A PRELIMINARY STUDY ON TORREFACTION PRETREATMENT OF HEMP STEM FOR WASTE-TO-ENERGY VALORIZATION OF WOODY BIOMASS FROM FLOWER HEMP CULTIVATION.

Massimiliano Parenti[1]*, Filippo Ottani[1], Marco Puglia[1], Nicoló Morselli[1], Simone Pedrazzi[1], Giulio Allesina[1], Massimo Montanari[2], Roberta Paris[2]
1Department of engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Italy
2CREA – Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria
*Corresponding Author: massimiliano.parenti@unimore.it

ABSTRACT: Hemp cultivation gained an important role in recent years. Two major production chains can be defined, one dedicated to the cultivation of hemp for the production of fiber and wood and the other relating to the production of inflorescences for the market of derivative products containing cannabidiol, better known as CBD. The problem that will be highlighted and addressed in this article is related to the enhancement of cannabis production waste for CBD. In particular, since flowers are the only useful part of crops dedicated to this purpose, to date the stems of plants are considered a difficult waste to exploit. The alternatives are few and one of the simplest and most immediate is certainly the waste-to-energy process of this material; in fact it is not possible to obtain fiber and wood of good quality from the CBD production chain, because these crops are optimized for flower production. Waste-to-energy, on the other hand, requires mechanical pre-treatments in order to use the raw material within the typical thermal conversion systems (e.g. biomass boilers, pellet stoves, gasifiers). The great obstacle to being able to efficiently transform these wastes into fuel, lies in the very nature of the hemp stems as the fibers constituting the outermost part of the plant stems are well known for their good mechanical resistance. These properties however become a problem when the material has to be treated with standard machinery for pelleting and briquetting, as they hind the mechanical components suitable for the purpose giving rise to maintenance and breakdown issues. To solve the problem, the possibility of decreasing the mechanical properties of hemp fibers has to be investigated, so as to permit the transformation of this material into an economically sustainable fuel. It was therefore decided to pre-treat the stems of the plants with a torrefaction process, to sufficiently weaken the fibers to be mechanically treated. Shear resistance was tested with a "piston device" to obtain a qualitative estimate of the mechanical behaviour of the hemp fibers only; in fact it is assumed that to solvethe problem, it is sufficient to concentrate on the weakening of the fiber instead of the entire stem of the plant. In conclusion, a first estimate is defined of the minimum energy necessary for the roasting of the plant stems, sufficient to weaken the fibers to make the mechanical transformation of the stems of hemp plants into fuel, possible and economically sustainable.

1 INTRODUCTION

Hemp cultivation gained an important role in recent years [1]. Two major production chains can be defined, one dedicated to the cultivation of hemp for the production of fiber and wood and the other relating to the production of inflorescences containing cannabidiol, better known as CBD.

The problem that will be highlighted and addressed in this article is related to the enhancement of cannabis production waste for CBD. In particular, since flowers are the only useful part of crops dedicated to this purpose, to date the stems of plants are considered a waste.

The stem is the least valuable part of the hemp plant, from which therefore no useful product is obtained. The composition is similar to wood: cellulose is present at 34-48%, hemicellulose at 21-25%, lignin at 17-19%, 4% of oil, pectin, and similar products and ash for 1/2% [2].

The alternatives for the use of these by-products are several and one of the simplest and most immediate is certainly the waste-to-energy process. Some studies have shown how this biomass, opportunely pre-treated, can be used in the most known applications, such as pellet stoves [3, 4], gasifiers [5] or pyrolizers, for production of thermal energy.

Waste-to-energy, most of time, requires mechanical pre-treatments in order to use the raw material within the typical thermal conversion systems, whether they require pellets, briquettes or wood chips. The major obstacle to being able to efficiently transform these wastes into fuel, lies in the nature of the hemp stems as the fibers constituting the outermost part of the plant stems are well known for their good mechanical resistance. These properties however become a problem when the material has to be treated with standard machinery for pelleting and briquetting: the strong fibers hind the mechanical components of the machine giving rise to maintenance and breakdown issues.

To solve this problem, the possibility of decreasing the mechanical properties of hemp fibers must be investigated, to permit the transformation of this material into an economically sustainable fuel. It was therefore decided to pre-treat the stems of the plants with a torrefaction process order to modify the mechanical properties of the stem. The choice fell on torrefaction because it is an simple treatment that can be optimized to weaken only the external fiber of the stem.

Torrefaction process is a simple process in which biomass is roasted [6], usually in an atmosphere of inert gases, at temperatures below 300 °C. The two main parameters of torrefaction process are the temperature (in the range of 200-300 °C) and the residence time, the duration of the treatment during which the biomass is left in the roaster).

During the torrefaction process, about 80% of the total hemicellulose in the plants is dissolved [7] at temperatures even below 200 °C. Furthermore, the process allows to increase the energy density of the biomass [8] and, at the same time, if the biomass is used in a gasifier or pyrolizer, it increases the production of biochar, compared to an un-torrefied feedstock [9]. Consequently, torrefaction permits also to reduce the energy costs for shredding or grinding process of the stems.

Finally, torrefaction turns out to be a good candidate as an economical pre-treatment for hemp plants since, especially for low temperatures, it requires low thermal energy consumption. In addition, it can also be applied in a non-inert atmosphere [10], at the expense of slightly worse results compared to processes with inert gas but reducing the complexity of the technical system.

2 MATERIAL AND METHODS

2.1 HEMP FOR FLOWER AND SEED

Considering the objectives of this study, we want to focus on the enhancement of wood waste from the flower and seed hemp supply chains. We therefore opted for stems deriving from the production of cannabis sativa from seed. Once harvested, the plants were left to dry outside for six months; however, it will be better outlined in the conclusions of this article, this choice adds uncertainty to the interpretation of the results. Fig.1 shows the plants as they are, after harvesting and after the six months drying phase in open air. Plants have many fibers that are visible even at first glance. The problem of the fiber, in fact, already manifests itself during the harvesting phase (in bales or bundles), even if in a manageable way compared to the processing.

Figure 1 - Hemp plants used during the test.

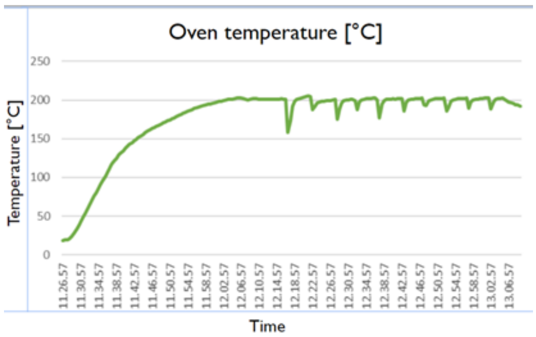
It is important to underline that in this preliminary study it was decided to take into consideration only the fiber constituting the external part of the stem. This was done for two reasons: the first is that the part of the stem that creates problems in the mechanical processing of hemp is exclusively the fibrous one coinciding with the outermost part of the stem; in fact, the innermost part of the stem, the so-called hemp wood, does not create problems for the mechanical transformation of hemp into fuel. The second reason for we chose to only consider the fibrous part of the stem, is that the device used to measure the shear resistance of the material has a work range, in terms of applied force, that is not sufficient for measuring the shear resistance of the entire stem.

For the reason herein discussed, we chose ten plants among a hundred available. The only parameters considered for this choice were visual and geometric. Indeed, probably due to the six months drying phase in open air, part of the biomass was affected by fungal degradation; therefore, we tried to select what looked like the most intact stems. Subsequently, we peeled 10 strips of the outer part of each plant. These fibrous strips where afterwards standardized in shape with a cutting device, for better comparison.

Figure 2 – Fiber strips of a single hemp stem

2.2 Hemp torrefaction

The hemp strips were then divided into two equal parts: one left “as it is” and one subjected to the torrefaction process. The samples were numbered from 1 to 10: "as it is” = S1, S2, …, S10.; torrefied samples = ST1, ST2, …, S10. The torrefaction process was carried out using a laboratory oven, MEMMERT UM 100, with a nominal power of 600 W and a maximum temperature of 220 ° C. The samples were torrefied at different residence times: ST1 was placed in the oven for 10 min, while for the subsequent samples the time was increased by 5 min each time. (ST2 = 15 min; ST3 = 20 min,…, ST10 = 55 min). The temperature was set at 200 °C. Through this procedure we want to identify the minimum residence time that causes the minimum weakening effect of the fibers, useful for the mechanical processing of the hemp plant. In fact, by minimizing the residence time, the costs related to the energy necessary for the process are also minimized. In Graph. 1, the temperature trend during the test is shown.



Graph. 1 - Oven temperature trend. The 10 samples were placed in the oven before it was switched on.

2.3 Shear resistance test

To assess the mechanical weakening effect of torrefaction hemp fibers, it is important to take into account its natural behavior when mechanically processed. In fiber hemp production, the standard procedure is to divide the fiber from the wood with simple mechanical stress of the stem of the plant; the goal in this case is too we can the woody part of the stem for the fiber to be easily peeled off. Indeed, this natural tendence becomes an obstacle when the stem has to be mechanically processed for waste two energy use, i.e. pelleting or briquetting. In trying to be simple we therefore considered the shear resistance has the governing parameter of this behavior.

Shear resistance was tested with a “piston device” to obtain a qualitative estimate of the mechanical behavior of the hemp fibers. For each sample, 10 shear tests were carried out: 5 on torrefied strips and 5 on non-torrefied strips. Figure 3.a shows the piston device used for shear resistance measurement. Figure 3.b shows a detail of the knife and counter-knife specifically designed for this preliminary test; we chose to have a two-cutting points kind of test so that traction and lateral bending forces on both sides of the cutting knife compensate each others, resulting in a negligible sum. The fiber was in the meantime kept in place by a manual tong, which also prevented the fiber from sliding away when stressed by the piston.

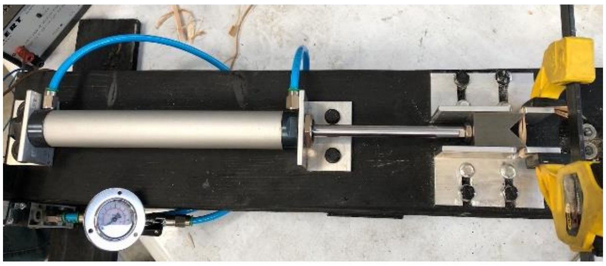


Figure 1.a - piston device used for the shear test.

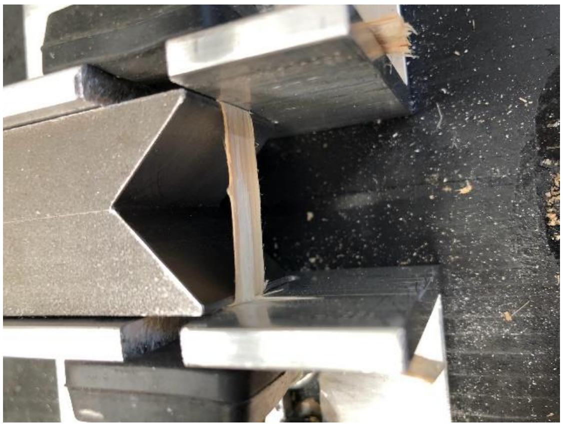


Figure 2.b - particular of the knife and counter-knife used for shear test on the fiber strips.

The force applied from the piston to the sample test, has been considered as the most reliable one. As a matter of fact the shear force acting on the sample should be taken into account, but considering a non-negligible geometric variability of the stressed section surface of each sample, a further stage of uncertainty would be introduced in the problem. Also, it is a complex problem to determine the exact section surface stressed in each sample, for two reasons: first we are not dealing with an artificial material which by its nature has a limited geometrical variability and second, a resisting surface measurement for this kind of samples would require a pointless effort for a preliminary study. This point will be better cleared, within the conclusions chapter.

The force applied from the piston has been calculated considering the air pressure applied within the piston and its diameter (i.e, the piston surface on which the pressure is applied). The air pressure has been measured with a manual monometer. For the piston used in this study the minimum useful pressure to move it is 1.6 bar and the maximum pressure is 6.25 bar. The diameter of the piston is 3.2 cm. Given these data, the minimum piston force is 129 N and the maximum piston force is 503 N.

The shear test was considered concluded either when the fiber strips was broken or when the maximum force of the piston was not enough to break the sample. As a consequence, it is possible to identify three types of data:

- Numerical data: the force at which the sample broke;
- “MAX”: indicates that the sample was not broken even at maximum force;
- “Min”: indicates that the sample was broken at the minimum force.

3 RESULTS

3.1 Torrefaction results

After the roasting process at 200 ° C, the hemp fibers appear as shown in Fig. 4. The brown color, even if not clearly, gradually becomes darker as the residence time increases.

Figure 3 - Torrefied samples. From left to right the resident time increases.

During the torrefaction there is a reduction in biomass as moisture and the light components of the stem are lost. This causes the fiber to become weaker and hydrophobic. A percentage reduction was measured, with respect to the initial weight, ranging between 10% and 15% for each sample. As the residence time increases, there is no increase in weight reduction as the samples come from 10 different plants and therefore have different behaviors.

3.2 Shear resistance test results

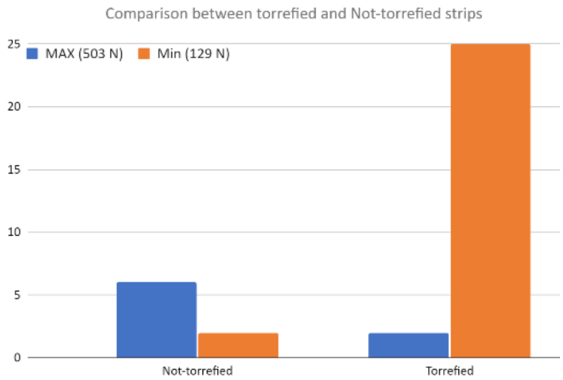
Not-torrefied samples (left in Table 1) require higher forces than the forces required to break torrefied samples (right in Table 1). Five not-torrefied specimens fail to break even by exerting the maximum pressure of the piston device, while torrefied samples almost all break with lower forces than non-torrefied samples.

Shear tests result – forces exerted on the strip are expressed in Newton [N]										
	Not torrefied					Torrefied				
	Strip1	Strip 2	Strip 3	Strip 4	Strip 5	Strip1	Strip 2	Strip 3	Strip 4	Strip 5
1	MAX	241 N	MAX	161 N	241 N	322 N	Min	165 N	169 N	Min
2	422 N	MAX	1442 N	330 N	306 N	241 N	442 N	281 N	241 N	161 N
3	483 N	362 N	290 N	402 N	402 N	Min	201 N	233 N	MAX	298 N
4	193 N	185 N	322 N	145 N	161 N	Min	Min	Min	Min	Min
5	145N	MAX	290 N	145 N	MAX	314 N	281 N	Min	129 N	322 N
6	Not representative sample, the strips are undersized for testing whit the "piston device"									
7	145 N	141 N	233 N	233 N	145 N	Min	Min	Min	137 N	Min
8	233 N	145 N	281 N	137 N	161 N	Min	Min	Min	145 N	Min
9	306 N	161 N	137 N	Min	137 N	322 N	Min	177 N	Min	Min
10	475 N	281 N	314 N	Min	273 N	Min	Min	Min	Min	Min

Table 1 - collection of the breaking forces of the samples. The strips that did not break were marked in orange (the maximum applicable force is equal to 503 N), the strips broken at the minimum pressure that can be set in the piston device (129 N) were marked in green.

For "long" torrefactions the force required to break the torrefied strips is approximately half of that required to break the not-torrefied strips. For the first 3 samples, on the other hand, the force required to break the torrefied strips is similar to the shear force applied to the not-torrefied samples: therefore, there might be no substantial difference between pre and post torrefaction for "short" resident time.

Graph. 2, shows that, the data collected from the repetitions allows to confirm that there is a weakening of the hemp fiber. The number of samples that break at the minimum force visibly increases.



Graph. 2 – Numerical comparison between non-torrefied and torrefied sample.

4 CONCLUSIONS

Torrefaction is a suitable pre-treatment in order to weaken the fiber. In fact, from the experimental tests carried out, the fibers become weaker even if subjected to a "light torrefaction process" of 200 °C. As a proof, the torrefied fibers subjected to shear stress come to break with lower forces than the fibers that have not been treated.
It was also observed that the torrefaction resident time affects the strength of the fiber. Long resident time (> 40 minutes) have better results than short process (<20 minutes). For short torrefaction processes it is necessary to increase the temperature to which the stems are exposed (for example 300/350 °C).
Finally, new tests will be necessary to evaluate the optimal 'residence time – temperature' combination, to obtain a product that can be processed with standard machines and processing methodologies.

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