



BIOMASS PROCESSING FOCUSING ON SUGAR CANE BAGASSE¹

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Abstract

Biomass, as a renewable energy source, is one of the world's main research and discussion topics. This is mainly for burning bio-fuels do not generate green-house gases and biomass source is not finite. At IPT, there is a research project concerning entrained flow gasification of sugar cane bagasse, which it is this work motivation. The chosen gasification technology works with liquid or sub-millimeter solid particles, and for the last the bagasse needs to be milled. Milling of *in-natura* bagasse is not economically and technically advantageous, because it consumes high amounts of energy and generates needle-like particles instead of round shape, needed for a stable gasifier operation. Torrefaction is a thermal treatment, run at temperatures below 573K and in free-O₂ atmosphere that changes biomass structure and properties making its use more viable. The focus is on grindability enhancement, due to cellulosic structure breakage. This work presents a bibliographic review on torrefaction, containing the chemistry of torrefaction, mass and energy balance and recent technology developments.

Key words: Biomass; Sugar cane bagasse; Torrefaction.

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1 INTRODUCTION

Biomass, as a renewable energy source, is one of the world's main research and discussion topics. This is mainly because burning bio-fuels do not generate greenhouse gases and biomass source is not finite.

IPT (Institute for Technological Research) is coordinating a 5-year project to build a 500kg/h biomass gasification pilot plant in Piracicaba: the Biosyngas Project.

Gasification is a controlled sub-stoichiometric fuel burn. The generated gas is constituted mainly of CO, CO₂, H₂ and H₂O, and is processed to give high CO and H₂ contents – called syngas.

Four industrial partners (Oxiteno, Vale, Petrobrás and Raízen) are interested in developing - outside the project and using the produced syngas - the technologies for biofuels, biochemicals and electrical energy.

Sugar cane bagasse will be used in trials due to its availability and future potential. Currently, the bagasse is used in boilers to produce energy and heat, usually with its ~50% moisture content (MC). Sugar cane production in 2010 was 650 Mt which generated ~140Mt of wet bagasse and straw.⁽¹⁾

Figure 1 shows the cane production in Brazil between 1990 and 2010 and its forecast to 2030. Production from 1990 to 2010 (Figure 1b) had an average annual increase of 5%. So this was the used annual increasing rate for forecasts until 2030 (Figure 1a). The projection is that this gasification technology will be available in the 2020's, to be used by the new installed sugar/alcohol mills. According to the forecast, in the 2020's, cane production will increase by 550Mt. The typical size of a greenfield sugar cane mill is ~4 Mt/yr of cane, which results in 140 new mills by then. Each of these new mills will generate ~800kt/yr of bagasse and straw (dry basis), and supposedly half of it (400 kt/yr) would be available for gasification.

Therefore, the aim of Biosyngas is to evaluate technical and economical data to assist decisions for a future 400 kt/yr industrial plant.

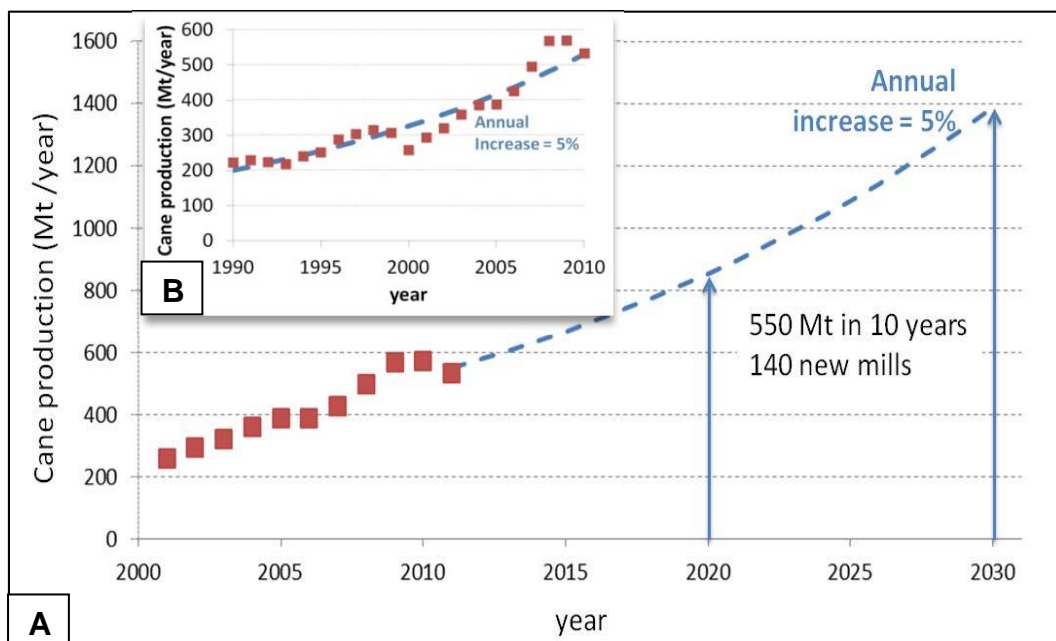


Figure 1. A - Brazilian cane production from 2000 to 2010 . Forecast up to 2030 considering the same increasing rate observed from historical data from 1990 to 2010, showed in B.⁽¹⁾



The chosen gasification technology is of the entrained-flow type, which works by fuel injection in a burner and, hence, only liquid or sub-millimeter solid fuels can be treated. The entrained-flow gasification reactor is shown in Figure 2, along with the process flowsheet from wet bagasse to syngas.

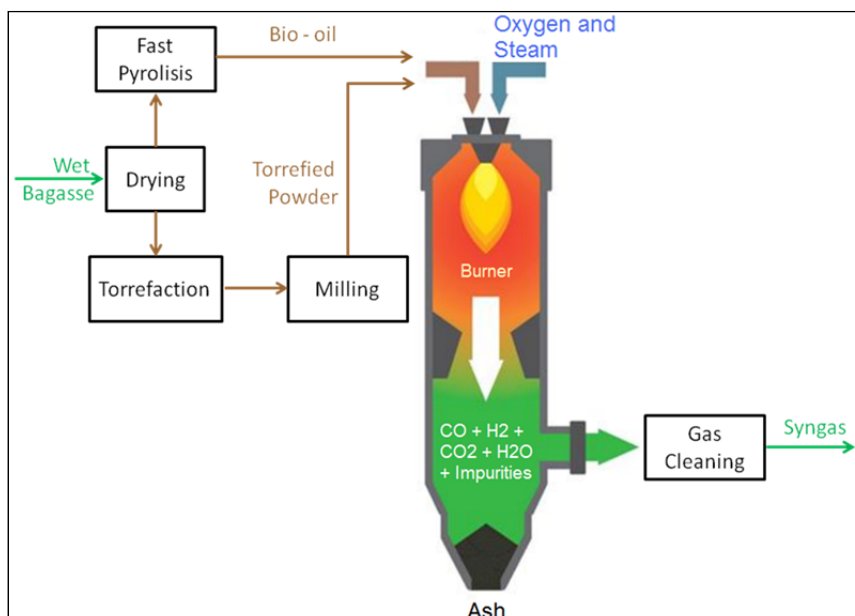


Figure 2. Wet bagasse to Syngas process flowsheet showing pre-treatment steps, entrained-flow gasification reactor and gas post-treatment.

Bagasse needs to be pre-treated before its injection in an entrained-flow gasifier. Fast pyrolysis was chosen to transform biomass into liquid fuel. To obtain a fine powder, a milling step is required. However, *in-natura* biomass milling is not economically and technically advantageous, because it consumes high amounts of energy and generates needle-like particles instead of round-shaped ones, needed for a stable gasifier operation.⁽²⁾

Torrefaction is a possible solution for poor grindability biomass behavior, because it causes cellulosic structure breakage, lowering biomass milling energy consumption.⁽²⁾

This work aims to present a literature review on torrefaction fundamentals, a market research on available technology developments on torrefaction.

2 LITERATURE REVIEW

Torrefaction is a thermal treatment run at temperatures between 200°C and 300°C in a free O₂ atmosphere, giving a torrefied product and low energy content volatiles.

As a result of torrefaction, some biomass properties are changed: i) torrefied product is hydrophobic allowing outside storage, ii) calorific value is enhanced, and iii) grindability is improved.⁽²⁾

2.1 Chemistry of Torrefaction

Biomass is composed by three main constituents: cellulose, hemicellulose and lignin, which determine its behavior under thermal treatment. Figure 3 depicts this behavior correlating temperature and weight loss. Torrefaction temperature range is marked by the green lines.



In the torrefaction region, hemicellulose (Xylan) is the most affected constituent, followed by lignin. Cellulose weight loss is low and corresponds just to its depolymerization.^(2,3) As biomass fiber structure is a sequence of lengthy cellulose molecules, this depolymerization phenomenon is the cause for biomass milling enhancement. After depolymerization the large molecules are transformed in smaller ones causing particle embrittlement, making its milling easier.

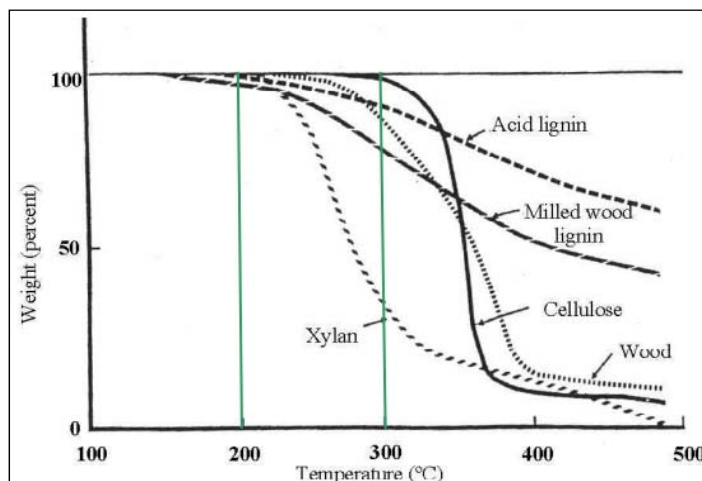


Figure 3. Behavior of wood and its constituents under thermal treatment. Torrefaction temperature range is marked by the green lines.⁽²⁾

Biomass pyrolysis products can be divided into three groups: solid, condensable gases and permanent or non-condensable gases.

Condensable gases are gas form at working temperature but they are liquids at room temperatures. Permanent gases are in gas form, both at working and room temperatures.

Figures 4 and 5⁽⁴⁾ show the products of dried biomass (Willow) torrefaction at 280°C, with their mass and energy contents relative to the initial dried biomass. *Organics*, *Lipids* and *Reaction Water* correspond to the condensable gases. This water is a result of biomass decomposition reaction, not of moisture.

It's possible to see that the solid product is energetically denser than the biomass, because it contains 87.5% of initial mass, but 94.9% of initial energy, resulting in $94.9/87.5 = 1.08$ energy densification. This densification occurs due to low energy content in gaseous products that are mainly *Reaction Water*.

It's worth noting that pyrolysis products vary accordingly to treated biomass.

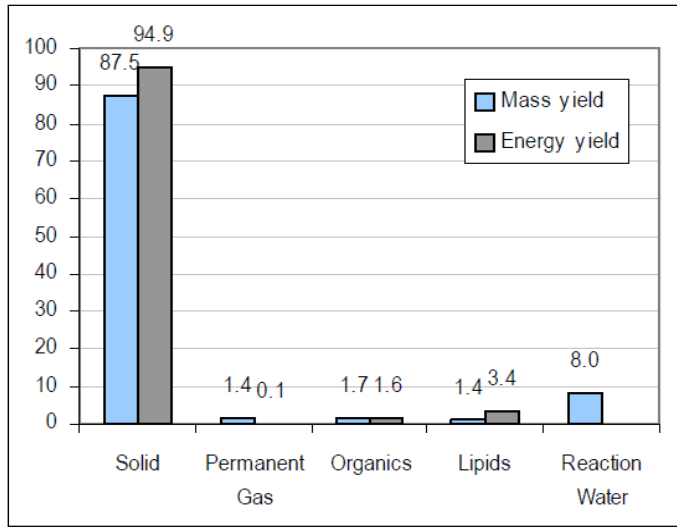


Figure 4. Products of biomass pyrolysis.⁽⁴⁾

Permanent Gas and Organics compositions can be seen in Figure 5. Permanent Gas is mainly CO and CO₂, while Organics are composed by several organic compounds like acetic acid and methanol.

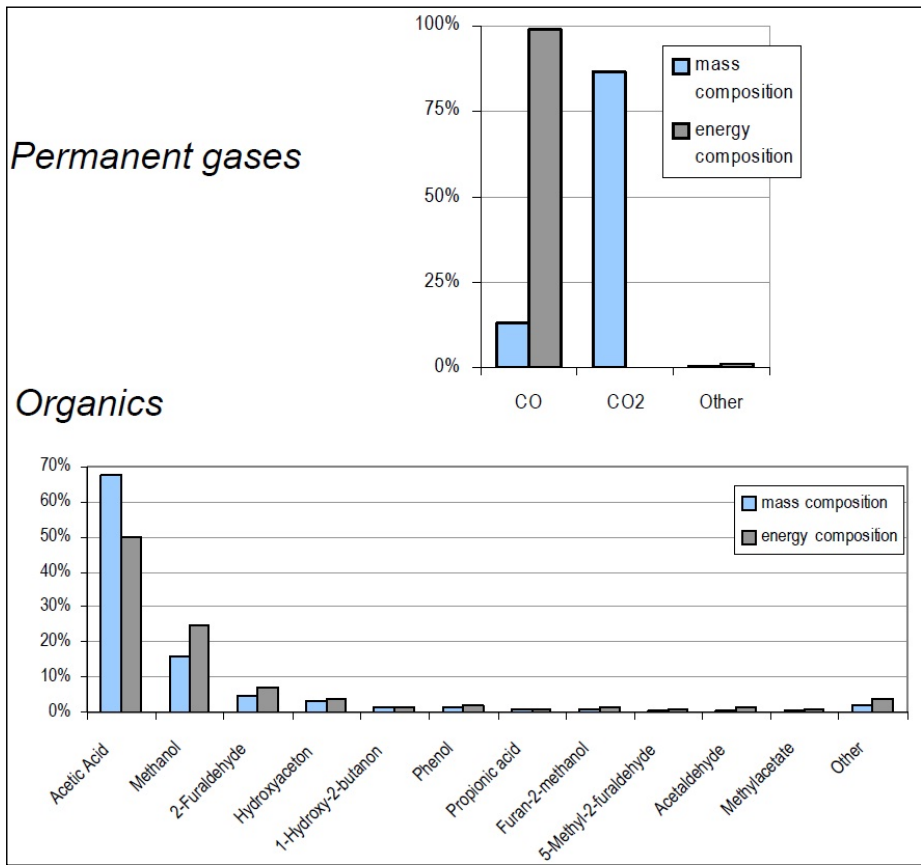


Figure 5. Compositions of Permanent Gas and Organic fractions of products of biomass pyrolysis.⁽⁴⁾



2.2 Mass and Energy Balance

Figure 6⁽⁵⁾ shows mass and energy balance for dried wood (Willow) torrefaction in two different conditions of time and temperature, one at 250°C during 30 minutes and another at 300°C during 10 minutes. Most of the presented data was experimentally measured, including: initial wood and torrefied wood calorific value; every mass and volatiles compositions. Volatiles sensitive and latent heat and solids sensitive heat were all calculated. No thermal losses were considered.

The required process heat was determined by the difference between input and output heat contents. Its error is much higher than its value (4 to 5 times) due to the error associated with low heating value determination for wood and torrefied wood.⁽⁵⁾

A higher temperature caused a lower solid yield and consequently a higher gas yield, as expected, according to Figure 3. The same is observed for energy yield. Nevertheless, low heating value (MJ/kg) for torrefied wood is higher for 300°C than for 250°C and both are higher than wood, showing energy densification.

Required process heat is lower for 250°C, 87kJ, than for 300°C, 124kJ. It's possible to see that volatiles heating content is higher than the required process heat in both conditions. This is a key point for torrefaction feasibility, because it enables a process with little surplus of energy. Its main energy source would consist of burning the volatiles and using their latent and sensitive heat content. And this is more important for higher temperatures since, at 300°C, volatiles heating content was ~30x higher than the process heat and, at 250°C, ~ 7x.

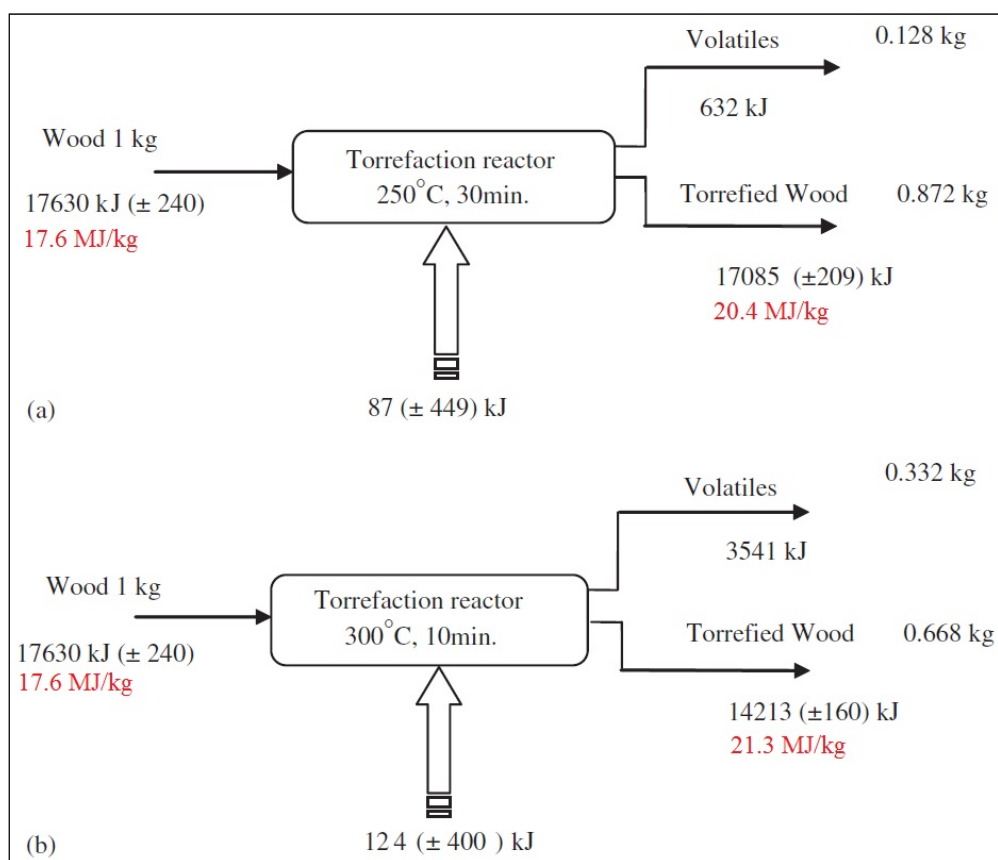


Figure 6. Mass and energy balance of wood torrefaction in two different conditions. (a) 523 K, 30 minutes and (b) 573 K, 10 minutes.⁽⁵⁾



2.3 Grindability x Torrefaction

Bergman et al.⁽²⁾ performed milling tests on different types of wood, *in-natura*, dried and torrefied. The results can be seen in Figure 7 and are presented in kWe (electrical kilo watt) used in milling per MWth (thermal megawatt) which represents the energy content of the milled biomass.

It's possible to distinguish three separate regions. First one, for untreated biomass, where higher values for milling energy were obtained. Second one, for dried and torrefied biomass at 230°C, where intermediate values appear. Third one, for torrefied biomass at temperatures above 250°C, where lower values are presented. There was no difference in the milling behavior among samples treated at 250°C, 260°C and 270°C. This means that the optimal treatment temperature is around 250°C and no improvement is reached above this point. On the other hand, with lower torrefaction temperatures higher milling energy are necessary.

For entrained-flow gasification particle size should be ~100 µm, which means 15 kWe/MWth for torrefied biomass above 250°C and 30 kWe/MWth for torrefied biomass below 230°C. Assuming torrefied biomass low heating value to be 20.4 MJ/kg (5.7×10^{-3} MWh/kg), the energy consumption is 307 to 614 kJ/kg of torrefied biomass. Comparing to coal milling, which consumes ~ 50kJ/kg,⁽⁶⁾ the values are 6 to 11 times higher.

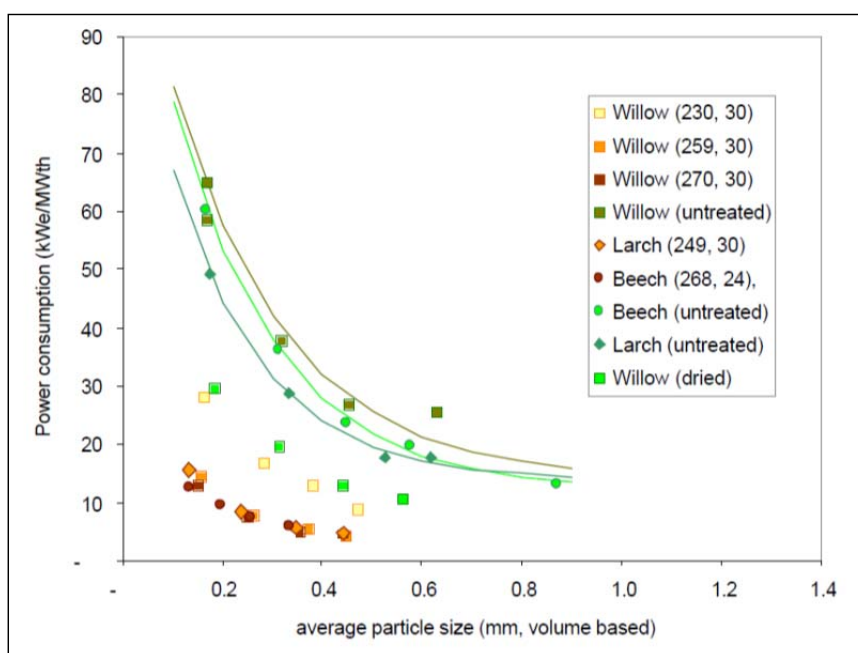


Figure 7. Power consumption for biomass milling in different conditions.⁽²⁾

The torrefied bagasse behavior under milling is still not known and no data were found in literature. Tests are being performed and will be published in the future.

3 RECENT TECHNOLOGY DEVELOPMENTS

Many companies have been trying to develop and construct pilot and industrial plants for biomass torrefaction. Table 1 gives a summary on developed technologies and companies involved with torrefaction.



Table 1. Biomass torrefaction equipment developments with its technologies and companies involved⁽⁷⁾

Reactor Technologies	Torrefaction Supplier
Rotary drum reactor	CDS (UK), Torr-Coal (NL), BIO3D (FR), EBES AG (AT), BioEndev (SWE), Atmosclear S.A. (CH)
Screw conveyor reactor	BTG (NL), Biolake (NL), FoxCoal (NL), Agri-Tech producers (US)
Multiple Hearth Furnace / TurboDryer®	CMI-Nesa (BE), Wyssmont (US)
Torbed Reactor – fluidized bed	Topell (NL)
Microwave reactor	Rotawave (UK)
Compact moving bed	ECN (NL), Thermya (FR), Buhler (US)
(Oscillating) Belt conveyor – fluidized bed	Stramproy Green Investment (NL), New Eath Eco Technology (US)

Most of the technologies for torrefaction have been applied successfully in other applications such as drying, pyrolysis and combustion.

All the companies listed in Table 1 were contacted and the information presented below is resulted of this.

The rotary drum reactor is used in two different ways according to heat transfer method that can be direct and indirect. In the direct type, hot gases are put directly in contact with biomass, so heating transfer is enhanced. In the indirect type, the drum is heated, so biomass heating depends on biomass contact with drum internal wall and radiation. Therefore, heating transfer is worse but atmosphere and temperature control are better. The same happens for screw conveyor, the only difference is that biomass is now transported due to screw movement inside a tube.

Agri-Tech's process accepts biomass with moisture content up to 40% with no need of additional fuel. This is because torrefaction gases, generated from biomass decomposition, are collected and burned, supplying all needed energy. Heat is indirectly transferred to biomass. The company has a demonstration plant to produce 150 kg/hr of torrefied biomass. Biolake's process treats materials with moisture up to 15% and is composed by three consecutive screw reactors, separating moisture removal in the first one, reaction water removal in the second one and torrefaction in the third one. Torrefaction gases are burned and supply heat for the three reactors, with no need of surplus of energy. The company owns a 1ton/hr demonstration plant. Torr-coal has a demo plant to produce 3 ton/hr of torrefied product, and no further information was given.

The multiple hearth furnace and Turbodyrer® are a rotating tray reactor, where hot gases are circulated inside of this reactor having direct contact with biomass. Usually, material is fed onto the top tray and rotates around until it is wiped down through the slots to the next tray where the process is repeated, until discharge on reactor's bottom. Wyssmont operated a demo plant with its Turbodyrer® reactor, but it is not running anymore. No reasons for this were informed. A schematic representation of this reactor can be seen in Figure 8 – A. Torrefaction gases are burned and it is possible to operate without additional fuel with biomass with moist up to 15%.

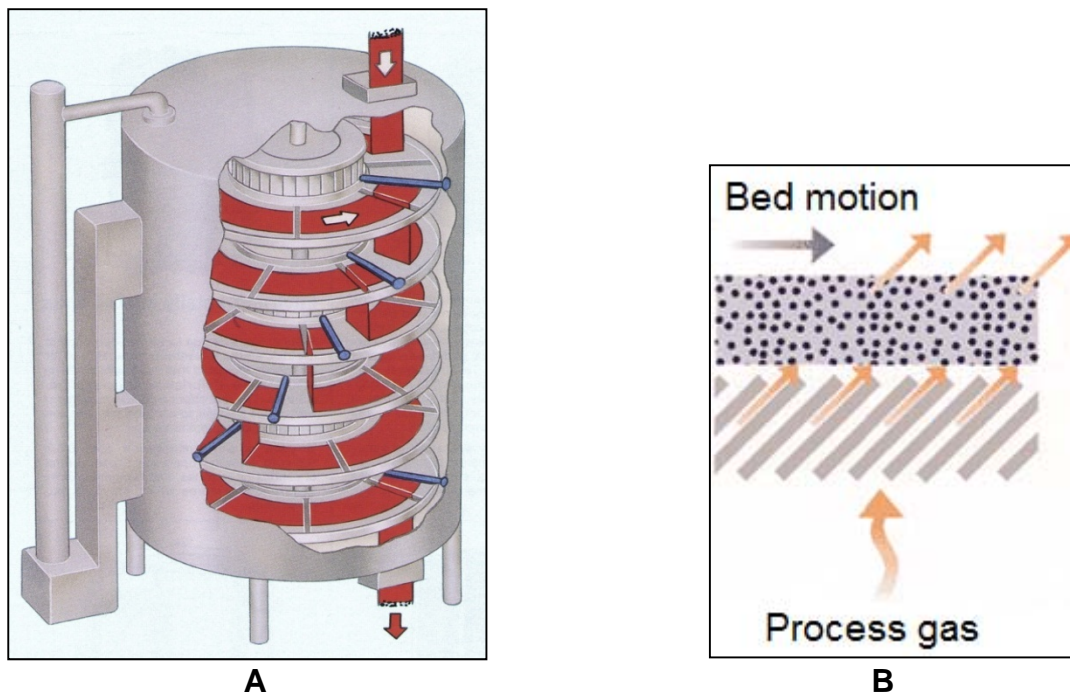


Figure 8. A – Turbodyrer® reactor showing charge path way during torrefaction. B – Torbed's fluidized bed showing diagonal gas flow.

The Torbed® Reactor was developed for processes that solid-gas interaction occurs and is used for many applications. It is based on a fluidized bed that moves circularly around the reactor's center axis, causing a toroidal bed motion. This motion is caused by metal plates that direct gas flow in diagonal direction, as shown in Figure 8b. Because of this motion, torrefaction time is very short, less than two minutes. Topell is commissioning a plant for 10 ton/hr of torrefied product where one Torbed® reactor is used for drying and another for torrefaction. Torrefaction gases are burned and supply needed heat.

The use of microwave energy is the key factor of Rotawave process. Flue gas from torrefaction gases burn is also used to heat up the charge. According to the company, the use of microwave energy maximizes gas yields and minimizes liquids as result of pyrolysis.

The compacting moving bed is a shaft reactor where biomass has a downward movement, due to gravity forces. Heating is made through a gas flow up or downward having direct contact with biomass. In the case of upward flow, produced torrefaction gases leave the reactor in the cold zone and some of condensable gases and steam condensates generating a liquid product that is acid and must be treated before discard. As some of torrefaction gases are condensed, additional fuel is needed to run the process.

The belt conveyor reactor is also based in fluidized bed, but in this case it's smother than in the Torbed® case. The fluidized bed is transported on top of a vibrating plate, making the bed moves from reactor inlet to outlet. The heating is direct, as the fluidizing agent is a hot gas that flows upwards through the biomass. Stramproy Green has a plant for 5 ton/hr of torrefied product. Torrefaction gases are burning and no surplus of energy is necessary.

Due to the number of different technologies and size of installed plants it's possible to conclude that these processes are still under development. So any attempt to use torrefaction in large scales (higher than 1 ton/hr) will require further improvements.



None of the contacted companies have experience treating bagasse in larger scales than few kilograms.

The most used biomass in the cited developments is wood chips which have different properties from bagasse's. Particle size distribution is the main concern as bagasse is composed by fine particles (< 1mm) and fibers some centimeters which make difficult to have a uniform heating, mainly in direct heating processes. This results in non-uniform torrefied material, as fine particles will reach higher temperatures. And for this, oxygen concentration inside reactor must be better controlled. Another issue is the fluidization behavior, as air velocity for fluidize the fibers will drag away fine particles.

4 POSSIBLE USES FOR TORREFIED BIOMASS

The most cited end use for torrefied biomass is energy generation, especially as a substitute for coal in power plants and gasification units. This is because torrefied biomass properties are similar to coal ones which makes possible a combined use in the existent installations, saving new investments costs.^(5,7)

Another possibility is the injection of milled torrefied biomass in blast furnace tuyere, as it's already done with coal and charcoal fines. As result of this, the CO₂ emission regarding ironmaking process would be decreased. Another improvement is related to the higher hydrogen content in torrefied biomass compared to coal or charcoal. The chemical equilibrium between FeO/H₂ is more dislocated to the Fe side than the FeO/CO one, which means that the productivity (ton of pig iron/ furnace m³) is expected to increase. An accurate technical and economic analysis must be done to confirm this possibility, as biomass logistics, torrefaction and grinding costs may be prohibitive.

5 CONCLUSIONS

- Torrefaction is a thermal treatment run at temperatures between 200°C and 300°C in a free O₂ atmosphere changing biomass properties.
- Torrefaction is capable of lowering biomass milling energy consumption as it breaks biomass cellulosic structure.
- There is an optimum point for torrefaction temperature and milling energy consumption of biomass.
- Available torrefaction technologies in the market are still under development and none of contacted companies has experience with bagasse.

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