

## Torrefied Biomass a Substitute for Wood and Charcoal

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### ABSTRACT

This paper presents a work on biomass torrefaction performed in a laboratory unit with a reactor tube of a length of 0.5 m and an inner diameter of 0.04 m). The experiments are conducted with two species of wood, birch and pine, and sugar cane bagasse. The reactor was heated to the selected temperature (230°C, 250°C or 280°C) and kept at the final temperature for a period of 1, 2 or 3 hours. The effect of the raw material, temperature, residence time and nitrogen flow on the properties of the torrefied products is studied. The torrefied biomass products are characterized with elemental composition, energy content, moisture content, ash content, volatile fraction. The gaseous products are also analysed. The type of biomass influenced the product distribution. During torrefaction biomass undergoes changes in physical and chemical properties. The fixed carbon content and energy density increase with both time and temperature of torrefaction, while the yield on a weight basis decreases. The torrefied biomass has hydrophobic properties and a higher calorific value than the raw material.

**Keywords:** Torrefaction, Biomass, Wood, Bagasse, Mild Pyrolysis.

### 1.0 INTRODUCTION

Torrefaction is a feasible method for improvement the properties of biomass as a fuel. It consists of a slow heating of biomass in an inert atmosphere to a maximum temperature of 300 °C [1]. The treatment yields a solid uniform product with a lower moisture content and a higher energy content compared to those in the initial biomass.

The process may be called mild pyrolysis, with removal of smoke producing compounds and formation of solid product, retaining approximately 70% of the initial weight and 80-90% of the original energy content [2].

Torrefied products can substitute charcoal in a number of applications such as fuel for domestic cooking stoves, residential heating, manufacture of improved solid fuel products such as fuel pellets, compacted fireplace logs and barbecue briquettes for commercial and domestic uses [3,4,5]. Torrefied biomass can be also used as fuel for industrial applications. With a 30-35% fixed carbon content, torrefied wood has a promising potential as a reducer. [4]. Torrefied biomass can be blended with coal and co-fired in a Pulverized Coal Boiler (PBC). Important advantage of torrefied wood compared to untreated wood is its uniformity. Due to the low moisture content of torrefied wood the transport cost is lower and the quality as a fuel better. It is easily packaged and transported, and thus constitutes an efficient fuel. The properties of torrefied biomass should lead to an improved operation in gasifiers for which the stability of the process is important [3].

### 2.0 EXPERIMENTAL

In each experiment 65 g of the biomass sample were subject to torrefaction at atmospheric pressure. A nitrogen flow was used to keep the reaction in absence of oxygen. The nitrogen flow was 5 litre/hour. Some experiments were also performed with a nitrogen flow of 10 litre/hour. The reactor was heated 230°C, 250°C and 280°C) and was kept at the selected final temperature during different periods of time (1, 2 or 3 hours) and then the electrical heaters were switched off. After the treatment the samples are left to cool down. Before each experiment 12 litres of nitrogen was led through the system to remove the air.

The collected torrefied solid product was weighed and characterized. The influence of the experimental conditions (temperature, residence time and inert gas flow) on the product distribution and on the properties of the products was studied.

## 2.1 Biomass

Two wood species, birch and pine, and sugar cane bagasse were selected as a raw materials. Sugar cane bagasse is the waste material obtained in sugar factories after extraction of the sugar juice. The wood samples were milled, sieved and separated in fractions. A fraction of particles with diameter 1-3.2 mm was used in the experiments with pine and 1.0-1.35 mm for birch. Bagasse was not sieved or separated in fractions. The ash and moisture contents of the raw materials are shown in Table 1.

Table 1. Raw materials

Biomass	Ash	Moisture
	wt% mf	wt%
Birch	0.50	5.4
Pine	0.14	5.1
Bagasse	2.24	4.4

mf: moisture free

## 2.2 Equipment

The equipment used in the experiments, shown in Fig. 1, included a cylindrical reactor equipment with a device for removal of the liquid products and measurement of the gaseous products. The reactor tube is heated by electric heaters. The reactor consists of two cylinders. The sample is placed in the removable inner cylinder with a net in the bottom. The outer cylinder is cone shaped at the bottom and connected to a metal tube with a screw, that makes it easier to open and clean. The volatiles are cooled in a water-cooled condenser, where the tar and the water phase is condensed. The gas is led through a cotton filter and a gasmeter and then collected in a bag. The gas composition is analyzed by a gas chromatograph for CO<sub>2</sub>, CO, N<sub>2</sub>, CH<sub>4</sub>, and C<sub>2</sub>-hydrocarbons (ethane, ethene and acetylene).



Figure 1. Equipment

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Distribution of torrefaction products

Table 2 shows the yield of products obtained in the performed experiments as well as the ash and the moisture contents of the torrefied solid product.

Table 2. Distribution of torrefaction products

Biomass	Treatment Conditions			Yield of Products			Ash wt% mf	Moisture wt%
	T °C	time hour	N <sub>2</sub> Flow l/h	Solid yield wt%maf	Liquid yield wt%maf	Gas yield wt%maf		
Birch	230	2	5	86.9	11.5	1.6	0.60	1.7
Birch	250	1	5	85.5	12.8	1.7	0.64	1.6
Birch	250	2	5	85.0	12.9	2.1	0.65	1.6
Birch	250	3	5	82.1	13.9	4.0	0.67	1.3
Birch	280	2	5	68.9	26.3	4.8	0.75	1.3
Pine	230	1	5	92.4	7.0	0.6	0.15	2.1
Pine	230	2	5	90.4	8.9	0.7	0.16	2.0
Pine	230	3	5	86.7	11.7	1.6	0.16	1.6
Pine	250	1	5	88.2	10.8	1.0	0.16	1.9
Pine	250	2	5	85.4	13.1	1.5	0.16	1.8
Pine	250	3	5	83.3	14.4	2.3	0.17	1.6
Pine	280	1	5	78.1	19.8	2.1	0.18	0.8
Pine	280	2	5	72.1	23.2	4.7	0.20	0.6
Pine	280	3	5	69.0	25.7	5.3	0.21	0.5
Bagasse	230	1	5	87.5	9.9	2.6	2.41	2.5
Bagasse	230	2	5	85.0	10.0	5.0	2.66	2.2
Bagasse	230	3	5	83.7	10.3	6.0	2.46	2.0
Bagasse	250	1	5	78.9	10.7	10.4	2.84	1.9
Bagasse	250	2	5	77.5	10.9	11.6	2.89	1.7
Bagasse	250	3	5	75.4	12.6	12.0	2.97	1.6
Bagasse	280	1	5	68.6	18.5	12.9	3.27	1.8
Bagasse	280	2	5	64.7	20.5	14.8	3.46	1.7
Bagasse	280	3	5	63.8	21.0	15.2	3.51	1.0
Pine	230	1	10	92.1	7.3	0.6	0.15	1.7
Pine	230	2	10	90.3	9.0	0.7	0.15	1.5
Pine	230	3	10	89.2	9.4	1.4	0.16	1.4
Pine	250	1	10	87.1	11.2	1.7	0.16	1.2
Pine	250	2	10	85.3	13.0	1.7	0.16	0.9
Pine	250	3	10	83.5	14.4	2.1	0.17	0.9
Pine	280	1	10	77.3	19.6	3.1	0.18	0.8
Pine	280	2	10	70.4	23.3	6.3	0.20	0.6
Pine	280	3	10	67.1	26.0	6.9	0.21	0.5

T: temperature, time: residence time: duration of the treatment at the final temperature  
maf: moisture and ash free, mf: moisture free

The type of biomass influenced the product distribution. The samples of wood (birch and pine) gave more solid products and less tar, water and gas than the studied agricultural residue (bagasse).

As expected, when the temperature increases from 230°C to 280°C, the yield of the solid torrefied product decreases while the yield of gas, tar and water increases. The effect of the temperature on the distribution of the products is more pronounced between 250°C and 280°C than between 230°C and 250°C. An increase of the duration of the heating at the final temperature from 1h to 3h results also in a decrease of the yield of torrefied biomass and in an increase of the volatiles. Furthermore, the results show that there is not strong influence of the role of the inert gas flow in the selected experimental conditions (experiments with pine changing the nitrogen gas flow from 5 to 10 l/h).

The torrefaction process aims at a hydrophobic product, which prevents it from regaining humidity from the air during storage. Table 2 shows the amount of moisture in the torrefied samples of wood and agriculture residue after a period of time of 30 – 45 days in storage. The result shows that the product, after a period of 30-45 days, has absorbed small amounts of moisture, however the moisture content is much less compared to the content of moisture of the raw material (approx. 5%).

### 3.2 Chemical composition of the solid products

The elemental analysis of the raw material and the torrefied products (table 3) shows that the content of carbon increases at higher temperature of the torrefaction while the contents of hydrogen and oxygen decrease. Losses in hydrogen and oxygen are due to the formation of water and carbon monoxide and dioxide during the torrefaction. Lower carbon content in the torrefied product is obtained in the experiments with bagasse in comparison with the experiments with pine and birch.

Table 3. Properties of the torrefied biomass

biomass <sup>a</sup>	T	time	C	N	H	O	CV	$\frac{CV_p}{CV_b}$ <sup>c</sup>	Energy recovery	H/C	O/C
	°C	hour	wt% maf <sup>d</sup>	wt% maf <sup>d</sup>	wt% maf <sup>d</sup>	wt% maf <sup>d</sup>	MJ/kg		% <sup>e</sup>	atomic Ratio <sup>f</sup>	atomic Ratio <sup>g</sup>
Birch, raw			45.5	0.1	6.2	48.2	16.44			1.64	0.79
Birch	230	2	50.8	0.16	6.0	43	18.79	1.14	99.34	1.42	0.63
Birch	250	1	51.5	0.15	5.8	42.5	18.83	1.15	97.94	1.35	0.62
Birch	250	2	51.6	0.17	5.9	42.2	19.19	1.17	99.24	1.40	0.61
Birch	250	3	52.6	0.16	6.2	41	20.00	1.22	99.91	1.41	0.58
Birch	280	2	56.6	0.17	5.6	37.6	21.07	1.28	88.31	1.19	0.50
Pine, raw			46.6	0.06	6.4	46.9	17.30			1.65	0.75
Pine	230	1	49.7	0.06	5.9	44.3	18.07	1.04	96.51	1.42	0.67
Pine	230	2	50.0	0.05	5.9	44	18.22	1.05	95.21	1.42	0.66
Pine	230	3	51.5	0.05	6.2	42.2	19.44	1.12	97.41	1.44	0.61
Pine	250	1	50.9	0.06	5.8	43.2	18.51	1.07	94.39	1.37	0.64
Pine	250	2	51.8	0.07	5.8	42.3	18.96	1.10	93.61	1.34	0.61
Pine	250	3	52.4	0.06	5.9	41.6	19.42	1.12	93.51	1.35	0.60
Pine	280	1	56.4	0.06	5.5	38	20.80	1.20	93.88	1.17	0.51
Pine	280	2	59.1	0.07	5.6	35.2	22.30	1.29	92.95	1.14	0.45
Pine	280	3	59.6	0.07	5.7	34.6	22.71	1.31	90.57	1.15	0.44
Bagasse, raw			44.8	0.25	5.8	49.10	15.50			1.55	0.82
Bagasse	230	1	48.6	0.25	5.6	45.50	17.08	1.10	96.47	1.38	0.70
Bagasse	230	2	48.8	0.26	5.6	45.30	17.18	1.11	94.26	1.38	0.70
Bagasse	230	3	49.2	0.28	5.7	44.90	17.49	1.13	94.47	1.39	0.69
Bagasse	250	1	50.6	0.30	5.6	43.50	18.08	1.06	92.04	1.33	0.64
Bagasse	250	2	50.6	0.30	5.6	43.50	18.08	1.05	90.45	1.33	0.64
Bagasse	250	3	51.5	0.32	5.7	42.50	18.69	1.07	90.94	1.33	0.62
Bagasse	280	1	52.8	0.39	5.3	41.50	18.73	1.04	82.93	1.20	0.59
Bagasse	280	2	54.7	0.41	5.4	39.50	19.84	1.10	82.83	1.18	0.54
Bagasse	280	3	55.4	0.44	5.5	38.70	20.34	1.09	83.76	1.19	0.52

<sup>a</sup>Biomass:gas flow used in those experiments 5 l/h, <sup>b</sup>O diff : oxygen is assessed by difference

<sup>c</sup> CV<sub>p</sub> : Calorific Value of torrefied solid product CV<sub>b</sub> : Calorific Value of initial biomass

<sup>d</sup>maf: moisture and ash free

<sup>e</sup>energy recovery = CV<sub>p</sub> \* solid yield / CV<sub>b</sub>

<sup>f</sup>ratio = number of H atoms/number of C atoms = (%H/1) / (%C/12) ,

<sup>g</sup>ratio = number of O atoms/number of C atoms = (%O/16) / (%C/12)

At higher temperature, the content of C in the solid product increases while the contents of H and O decrease. Thus, the calorific value (CV) of the solid product increases with the temperature. More significant effect on the CV is observed at temperatures above 250°C,. Also when the residence time was increased the CV was higher. The calorific values are calculated using the elemental composition of the samples [6]:

$$CV = 0.34\%C + 1.40\%H - 0.16\%O \quad (\text{MJ/kg})$$

The solid products obtained in the experiments with birch, pine and bagasse have similar degree of carbonization ( $CV_p/CV_b$ ). The degree of carbonization is assessed as a ratio between the calorific value of the torrefied biomass product and the calorific value of the raw material. The degree of carbonization increases with the temperature.

During torrefaction wood undergoes changes in the chemical composition. As it is shown in table 3, the carbon increases at the expense of oxygen and hydrogen thus leading to a decrease in both the H/C and O/C atomic ratios.

### 3.3 Composition of the gaseous products

Table 4 shows the composition of the gas obtained in the torrefaction.

Table 4. Composition of the gaseous products in torrefaction of biomass (nitrogen and waterfree basis)

Biomass	T °C	Time hour	N <sub>2</sub> Flow L/h	CH <sub>4</sub> vol %	C <sub>2</sub> vol %	CO <sub>2</sub> vol %	CO vol %
Birch	230	2	5	0.1	0.05	81.0	18.8
Birch	250	1	5	0.1	0.05	81.2	18.6
Birch	250	2	5	0.1	0.06	80.3	19.5
Birch	250	3	5	0.2	0.10	77.0	22.7
Birch	280	2	5	0.3	0.13	75.0	24.5
Pine	230	1	5	0.2	0.05	76.7	23.0
Pine	230	2	5	0.2	0.08	70.0	29.4
Pine	230	3	5	0.3	0.10	69.5	30.1
Pine	250	1	5	0.2	0.05	76.4	23.3
Pine	250	2	5	0.2	0.07	70.0	29.7
Pine	250	3	5	0.3	0.09	64.5	35.1
Pine	280	1	5	0.3	0.09	68.2	31.4
Pine	280	2	5	0.4	0.12	64.3	35.1
Pine	280	3	5	0.4	0.36	62.3	36.9
Bagasse	230	1	5	bdl	0.05	84.4	15.5
Bagasse	230	2	5	bdl	0.06	83.0	16.9
Bagasse	230	3	5	0.2	0.08	81.1	18.6
Bagasse	250	1	5	bdl	0.10	78.1	21.8
Bagasse	250	2	5	bdl	0.10	77.1	22.8
Bagasse	250	3	5	0.4	0.10	73.5	26.0
Bagasse	280	1	5	0.1	0.06	78.1	21.7
Bagasse	280	2	5	0.3	0.13	75.5	24.0
Bagasse	280	3	5	0.8	0.17	71.0	28.0
Pine	230	1	10	bdl	bdl	80.0	20.0
Pine	230	2	10	0.2	bdl	66.6	33.2
Pine	230	3	10	0.2	0.04	59.5	40.2
Pine	250	1	10	0.2	0.05	69.5	30.2
Pine	250	2	10	0.3	0.06	63.8	35.8
Pine	250	3	10	0.4	0.10	59.0	40.5
Pine	280	1	10	0.4	0.06	58.2	41.3
Pine	280	2	10	0.6	0.18	60.3	38.9
Pine	280	3	10	0.7	0.23	55.9	43.1

T: temperature, time: duration of the treatment at the final temperature

bdl: below detection level

A higher treatment temperature favoured the production of CO, methane and C<sub>2</sub> hydrocarbons while the CO<sub>2</sub> content in the gaseous mixture decreased (Table 4). The effect of the temperature on the composition of the gaseous products is more pronounced between 250°C and 280°C than between 230°C and 250°C.

Longer residence time produce the same effect on the composition of the gaseous product than a higher temperature treatment.

#### 4.0 CONCLUSIONS

The type of biomass influenced the product distribution. Samples of wood (birch and pine) gave more solid and less liquid and gaseous products than the studied agricultural residue (bagasse). The yield of solid product decreases while the yield of gas, tar and water increases with the temperature and the residence time. It was not found a strong influence of the inert gas flow on the product distribution at the selected conditions.

The content of carbon in the solid product increases at higher temperature of the torrefaction and longer residence time while the content of hydrogen and oxygen decrease, increasing the calorific value of the torrefied biomass.

The content of CH<sub>4</sub>, H<sub>2</sub>, C<sub>x</sub>H<sub>y</sub>, and CO in the product gases increases when the temperature is increased while the content of CO<sub>2</sub> decreases.

The torrefied samples absorb small amounts of moisture, however the moisture content is much less compared to the content of moisture in the raw material.

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