BIOMAS TORREFACTION PROCESS

Cristian GRIGORAȘENCO, Corina GUȚU – CHETRUȘCA

Technical University of Moldova

Abstract: *Torrefaction is a thermal pretreatment technology. It is also defined as isothermal pyrolysis of biomass occurring in temperature ranges of 200–300°C and performed at atmospheric pressure in the absence of oxygen. Common biomass reactions during torrefaction include devotilization, depolymerization and carbonization of hemicellulose, lignin and noncondensable gases. Typically during torrefaction 70 % of mass is retained as a solid product, containing 90 % of the initial energy content, while 30 % of the lost biomass is converted into condensable and noncondensable products. Torrefaction of biomass improves energy density, grindability, and pelletability index and decreases the moisture content.*

Key words: *Biomass, torrefaction, calorific value, depolymerization, hemicellulose.*

1. Introduction

The world is currently challenged to reduce dependence on fossil fuels and achieve a sustainable, renewable energy supply. Energy produced from biomass is considered carbon - neutral because the carbon dioxide released during conversion is already part of the carbon cycle. Increasing biomass use for energy can help reduce greenhouse gas (GHG) emissions. Energy from biomass can be produced from different thermochemical (combustion, gasification, and pyrolysis), biological (anaerobic digestion and fermentation), or chemical (esterification) processes, where direct combustion can provide a near - term energy solution.

The growing interest in biomass as a solid fuel includes combustion to produce steam for electrical power and commercial plant uses, as well as gasification to produce a combustible gas (large partial pressure of nitrogen and CO_2, called producer gas) and syngas (carbon monoxide and hydrogen with low amounts of nitrogen and CO_2). Still, the use of either producer gas or syngas in modern reciprocating or gas turbines, or to produce higher value chemicals and fuels, is limited due to biomass feedstock preparation, accumulation logistics, and economics.

2. Limitation of biomass as a fuel

Some of the inherent problems with raw biomass materials compared to fossil fuel resources (low bulk density, high moisture content, hydrophilic nature, and low calorific value) render raw biomass difficult to use on a large scale. These limitations greatly impact logistics and final energy efficiency. Due to its low energy density compared to fossil fuels, very high volumes of biomass are needed, which compounds problems associated with storage, transportation, and feed handling at cogeneration, thermo-chemical, and biochemical conversion plants. High moisture in raw biomass is one of the primary challenges, as it reduces the efficiency of the process and increases fuel production costs. High moisture content in biomass leads to natural decomposition, resulting in loss of quality and storage issues such as off - gas emissions. Another consequence of high moisture content is the uncertainty it causes in biomass's physical, chemical, and microbiological properties. Irregular biomass shapes constitute another issue, especially during feeding in a gasification system. In addition, biomass has more oxygen than carbon and hydrogen, making it less suitable for thermochemical conversion processes. Considered collectively, these properties make raw bio - mass unacceptable for energy applications. To overcome these challenges and make biomass suitable for energy applications, the material must undergo a special pretreatment process. One of the commonly used preprocessing operations is grinding, which helps to achieve a consistent particle size; however, the moisture content of the biomass limits the performance of many grinders.

Also, raw biomass is thermally unstable due to high moisture, which results in low Calorific Values and inconsistent particle - size distribution issues when used in thermochemical processes such as gasification. This can lead to inconsistent products and the formation of condensable tars, which results in problems like gas-line blockage. A viable option is to pretreat the biomass before the end - use application. Pretreatment helps alter biomass's physical properties and chemical composition and makes it more suitable for conversion.

The pretreatment can be a chemical, thermal, or mechanical process, like ammonia fiber explosion, torrefaction, and steam explosion, respectively. These pretreatment processes help alter the amorphous and crystalline regions of the biomass and bring significant changes in structural and chemical compositions. Figure 1 shows how the pretreatment of biomass makes it easier to convert.

3. Torrefaction process overview

Torrefaction is a thermal pretreatment technology. It is also defined as isothermal pyrolysis of biomass occurring in temperature ranges of 200–300°C and performed at atmospheric pressure in the absence of oxygen. Biomass torrefaction has been recognized as a technically feasible method of converting raw biomass into a solid that is suitable for commercial and residential combustion and gasification applications, given that it has high energy density, is hydrophobic, compactable, and grindable, and has a lower oxygen-to-carbon (O/C) ratio.

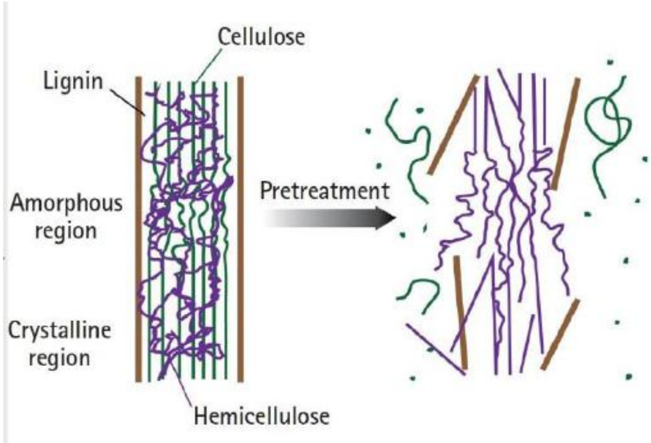

Figure 1. Pretreatment effect on lignocellulosic biomass[1]

During the initial heating of lignocellulosic materials, water due to chemical reactions is removed through a thermocondensation process. This happens at temperatures between 160 and 180°C and results in the formation of CO_2. At temperatures of 180–270°C, the reaction is more exothermal, and the degradation of hemicellulose continues. At these temperatures, biomass begins to brown and give off additional moisture, CO_2, and large amounts of acetic acid with some phenols that have low energy values.

During torrefaction, the major decomposition reactions affect the hemicellulose. Lignin and cellulose also decompose in the range of temperatures at which torrefaction is normally carried out, but to a lesser degree. Torrefied biomass retains most of its energy and simultaneously loses its hygroscopic properties. For torrefaction process temperatures over 300°C are not recommended, as these may lead to extensive devolatilization of the biomass due to the initiation of the pyrolysis process.

4. Torrefaction process technique

Torrefaction is a thermochemical process involving the interaction of drying and incomplete pyrolysis. The different parameters that influence the torrefaction process are (a) reaction temperature (b) heating rate (c) absence of oxygen (d) residence time (e) ambient pressure (d) flexible feedstock, (e) feedstock moisture and (f) feed - stock particle size. Biomass feedstock is typically predried to 10% or less moisture content prior to torrefaction. Particle size plays an important role in torrefaction in that it influences the reaction mechanisms, kinetics, and duration of the process, given a specific heating rate.

The chemical reactions that occur when reactive inter-mediates are trapped in a thick matrix differ from the situations in which products can escape and be swept away in a gas stream. The duration of the process is basically adjusted to produce friable, hydrophobic, and energy-rich enhanced biomass fuel.

5. Torrefaction products

During torrefaction, three different products are produced: (1) brown to black uniform solid biomass, which is used for bioenergy applications, (2) condensable volatile organic compounds comprising water, acetic acid, aldehydes, alcohols, and ketones, and (3) non condensable gases like CO_2, CO, and small amounts of methane. Release of these condensable and non-condensable products results in changes in the physical, chemical, and storage properties of biomass.

Several studies have also investigated the physical properties and chemical composition of the liquids and gases released during torrefaction. An overview of the torrefaction products, based on their states at room temperature, which can be solid, liquid, or gas is shown *in Figure 2.* The solid phase consists of a chaotic structure of the original sugars and reaction products. The gas phase includes gases that are considered permanent gases, and light aromatic components such as benzene and toluene.

The condensables, or liquids, can be further divided into four subgroups: (1) reaction water produced from thermal decomposition, (2) freely bound water that has been released through evaporation, (3) organics (in liquid form), which consist of organics produced during devolatilization and carbonization, and (4) lipids, which contain compounds such as waxes and fatty acids.

Condensable and noncondensable products are emitted from the biomass based on heating rate, torrefaction temperature and time, and biomass composition. The emission profiles of these products greatly depend on the moisture content in the biomass.

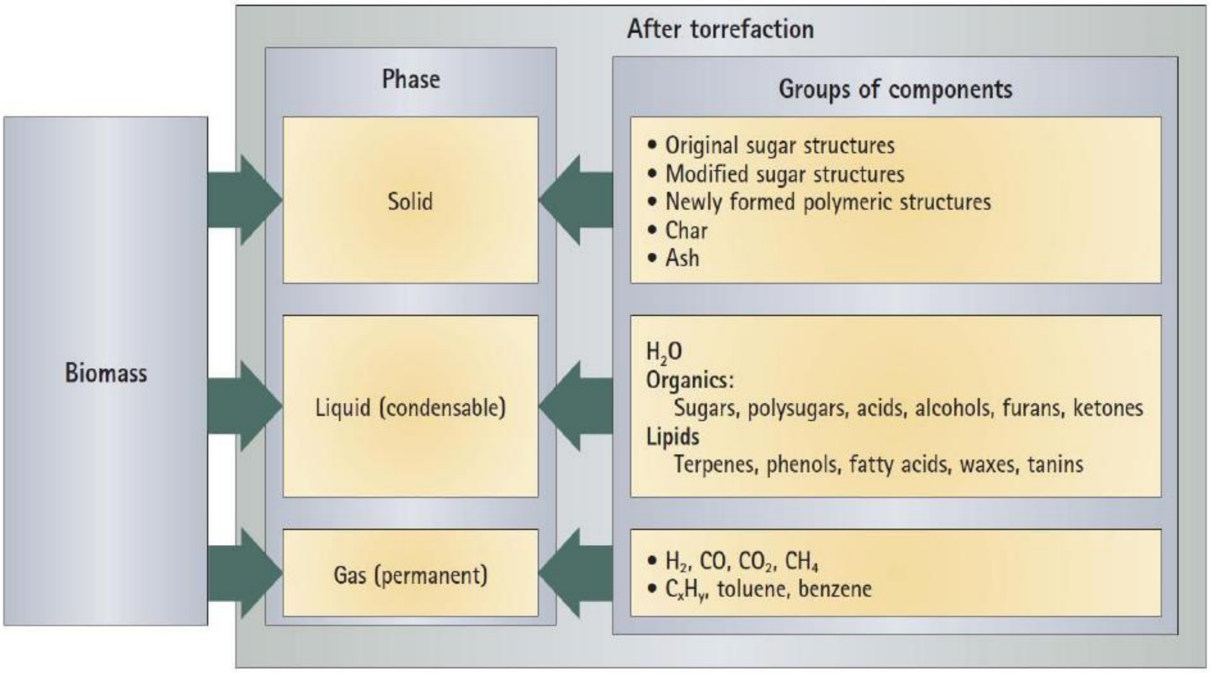

Figure 2. Products formed during torrefaction of biomass[1]

6. Solid torrefied biomass properties

Torrefaction of biomass significantly changes its physical and chemical properties like moisture content, density, grindability, pelletability, hydrophobicity, calorific value, proximate and ultimate composition, and storage behaviors in terms of off-gassing, spontaneous combustion and self-heating.

Moisture content: Normally, feedstock moisture content ranges from 10–50%, but because torrefaction is a deep drying process, moisture content is reduced to 1–3% on a weight basis, depending on the torrefaction conditions. Typically, torrefaction achieves an equilibrium moisture content of 3% and a reduction of mass by 20–30% (primarily by release of water, carbon oxides, and volatiles), while retaining 80–90% of the wood's original energy content. Reduction in moisture during torrefaction provides three main benefits: (1) reduced moisture level for the conversion process, (2) reduced transportation costs associated with moving useless water, and (3) the prevention of biomass decomposition and moisture absorption during storage.[2]

Bulk and energy density: Mass loss in the form of solids, liquids, and gases during torrefaction cause the biomass to become more porous. This results in significantly reduced volumetric density, typically between 180 and 300 kg/m^3, depending on initial biomass density and torrefaction conditions.

Grindability: Biomass is highly fibrous and tenacious in nature; fibers form links between particles and make handling the raw ground samples difficult. During torrefaction, the biomass loses its tenacious nature, which is mainly associated with the breakdown of the hemicellulose matrix and depolymerization of the cellulose, resulting in decreased fiber length. Particle length is also decreased, but not the diameter, resulting in better grindability and handling characteristics.

Calorific Value: Biomass loses relatively more oxygen and hydrogen than carbon during torrefaction, which increases the calorific value of the product. The net Calorific Value of torrefied biomass is 18–23 MJ/kg (lower heating value [LHV], dry) or 20–24 MJ/kg (higher heating value [HHV], dry). The mass and energy in the torrefied biomass is preserved in the solid product for a long time, as the material does not degrade with time. The highest heating value of 22.75 MJ/kg was achievable at torrefaction conditions of 315°C and 3 h[1][2][4].

Mass Density of the torrefied pellets is in the range of 800 to 1000 kg/m^3 mass density of torrefied wood is in the realm of 200 to 250 kg/m^3 [2]

Conclusions

Interest in research on torrefaction of biomass materials is growing. Its potential to improve the quality of both herbaceous and woody materials provides a path for using these resources in many energy applications.

- Torrefied biomass, in general, defines a group of products resulting from the partially controlled and isothermal pyrolysis of biomass occurring at the 200–300°C temperature range.

- The most common torrefaction reactions include (a) devolatilization and carbonization of hemicelluloses, and (b) depolymerization and devolatilization of lignin and cellulose.
- Typically – 10% of the original energy contained in the biomass is driven off in the torgas.
- Torrefaction of the biomass helps in developing a uniform feedstock with minimum variability in moisture content.
- Torrefaction of biomass improves (a) energy density, grindability, and pelletability index ratings, (b) ultimate and proximate composition by increasing the carbon content and Calorific Value and decreasing the moisture and oxygen content, and (c) biochemical composition by decomposing the hemicelluloses and softening the lignin, which results in better binding during pelletization
- During torrefaction the biomass loses most of the low energy content of the material, like (a) solids, which include original sugar structures and other newly formed polymeric structures, and (b) liquids, which include condensables, like water, organics, and lipids, and (c) gases, which include H_2, CO, CO_2 and CH_4, C_xH_y, toluene, and benzene.
- Torrefaction preserves the biomass for a long time without biological degradation due to the chemical rearrangement reactions and formation of nonpolar unsaturated structures.

Bibliography:

1. Jaya Shankar Tumuluru, Shahab Sokhansanj, J. Richard Hess, Christopher T. Wright, and Richard D. Boardman. *A review on biomass torrefaction process and product properties for energy applications.*
2. *Torrefaction – A New Process In Biomass and Biofuels.*
3. Grigore MARIAN, Andrei GUDIMA, Andrei PAVLENCO, Vladimir GOROBEȚ. *TOREFIEREA – O NOUĂ DIRECȚIE DE SPORIRE A CALITĂȚII PELEȚILOR DE FOC PRODUȘI DIN BIOMASĂ AUTOHTONĂ.*
4. Tatiana B. GRÎU. *EVALUAREA ȘI MĂRIREA PUTERII CALORICE A BIOMASELOR LEMNOASE.*