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PRODUCTION AND PRODUCTION-INCREASING FACTORS OF BIOCHAR

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Abstract: In the article, we deal with biochar-related research and our own developments. Studies in the literature show that biochar can be used as a soil conditioner in agriculture and horticulture. It improves many physical, chemical, and biological properties of the soil and substrate. It increases the water retention capacity while reducing the leaching of nutrients. Through these, you can improve the profit of producers, the sustainability of production, and the efficiency of fertiliser use. By increasing water retention, biochar can reduce irrigation needs and enable production on limited water resources. The developed and presented equipment was called the resting bed (fixed bed) version. Drying and carbonization are also carried out by direct heat transfer. The material, with a temperature equalised by moving drying and a homogeneous composition, enters the reactor. The high-temperature gas and air mixture is introduced into the dryer by a gas jet pump. The energy obtained by burning the pyrolysis gases produced during carbonization ensures the heating of the system, so there is no need for significant external energy input. Due to the structure of the system, the PAH content of the final product is low.

Keywords: biochar, effect of biochar on soils, production of biochar

1. Introduction

Nowadays, the price increases in the secondary materials traditionally used for agricultural production – energy, insecticide, fertilizer – have become an everyday occurrence.

For the population on planet Earth is on the rise, which means that a growing population requires a growing food supply. The necessary area to produce foodstuffs is reducing in concert with the climate change. Another factor influencing the process is the incorrect land usage, which is the cause of, among other issues, desertification. Parallel to these issues, an increase in water demand from both plant production and other organic lifeforms is also apparent. Today, these are the most notable, and most critical issues for humanity to solve.

As a possible solution to produce foodstuffs, producing a larger amount of food on the same unit of area is an option. However, this may only be implemented if the richness of the soil and the other circumstances and conditions of production make it possible.

There are many various instances of research dealing with the improvement of soil that degraded due to incorrect use, but the areas so far determined to be unsuited to agricultural production being improved to a point where they can host agriculture is also an often-explored option. Most of the researchers consider the renewable energy sources found in nature to be the source of technologies and techniques supporting these goals. Such sources are the various forms of bio-waste used for energy production, and producing materials which conserve the productivity of soil, or even improve it.

In this paper, we explore one of these options, related to the production and application of using biochar.

2. Materials and Methods

2.1. What is biochar?

Biochar is a material reminiscent of coal (Fig. 1), which is produced out of plant materials like wood waste, secondary products made from herbaceous plants, and remains of agri- and sylviculture. These materials are decomposed using heat, which also generates renewable energy (depending on the process).

During the process, the physical and chemical nature of the plant materials are changed into a porous and from a biological perspective, structurally stable (hard to decompose) material rich in carbon.

Research done with this material shows that it can be used as a soil improvement material in agriculture and gardening (which means it influences several physical, chemical and biological attributes of the soil).

However, its beneficial effects rely on the method of the coal's production, whether the source materials used are applicable or not, and the system of usage (production) the end product will be implemented in.

Figure 1. Wood waste (A), processed into biochar (B) and biochar processed from short-blade grass (C).

Biochar (also called biocoal, or syn-coal, for synthetic coal) improves the nutrient accessibility of plants and improves the water-sealing capacity as well. It also prevents nutrients from getting washed out of the soil. Due to the improvement in water-sealing, biochar can reduce watering needs, and makes the expansion of production possible even in the case of limited access to water sources.

The abovementioned advantages together can modify the microbe culture in the rooting zone of plant life, which leads to a higher richness of microbes and activity of them. This increases the yield. A high number of studies show that biochar was successful in improving the growth of plant life (Tab. 1), though others reported that there's no observable effect in specific types of soil.

Table 1. Biochar attributes by base material [1]

What do we produce biochar from?	Soil and soil substance used for	Effect on plant growth	Analysis using
Hardwood	In soil (as is)	Increase	Corn
Hardwood pellet and straw pellet	Mixed with muskeg	Small- or no increase	Tomato
Hardwood mixture	Hardwood and pine bark	Increase	Flowers

2.2. Production of biochar

Fig. 2 shows the *generic pyrolysis process (thermic decomposition)* of biomass materials. If the process requires a temperature higher than the one noted on the figure, it is required for a different specified process, for example, production of power-gas.

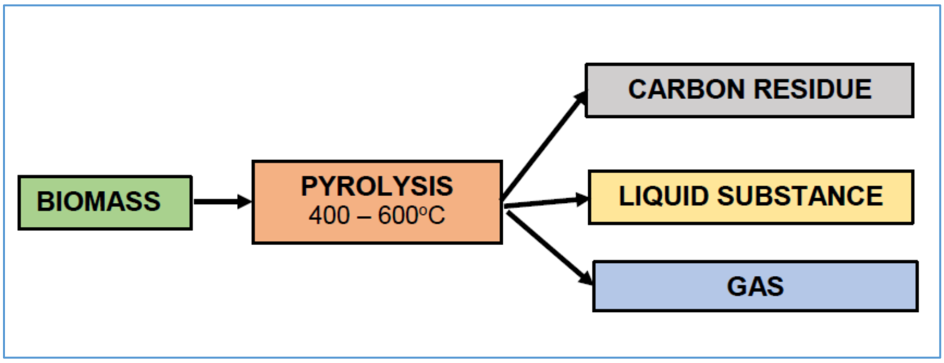

Figure 2. Generic thermic decomposition (pyrolysis in general)

The varied use of thermic decomposition is illustrated on Fig. 3, where the process separates into two parts. One is the creation of coal called torrefaction, which basically includes heat tempering of biomass only, meaning we're processing a heat-tempered (coal-like) biomass. Real biochar is more stable than this, which means it won't decompose even in the case of being left in soil for longer periods of time. The other branch of the process includes energy-production goals as well. If the goal is only the production of power-gas, only a small quantity of by-products in the form of ashes remain, amounting to a few percent. However, in this process, the quantity of coal can be increased, while improving its quality simultaneously.

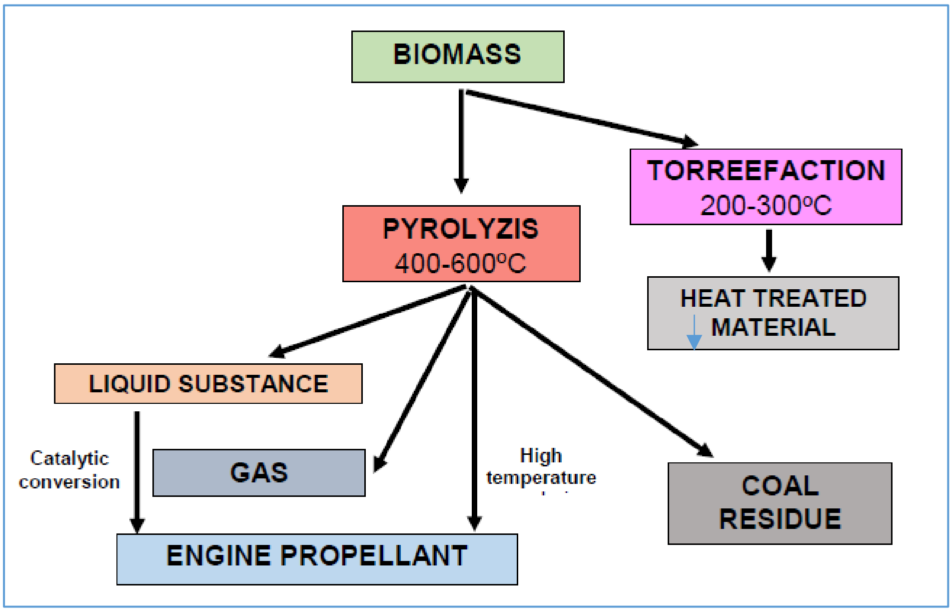

Figure 3. Thermic process producing biomass materials for several uses

Pyrolysis is a thermochemical process which consists of the decomposition of organic polymers and some biomass minerals, mainly restricted to lingo-cellulose sources. The decomposition results are produced somewhere between 400 and 800 degrees centigrade without oxygen (Fig. 4). The product is usually generator gas, or liquid-phase bio-oil. The so-called "slow pyrolysis" (300 to 400 degrees centigrade) is mainly used to produce coal with long reaction times (this is usually conducted on 500 to 650 degrees centigrade when accelerated). In order to produce a gaseous product usable as fuel, a temperature higher than 7-800 degrees centigrade is required.

A wide variety of technological systems were designed for these processes, with the fundamental goal of improving the end materials, and the performance of the process. This means that the goal is to get the highest possible usable energy resources from a single unit of energy content input (biomass). In other words, reducing the difference between source material and end energy output as much as possible, while simultaneously keeping the negative environmental effects of the production process to a minimum.

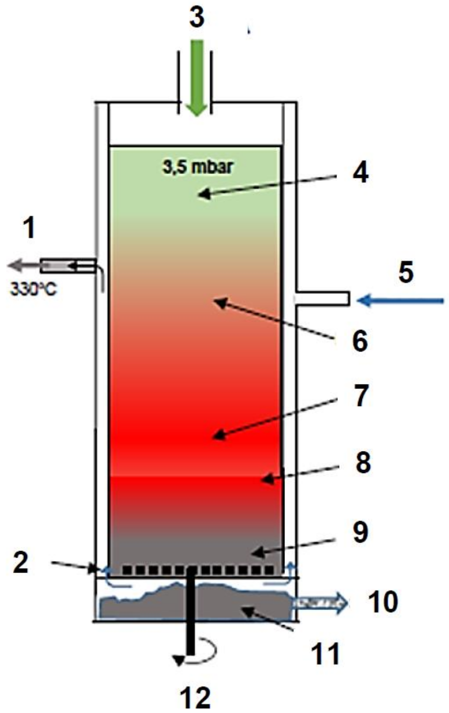

Figure 4. Technological process of thermic decomposition (resting bed system)

- *gas air mixture,*
- *gas between the walls of the mantle*
- *biomass*
- *dryness, humidity*
- *air intake*
- *start of combustion*
- *start of combustion*
- *burn*
- *start of cooling*
- *cooling coal*
- *biochar removal*
- *biochar*
- *scraper unit*

2.2.1. Effects of biochar production conditions on attributes

The zones, ie. the various temperature areas have no distinct differences, the oxidation agent may be air, steam, etc. In the end, the heating temperature of the input material, and the time being subject to heating are important [2]. In other words, the temperature transmission process may be fast or slow, depending on the heating velocity and duration of exposition. If the heating process is fast, and the plant material reaches a high temperature (roughly above 660 degrees centigrade) in a short timeframe, the biochar product will generally contain very fine grains. Similarly, lower temperatures (between 450 and 550 degrees centigrade) and slower heating velocity will create biochar with larger grains.

When creating biochar in practice, the goal is to achieve the optimal temperature (Fig. 5), meaning the temperature to heat to needs to be chosen to reach the highest possible specific grain area size in the remaining coal. At the same time, the carbon content compared to the base material should be acceptable (meaning its carbon-sealing is good), and its capacity for exchanging cations (CEC) should also be good. The cation exchange capacity of coal is very important, because negative polarity cations sticking to the grains are replaced by other cations (for example, potassium is changed by hydrogen, or vice-versa). Finally, the capacity for exchanging cations is fundamentally the quantity the soil is capable of sealing off. During production, one must aim to reach the highest possible number for this attribute. We can see the optimum temperature of the heat zones on Fig. 5, when the median of the temperature is somewhere around 500 degrees centigrade. At this point, the inner surface area is the highest, the pH value is the most advantageous, and the CEC value is average as well. We can obtain roughly 65% of the initial coal amount in biochar. In a short cycle, the material also goes through a higher temperature zone than this, which is advantageous for the degradation of PAH materials. The material may not be in higher temperatures for long, because the quantity of biochar we can produce decreases significantly, but the surface area is also reduced at the same time.

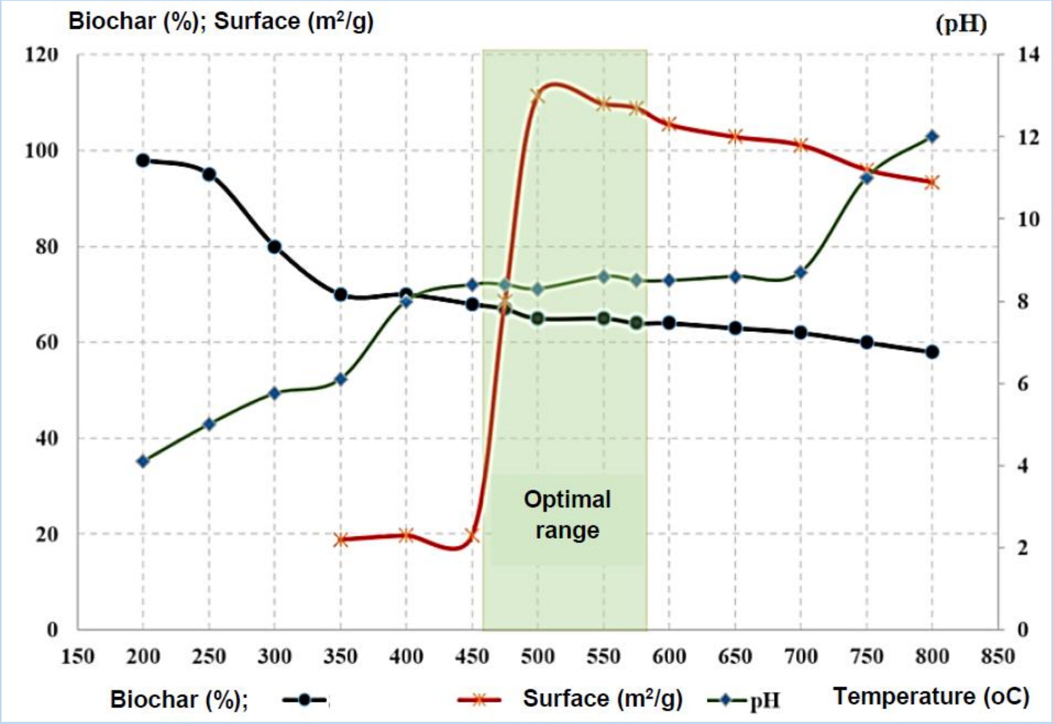

Figure 5. Changes in biochar attributes based on temperature.

In the case of a faster heating with higher temperature, a more porous, higher inner surface area biochar will be produced, with a higher pH value. Therefore, the production attributes have to be closely followed, such as: types of biomass, temperatures of decomposition, times of lingering in parts of the system, heating velocity values, pressure of the production area, etc. [3, 4, 5].

In summary, the advantages of biochar shine when:

- surface area is big,
- porosity is substantial,
- has a high CEC value,
- highly stable in different applications, etc.

Other attributes in more detail can be seen on Fig. 6.

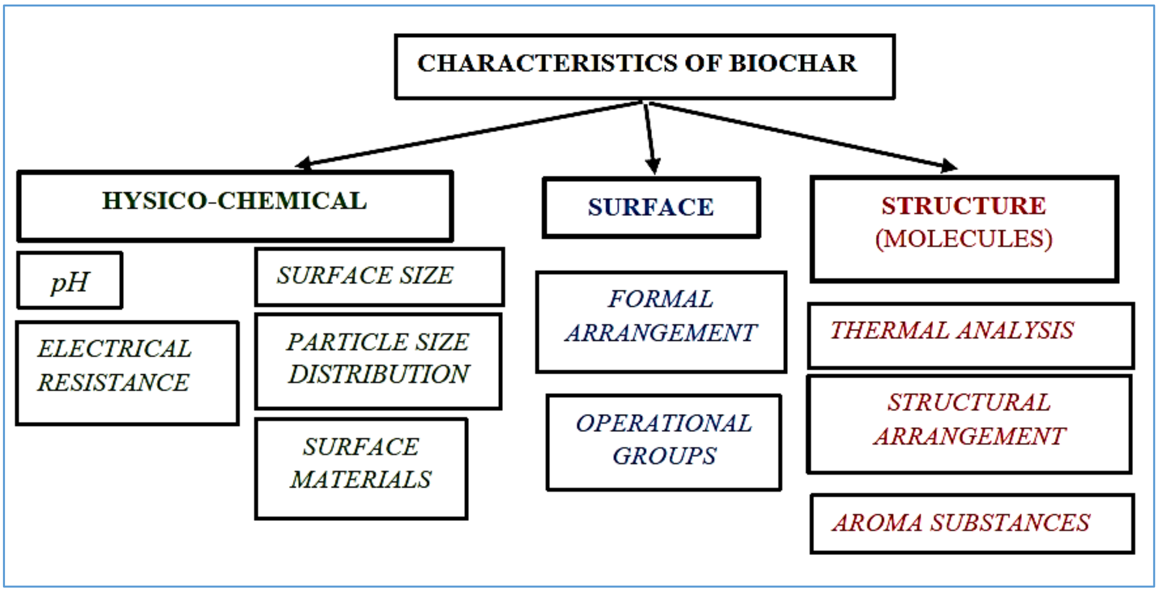

Figure 6. Physical-chemical surface area and structural attributes of biochar. [6]

2.3. Usage of biochar

2.3.1. Effects on agriculture

Degraded, dry soils and bad production capacity, low organic nutrient-content soils can improve in quality, and be more useful with the modifications accessible through biochar. In several documented cases, biochar improved nutrient- and water-sealing capacity, improved production capacity, and the efficiency of yield management. Further advantages are offered by the biochar's nature of absorbing the inorganic and organic impurities found in the water washing out the soil.

Biochar is capable of holding distributed fertiliser and other nutrients, which can be used later on. For clarity's sake, we must differentiate between biochar and compost. Biochar is different compared to the compost generally added to the soil for traditional agricultural production in that compost is a direct source of nutrients, decomposing with other nutrients when used. Biochar, however, doesn't decompose even after a longer timeframe, thereby making new additions to the soil unnecessary. Spokas and colleagues concluded that biochar may lead to positive effects in agricultural production, after reviewing the literature on biochar [7]. Laird conducted research using biochar on strongly fragmented and infertile soil, where advantages of its use were documented plentifully, for example, in the low fertility, sandy soil of Florida [8].

On rich, fertile soil, using biochar is only advised in smaller amounts. Carbon has a very important role in the various chemical and biological reactions during its cycle. The carbon source of plants is both the soil and the atmosphere, from where they absorb carbon in the form of CO_2 (Fig. 7).

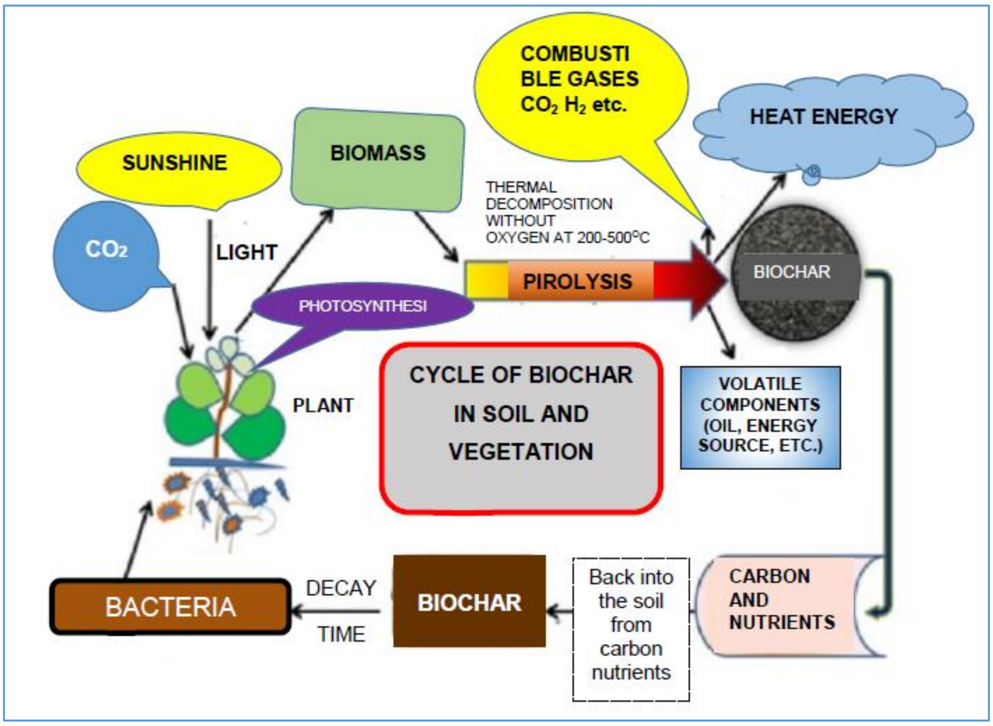

Figure 7. Carbon cycle in nature

Advantageous effects on the environment can be measured during the process:

- In the biochar manufactured from a kilogram of biomass, roughly 300g CO_2 is sealed, and remains in the soil for a long-term.
- Therefore, unlike the natural degradation of biomasses, instead of 900 g CO_2, only 600g CO_2 returns into the atmosphere – in other words, the difference is 'subtracted' from the GHG effect, while,
- ~1,0 kWh energy is obtained**.**

Fine grain biochar is a strongly porous material, with the most notable attribute of having a large surface area (200-300m^2/g), which is basically created during the 500°C-os heat tempering [9]. Compared to other soil improvement agents, its large specific area and porosity makes it possible to absorb water and conserve nutrients within itself, while it also offers a habitat for useful micro-organisms [10]. They also concluded that the reproduction rate of microbes showed an increase within soil treated using biochar [11].

Porosity has an influence on the processes that happen in the root zone, including the breathing of plants, and the absorption of root water. Biochar also modifies the soil, improving its porosity and structure. Sandy soil and clay soil improved significantly in SBD, porosity, and water content. Porous structure (Fig. 8) aids with conserving water in the soil, but in truth, doesn't increase water content to utilise.

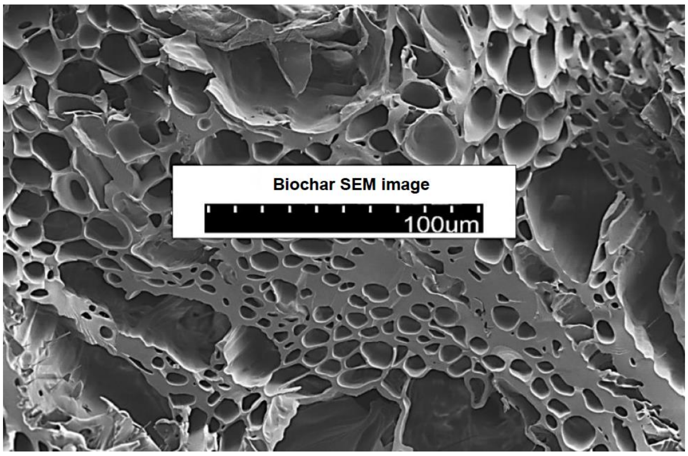

Figure 8. Porosity of biochar made out of rice straw, (SMC image after heat tempering on 500ºC)

Raw organic materials serve as nutrients in the soil, for plants and the micro-organisms found inside the same soil, while biochar acts as a catalysing agent, improving the absorption of nutrients done by plant life [12]. Commercially available biochar-based soil improvement agents can increase the specific surface area of soil by changing the pore sizes and density of the original soil [13].

The chemical and physical attributes of biochar are improved if the material interacts with steam and carbon-dioxide during the manufacturing process. The carbon content of biomass can only be changed into aromatic carbon groups, amorphous- and graphite structures like this. During the pyrolysis, organic mixtures within the biomass may be diluted into the mass, and may unify dioxides, furans, but mostly polycyclic aromatic carbon hydrogens. The resulting PAH-s are contaminating the soil due to their lypophylic structures, meaning the biochar with such content has no advantages, or is disadvantageous [14]. The most important quality monikers of biochar are high absorption and CEC values, and low mobile material content (sludge, resin, and similar short life cycle mixtures) [10].

Production temperature is also a definitive factor. Wood-based biochars produced above 450 degrees centigrade are more prone to result in higher stability and porosity, and absorption capacity products, compared to those manufactured on lower temperatures [15]. On lower temperature spectrums (300–350°C) carbonization only concludes partially, which results in smaller pores, and smaller surface area [16].

Often advertised plant conditioning products primarily affect plant life cycles through influencing the nutrient cycles. Biochar can also be placed in this group, and often a part of these wares, but is also sold as a separate ware (Fig. 9)

Figure 9: Domestic[1.] and USA-sold[2.] material *Source: [1.] Agrofutura Hungary Co. Ltd.,*
[2.] https://www.biogreen-energy.com/biochar-production.

3. Results and Discussion

3.1. Domestic-developed carbonizer and measurement results

Based on literature sources and our own measurements, the design of the carbonizer were created. The goals of the manufacturer and the designer were to create simple, but automated, easily applicable machine for smaller enterprises and industrial units. From a mechanical-technological perspective, we wanted to design a system that produces excellent quality products at a lower PAH (pollutant) content compared to other domestic products, which gets closer to the standard (EU requirements).

Finally, the detailed designs and manufacturing were done by Pyrowatt Co. Ltd. (Fig. 10).

Main attributes of the machine are detailed below.

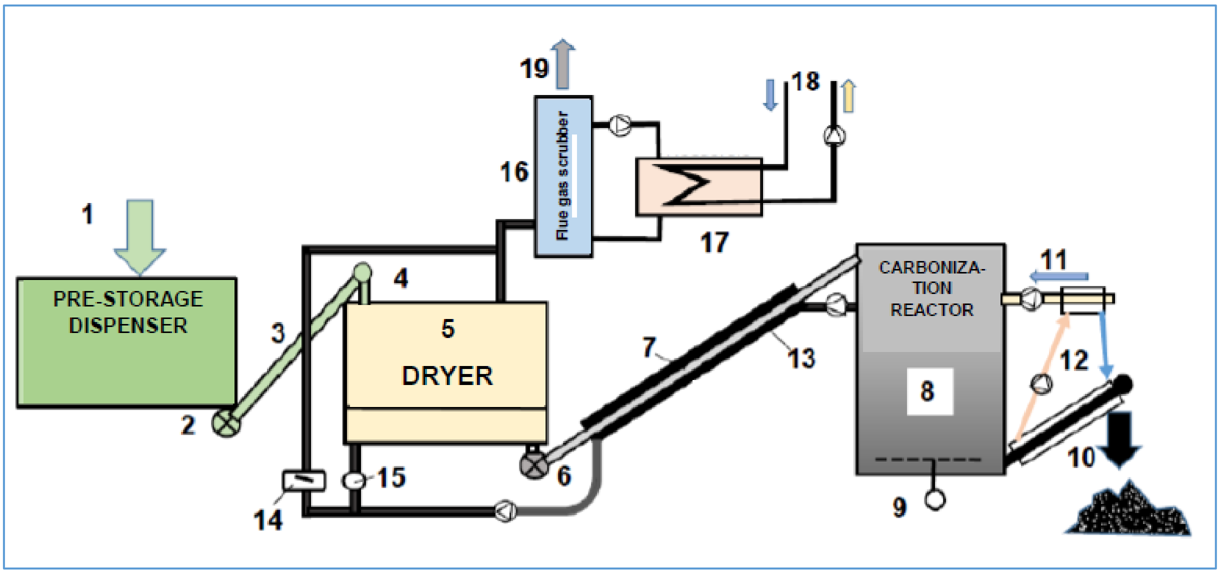

Figure 10. The process of the system

where:

1. *Biomass into the precontainer-feeder intake*
2. *cell feeder*
3. *conveyor transport*
4. *material intake into the dryer*
5. *double dryer (fan mixer and screw excavator unit)*
6. *cell feeder*
7. *conveyor transport*
8. *reactor*
9. *mixer- and excavator structure (with electric engine)*
10. *biochar excavator screw (and the processed material)*
11. *air intake*
12. *preheating of air (through the mantle of the biochar excavator and air intake pipe)*
13. *heating mantle pipe*
14. *regulator (with applicable heat exchanger)*
15. *air-gas mixture intake into the dryer*
16. *intake of the gas flowing out from the dryer, into the washing unit*
17. *heat exchanger (heat absorption recuperator)*
18. *regain of recuperated heat, intake of external airflow*
19. *cleaned smoke gas*

The open fuel container has a filter on top, in order to separate the very big grains (material remains). Carrying out the completed fuel is done by the rotating excavator at the bottom part of the containment unit (electric, 0,75 kW). The size class of the required fuel is G30 - G50, M7133 in the Önorm classification.

- Containment unit width: 1,5m
- Containment unit length: 1,0 m
- Maximum size of fuel: 1,0 m
- Nominal capacity: 1,5 m^3
- Highest mass flow of the excavator: 400 kg/h

Operating the carbonizer requires fuel with ~18% moisture content, if it’s any higher, the fuel needs to be dried [17, 18]. The drying of the fuel was done using screw churner. Fuel input is done through a feeder going from the precontainment unit to the dryer. Energy necessary for drying is obtained from the 300-400 °C gas coming out of the carbonizer. The gas is transported with a radial ventilator. The dryer has a steel structure, and is completely enclosed, its surface insulated. The maximum temperature of the part is 65 ºC. The performance of drying can be modified with the gas used to dry, the temperature of the steam, and its capacity flow. At the end of the drying section, an excavator screw is placed, which transports the dry fuel into the carbonizer.

Main data:

- Necessary heat performance: 200 kW (for biggest mass flow)
- Material performance 240,0 kg/h (from 40% moisture content to 15%)
- Drying temperature: 180-230 °C
- Required electric performance: 3,0 kW

Drying and carbonizing are done through direct heat exchange. Using the material transport, identical material is consistently being fed into the internal space, which makes the processed material consistent in homogeneity and quality. Better heat exchange and equalised heat energy distribution is supported by circulating the gas sourced from the reactor mantle, and the drying space filled by it. The intake of high-temperature gas is done by a gas stream pump. In truth, during the carbonization process, pyrolysis gases from the process are being combusted, which supplies the energy required for the system's heat requirement.

The carbonization reactor's:

- temperature setting is 600-900 °C.
- biochar production capacity is 50-100 kg/h
- exhaust gas temperature is 300-400 C°
- electric performance requirement is 5,0 kW
- main dimensions are 6,0 x 2,4 x 3,6 m
- weight is 3400 kg
- manufactured material temperature is 180 C°
- performance from absorbing exhaust gas temperature is 100 kW.

The control of the entire system is done via a digital interface. The central panel shows not only the current data of the process, but also possible errors in real time (Fig. 11)

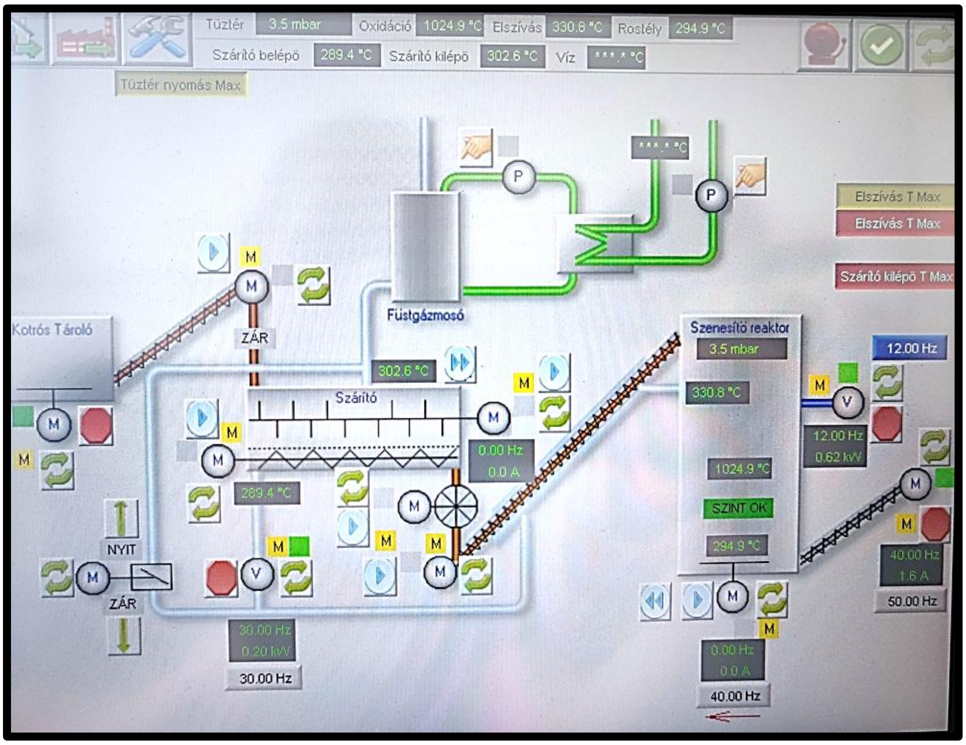

Figure 11. Management panel of the device

The filtered hardwood fed into the machine during startup was carbonized. We determined the size dimensions of the resulting carbon grains (Table 2)

Table 2. Biochar grains classified by size

Grain size [mm]	**Mass [%]**
3,15-6,3	3,9
2,0 - 3,15	15,1
1,6 – 2,0	8,2
1,0- 1,6	**26,2**
0,63 -1,0	**19,5**
0,1 - 0,63	**18,18**
0,05	8,3

Hao Liang, et al stress the importance of this analysis, as within the biochar, several different size groups of pores exist, classified into micro- (<2 nm), mid- (2 - 50 nm) and macro- (>50 nm) sized [**19**]. Smaller pore size biochar can only absorb f.e. pesticides in limited amounts. Grain size groups are better when biochar is made with a machine, roughly 65-70% if the resulting grains in the 1-1,6mm range. Therefore, the internal surface and the porosity are advantageous.

We analysed the composition of the material in an accredited lab, mainly from the perspective of various micro-element contents. Mulched and minced materials turned into biochar had a large variety of elements, of which heavy metals are way above the tolerable content limits. Due to the short-term heat zone, PAH materials decompose, which results in a low PAH content (PAH: 1,27mg/kg, total PCB <0,01mg/kg).

3.2. Biochar cost

The usage of biochar changes the properties of the soil, the production capacity of the soil is increased, and the costs of plant production are decreased (both in agricultural fields and greenhouses). Biochar remains in the soil in the long-term, throughout several production cycles, by which it expends its advantageous effects in the long-term too. Its usage reduces the necessity of phosphorus and potassium-containing fertilizers, which also reduces expenses used for these. The investment comes with an assured return.

Considering that biochar can be made out of various biological materials, waste, by-products, which are usually at hand in areas where plant production is also conducted, there is a possibility of making biochar a locally procurable resource. Local production reduces the transport costs, and the income of the production process also remains in local cashflows.

4. Conclusions

Biochar is a material reminiscent of coal, which is produced out of plant materials like wood waste, secondary products made from herbaceous plants, and remains of agri- and sylviculture. These materials are decomposed using heat, which also generates renewable energy. During the process, the physical and chemical nature of the plant materials are changed into a porous and from a biological perspective, structurally stable material rich in carbon. Research done with this material shows that it can be used as a soil improvement material in agriculture and gardening, which means it influences several physical, chemical and biological attributes of the soil. It may also increase the water-sealing capacity. It minimises the alkalisation of nutrients, may improve the income of producers and sustainability of their businesses by increasing efficiency of fertilizer usage and reducing fertilizer costs. By increasing water-sealing capacity, biochar can decrease watering requirements, and may enable the extension of production even in less water-rich areas.

In summary, it modified the microbe culture of plants' root zones, and their habitat, which often leads to a bigger abundance of microbes, and better activity of them as well. This increases production yield. One must know that the usage of biochar is the most advantageous in a controlled environment. In the case of sandy, sour soil variants, every feedback is positive. We cannot exclude the fact that considering the production process, and entire effect mechanism of biochar, reduces the carbon-dioxide emission into the atmosphere. Therefore, it is also an advantageous material for climate protection.

The machinery introduced is a so-called fixed bedding structure. Drying and carbonization is done via direct heat transfer. The material fed into the reactor is equalised in quality due to the pre-dryer. Better heat exchange and equalised heat energy distribution is supported by circulating the gas sourced from the reactor mantle, and the drying space filled by it. The intake of high-temperature gas is done by a gas stream pump. In truth, during the carbonization process, pyrolysis gases from the process are being combusted, which supplies the energy required for the system's heat requirement.

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