

THE TORREFACTION

A „TORREFACTION” TECHNOLÓGIÁJA

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ABSTRACT

The goal of this article is to present details about one possible thermal treatment on agricultural residues to increase the heating value of its. In Hungary are generated a huge amount of agricultural residues[1]. Nowadays the incineration of – for example – the wheat straw is subjected to the directives of the European Union. This causes a new way to fertilize the fields. It means the husbandmen plow the grinded straw with depleting bacteria and N₂ to provide the nutrients for the topsoil[2]. But this process takes about one and a half year, so as one husbandman told me this is just a makeshift to hide the straw and to provide somehow the nutrients. The best solution for that problem is to incinerate these kinds of residues, for example in domestic boilers to get heating energy or in a combined heat power plant (CHP). And to provide the nutrients for the topsoil the real environmental friendly solution is to use liquid natural fertilizers or composted waste.

1. INTRODUCTION

The usage of biomass to generate electric or heat energy is not recommended by some researchers, because there are lots of unsolved problems with these materials. Firstly what I underline is the transportation. This is not environmental friendly below certain distance[3], however it could be economical because of the subsidizations by the government. If the energy density of the biomass would be increased it can be transported for longer distances in an environmental friendly way. The second problem of the biomass is the storage. If we store under the open sky, it absorbs moisture what causes incinerating problems and decrease the heating value, for example the dry wood has 19 MJ/kg while the 30% moisture content wood has 12.5 MJ/kg heating value¹ only. The following research results are all about the torrefied wood. During my literature research I did not find any books, articles or studies about the torrefied agricultural residues.

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¹ Heating value of the wood, available:

http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,20041&_dad=portal&_schema=PORTAL

2. CHEMICAL PROPERTIES OF THE WOODY BIOMASS

As I wrote in the [1] article the torrefaction is similar to the traditional heat treatment of metal articles, but it passes off in a pressure vessel at ambient pressure in an anaerobic atmosphere and in a medium-high (about 280°C) temperature. During the treatment the chemical properties and the structure of the molecules are changing. The most reactive part of the wood during that heat treatment is the hemi-cellulose. High hemi-cellulose content causes high reactivity, it means that those plants what have relatively high hemi-cellulose content can be treated with this method not just the wood, or the residues of the wood. I think the researchers make this technology firstly for wood because the wood is homogenous and has low mineral content as compared to agricultural residues. The trees are perennial plants; it can deflate the accumulated minerals while the agricultural residues have no time to make that. It will cause a lot of changes in the parameters of the technology if I would like to adapt to the residues.

Elements	Average of 11 hardwood ²	Wheat straw ³
Carbon	50.1%	47.6%
Hydrogen	6.2%	5.8%
Oxygen	43.5%	44.4%
Nitrogen	0.1%	0.68%
Sulfur	<0.05 %	0.08 %
Potassium	-	1%
Chlorine	<0.01	0.24%

1. Table: The chemical composition of wood and the wheat straw

The above table shows the average chemical composition of the wood. It has high carbon and oxygen content and low content of minerals. Comparing the chemical composition of the wheat straw the wood has higher carbon and oxygen content while the straw has lower carbon and higher mineral content. These minerals cause some problems during the incineration; the potassium decrease the melting point of the ashes, the Potassium favors generating the slag in the grate

² Tillman et al. 1981

³ Measured in ÁNTSZ labor, Miskolc

what causes significant problems during the combustion; and the reaction of the chlorine generates hydrochloric acid and furans. Most of the Chlorine fly with the ash (fly-ash), the rest goes HCl, and it causes corrosive effects on the inner parts of the boilers.

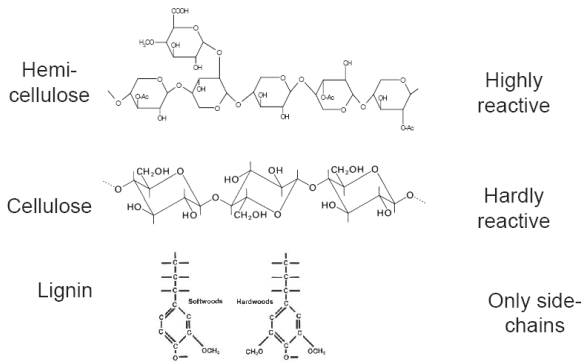
3. THERMAL TREATMENT OF BIOMASS

The torrefaction is a three-phase heat treatment technology, a heating, a torrefaction and a cooling phase included. Inside the reactor firstly the moisture content evaporates, when the biomass reaches the 200 °C the physically bounded water is released. When the temperature reaches 280°C the de-polymerization of the hemi-cellulose eventuates. The torrefaction liberates the water, the volatile organic compounds, and the hemicellulose from the cellulose and lignin.

At the temperature of torrefaction the hemicellulose degraded into permanent gases, condensable liquids, and solids (Table 1.).

Gas phase	Liquid phase	Solid phase
H ₂ , CH ₄ , CO, CO ₂ , C _x H _y , aromatics	Acids, ketones, furans, alcohols, terpenes, phenols, waxes, tenins, water	Char, new sugar structures, new polymers, ash

2. Table



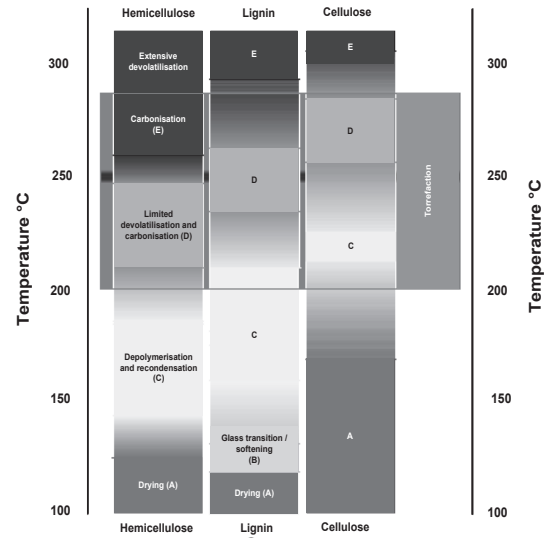
1. Figure: The structure of the woody polymers[5]

With all of the polymers happen the dehydration process, it destroys the “OH” groups that are responsible for H₂ bonding the water. This reaction limits the ability to absorb water into the torrefied material [4]. This is a significant feature of the torrefied materials, think about the storage. It lets optionally to

store under the sky, without an expensive storage building.

On Figure 1. [5] the reactive property of the hemicelluloses, and cellulose is shown. As I mentioned the “OH” groups degraded by the treatment, and the hemi-cellulose contains “OH” groups in a high amount. The cellulose is the thermo stable part of the polymeric structure of the woody biomass. The cellulose is the hardly reactive part. The lignin has “OH” groups in the side-chains, that is why it has a low reactive property.

If we examine the processes depending on the temperature we experience different reactivity, according to the “OH” groups’ situation. As shown in the Figure 1. polymer structure mark out from, the hemi-cellulose has to be the highly reactive. On Figure 2. one can see that, this polymer is depolymerised and recondensated (C part) it suffers a reaction firstly.

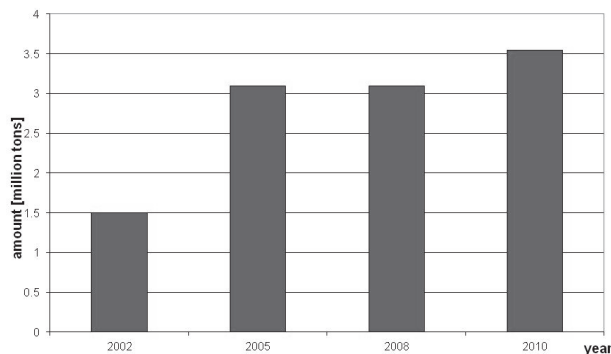


2. Figure: The phenomenon of the physical and chemical background of the torrefaction[5]

It follows that the lignin and then the cellulose structure changes. The next period of the torrefaction is the (D part) limited devolatilisation and carbonization above 200 °C temperature. If we increase the temperature till 250°C the carbonization of the hemi-cellulose starts (E part) it ends above 280°C, but the lignin’s carbonization begins in that temperature. If the temperature increasing carries on to reach above 300 °C the unfavorable processes start off. The gas/solid fraction change the amount of gas and it will be higher than the solid phase. So the torrefaction ends on 280°C when most of the hemi-cellulose is carbonized it takes about an hour or a little bit more, but surely it also depends on the raw material and the construction of the equipment.

4. INSERT TO THE MANUFACTURING PROCESS

Nowadays the demand for the alternative fuels is increasing. In Hungary for example the firing wood's consumption doubled between 2002 and 2005⁴. The trend is further growing consumption as we see on Figure 3.

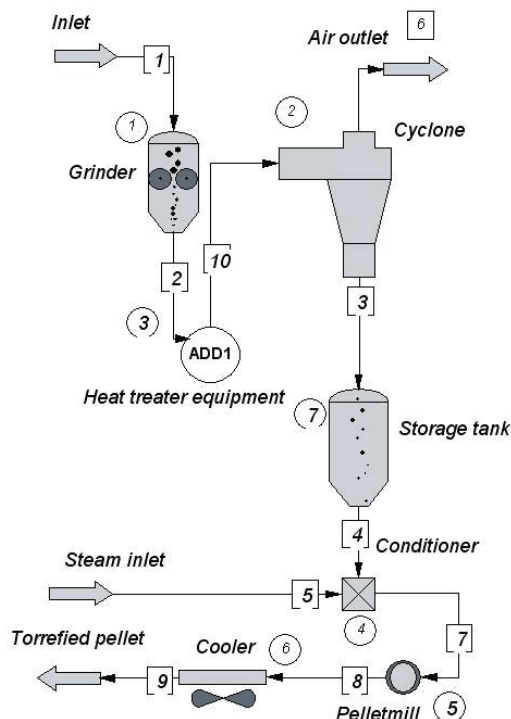


3. Figure: Wood consumption for firing

To use the wood in a domestic boiler, in Hungary called mixed-firing boilers, is not efficient. The efficiency of the wood firing is about 70-80%, it depends on the construction of the boiler. In the early 1990 years there was a period when the gas was really cheap. Most of the population of the country changed the fuel to natural gas from coal, and leave the mixed-firing boilers there without usage. In the last few years things change again, because the price of the natural gas is increasing. The population's wood consumption is continuously increasing, because of its price.

I am sure most of the people never heard about the pellet firing. The biggest advantage of the pellet firing boilers (following the fuel's price) is: it can be fully automated like a gas boiler. There is a storage tank, it has to be filled with pellet and the system dosed the necessary amount of the pellet. One does not have to throw every hour or two hours wood pieces on. You will feel the same comfort like you would have a gas boiler.

I would like to use the agricultural residues to make pellet but I would like to insert a technological step into the manufacturing process (Figure 4). Basically the palletizing is a compressing, is a density increasing manufacturing process. To pelletize the raw material it needs a 13-15% moisture content and 3-6 mm particle size. The agricultural residues do not require drying, because as I wrote in [6] the harvesting begins when the wheat's moisture content is below 15%.



4. Figure: Manufacturing flowchart of the torrefied straw pellet

When the straw arrives from the bale crusher it goes to the grinder (Equipment 1. on Figure 4). Here the particle size of the straw will be 3-6 mm after the raw material goes into the heat treatment equipment, to reach the higher heating value. The theory of the operation of that machine was written above.

When the straw finished the residence time inside of the treatment equipment, a fan blows the grinded, treated material to a temporary storage tank to provide the continuous operation. The next step is conditioning the straw with steam. It needs to reach the adequate moisture content 13-15%; during the heat treatment the bounded water also released so we need to replace the water. The amount of the stream is maximum 5 % of the raw material. Than the torrefied straw fall on the pellet mill, during the compression the pellet is heated up to 80°C because of the friction.

The next step, almost the last it has to be cooled to a temperature below 40°C, to prevent the initiation of biological processes during the packing. However the torrefied pellets do not need to pack immediately after the cooling because of the hydrophobic nature.

The flowchart on Figure 4 was made with the ChemCAD software what enables to define and solve manufacturing processes. With that software we can easily analyze mass, energy flows and costs.

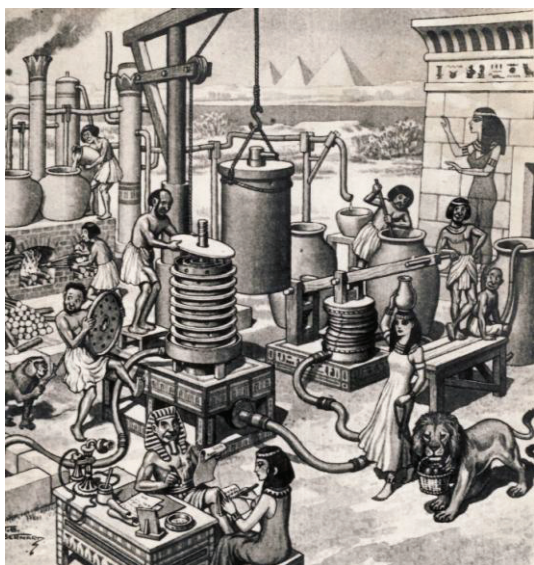
⁴<http://www.kvvm.gov.hu>

5. SUMMARY

For an adequate decision whether this technology is usable or not for wheat straw carbonization we have to design a heat-treatment furnace and we have to make experiments to find out the proper parameters of the technology. There are lots of dependent variables; for example the pressure. It may be that it would be better if we use vacuum than the ambient pressure. If we use vacuum the equipment will have to have specific inner parts, think about the sealing system. But if we use vacuum the continuous suction whip up the grinded grain. The next important question is the temperature, as I present, the carbonization is the function of the hemi-cellulose content. If we use a lower hemi-cellulose content material, maybe we need less operation time to reach the adequate material properties.

6. ÖSSZEFOGLALÁS

Ahhoz, hogy megfelelő választ kapjunk arra a kérdésre, hogy érdemes-e egy ilyen technológiát alkalmazni búzaszalma hőkezelésére, egy kísérleti berendezést kell tervezni és építeni, hogy megfelelő mennyiségű kísérleti eredmény birtokában el tudjuk dönteni a kérdést. Nagyon sok paramétert kell megválasztani ahhoz, hogy megfelelő berendezést építsünk, például a nyomást. El kell dönteni, hogy vákuumos vagy inert gázos, tehát túlnyomásos rendszert gyártunk. A következő megválasztandó ismeretlen a hőmérséklet, illetve a tartózkodási idő. Mindkettő összefüggésben a betáplált anyag hemi-cellulóz tartalmával. Alacsonyabb tartalom vélhetően kevesebb tartózkodási időt igényel.



7. ACKNOWLEDGEMENT

The described work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

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