TECHNICAL PAPER

BIOMASS CONTAINING MATERIAL AS FEEDSTOCK FOR THE CARBONISATION PROCESS

An overview of different kind of feedstock, used by Perpetual Next Dilsen, in the carbonisation process on industrial and test scale

Jo Sluijsmans
Manager process and product development
Manager Quality, Environment, Safety and Health
Perpetual Next Dilsen

ABSTRACT

Different kind of biomass containing feedstocks have been tested by Perpetual Next Dilsen (located in Dilsen-Stokkem Belgium): mixed woodchips, acacia wood, eucalyptus wood, used untreated pine/spruce wood, treated used mixed wood, blends of Solid Recovered Fuel (SRF) and mixed woodchips. Also different kinds of herbaceous biomass have been tested on laboratory scale.

This technical paper describes which carbonisation tests have been carried out with these raw materials and which carbonised product has been realized under the stated conditions. Next to that it indicates which problems can be expected by using these different kind of feedstock for the carbonisation process.

The main conclusion is, that looking to availability and business economic reasons, shredded used treated wood (B-wood) and SRF or blends from both are the most promising feedstock for the carbonisation process in West-Europe. However, using these kind of feedstocks one must realize, that the ash, chlorine and sulphur content and presence of toxic heavy metals can give rise to problems at the carbonisation process and different kind of applications of the carbonised product at the customer.

CONTEXT OF THE PAPER

This technical paper is part of a number of articles that describe the use of low-value biomass, containing residual flows as a raw material for the carbonisation process, whereby the carbonised product (biocarbon) must replace fossil black and brown coal in various types of applications.

BIOMASS CONTAINING MATERIAL AS FEEDSTOCK FOR CARBONISATION

There are known several feedstocks, which can be used for carbonisation in an indirect heated rotary drum reactor.

However it has to be said, that a certain bulk density, particle size and embodiment of this feedstock is needed to get an optimal carbonisation result. Next to that, requirements are imposed on the carbonised product, depending on application of this carbonised product. Of course, this also determines which feedstock can be used for carbonisation process to get the optimal desired carbonised product for further application.

Feedstocks, which have been tested by Perpetual Next Dilsen are: mixed woodchips, acacia wood, eucalyptus wood, used untreated pine/spruce wood, treated used mixed wood, blends of Solid Recovered Fuel (SRF) and mixed woodchips.

Also different kinds of herbaceous biomass have been tested on laboratory scale. Table 1 shows an overview of all kinds of feedstock, which have been used and tested by Perpetual Next Dilsen (former TorrCoal Production Center).

Input > 98 % renewable			**Torr-Coal process**	
classification according ISO 17225-1: 2014			process max. torrefaction temp.	
1 Woody biomass 1.1 Forest, plantation and other virgin wood	fresh mixed woodchips West Europe		mild torrefaction	290 °C
			severe torrefaction	320 °C
				340 °C
			pyrolysis	400 °C
				450 °C
	eucalyptus woodchips Portugal		290 °C	
	shredded acacia wood South Africa		285 °C	
1 Woody biomass 1.3 used wood	shredded used untreated pine / spruce wood	A-wood	290 °C	
	shredded used treated mixed wood	B-wood	pilot scale different tests	
2 Herbaceous biomass	Bagasse; Banagrass; Miscanthus; Empty Fruit Bunches (EFB); HiCross; Palmoil Kernel Scales (PKS)		lab. scale different tests	

Input partly (> 50 %) renewable	**Torr-Coal process**
	process max. torrefaction temp.
blends of Solid Recovered Fuel (SRF: classification according NEN-EN 15359: 2011) and woody biomass (classification according ISO 17225-1: 2014)	340 °C - 360 °C pilot scale different tests

Table 1

The embodiment of fresh woody biomass will be mostly chips with a bulk density (dry) of about 0,20 ton/m³. Used wood (treated and untreated, a mixture of particleboard, multiplexing plates, osb-plate, painted wood, demolition wood, furniture wood, MDFs, hard and soft board plates, paper and cardboard) mostly have been shredded and shows a somewhat lower bulk density (about 0,18 ton/m³).

Herbaceous biomass shows different kind of embodiment like shells, leaves, straw, cut stems, etc. Mostly the bulk density of this kind of biomass is rather low (about 0,10 ton/m³ or even lower, shells excepted) and by that it is difficult to get sufficient mass amount per unit time in the Perpetual C-Vertr R1 carbon converter reactor (less product output per unit time). Also there is a large chance on bridging and clogging.

Solid Recovered Fuel (SRF) is a rest stream of diminished, dried and separated house hold waste and mainly consists of wood, plastics, paper, leather, cotton/linen and fruit/vegetable. SRF is available in three different embodiments: fluff, soft pellets and hard pellets.

SRF fluff shows rather some disadvantages for use in carbonisation. The bulk density is rather low (about 0,12 ton/m³) and not easy to get it in the carbonisation reactor because of bridging and clogging.

SRF soft pellets are more suitable for the carbonisation process. The bulk density is about 0,3 ton/m³ and the chance on bridging and clogging is small.

SRF hard pellets show a bulk density of about 0,5 ton/m³. At this moment no carbonisation experience by Perpetual Next Dilsen with SRF hard pellets embodiment.

A certain particle size is clearly preferred for the carbonisation process. Too small particles (less than 4 mm) means of course dust problems. Next to that it has been observed, that for this small size fraction the ash content is particularly high with woody biomass (up to 30%). It is therefore recommended to remove by sieving these small particles by preference after pre-drying. Pre-drying to a moisture content of about 5% is an essential process step of carbonisation and have to take place before entering the carbonisation reactor. During this pre-drying trapped sand (component of ash content) will come off in the form of small particles and can be removed by sieving.

Too large particles (> 50 mm) means especially transport problems. These large particles are able to block and damage these transport systems mechanically and will lead to a disruption of the carbonisation process. Particles of about 50 mm can be carbonised in an optimal way (still carbonised to the core of the particle).

The elemental composition of the biomass containing feedstock used determines to a great extent whether the optimal desired carbonised product for further application has been obtained. See table 2 for overview of the parts, that apply in determining the biomass composition.

Proximate

Moisture	% (a.r.)
Ash	% (d.b.)
Volatiles	% (daf)
Fixed Carbon	% (daf)

Ultimate

Hydrogen	% (daf)
Carbon	% (daf)
Nitrogen	% (daf)
Oxygen	% (daf)

Clorine	% (d.b.)
Sulfur	% (d.b.)

Calorific value

GCV (daf)	MJ/kg
NCV (a.r.)	MJ/kg

Table 2

elements (determines to a great extend ash compostion)

Ca	g/kg (d.b.)
Na	g/kg (d.b.)
K	g/kg (d.b.)
Mg	g/kg (d.b.)
Fe	g/kg (d.b.)
Si	g/kg (d.b.)
Al	g/kg (d.b.)
Fe	g/kg (d.b.)
P	g/kg (d.b.)

Table 3

trace elements (can be toxic)

Cd	mg/kg (d.b.)
Pb	mg/kg (d.b.)
Hg	mg/kg (d.b.)
Cr	mg/kg (d.b.)
Cu	mg/kg (d.b.)
Ni	mg/kg (d.b.)
Zn	mg/kg (d.b.)
Sb	mg/kg (d.b.)
Mn	mg/kg (d.b.)

Table 4

Woody biomass consists mainly of the following components: lignin, cellulose and hemicelluloses.

Polymer (wt%)	Deciduous	Coniferous	Herbaceous
Lignin	18-25	25-35	15-25
Cellulose	40-44	40-44	30-50
Hemicellulose	15-35	20-32	20-40

Table 5

Lignin is an amorphous, highly branched, cross-linked macromolecular polyphenolic resin with no exact structure. Lignin fills the spaces in the cell wall between cellulose, hemicellulose and pectin components. It is covalently linked to hemicellulose and thereby cross-links different plant polysaccharides, conferring mechanical strength to the cell wall and, by extension, to the plant as a whole.

Cellulose is a long chain polymer of glucose that can establish intra-molecular and inter molecular hydrogen bonds. Cellulose (C6H10O5) is characterized by its large molecular weights of 500,000 units monomers.

Hemicelluloses are composed mainly of heteropolysaccharides such as hexoses (glucose, mannose, and galactose) and pentoses (xylose and arabinose). Hemicelluloses are polysaccharides of plant's walls, which strengthen the primary cell walls.

Information about elemental composition and components of woody biomass can be found in Phyllis2 (https://phyllis.nl). Phyllis is a database containing information on the composition of biomass, macro- and micro-algae, feedstocks for biogas production, biochar and carbonised biomass. Phyllis provides data for individual materials or average values for a group of materials.

Phyllis is an initiative from ECN and the database has been combined with the BIODAT database from the PHYDADES project. Phyllis is maintained by ECN.TNO Biomass & Energy Efficiency. At present it contains around 3000 data records. Thermal treatment at about 250°C in a low oxygen environment means the start of decomposition of hemicelluloses (Xylan) and to a lesser extend of lignin. At about 350°C also cellulose starts to decompose.

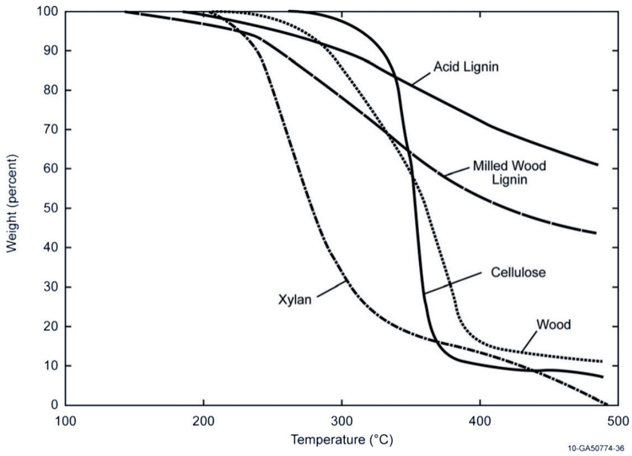

Figure 1

Thermal treatment in a low oxygen environment can be performed at different temperatures. At temperatures between 270°C and 330°C this process is known as carbonisation. Increase of carbonisation process temperature means for the solid carbonised biomass containing material: an increasing hydrophobic behaviour, a more favourable grinding behaviour, a further increase of the energy density, decrease of the volatile content, an increase of the total carbon content.

However, one must realize that there is an increasing loss of solid mass (increasing amount of process-gas) at a higher process carbonisation temperature (above torrefaction temperatures) and by that the energy efficiency decreases.

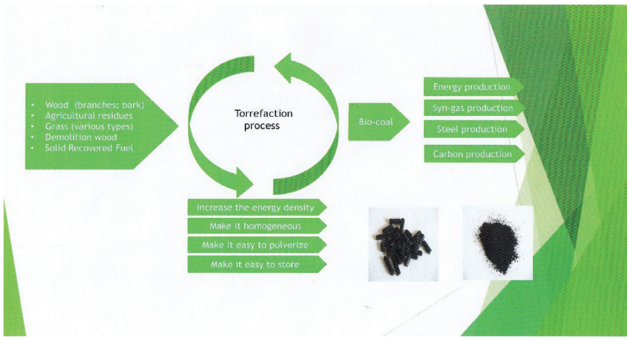

Figure 2

As mentioned in table 1, all kind of feedstock have been used and tested by Perpetual Next Dilsen. The proximate, ultimate and calorific value have been determined for the carbonised output of all these feedstock used as mentioned in table 6.

Input > 98 % renewable		Torr-Coal process		Output
classification according ISO 17225-1: 2014		process max. torrefaction temp.		analysis results
1 Woody biomass 1.1 Forest, plantation and other virgin wood	fresh mixed woodchips West Europe	mild torrefaction	290 °C	1
				2
		severe torrefaction	320 °C	3
			340 °C	4
		pyrolysis	400 °C	5
			450 °C	6
	eucalyptus woodchips Portugal	290 °C		7
	shredded acacia wood South Africa	285 °C		8
1 Woody biomass 1.3 used wood	shredded used untreated pine / spruce wood A-wood	290 °C		9
	shredded used treated mixed wood B-wood	pilot scale different tests		10
2 Herbaceous biomass	Bagasse; Banagrass; Miscanthus; Empty Fruit Bunches (EFB); HiCross; Palmoil Kernel Scales (PKS)	lab. scale different tests		not available

Input partly (> 50 %) renewable	Torr-Coal process	Output
	process max. torrefaction temp.	analysis results
blends of Solid Recovered Fuel (SRF: classification according NEN-EN 15359: 2011) and woody biomass (classification according ISO 17225-1: 2014)	340 °C - 360 °C pilot scale different tests	11

Table 6

The analysis results of the carbonised output 1 up to 9 are presented in table 7.

		1	2	3	4	5	6	7	8	9
Moisture	% (a.r.)	4,4	0,9	2,2	0,9	1,1	1,3	0,6	0,8	4,2
Ash	% (d.b.)	2,9	2,7	2,5	3,0	4,9	6,6	1,7	6,7	1,4
Volatiles	% (daf)	69,9	71,3	48,3	28,4	24,8	27,2	62,5	59,6	70,0
GCV (daf)	MJ/kg	23,8	23,6	28,4	31,5	35,2	34,0	25,4	26,1	23,7
NCV (a.r.)	MJ/kg	20,9	21,6	26,0	29,4	33,8	32,6	23,7	23,0	21,1
Hydrogen	% (daf)	5,9	5,7	5,2	4,1	3,7	3,4	5,5	5,4	6,0
Carbon	% (daf)	60,8	59,2	71,8	81,0	84,8	86,3	62,8	65,1	60,7
Nitrogen	% (daf)	0,68	0,47	0,30	0,56	0,60	0,71	0,27	1,03	0,62
Sulfur	% (daf)	0,04	0,05	0,07	0,02	0,03	0,02	0,01	0,04	0,02
Oxygen	% (daf)	32,6	34,6	22,6	14,3	10,9	9,6	31,5	28,4	32,6

Table 7

More carbonisation tests (increase of carbonisation temperatures) have been done for shredded used treated wood (B-wood). This means carbonised output 10 (according table 6) shows due to increase of carbonisation temperature an increase of mass loss, increase of calorific value, increase of carbon content and decrease of volatile content. See table 8 for the analysis results of carbonised output 10.

feedstock B-wood									
GCV (daf) MJ/kg	NCV (daf) MJ/kg (cV)	Volatiles (daf)	C (daf) content	O (daf) content	H (daf) content	N (daf) content	S (daf) content	Cl-content on dry base	ash content on dry base
20,46	19,22	81,5%	52,3%	39,7%	6,02%	1,86%	0,06%	0,086%	3,30%

torrefaction product										
mass loss on dry base	GCV (daf) MJ/kg	NCV (daf) MJ/kg (cV)	Volatiles (daf)	C (daf) content	O (daf) content	H (daf) content	N (daf) content	S (daf) content	Cl-content on dry base	ash content on dry base
33,0%	24,74	23,72	60,7%	63,9%	28,5%	5,01%	2,49%	0,13%	0,038%	6,55%
45,0%	26,64	25,73	52,0%	69,8%	22,9%	4,47%	2,69%	0,19%	0,047%	7,80%
52,9%	28,56	27,81	42,6%	73,8%	19,5%	3,77%	2,74%	0,21%	0,051%	10,78%
55,7%	29,02	28,28	39,8%	77,5%	15,5%	3,66%	3,14%	0,20%	0,043%	12,02%

Table 8: Analysis results carbonisation trials B-type waste wood in pilot scale indirect heated C-Vertr R1 drum reactor

Solid Recovered Fuel (SRF) also has been tested. These tests have been done by using a blend feedstock of SRF and fresh mixed woodchips: one test (carbonisation temperature 340°C) with 30 w-% SRF and 70 w-% fresh mixed woodchips, another test (carbonisation temperature 360°C) with 50 w-% SRF and 50 w-% fresh mixed woodchips. See table 9 for the analysis results of carbonised output 11 (according table 6).

		30 % / 70 % 340 °C	50 % / 50 % 360 °C
Moisture	% (a.r.)	0,1	0,1
Ash	% (d.b.)	4,7	13,1
Volatiles	% (daf)	38,0	60,9
GCV (daf)	MJ/kg	31,6	34,4
NCV (a.r.)	MJ/kg	29,1	28,5
Hydrogen	% (daf)	5,1	7,6
Carbon	% (daf)	79,7	78,3
Nitrogen	% (daf)	0,74	0,88
Sulfur	% (daf)	0,18	0,31
Oxygen	% (daf)	14,3	12,8

Table 9: Carbonisation analysis results blends of Solid Recovered Fuel (SRF) and woody biomass (*)

Looking to availability and business economic reasons shredded used treated wood (B-wood) and SRF or blends from both are the most promising feedstock for the carbonisation process in West-Europe.

However using these kind of feedstock one must realize, that the ash, chlorine and sulphur content and presence of toxic heavy metals can give rise to problems.

Shredded used treated wood (B-wood) will show an ash content up to 5 w-% and SRF even up to 10 w-%.

B-Wood will show a chlorine content up to 0,2 w-% and sulphur content also up to 0,2 w-%. SRF will show a chlorine content up to 1,0 w-% and sulphur content up to 0,3 w-%.

Total amount of toxic heavy metals in SRF and B-wood can be up 1000 mg/kg (dry base). Maximum expected values for the individual heavy metal elements can be seen in table 10.

max. expected heavy metal content of SRF and B-wood

Cd	mg/kg (d.b.)	4
Pb	mg/kg (d.b.)	400
Hg	mg/kg (d.b.)	0,4
Cr	mg/kg (d.b.)	150
Cu	mg/kg (d.b.)	150
Ni	mg/kg (d.b.)	50
Zn	mg/kg (d.b.)	500
Sb	mg/kg (d.b.)	150
Mn	mg/kg (d.b.)	200

(*) Due to inhomogeneity and composition "variation over time of SRF and B-wood feedstock, wide spread on analysis results can be expected. The results reported are based on limiting number of sample analysis and therefore values" presented should be considered indicative.

Table 10

Due to this higher chlorine and sulphur content in the feedstock, the carbonisation process needs a flue gas cleaning system to fulfil the maximum allowed emission quantities of HCl and SO2. It is known, that chlorine and sulphur, present in the feedstock, will be after carbonisation present partly in the solid carbonised material and partly in carbonisation process gas. This carbonisation process gas is burned and flue gas is produced with a certain amount of HCl and SO2., which at the end (after useful heat exchange) will be emitted to open air.

The rather high ash content of the feedstock is not really a problem for the carbonisation process. However one has to realize, that after carbonisation ash content of the carbonised product is nearly doubled. Depending on the application of the carbonised product this ash content can lead to challenges for certain applications, like an unacceptable ash melting and ash drain behaviour. Ash melting behaviour (temperature) is strongly determined by the ash composition (Si, Ca, Na, K, Mg ratio) and will give rise to fouling and blocked ash drain.

Despite the non-alarming amounts of heavy metals in the SRF/B-wood feedstock, this remains a point of attention. Due to inhomogeneity and composition variation in time it cannot be excluded that sporadically elevated unacceptable values are found. Depending on the application of the carbonised product this can limit the possibilities for these type of feedstocks (soil, water and air pollution).

CONCLUSION

Different kind of biomass containing materials are eligible as raw material for the carbonisation process. It has been shown by Perpetual Next, that mixed woodchips, acacia wood, eucalyptus wood, used untreated pine/spruce wood, treated used mixed wood, blends of Solid Recovered Fuel (SRF) and mixed woodchips can be used for carbonisation in an indirect heated C-Vertr R drum reactor.

The main conclusion is, that looking to availability and business economic reasons shredded used treated wood (B-wood) and SRF or blends from both are the most promising feedstock for the carbonisation process in West-Europe.

However, using these kind of feedstocks one must realize, that the ash, chlorine and sulphur content and presence of toxic heavy metals can give rise to problems at the carbonisation process and different kind of applications of the carbonised product at the customer.

REFERENCES/LITERATURE

TorTech Carbonisation Technology for the production of solid bioenergy carriers from biomass and waste
F. Verhoeff (ECN), A. Adell i Arnuelos (ECN), A.R. Boersma (ECN), J.R. Pels (ECN), J. Lensselink (ECN), J.H.A. Kiel (ECN), H. Schukken (GF Energy). ECN-E--11-039 (May 2011).

A Review on Biomass Classification and Composition, Co-Firing Issues and Pre-treatment Methods
Jaya Shankar Tumuluru (1), Shahab Sokhansanj (2), Christopher T. Wright (1), Richard D.Boardman (1) and Neal A. Yancey (1) August 2011
(1) Idaho National Laboratory, 2525 North Fremont Ave., Idaho Falls Idaho 83415.
(2) Oakridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN 37831-6422

ISO 17225 1-8 Solid biofuels - Fuel specifications and classes

Phyllis2 (https://phyllis.nl)

Beschikbaarheid en toepassingsmogelijkheden van duurzame biomassa
Verslag van een zoektocht naar gedeelde feiten en opvattingen
Beleidsstudie Bart Strengers en Hans Elzenga, 8 mei 2020, PBL Planbureau voor de Leefomgeving.

Analysis results suppliers Solid Recovered Fuel and B-wood
(Renewi, Suez, Gielen Genk, Herhof Osnabrück, Remondis Duitsland, Smurfit Kappa Roermond, N + P Recycling BV Nederland, van Heede Environment België).