon, serve as a soil amendment, and improve soil aggregation. Modern engineered amorphous carbons with promising properties, such as porous structure, surface functionalities (O, N, P, S) and layers with large number of defects, are used in the field of adsorption and catalysis. There is a growing interest in the production of nitrogen-doped carbonaceous materials because of their excellent properties in a variety of applications such carbon electrodes, heterogenous catalysis adsorption and batteries. However, quantifying the surface nitrogen and oxygen content in amorphous nitrogen doped carbons via deconvolution of C 1s x-ray photoelectron (XPS) spectra remains difficult due to limited information in the literature. No suitable method exists to accurately correlate both the nitrogen and oxygen content to the carbon (C 1s) XPS spectrum in the literature. To improve the interpretation of spectra, the C 1s, N 1s and O 1s core level energy shifts have been calculated for various nitrogenated carbon structures from first principles by performing density functional theory (DFT) based calculations. Furthermore, we propose a new method to improve the self-consistency of the XPS interpretation based on a seven-peak C 1s deconvolution (3 C-C peaks, 3 C-N/-O peaks, and π-π* transition peaks). With the DFT calculations, spectral components arising from surface-defect carbons could be distinguished from aromatic sp^2 carbon. The deconvolution method proposed provides C/(N+O) ratios in very good agreement (error less than 5%) with those obtained from total C 1s, N 1s and O 1s peaks. Our deconvolution strategy provides a simple guideline for obtaining high-quality fits to experimental data on the basis of a careful evaluation of experimental conditions and result

COMPARATIVE ANALYSIS OF LOW NITROGEN EMISSIONS FERTILIZERS BASED ON ACTIVATED CARBON FROM RESIDUAL MATERIALS

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Key Words: biocarbon, fertilizer, nitrogen emissions, environmental analysis, reactive nitrogen saving

Nitrate leaching and ammonia volatilization are the main pathways of nitrogen loss in agriculture. New environmentally friendly fertilizers have been investigated in recent years in order to reduce nitrogen losses and associated impacts [1]. One suggested solution has been to incorporate biochar as soil amendment, since its effects on nitrogen retention and soil fertility are well known [2, 3]. Fertilizer production from activated biocarbon is the researched line explored in this work. Biochar has been produced from two different raw materials, residual biomass and coal mine residues. Both have been produced through a physical activation process in an externally heated quartz tubular reactor [4]. After an experimental period, the optimized conditions were reached and the biochar product was obtained showing good microporosity and adsorption characteristics. The final product was used to set up the new fertilizer, and its nitrogen retention capacity was experimentally tested by laboratory and pot trials.
Urea is one of the most commonly used mineral fertilizer in Spain so it was included in the comparative analysis. A 150 kg N/ha dosage was set for all the fertilizers. The study is framed in Aragon (Spain), therefore typical weather conditions, regional crop type or local agricultural soil were used as reference.

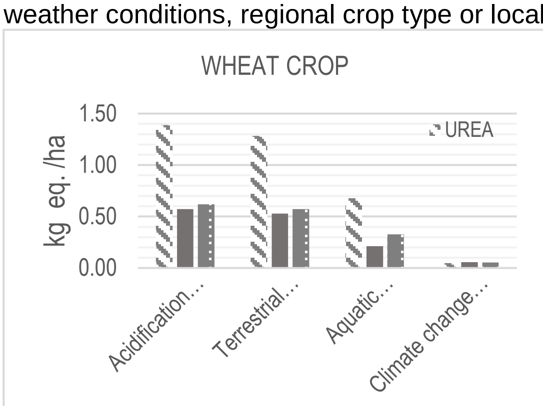

Fig. 1- Impacts assessment of new fertilizers and Urea.

On-field nitrogen emissions (NH_3, NO_3^- and N_2O) were estimated using own predictive models based on bibliographic data from experimental studies of nitrogen losses by volatilization and leaching. The theoretical analysis was based on LCA tools and footprint approach [5, 6] and brings to light the main environmental impacts associated with application of nitrogen fertilizers (Fig. 1).
Next stage was the analysis of environmental benefit of new fertilizers application in terms of reactive nitrogen saving. Obtained results confirm a substantial saving (64% and 51% of Nr saving regarding urea) in the reactive nitrogen emitted when AC fertilizers are applied in a wheat crop under particular conditions. Finally it can be concluded that residual biomass material offers better results compared to the coal waste material, getting a 13% more of Nr saving.

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BIOCHAR CHARACTERIZATION OF RAW VERSUS SPENT COMMON IVY: INORGANIC NUTRIENT BEHAVIOR

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Key Words: Common Ivy, conventional pyrolysis, biochar, nutrients, triterpene saponins

Hedera sp., common Ivy, a lignocellulosic evergreen vine, is commonly seen in gardens and yards all over the globe. It is an excellent candidate to be applied in vertical green walls to improve ecosystems in future green cities (e.g. fine particulate matter adsorption). These green walls need to be trimmed regularly, thus leaving a major residue stream which could be promising as biomass feedstock for biochar fertilizer production. However, common Ivy contains valuable compounds (e.g. etheric oils and triterpene saponins) increasing the process' added value. These should preferably be extracted prior to thermal conversion. The aim of this study is therefore to investigate the influence of extraction methods on the final properties of common ivy's biochar using conventional pyrolysis. Investigated extraction methods include a Soxhlet ethanol extraction and a steam distillation, to obtain respectively a triterpene saponin and volatile oil extract. The influence of these extractions on the biochar properties was studied by comparing the thermal conversion and biochar properties of spent, extracted, biomass with raw biomass. Studied properties include biochar yield, elemental composition (CHNO), amount of inorganic nutrients, specific surface area, and presence of harmful heavy metals. The guidelines of the European Biochar Certificate are used to evaluate said properties. Furthermore, the pyrolysis process parameters, temperature and heating rate, were optimized to improve said biochar properties for application as fertilizer. Tested pyrolysis temperatures were 400, 550 and 700 °C. Results show that biochar yield from raw ivy was inversely proportional with pyrolysis temperature ranging from 29.6 ± 0.6% at 400 °C, 25.4% ± 0.03 at 550 °C and 23.0 ± 0.06 % at 700 °C. It was found that steam distillation lowers the amount of heavy metals in the material, whilst the inorganic nutrients are retained, thus enhancing the biochar's potential as fertilizer. Furthermore, nitrogen content remained constant, around 2%, before and after pyrolysis both for raw and spent ivy, these results indicate that high-quality biochars were produced. To further understand biochar's chemical behavior in soils, structural properties and morphology are being investigated further, specific surface area via BET, general pore structure using SEM, surface functional groups with FT-IR and, aromaticity with CP/MAS 13C NMR results will be presented accordingly.

THE ROLE OF FEEDSTOCK FOR BIOCHAR & ENERGY IN REDUCING THE CARBON FOOTPRINT OF BIOENERGY PROJECTS — A CASE STUDY IN NORTH EUROPE

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Key Words: Biochar, peat, substrate, CCS.

The study evaluates the GHG emissions of biochar & bioenergy production in a low temperature gasifier based on various feedstocks. A LCA approach is used to assess the environmental impact of the production and use of biochar for selected applications including the whole feedstock supply chain. Three kinds of feedstock were evaluated, namely (1) agro-residues and municipal forest residues (2) clean wood from sustainable forestry (e.g. pine) and (3) fast growing energy crops (short rotation coppice) Miscanthus and/or willow.

The scenarios considered are:
(1) Co-production of bioenergy (syngas) and biochar in a low temperature gasification unit, feedstock used agro-residues and park residues. The biochar is used as soil improver due to its high nutrient content. Syngas is used for heat production in a gas boiler, replacing NG boilers, while biochar is considered a CCS option (BECCS = BioEnergy Carbon Capture & Storage). The reasoning is, residual feedstock streams (agro-waste and park residues) are abundant, and need to be treated anyway. The option of gasification as a treatment process offers the possibility to return part of the carbon to the soil and sequester it (negative CO2 flow = CCS) and also replace part of fossil energy demand by producing energy from waste material (neutral CO2 flow).

(2) Dedicated production of biochar in a pyrolysis unit (PyroCCS_1). Feedstocks used agro-residues and park residues, same as in Case 1. The product is used as soil improver, for example in poor degraded soils. In contrast to option (1, BECCS) , no fossil energy is replaced because no surplus energy is co-produced.

(3) Dedicated production of biochar in a pyrolysis unit, feedstock used is pine and miscanthus from sustainable forestry. The product, due to its high quality, is entirely used in sustainable growing media replacing peat (PyroCCS_2), and at the end of life it is disposed in the soil. The reason is, high quality biochar should be used for high value end products, such as substrates for high market price products (strawberry, tomato, horticulture).

The functional unit is the use of 1 kg feedstock. All results on GHG emission reduction and other impact categories refer to 1 kg input feedstock. The choice of this functional unit allows the comparison of the scenarios that may have a different purpose, namely producing only biochar or co-producing biochar and bioenergy. In the case of co-produced bioenergy (in the form if syngas) and biochar, the bioenergy part replaces fossil energy from natural gas.Tradeoffs are identified, which influence the final GHG emission mitigation potential per case; biochar is always disposed of in the soil and thus is considered a CCS option.

UKBRC STANDARD BIOCHAR AND ITS USE BY THE GLOBAL SCIENTIFIC COMMUNITY IN ITS FIRST 5 YEARS OF EXISTENCE

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Key Words: standard biochar, characterization, applications

Since it was first made available to the scientific community, the UKBRC standard biochar has been used by more than 100 research groups worldwide in a wide range of applications including contaminated soil remediation, water treatment, nutrient management, polymer additives, additive for anaerobic digestion, and many more. In this presentation I will provide an overview of the they key areas of research where this set of biochar has been used and highlight new opportunities that a widespread adoption of a common standard set of materials offers to the research community.

Figure 1 – UKBRC standard biochar set consisting of 12 biochar produced from 6 feedstock

ARTISANAL AND INDUSTRIAL BIOCHAR PRODUCITON AND CO-COMPOSTING FOR ACIDIC MINE WASTE RECLAMATION

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Key Words: gasification, kon-tiki, co-compost, mine, restoration

Frequently, mine wastes tend to be acidic with little to no organic matter and CEC, and present phytotoxic concentrations of available metals as well as unfavorable hydraulic properties. Biochar and compost have been shown to have a great potential to improve mine waste physicochemical properties, however, most research has been done applying them independently or mixing them right before application. Biochar has potential as a soil amendment due to its capacity to, reduce soil acidity, improve hydraulic properties, retain nutrients and immobilize organic and inorganic pollutants. It also has potential as a C capture medium given its recalcitrant nature. Despite its potential, biochar, in general, provides low nutrient and labile C inputs and is expected to contain polycyclic aromatics. Here we present a strategy to address these shortcomings by co-composting, a process in which biochar is part of the composting matrix from the start. We expected that biochar would aid in N and P enrichment of the final product and that co-composting would improve its surface functionality, providing increased CEC. Furthermore, we study the use of these biochars and co-composts as amendments to a highly acidic mine tailing substrate in a pot experiment with the aim of reducing pollutant dispersion by favoring the development of a sustainable vegetative cover so stabilize the material and reduce its erodibility and retain soluble metals within the amended material. We expected the amendments to increase water holding capacity and available water content while decreasing bulk density, acidity and metal mobility, resulting in a higher biomass production.

Biochar was produced by gasification (Ankur Scientific PG-45 downdraft gasifier) and flame curtain pyrolysis (Kon-Tiki pyrolizer) of woodchips from programed and weather-related tree removal. Temperatures on both systems (~1,000°C and ~650°C) were higher than those of conventionally used processes, deriving in high amounts of fixed C (>70%), indicative of C sequestration potential, and high pH values (>10) and $CaCO_3$ equivalence, indicative of pH adjustment potential. Kon-Tiki is a semi-artisanal production technique with reduced emissions as pyrolysis gases are mostly combusted and do not escape to the atmosphere. Gasification is a technology aimed at producing energy. Energy derived from gasification of woodchips was ~700 kW_eh per ton of sun-dried biomass with a biochar yield of 19.97%.

Co-composts were produced during six months using yard waste and gasification- or kon-tiki-derived biochars added at a 17.6% w/w ratio within 210 Lt insulated reactors. Composts with biochar showed a slight tendency of N and P enrichment as well as higher pH and $CaCO_3$ equivalence, indicating a higher potential to work as pH adjustment agents. Biochar co-compost had a higher content of fixed C, indicative of its capacity to function as C capture medium. A pot experiment was set up to study the effects of pure compost, raw biochar and co-compost on a highly acidic mine tailing (pH 2-3). Three w/w doses (2.5, 7.5, 15%) were selected with the aim of evaluating the effects of low doses which could be more economically viable to apply in reclamation schemes as well as to analyze the metal immobilization potential associated with organic matter under acidic conditions, as substrate pH was not expected to rise more than 3 pH units. *Lolium perenne* was selected as plant cover. Preliminary evaluations show raw biochar has the greatest potential to increase pH while also increasing electrical conductivity the most. All amendments increase water holding capacity and available water content. Biomass production in pots was favored by all amendments but was highest in compost and co-compost.

ANALYSIS OF PEAT-BASED BIOCHAR AS AN ADDITIVE TO CONTROL GREENHOUSE GAS EMISSIONS IN MANURE MANAGEMENT SYSTEMS

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Key Words: peat, biochar, muffle furnace, greenhouse gas abatement, manure management.

The agricultural sector accounts for 10-12% of global greenhouse gas emissions. Within the agricultural sector manure management causes almost 10% of these agricultural greenhouse gas emissions, making it an important target area for mitigation strategies. The role of biochar as a regulator of greenhouse gas (GHG) emissions from soil has been well established, while its application in manure management holds promise considerable uncertainties remain regarding operational setting and efficacy. Traditional applications of biochar have used a wide variety of feedstock sources and production pathways which in turn determine the outputs of the resultant biochar as a GHG regulator. In this study slow pyrolysis, at temperatures of 450 - 750 °C with a heating rate of 7.5 °C min^{-1} and a residence time of 20 minutes, was used to produce biochar in a muffle furnace. Different temperatures were used to explore the unique characteristics of biochar and compare them throughout the temperature values in production. Even though the biochar production from many sources is well understood, there remains considerable uncertainty over the effectiveness of biochar production from defined peat sources and the ability to reliably replicate feedstock-production systems. This study attempts to explore the production and utilization of biochar produced from harvested peat in the Irish midlands relative to other feedstock sources to mediate reductions in greenhouse gas emissions for manure management systems. To do so a detailed analysis of the feedstocks and biochars will be carried out in order to establish appropriate protocols for the optimal production and application of biochar in GHG-manure management. Results indicate that drying as a pre-treatment in production does not increase the peat-based biochar yield, if calculated on a dry matter basis, making the process less emission intensive. It was also observed that the thermal treatment increases the pH of the tested materials irrespective of whether they were fresh or pre-dried, making the biochars more alkaline than the original materials. At the same time, rising process temperatures have been noted to lead to a decrease in yield for all materials used. The yield reduction with increasing temperatures was found to be slightly lower for pre-dried materials than for fresh materials. When focusing on yield and costs for drying, these preliminary results indicate that biochars produced from untreated feedstocks at lower temperatures are more environmental and economically viable than biochars produced from pre-dried material at high temperatures.

BIOCHAR-MORTAR COMPOSITE: MANUFACTURING, EVALUATION OF PHYSICAL PROPERTIES AND ECONOMIC VIABILITY

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Key Words: Strength; Biochar; Pyrolysis; Permeability; Sorptivity.

Singapore generates about half a million ton of wood waste annually, which constitutes a major fraction of disposed waste. Pyrolysis of wood waste to produce biochar, which can be used as additive in cement mortar, is a viable alternative to increase recycling rate of woody residues. This study explores the influence of biochar, prepared from mixed wood saw dust, on strength, elastic modulus, drying shrinkage and permeability of cement mortar.

Biochar prepared by pyrolysis at 300 ^{o}C (BC 300) and 500 ^{o}C (BC 500) was added to mortar at 1–8% by weight of cement. Results show that addition of 1–2 wt% BC 300 and BC 500 improve early age (7-day) compressive strength of mortar, which is related to high water retention of 7.50 g/g and 8.78 g/g by dry BC 300 and BC500 respectively.

However, addition of biochar did not significantly influence flexural strength, drying shrinkage and modulus of elasticity. Mortar with 1% addition of BC 300 and BC 500 showed about 58% and 66% reduction in water absorption and depth of water penetration respectively compared to control.

Based on the experimental findings, it is concluded that 1–2 wt% addition of biochar may be recommended to improve strength and reduce permeability of cement mortar. Added at these proportions, we showed that the price of biochar mortar is still reasonably close to that of conventional mortar.

Therefore, this study suggests that biochar from wood waste has the potential to be deployed as carbon sequestering admixture to improve performance of cementitious mortar at a price that is likely to be acceptable to the building industry.

BIOCHAR BASED SILICON COMPOSITES FOR SENSORS APPLICATIONS

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Key Words: Biochar, Sensors, Silicon composite

Nowadays, the development of innovative sensors represents a field of great interest in the scientific community because of their ever increasing application in everyday life. Piezoresistive transducers are among the most interesting not only as sensors but also as actuators. They are of interest for a number of applicative fields ranging from pressure sensors to applications in nanomanipulation.

In order to create a high sensitivity sensor based on a polymer matrix, the silicones are ideal candidates because, as a consequence of their low Young's modulus, they are subject to large deformation even in presence of weak mechanical solicitations. This effect can be exploited in order to change the electrical conductivity of the material provided that the material is conductive enough. The correct level of conductivity is achieved by adding a conductive filler to the silicones. In order to produce suitable composites carbon fillers such as graphene, carbon nanotubes and graphene nanoplatelets have been tested.

In this work, instead of those oil derived fillers we use a more ecofriendly one: biochar obtained from the pyrolysis of olive tree waste at high temperature. By dispersing appropriate quantities of this biochar into the silicon host we are able to tune the composite conductivity in a range which is of interest for piezoresistive applications. We will report on the correlation between the biochar amount and the electrical conductivity and on the variation of the electrical conductivity as a function of the mechanical tensile and compressive stress applied to the composite.

Figure 11 – set up Biochar/silicon sensor test

POST-PROCESSING OF BIOCHARS TO ENHANCE PLANT GROWTH RESPONSES: A REVIEW AND META-ANALYSIS

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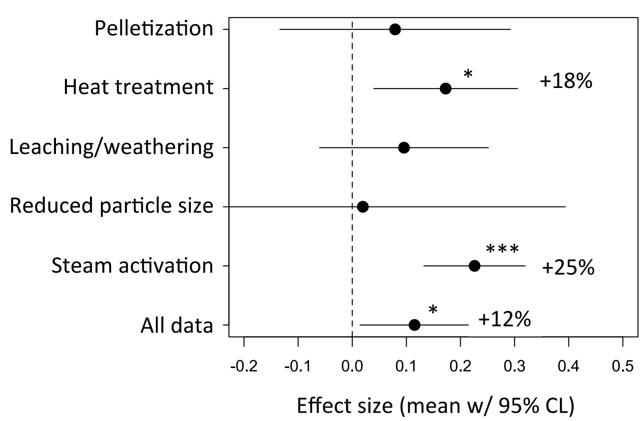
Key Words: activation; leaching; meta-analysis; particle size; plant growth.

A number of physiochemical processes for post-production treatment of “raw” biochars have been suggested as a means to enhance effectiveness in agronomy, forestry, and environmental restoration. The main processes that have been studied include leaching and water washing, ageing and weathering, heat treatments and aeration, grinding and/or sieving to reduce biochar particle size, and steam activation; additional treatments that have received less attention include production of biochar nano-particles, acid and alkaline treatments, oxidation with reactive oxygen species, pelletization and granulation. In part, post-production processes that have been suggested or are in use are intended to “clean” biochars of liquid- and gas-phase products sorbed during the pyrolysis process; in part post-processing may also increase contact between biochar and soil particles and/or enhance biochar surface area, porosity, and sorption properties.

Where biochar is used as a soil amendment, post-processing methods are ultimately intended to increase growth and yield of crop plants or natural vegetation; however, relatively few studies have compared the performance of “raw” biochars to post-processed biochars. I review the existing data from such studies, using biomass production of test crop plant species as a common metric for statistical meta-analysis (and excluding studies on biochar mixtures with fertilizers or composts, co-composting, or fungal or bacterial inoculation). Data from 7 published and 1 unpublished study provide a total of 26 comparisons, essentially all based on short-term pot trials. The mean effect of unprocessed biochars on plant biomass production was similar to that observed in prior meta-analyses (+17.3% [95% CL: 6.1-29.8%]). Overall, post-processed biochars resulted in significant and quantitatively larger improvements in average plant growth responses, with a mean effect of +28.9% [95% CL: 17.1-48.9%]). Plant growth benefits varied greatly among post-processing methods and individual trials. The largest and most consistent positive effects of post-processing methods were from steam activation and heat treatment of biochars.

Additional effect of post-processing on plant yield



I conclude that physiochemical post-processing of biochar offers substantial additional agronomic benefits compared to the use of unprocessed biochar. However, there is also evidence for large variation among post-processing methods, and variability in crop species responses to biochar post-processing. This area of investigation warrants considerably more research attention: by comparison recent meta-analyses of biochar effects on crop yields have been based on >500 comparisons and 100s of published studies that include large-scale field trials. Moreover, a number of promising post-processing treatments that appear effective in enhancing physical properties have not been tested at all in terms of effects on plant performance. Better information on post-production treatments effects will likely be necessary for biochar utilization to achieve “win-win-win” scenarios that maximize benefits to carbon sequestration, waste management, and vegetation performance in agronomy, forestry, and environmental restoration.

BIOCIDAL ACTIVITY IN SOILS BY BIOCHAR FROM PYROLYSIS BIOREFINERY PROCESS

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Useful soil applications of biochar, the biocarbon solid coproduct of biomass pyrolysis, will likely improve the economics of pyrolysis biorefineries. Adding biochar to soils to achieve any number of goals should also consider unintended effects upon soil biology. Herein, we explored two biocidal activities of fluidized-bed fast pyrolysis biochars (FPBC) created over a temperature range of 450-700 ^{o}C on the survival of pathogenic E. coli O157:H7 and beneficial arbuscular mycorrhizas (AM) symbioses in soils. For pathogen decontamination, FPBC created at < 500°C proved microbiologically inert, while that created at 600°C proved biocidal over 7 weeks of sampling ($P < 0.05$) with populations significantly reduced at 3% and 3.5% concentration (5.34 and 5.84 log CFU/g, respectively) compared with concentrations of 0.0-2.0%. Ageing of FPBC created under similar conditions for 2 years resulted in loss of efficacy. FPBC greatly reduced colonization of roots by the AM fungus when we examined the interaction of biochar addition and arbuscular mycorrhizal (AM) fungus inoculation upon growth and phosphorus (P) uptake by Allium porrum L. These responses could be related to physicochemical properties of the biochars as higher surface areas were accompanied by higher AM fungus colonization. The findings are pertinent to selecting pyrolysis biorefinery biochars for application to agricultural soils for purposes such as inactivation of pathogenic bacteria while being mindful of potential impacts upon the AM symbiosis if applied.

Biochar II: Production, Characterization and Applications. Cetraro (Calabrial) Italy, September 15-20, 2019.

SYNERGISTIC EFFECTS BETWEEN NITROGEN FUNCTIONALITIES AND METALS CONTENT ON THE REMOVAL OF PHOSPHATE IONS

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Keywords: N-Doped Biochar, Magnesium, Phosphates Ions

The release of phosphate ions in the runoff is today a major threat to the environment and humans. Therefore, it is vital to develop effective technologies to remove phosphate ions from aqueous solutions before they are discharged into runoff and natural water bodies. This study aims to evaluate and proposed a mechanism of phosphate adsorption by using nitrogen and metals-functionalized chars. In order to isolate the contribution of individual components of lignocellulosic biomass, simple cellulose was used for the char production.

Five samples of nitrogen-doped chars were produced via annealing cellulose under ammonia gas at different temperatures (500, 600, 700, 800, 850 and 900 ℃). Some of the analytical techniques used for the chars characterization were: Elemental and proximate analysis, gas physisorption analysis, Scanning Electron Microscopy and X-ray photoelectron spectroscopy analysis. These samples were subsequently used for phosphate adsorption. Characterization of the resulting chars shows an increase of the nitrogen content in the samples, where the greater percentage of it appears at a temperature of 800 ℃ (12.5 wt%) and the maximum surface area was for char produced at 900 ℃ (1314 m^2/g).

To evaluate the effect of nitrogen and metals in char to adsorb phosphate ions, three sets of chars were produced at 800 ℃; char with magnesium and nitrogen (Mg_N_char); char with nitrogen (N_char) and char with magnesium (Mg_N_char). The results show that Mg_N_char sample exhibits a maximum adsorption capacity of 340 mg/g, whereas the Mg_char and N_char samples give an adsorption capacity of 7.8 mg/g and 21.4 mg/g respectively. These results demonstrate that the presence of magnesium and nitrogen in chars is very effective in the retention of phosphate ions. Other metals such as Fe and Ca combined with nitrogen will also be tested, details of the results will be presented at the conference.

ASSESSMENT OF THE EFFECT OF PYROLYSIS OPERATING CONDITIONS ON PHYTOTOXICITY AND POTENTIAL AS CARRIER FOR AM FUNGI OF VINE SHOOTS-DERIVED BIOCHAR

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Key Words: Biochar, slow pyrolysis, vine shoot, mycorrhizal fungi, phytotoxicity

Biochar production from vine shoots appears as an interesting option to manage this agricultural waste for both environmental and agronomic benefits. In order to produce biochar from biomass at appropriate yields, slow pyrolysis is a particularly suitable option. However, the properties of the resulting biochar strongly depend on the process operating conditions. In this sense, establishing the most appropriate operating conditions is still required with the aim at producing engineered biochars. Furthermore, it should be kept in mind that a certain compromise between the pyrolysis operating conditions and the expected properties of biochar has to be achieved. In other words, the most appropriate conditions to produce a biochar with the desired properties for a given purpose might not be suitable for another one (e.g., pyrolysis conditions leading to a maximization of the carbon sequestration potential can result in biochars with high phytotoxicity and thus not suitable for soil amendment purposes).

The highest temperature reached in the pyrolysis process (i.e., peak temperature) has proven to be a fundamental parameter in determining the physicochemical properties as well as the potential stability of biochar [1]. Nevertheless, few earlier studies have focused on assessing the combined effect of both the absolute pressure and residence time of the vapor phase within the reactor [2].

In light of the above-mentioned considerations, the specific aim of this study is to analyze the effect of the peak temperature (350–500 °C), absolute pressure (0.1–0.5 MPa), and residence time of the vapor phase (50–150 s) on the distribution of pyrolysis products and key properties of produced biochar. In addition to the assessment of the potential stability of biochar (which can be related to its fixed-carbon content and atomic H:C and O:C ratios), its potential toxicity on seed germination as well as its interaction with arbuscular mycorrhizal (AM) fungi were also evaluated. A 2-level factorial design (with the addition of three replicates at the center point) was adopted to objectively analyze the effect of the selected factors on the response variables.

Pyrolysis experiments were conducted in a batch fixed-bed reactor, the details of which are available elsewhere [2]. The content of water in the total condensable fraction was measured using a Karl-Fischer volumetric titrator from Metrohm (Switzerland). The composition of the gas fraction (N_2, CO_2, CO, CH_4, C_2H_x and H_2) was determined using a micro-GC 490 from Agilent (USA). The initial sample mass of biomass was approximately 500 g. The raw biomass was previously sieved to obtain a particle size of 0.1–1.0 cm in diameter and 1.0–4.0 cm in length. To assess the potential stability of biochar, the fixed-carbon content (determined from the proximate analysis) and the atomic H:C and O:C ratios (calculated from the elemental analysis) have been taken as response variables. On the other hand, the potential phytotoxicity of produced biochars has been evaluated by three different tests, which have been based on previous studies [3,4], and using three different seed families (barley, lettuce and watercress). The germination index and radicle length have been selected as response variables. Furthermore, the potential of biochar as carrier for mycorrhizal communities has been measured as follows: a mixture of biochar and mycorrhizal inoculum was used as substrate on which barley seeds were planted in triplicate; the generated biomass after two months of growing as well as the mycorrhizal percentage of the roots have been taken as response variables. Experimental trials are almost finished and the results from the statistical analyses will be summarized and presented during the course of the conference.

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MULTI-PHYSICAL MODEL FOR DESCRIBING SELF-HEALING MORTAR CONTAINING BIOCHAR-IMMOBILIZED BACTERIA

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Key Words: self-healing; biochar; Pore Wall Bubbling Model; pore evolution; Bacillus sphaericus

This work aims to analytically and numerically describe and predict the ability of a particular kind of bacteria (Bacillus sphaericus) to heal cracks in mortar.

The ureolytic bacteria induces microbial calcium carbonate by releasing urease enzyme, which in turn stimulates the degradation of urea into carbonate and ammonium; the carbonate then reacts with the calcium ions (in calcium nitrate) to produce calcite to heal cracks.

A novel feature of our study is that the bacteria is immobilized in biochar, which is the solid by-product of pyrolysis. The biochar and bacteria are included in the mortar mixture together with special nutrient solution; the mixture of bacteria and nutrients is called the “spore solution”. Our prior (and published) studies found that biochar-immobilized bacteria heal cracks more efficiently.

The modeling approach consists of 4 major steps or sub-models.

Firstly, a Pore Wall Bubbling model is created to describe the protrusion and expansion of pores in biochar. The predicted pore size distribution, hence porosity, was then used to calculate the overall porosity of the biochar-containing mortar using a second sub-model known as the Fractional Porosity Model.

Next, an absorption model was used to describe uptake of the spore solution and then estimate the spore concentration within the biochar of a certain theoretical porosity. Finally, the rate of healing of a hypothetical cylindrical crack in mortar was estimated from the rate of production of calcite (due to the spore concentration calculated above), which depends on the rate of urea hydrolysis - the latter of which was described using a hydrolysis-diffusion model solved using Galerkin’s finite element method.

Theoretical predictions agree very well with experimental results. Several deductions and possible improvements to the model are also suggested.

BIOCHAR – JUST A BLACK MATTER IS NOT ENOUGH!

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What differs biochar from charcoal? The simple answer is: Biochar is a carbon rich product obtained from the thermal decomposition of organic material, at the presence of no or a little oxygen. As we can see in principle, the production of biochar is comparable to the production of charcoal, one of the oldest and most established processes used by mankind. While charcoal is made traditionally from wood, biochar can be based on a wide range of biomass and biomass residues.

However, a variety of technologies for the production of biochar was developed in the recent years. The technologies are based on pyrolysis, gasification or hydrothermal carbonization and are ranging from simple up units, like heated steel drums to full automated and controlled processes. Therefore, the obtained products have tremendous differences in its properties and respectively qualities. Not every quality is suitable for further application, or stable or as pure as required.

In literature many options for the application of biochar are described. The most famous one is the use as a soil amendment in agriculture and horticulture. In addition, the application as activated carbon to clean exhaust gases or waste water, as additive in construction industry to improve the insulation or the strength of the construction material or as carrier for catalysts is possible. In most of these cases biochar, its carbon, is sequestered. Depending on the quality, up to thousands of years, in worst case just a few years. Biochar reduces the CO_2 in the atmosphere and is therefore CO_2-negative, as it saves C as such.

To determine the quality, a comprehensive characterization of the biochar is required. That means the analysis of the chemical composition especially in terms of carbon, hydrogen, oxygen and ash content. While the ash content depends on the feedstock, the process itself influences the C, H and O content, as well as sometimes organic compounds, remaining on the surface of the biochar. Furthermore, the surface structure in terms of surface area, pore volume and pore size distribution as well as the presence of functional groups influences the properties of the char.

To obtain the required quality for each application, the right process is needed. Consequently, it is not enough to only enrich the carbon content by thermal decomposition of organic material. The production of tailor made biochar for specific high added value application is much more complex. If it is done right, biochar can be the solution to overcome problems of climate change. “So for the future of mankind this black matter might give the light at the end of the tunnel”.

BIOCHAR AS POTTING SOIL CONSTITUENT AND AS CARRIER OF *BACILLUS* IN THE CULTIVATION OF *CYCLAMEN*

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Keywords: Greenhouse horticulture, container cultivation, disease suppression, peat replacement, rooting media

There is a growing interest in peat alternatives for the preparation of horticultural potting soils. There is also a growing interest in preparing potting soil mixes with added micro-organisms to increase the resilience of the potting soil – plant combination against diseases. Our goal was to use biochar to partly replace peat as well as to carry a commercial *Bacillus subtilis* into peat based potting soils. Peat based rooting media were prepared with an increasing volume fraction of biochar (0, 20, 20, 35 and 50%-v/v). Two extra treatments based on 0 and 20%-v/v biochar were inoculated with *Bacillus subtilis* in a concentration of 10^{7} c.f.u./g dry rooting medium. *Cyclamen persicum* Halios® Blush were planted and cultivated during 4 months. The water content of the pot was monitored and the irrigation schedule was set to maintain a minimum volume of 32%-v/v of water. At the end of the cultivation period the fresh and dry biomass of the leaves, flowers and tubers was measured. Results showed an optimum *Cyclamen* growth in the treatment with 20%-v/v biochar. However the reduced biomass production at higher levels of biochar were caused by a lack of nutrients added and not by the biochar itself, as indicated by EC levels and levels of individual elements. The inoculated *Bacillus* population first decreased and finally stabilized in the rooting media. Bacillus inoculation had a negative effect on biomass production. In conclusion the use of biochar as peat alternative is possible if additional attention is paid to irrigation settings and nutrient levels. The use of biochar as carrier for resilience enhancing *Bacillus subtilis* was unsuccessful.

DESIGNING ACTIVATED MINERAL BIOCHAR COMPOSITES FOR THE ADSORPTION AND DEGRADATION OF EMERGING CONTAMINANTS

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Key Words: Mineral biochar composite, Activated biochar, Emerging contaminants, Wastewater treatment

The emergence of micropollutants such as pharmaceuticals in wastewaters presents a potential risk for human health as well as the aquatic environment. Current wastewater treatment plants are generally not capable of removing these pollutants without additional treatment steps. Adsorption on activated carbon is an effective way to remove these contaminants, however, the use of non-renewable feedstocks as well as low regeneration efficiencies increase the environmental costs of this method[1]. Biochar as an alternative carbon platform material can be specifically designed to overcome these drawbacks[2]. This study is aimed at designing activated mineral biochar composites with enhanced adsorption capacity for pharmaceuticals while simultaneously increasing its regeneration performance. Two standard biochars from the UK Biochar Research Centre produced at 550°C from softwood and wheat straw were activated in CO_2 at 800°C. Mineral biochar composites were produced by the addition of ochre – a Fe-rich mining waste - in a wet mixing step prior to pyrolysis for both feedstocks. The activated biochars were analysed for their maximum adsorption capacity for two common micropollutants. Furthermore, to test their regeneration performance, the biochars were loaded with a mix of 10 pharmaceuticals covering antibiotics, fungicides and antidepressants. The loaded biochars were then subjected to a high pressure treatment in a hydrothermal reactor at temperatures ranging from 160 to 320°C to determine the degradation rate of pharmaceuticals loaded on the different materials. Hydrothermal treatment was found to successfully degrade the micropollutants across all biochars. The mineral biochar composites showed increased pollutant degradation, lowering the necessary treatment temperature to achieve full decontamination. The results show that while designing biochar for certain applications, a simultaneous focus on both the application as well as the regeneration of the material can give a more comprehensive picture of the overall requirements for further optimisation of biochar adsorbents.

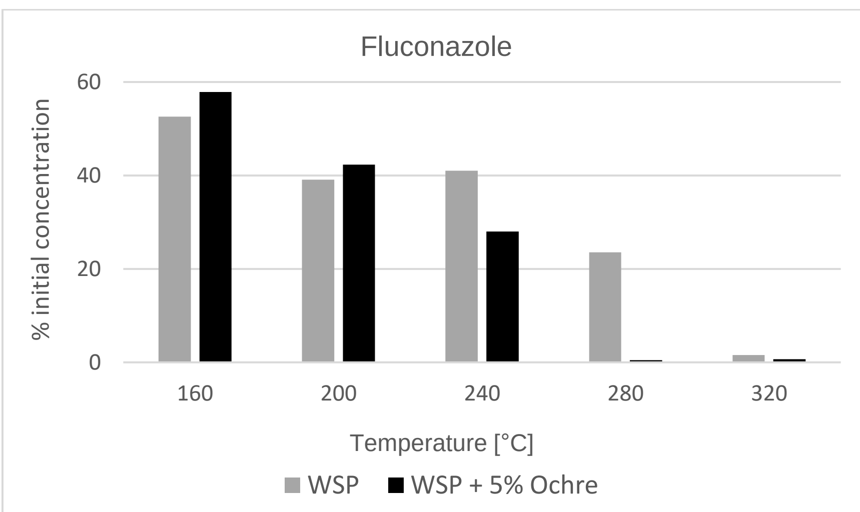

Figure 12: Residual Fluconazole concentration after hydrothermal treatment at 160-320 °C (WSP – Wheat straw pellet biochar

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REVIEW OF BIOCHAR APPLICATION IN ANAEROBIC DIGESTION PROCESSES

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Key Words: Anaerobic digestion; Biochar; Inhibition; Interspecies electron transfer; Process stability

Among a wide variety of promising uses, in recent years the possibility of using biochar (BC) as additive to improve anaerobic digestion (AD) processes has attracted a growing interest. AD is a well-established biochemical process converting biomasses into biogas, a renewable energy source that can be directly used in heating and power generation rather than upgraded to bio-methane. Further, digestate (i.e. AD solid residue) could be valorised as soil improver. However, despite a growing number of full-scale biogas plants in Europe, (from about 6,200 in 2009 to 17,600 in 2016, according to European Biogas Association), some challenges limiting optimal AD performances still exist. They mainly include risks of acidification and/or potential inhibition of methanogenesis, hazards of atmospheric and water pollution derived from digestate addition to soil, as well as high energetic and economic costs for cleaning and upgrading of biogas.

Thereby, many inorganic and carbonaceous additives have been investigated to stabilize AD and enhance methane production. Among them, BC is cost-effective and doesn't need to be separated from digestate at the end of the AD process. Actually BC can improve digestate quality in terms of nutrients retention, increase of carbon to nitrogen ratio and reduction of nutrient leaching to soil. In addition, BC production and AD do not appear as competing processes, since biomasses with high lignocellulosic and low moisture contents, optimal for BC generation, are scarcely biodegradable during AD.

Although a growing number of studies has verified the possibility of increasing methane production by BC addition during AD, to date, a clear comprehension of potential interactions between BC and AD process has not been fully reached. Since BC can be produced with a wide variety of physico-chemical properties adapted to specific applications, a proper knowledge of these mechanisms and of the related BC properties represent crucial issues. Therefore, the present study aimed to: 1. analyse the mechanisms by which BC would counteract some of the main AD limitations; 2. to perform an economic and environmental assessment of BC production and application in AD. Around 200 studies were selected and analysed by means of an extensive literature review on Science Direct, Scopus, and other scientific databases.

Based on the analysis of the reviewed literature, it can be observed that the positive influence of BC on AD processes may act through different potential mechanisms: (1) increase of the buffering capacity of the AD system; (2) mitigation of potential inhibitors (NH_3/NH_4^+ and others); (3) acting as a support medium for biomass immobilization and acclimation; (4) promotion of interspecies electron transfer between microbial populations; (5) enhancement of digestate quality; (6) in-situ biogas cleaning and upgrading (depletion of CO_2 and H_2S).
In general, some of the key properties of BC for the above-mentioned mechanisms are high alkalinity, adequate sorption capacity for specific compounds, high surface area and porous structure able to promote microbial population immobilization and inhibitors' adsorption, varied functional groups and superficial chemical properties, large electrical conductivity and electron exchange capacity.

The economic and environmental analysis suggested that BC environmental applications are encouraged by the net mitigation of carbon emissions; while the economic feasibility of BC production could be linked to the promising energy content of lignocellulosic feedstocks. Further, the environmental benefits related to BC application to AD processes can be synergistically improved by coupling the use of BC derived from lignocellulosic feedstocks to the carbon neutral AD to optimize biogas production.

CULTIVATING CAMELINA FOR SUSTAINABLE AVIATION FUELS IN EU MED MARGINAL LAND RECOVERED WITH CO-COMPOSTED BIOCHAR AND DIGESTATE: PRELIMINARY RESULTS

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Key Words: Biochar; co-composting; soil amendment; biofuel: marginal land

The H2020 BIO4A project aims at producing and deploying Sustainable Aviation Fuels (SAF) at large scale in Europe. A major oil refinery, owned and operated by Total based on Axen's technology, will run in non-segregated full jet-mode, targeting the production of 5 kt of ASTM-certified bio-based HEFA jet fuel. The produced SAF will then be used in commercial passenger flights: the demonstration activities will be complemented by market and policy analysis. While this part of BIO4A represent the industrial component of the project, the issue of developing additional alternative routes for supplying sustainable lipids to the HVO process represents the key R&D part: this addresses the production of Camelina in EU MED marginal land, recovered by biochar or COMBI addition.
The production of a novel soil amendment, here named COMBI (COMpost + BIochar), and the evaluation of its performances to increase soil resilience in marginal lands prone to desertification in Spain, are therefore the main R&D actions. Co-composted biochar and digestate obtained from biomass anaerobic digestion has been produced and characterized. The use of Biochar and COMBI in marginal land mostly aims at increasing organic matter to the soil, favouring nutrient recycling and availability, increasing soil water holding capacity, and sequestering fixed carbon, thus contributing to the Paris Climate agreement (Climate Change mitigation) and the UN Sustainable Development Goals. In particular, the carbon removed from the atmosphere, differently from most of the CCS routes, where C is stored, is employed to support the adaptation of difficult agricultural lands and regions to climate change, improving soil and agriculture resilience (Climate Change adaptation).
Biochar was produced from chestnut woodchips, thermo-chemically converted through the 50 kg/h oxidative slow pyrolysis unit developed at RE-CORD lab, while digestate was obtained from a mesophilic anaerobic digestion plant mostly fed with animal manure.
Co-composting was carried out in two different periods: the first one, during the Summer season in Tuscany (IT) in a greenhouse using static windrows, equipped with temperature and moisture sensors, and turned manually twice per week; the second campaign was conducted in the same location, but during the winter season.
The characteristics of different types of co-composted biochar-digestate-straw blends (COMBI) were assessed. Main physical and chemical properties were analyzed with respect to the European Biochar Certificate (EBC) standard and the European Compost Network specifications, that developed the European Quality Assurance Scheme (ECN-QAS), for the solid fraction of digestate. The potential dynamic respiration index (PDRI) test was carried out to investigate the biological stability of the solid digestate. The Brunauer–Emmett–Teller (BET) analysis was also performed on the biochar component, so to characterize the biochar in terms of total porosity and pore diameters distribution using the density functional theory (DFT) method.
The test compared the composting process of the digestate only with the co-composting process of the same organic matter with the addition of increasing rates of biochar, up to 15% w/w d.b. Results were compared in terms of duration of the bio-oxidative phase and the maximum temperature reached. Products obtained were characterized and compared as regards yield (in terms of organic matter), Humic and Fulvic Acid content, Nitrate and Ammonium-N content.
The products were then applied to two sites in Spain, before seeding Camelina crop: each site comprised 7 different microplots of 10 m^2 each, and 4 repetitions. The microplots included soil without fertilization (control), soil with NPK fertilization, soil with three different blends of COMBI, soil with only biochar, soil with composted digestate alone. The test sites were located in two different areas of Spain, one South and the other North of Madrid. The same site will continue to be tested in normal rotation with barley over the following two years.
The present works report the results of the on-going test campaign, assessing and discussing the benefits of the soil restructuring.

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ADSORPTION OF PB^{2+} ON MAGNETIC MODIFIED HEMP BIOCHAR PREPARED USING MICROWAVE-ASSISTED PYROLYSIS

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Key Words: Microwave pyrolysis, Biochar, Chemical modification, Adsorbent, Wastewater treatment.

Magnetic modified hemp biochar with an aim of high adsorption capacity and rapid adsorption rate was prepared by two simple steps using microwave pyrolyzed biochar. This was investigated as a potential green adsorbent for lead remediation from wastewater in a batch-mode experiment. The 150 – 300 µm biochar particles obtained from microwave-assisted pyrolysis of 1.5 kg hemp biomass batch at an average temperature of 600˚C were first impregnated with H_2O_2 and then magnetized by mixing aqueous biochar suspensions with aqueous Fe^{3+}/Fe^{2+} solutions. The composition, morphology and surface chemistries of this magnetic biochar was examined by scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), Fourier transform infrared spectroscopy (FTIR), vibrating sample magnetometry (VSM) and BET surface area (S_{BET}). The S_{BET} of the magnetic hemp biochar is 83.76 m^2 g^{-1}.

Batch sorption studies were performed for a 50 mg L^{-1} lead solution at room temperature and pH 5.5 using 0.02 g of the magnetic adsorbent in 20 ml solution for 2 hours. The experimental results have shown that the adsorption capacity of this magnetic adsorbent for Pb^{2+} is 43.97 mg g^{-1}, about 87.94% removal within the 2 hours. Both pseudo-second-order and pseudo-first-order kinetic model could predict the adsorption and desorption kinetic process on the modified sorbent. EDX analysis are used to show the mechanisms for the adsorption of Pb^{2+} onto the adsorbent via mainly ion exchange. The Freundlich, Temkin and Langmuir models are used to predict the sorption isotherm in the system. The as-prepared magnetic hemp sorbent demonstrated a potential in heavy metal wastewater treatment.

EFFECT OF CO-COMPOSTED CHARCOAL FROM GASIFIER PLANTS ON PLANT GROWTH, NUTRIENT UPTAKE AND SOIL FERTILITY

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Key Words: charcoal, composted, plant growth, soil fertility

Biomass gasification plants generate energy from woody materials. During the production process, charcoal is produced. Charcoal is a carbon rich material out of woody material with a high potential for different applications. In this study the usage of charcoal as a soil amendment is tested. In the experiments the influence of charcoal on plant growth and nutrient availability should be determined. Therefore a laboratory experiment and a trial under field conditions were performed.

In both experiments the plant growth testing was performed according to DIN ISO 11269-2 and OECD guidelines. These methods were developed to investigate the effects of contaminated soil on the emergence and early growth of higher plants (DIN ISO 11269-2, 2012) and to evaluate the possible effect of substances on the ability to germinate, and the growth of seedlings (OECD guidelines, 2003).

In a first step organic material (landscape care material) was composted with three different amounts of charcoal (5 % (v/v), 10 % (v/v), 25 % (v/v)). As a reference the organic material was composted without adding biochar. Under field conditions 2 t of compost was applied on each testing area, which has a length of 12.5 m and a width of 6 m. The amount of compost is equal to the legal requirements in Austria (160 t dry mass per hectare) for compost application on agricultural land with the aim of recultivation or protection against erosion. Silage maize was chosen as crop plant for cultivation. Soil samples, which were taken with an interval of two weeks during the experiment, were analyzed for nitrogen, nitrate, ammonium, potassium and phosphorus. After harvesting the fresh and dry mass of the plants were measured. Afterwards the biomass was mechanically decomposed to analyze the nutrient uptake.

First results showed significant positive effects on plant growth in the laboratory. In contrast no significant influence due to plant growth could be observed in the field. Indeed the influence of biochar on the availability of potassium was significant. Also an effect on nitrogen compounds could be observed. To determine if the application of co-composted biochar could improve plant growth more experiments should be done, especially the influence of proceedings should be determined. Long term effects, according to conventional compost, should be evaluated with multi-year trials. Even if biochar isn’t able to improve the plant growth or nutrient uptake significantly, it could become a leading part for carbon sequestration and further climate protection.

EFFECT OF OPERATING CONDITIONS ON THE YIELD AND COMPOSITION OF HYDROCHAR OBTAINED DURING THE HYDROTHERMAL CARBONIZATION OF DIGESTATE

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Key Words: Hydrothermal carbonization, hydrochar, digestate.

Hydrothermal carbonization (HTC) is a thermo-chemical process that uses water under subcritical conditions to convert biomass into a C-rich product known as hydrochar. HTC process takes place at relatively low temperature (generally in the 180–250°C range) under autogenous pressure. The process conditions promote the hydrolysis and dehydration reactions generating condensed aromatic structures having a high concentration of oxygenated functional group (OFG); these characteristics make hydrochar a promising candidate in several high-value applications [1–3]. HTC can be applied to a number of feedstocks, ranging from simple carbohydrates (i.e. glucose, cyclodextrins, fructose, sucrose, cellulose, starch, etc.) to more complex biomasses (such as lignocellulosic biomass, agricultural residues, municipal biowaste, etc.).

This study refers to an experimental campaign aimed to evaluate the role of reaction temperature and residence time on the yield and composition of hydrochar produced by using the digestate of anaerobic digestion of biowaste. The digestate was sampled after the completion of the anaerobic digestion period just before the HTC test, so avoiding the effect of storing, freezing, etc. The experimental tests have been conducted utilizing an externally heated stirred batch reactor having a reaction volume of 3.6 liters. The available reaction volume was filled by a mixture of digestate and water medium at a fixed ratio water/dry matter equal to 6 by leaving a head space of about 15%. The results indicated that both reaction temperature and reaction time affect the yield of the obtained solid product (hydrochar) as mass of hydrochar / mass of digestate (dry basis) and that the properties of this latter depends on the same parameters. This means that a high yield is not necessarily a positive result and that the yield itself cannot be used as a performance parameter. In particular, the yield decreases as temperature and reaction time increase. Figure 1 shows that for both investigated temperatures, i.e. 180 and 250°C, the hydrochar yield decreases from 0.92g/g to 0.85g/g and from 0.82g/g to 0.78g/g as the reaction time was increased from 2 to 6 h. A similar effect is produced by the increase of reaction temperature that affects the kinetic rate: the yield reduced from 0.92g/g to 0.82g/g, after 2 hours of reaction time, and from 0.85g/g to 0.78g/g, after 6 hours of reaction time.

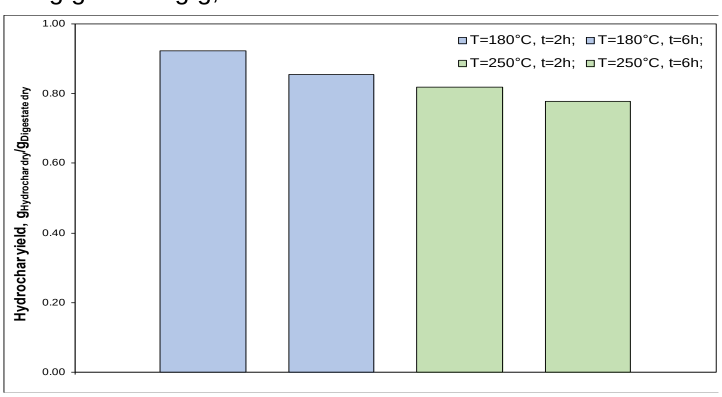

Figure 13 – Effect of operating conditions on hydrochar yield.

Test	C	H	N	O	H/C	O/C
Digestate	55.05	6.90	3.73	34.32	0.13	0.62
HY-180-2	56.32	6.59	3.30	33.78	0.12	0.60
HY-180-6	56.29	6.50	2.99	34.23	0.12	0.61
HY-250-2	60.87	6.65	3.45	29.03	0.11	0.48
HY-250-6	58.46	6.46	3.06	32.02	0.11	0.55

Table 14 – Ultimate analysis of digestate and hydrochar (daf).

The investigated operating parameters also affect the hydrochar composition. Table 1 reports the ultimate analysis on dry ash free basis (daf) of the starting feedstock and the hydrochar obtained during the experimental runs. It can be observed that the hydrochar produced from the HTC tests performed at 250°C contain a greater amount of carbon and lower ratios H/C and O/C than that obtained during the tests conducted at 180°C. This indicate that, in the range of the investigated operating parameters, the increase of temperature of about 40% is more affective to promote carbonization than an increase of reaction time of 200%.

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HYDROTHERMAL CARBONIZATION COUPLED WITH ULTRASOUND ASSISTED EXTRACTION FOR RECOVERY OF PHENOLIC COMPOUNDS

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Key Words: Spent Coffee Grains, Hydrothermal Carbonization, Hydrochars, Polyphenols, Ultrasound Assisted Extraction.

Since the world average population is expected to grow during the next years, also coffee production and consumption is going to increase as well. This makes necessary to find a valuable way to valorize the residues generated by instant coffee production called exhausted or spent coffee ground (SCG). SCG is a wet organic material with lignocellulosic structure (Silva et al. 1998), containing a high amount of valuable compounds, such as polysaccharides, proteins, lipids, aliphatic acids, alkaloids, tannins, polyphenols (Campos-Vega et al. 2015) and high calorific value. Thus aims to find a proper way to treat SCG to produce value-added products and/or use the remaining solid for a suitable application, depending on the specific scenario.

Hydrothermal carbonization (HTC) is a promising technology for the treatment of wet feedstock (up to 80 wt.%), at temperatures between 180 to 260 °C during a reaction time between 30 min to several hours. The main product of HTC is hydrochar, and a co-product called process water (PW). Ultrasound assisted extraction (UAE) is an eco-friendly technology suitable for the extraction of valuable compounds in the SCG, such as phenols and tannins. The target of this study is the production of hydrochar and the quantification of the total phenolic content (TPC) (mg GAE/g dry solid) after HTC and UAE.

With this objective SGC is initially treated by HTC under different temperatures (200, 230, 260 °C) and reaction times (1 and 3 h). Afterwards, it was applied a UAE to the produced hydrochars at determined as the optimum operating conditions to extract maximum phenolic compounds, 40°C, 40 min, S-L (1:25, g/ml), three solvents (water, methanol, water: methanol, 50:50) and an ultrasonic bath of 100W.

The results of the study may be summarized as follow:

a) The increase of the severity during HTC produces an increment of 71 wt. % of the fuel ratio (fixed carbon/volatile matter). Additionally, the low ash content 2.38 wt. % and 33.17 (MJ/kg) of the hydrochars make suitable to use them as co-fuel.

b) TPC (mg GAE/g dry solid) in the PW after HTC decrease with the increment of the severity during HTC.

c) The results obtained after the UAE of the produced hydrochars shows that the use of methanol as solvent increases the yield of extraction of the TPC (mg GAE/g dry solid) and hydrochars produced at 200 °C during 1h reaction time contains the highest amount of TPC (mg GAE/g dry solid).

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A CIRCULAR ECONOMY APPROACH BY CO-GASIFICATION OF WATER HYACINTH AND ALGAE BLOOM FOR HIGH-QUALITY BIO-CHAR PRODUCTION

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Key Words: Circular economy, Environment, Phytobioremediation, Water hyacinth, Biochar

Water hyacinth is of interest for biochar production due to its high biomass yields, high carbon content and environmental benefits of carbon sequestration and pollutants removal. Gasification technology has attracted considerable attention to design a renewable biochar production process to be performed on a larger scale for both separation and immobilization of contaminants from water hyacinth and the production of energy and multifunctional materials. The concept of the circular economy has become popular since it is a solution that will allow countries, firms and consumers to reduce harm to the environment and to close the loop of the product lifecycle through three main approaches of reusing, reducing and recycling materials, energy and waste. This study is focused on the sustainable management of water hyacinth biomass via gasification (300-900˚C) to high-value products of biochar, bio-oil and syngas, from the perspective of energy consumption, heat reduction and recycling, emissions to the air and residues in the biochar based on circular economy towards environmental sustainability. The objective is to compare two different types of processes of mono-gasification and co-gasification for environmental, economic and social benefits. The environment, economy and society are inter-related to highlight the new insights for the biochar utilization and resonate with phytobioremediation strategy. The process is based on lab-scale gasifiers/pyrolyzers and a functional unit of a 20KW downdraft gasifier. In our previous experience, we have successfully converted waste biomass from horse manure in Singapore Turf Club to syngas and biochar in the downdraft gasifier. In this study, an equipment level of optimization is implemented for best-operating conditions to improve energy efficiency. In the first process of mono-gasification, biochar is produced from water hyacinth. The alternative to this method is co-gasification, where biochar is now produced with addition of algae bloom. The cost-benefit analysis and life cycle analysis demonstrate the difference in sustainability between these two processes, which offers a higher understanding of biochar production and hence determine which method would be the preferable sustainable practice. It is expected that the co-gasification process could increase the syngas, heat and energy production with high-quality biochar production. One of the major challenges is to guarantee the water hyacinth resources are conserved and used efficiently and affordably.

IMMOBILIZATION OF HEAVY METAL IN CONTAMINATED MINE TECHNOSOLS USING BIOCHAR : A PHYTOMANAGEMENT STRATEGY

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Key Words: Biochar, Metal(loid)s, Mining, Technosol, Phytomanagement

Soil contamination by metal(loid)s is one of the most important environmental problem. It leads to loss of environment biodiversity and soil functions and can have harmful effects on human health. Therefore, contaminated soils could be remediated, using phytomanagement. Indeed, plant growth will improve soil conditions while accumulating metal(loid)s and modifying their mobility. However, due to the poor fertility and high metal(loid)s levels of these soils, amendments, like biochar, has to be applied. Phytomanagement is a technique for rehabilitating these soils and reducing the spread of pollutants. To this end, it is advisable to stabilize the mobility of pollutants in the soil before planting plants. Biochar, produced by the pyrolysis of biomass under low oxygen conditions, has gathered attention in the last few years due to its capability to reduce metal(loid)s bioavailability and mobility in soils, as well as its beneficial effects on soil fertility. Indeed, biochar amendment to polluted soil induced usually an increase of pH, water holding capacity, and nutrient contents, associated with a decrease of metal(loid)s concentrations in soil pore water, through sorption on biochar. We tested different biochar concentrations from different wood feedstock in mesocosm and then on a field experimental plot presenting a significant arsenic (500 to 1000 mg/kg) and lead (15000 to 20000 mg/kg) pollution. Biochar from hardwood feedstock and more particularly the one obtained from bark and presenting the finest grain size (Lebrun et al. 2018) has shown good efficiency by reducing the availability of lead in soil pore water by more than 90% and keeping arsenic levels in the soil pore water below critical environmental concentrations. For the all plant species tested (*Phaseolus*, *Populu*s, *Salix*, *Ailanthus altissima*, *Alnus*, *Agrostis*, and *Trifolium*) in biochar amended soils we show that biochar has allowed the establishment of a dense vegetation whereas until then the soils were bare and unsuitable for any plant development (Lebrun et al 2019, Nandillon et al 2019).
In conclusion, we can affirm from mesocosm and field tests that biochar obtained from bark and having a fine particle size is an efficient material for the stabilization of metal(loid)s pollutants in the soil allowing the decrease of As and Pb phytoavailability. The beneficial effect of biochar on the vegetalisation of soils contaminated with heavy metals has been improved by the addition of other amendments such as compost or red mud.

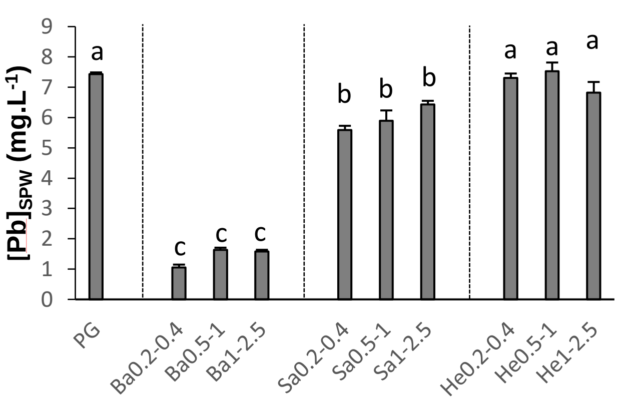

Fig: Effect of different biochar feedstocks (Ba = bark, Sa = sapwood, He = heartwood) and granulometry (0.2 to 0.4 mm, 0.5 to 1 mm and 1 to 2.5 mm) on Pb soil pore water concentration of a mining technosol (PG).

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TOXICITY SCREENING OF DIFFERENT MODIFIED BIOCHARS ON THE GERMINATION AND EARLY SEEDLING GROWTH

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Key Words: Toxicity Screening, Modified biochar, germination, seedling growth, seed size
Applying biochar as soil amendment improves soil physicochemical properties, carbon sequestration and plant growth. However, prior to use as amendment, BC must be investigated for both its potential positive and negative effects on soil and plants. Seed germination and early seedling growth are considered to be very sensitive to various external factors and are therefore frequently used for initial screening of different soil amendments. In this study we assessed the impact of different biochar modifications on seed germination, i.e., (germination rate and seedling growth). Ten different types of biochar representing different biochar modifications, such as physical and chemical activation, mineral (ash) enhanced biochar (Buss et.al.,2019) phosphorus-loaded biochar, and potassium-loaded biochar (Mašek et.al., 2019) were screened for their toxicity using sand with a uniform biochar application rate of 0.5% in petri dishes. The room temperature was (CRD maintained approx. 25 ˚C during the whole experiment period. The experiment was conducted under Complete Randomized Design). It is known that the size of a seed affects the fitness of the plant growing from it; larger seeds often have higher fitness (Kering and Zhang 2015; Giles 1990) and are therefore initially less affected by external conditions. Most past studies involving study of phytotoxic effects of biochar on seed germination have focused on a single crop and did not account for the effect of the seed size. Based on a relevant literature review and preliminary experiments, we selected seeds of different plants based on their size, such as, spring barley, white clover and cress seed. The result obtained to date show that biochar none of the biochar exhibited any significant detrimental effects on the germination of the barley seeds, however there are differences observed, depending on the type of biochar modification used and also the size of seeds selected for the tests figure 1.

Figure 1 Effects of biochar on early seedling growth of spring barley

In this presentation we will present results of a large number of experiments, focussed on assessment of impacts of biochar modifications aimed at production of engineered biochar on resulting biochars' phytotoxicity assessed based on an array of parameters, including germination time, germination percent, early seedling growth, seed vigour and chlorophyll content. These results will be the first in investigating the nature and role of seed size in assessing biochar phytotoxicity and the role played by biochar modifications aimed at designing engineered biochar. This work will provide an important new framework for designing guidelines for future studies related to safe application of biochar and engineered biochar development.

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HOUSEHOLD BIOCHAR PRODUCTION AND USE BY SMALLHOLDER FARMERS IN KENYA

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Key Words: microgasification, cookstove, emissions, maize

About 40% of the world population lack access to clean cooking fuels. In rural sub-Saharan Africa the majority of people prepare their meals with firewood on open three stone fires. Biochar-producing microgasification cookstoves provide an opportunity to reduce fuel consumption and reduce the indoor air pollution in the cooking area, while use of biochar in soils sequesters carbon and increases agricultural yields, thereby improving livelihoods, especially for women. This paper presents findings from transdisciplinary research that started with long-term biochar field trials established in 2006. During recent years this research has involved 150 farming households at 3 locations in Kenya that produce biochar in locally manufactured GASTOV Top-lit Updraft (TLUD) gasifier cookstoves and use the biochar in their own fields. Fuel use, indoor concentrations of CO, CO_2 and $PM_{2.5}$ in cooking areas, and biochar production potential was measured in 75 households during cooking of a common Kenyan meal. The produced biochar was used in field trials with maize (*Zea mays*) and kale (*Brassica oleracea*) comparing biochar to normal farming practices, at biochar doses of 1-10 t ha^{-1}. Findings from one of the sites, in Kwale County, show that for cooking a meal, on average 18 % of fuel was saved compared to the three stone open fire. In addition, 200 g biochar were produced which corresponded to 16.5% of the biomass used. Concentrations of CO and $PM_{2.5}$ were reduced by 57 and 79 %, respectively. Fuel use was dominated by the wood types neem (*Azadirachta indica*) and casuarina *(Casuarina equisetifolia)*, but a large variety of wood types were used by the households. Yield increases of maize in Kwale correlated positively with biochar dose. For the 20 farmers that finalized the trials in the first season, yields increased from 0.9 Mg ha^{-1} in the control plot to 4.4 Mg ha^{-1} in average in the biochar-amended plots. In addition to presentation of data on biochar production, we present data on biochar quality and use from all three sites. Implications and prerequisites for long-term success and upscaling will be discussed. This research contributes to knowledge on adoption of improved cookstoves by investigating how biochar production can be an additional incentive for cookstove uptake. Furthermore, it contributes to the understanding of biochar production potential in African rural areas. This case study shows that biochar systems in rural Africa can contribute to climate change mitigation. Biochar technology can at the same time help to solve the problems with energy and food security that farmers are facing, and thereby contribute to sustainable development.

STRUCTURAL AND CHEMICAL DEVELOPMENTS OF BIOCHAR USED IN HORTICULTURAL TRIALS FOR VARIOUS PERIODS OF TIME

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Key Words: Greenhouse horticulture, biochar as peat replacement, scanning electron microscopy (SEM), pore size distribution, adsorption.

There is a growing interest in peat alternatives for the preparation of horticultural potting soils. Pot trials have shown that Biochar can play an important role in decreasing the peat fraction and the associated GHG emissions. Biochar is very stable (no decay) and completely free of diseases. Despite some first successes up to 35% Biochar in the mixture, further application will require more knowledge to increase the share of biochar as well as the yield in horticultural production.

Pot trials in greenhouses provide a unique opportunity to follow the structural and chemical development of biochar over time, as the ingredients of the potting mix are known and all nutrient and water streams are recorded. Biochar grains can be retrieved from the pots at intervals during the trials. Precise pore size distributions at the start (t=0) were made (Hg-porosimetry and N2 adsorption) and followed over time using Scanning electron microscopy (SEM). Also the chemical composition and adsorption of compound on the biochar were measured over time for a number of pot trails. It was concluded that for the greenhouse application, clay-free mixtures might be better in order to avoid blocking of the internal pore structure of biochar and thereby maintaining the water holding capacity. For soil applications this may provide information on the formation of micro-aggregates.

A first attempt was made to include bacillus and Trichoderma in different pot trails on the biochar. Crop results on biochar as carrier for resilience enhancing Bacillus subtilis were not improved, although the bacillus could be found in samples after the trial under the SEM. The use of Trichoderma in biochar/peat pot trails is currently in progress. A number of sampling moment from the pots allows for a structural development screening of the biochar under well-known conditions in the greenhouse. The results will be presented. Tracing bacillus and Trichoderma in samples with the SEM is very difficult as very few previous examples are available. This presentation aims to add also to the knowledge base on following “life” under the low-pressure electron microscope.

BIOCHAR IN URBAN APPLICATIONS

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Key Words: Urban forests, raingardens, green roofs, soil biochar

Urban use of Biochar is increasing but the effect on the plant growth is neither verified nor estimated. Biochar use in urban tree plantings and raingardens is becoming generic in some of the largest Sweden Cities. The objective behind using biochar in tree plantations have been that it is safer to establish in this substrate than in structural soils and the trees grow well. Carbon/macadam and structural soils are used below hardcover surfaces and sustain the load from traffic. In raingardens, which is a dry system, biochar increases the water-holding capacity and thereby secure the establishment and growth of the plants. Biochar is also purifying the storm-water reducing the pollution loads to recipients. New applications that have been tested is in green roofs, in living walls, in parks, street trees, courtyards and urban meadows. Survival and growth of the vegetation is determined and preliminary results show that biochar can be used in and benefit these vegetation systems. By expanding the use of biochar into urban vegetation, the CO_2 mitigation potential is increasing.

Figure 1. Different types of urban vegetation systems, living wall, urban meadow, urban forest and green roof, which have been shown to benefit from biochar.