BO_2-technology for biomass upgrading into solid fuel – pilot-scale testing and market implementation

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BO_2-TECHNOLOGY FOR BIOMASS UPGRADING INTO SOLID FUEL – PILOT-SCALE TESTING AND MARKET IMPLEMENTATION

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ABSTRACT: This paper concerns the development of BO_2-technology, a new technology for biomass upgrading into commodity solid fuel. BO_2-technology consists of a new innovative torrefaction technology concept (mild temperature treatment between 200 and 300 °C) in combination with pelletisation. It enables energy-efficient and cost-effective production of 2nd generation pellets with superior properties in terms of high energy density (1.5-2x conventional pellets), excellent grindability and water repellant nature (eliminating/reducing biological degradation and spontaneous heating, enabling outdoor storage). BO_2pellets™ can be produced from a broad range of biomass streams, such as wood chips, agricultural residues and various residues from the food and feed processing industry. ECN now operates a 50 to 100 kg/h pilot plant and has teamed up with two industrial partners, Econcern and Chemfo, to bring BO_2-technology to the market.
Keywords: biomass pre-treatment, biomass/coal co-firing, costs, logistics, market implementation, pellets, pilot plant, solid biofuels, torrefaction

1 INTRODUCTION

Biomass is a difficult energy source in terms of transport, logistics and thermal conversion. Conventional pelletisation offers several advantages, but it is costly and energy consuming, particularly so for biomass streams other than clean, dry saw dust. Moreover, these pellets still have their limitations, e.g., with respect to durability and hygroscopic nature.

Torrefaction is a mild thermo-chemical treatment used for the upgrading of biomass into a high-quality solid fuel. It is performed at a temperature between 200-300 °C and carried out under atmospheric conditions in the absence of oxygen. During torrefaction, biomass properties are changed to obtain a much better fuel quality for combustion and gasification applications. In combination with pelletisation, favourable logistic properties are obtained, such as a high energy density and superior handling. Torrefaction also results in resistance against biodegradation and spontaneous heating.

Major end-use options for BO_2pellets involve direct co-firing (outdoor storage, co-milling with existing coal mills), transportation fuels production via entrained-flow gasification and small-scale combustion (pellet boilers and stoves).

Initial bench-scale testing with various woody biomass feedstocks has resulted in detailed understanding of the torrefaction principles [1-5]. This has been applied to develop a novel, dedicated reactor and process concept. Subsequently, a 50-100 kg/h torrefaction pilot-plant has been erected and the scope of the bench-scale work has been broadened to include other biomass feedstock such as straw, hay, bagasse, cocoa shells, and even refuse derived fuel. Moreover, ECN has entered into an agreement with two Dutch industrial parties, Econcern and Chemfo, to bring the technology to the market.

2 TORREFACTION OF WOOD

2.1 Basic principles

A typical mass and energy balance for woody biomass torrefaction is that 70% of the dry mass is retained as a solid product, containing 90% of the initial energy content. The other 30% of the dry mass is converted into torrefaction gases and vapours, which contain only approx. 10% of the energy of the biomass. An energy densification with typically a factor of 1.3 can be attained.

Moreover, the structure of the torrefied biomass is changed in comparison to the untreated biomass which makes it brittle and reduces the equilibrium moisture content. Even mild torrefaction reduces biodegradability [6].

There are conflicting claims about the reaction enthalpy of torrefaction between 250 and 300 ºC [7,8]. For larger-scale torrefaction reactors, the reaction is modestly exothermic and it has been surmised that this is due to exothermic condensation reactions more than compensating endothermic primary decomposition [8].

2.2 Grindability

A key property that is significantly improved through torrefaction is the grindability of the material. The reduction in power consumption is illustrated in Figure 1 with data obtained on a cutter mill. Torrefied wood and coal require the least power, and untreated biomass the most, with bone dry biomass situated in between. Power consumption also rises substantially for smaller required particle diameter after grinding.

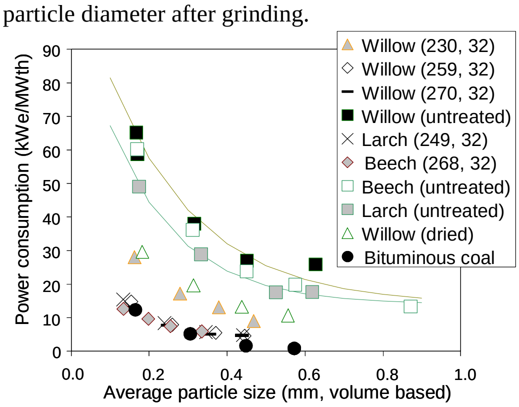

Figure 1: Power consumption as a function of final particle size (torrefaction conditions in brackets, temperature in °C, residence time in minutes)

3 TORREFACTION OF RESIDUES AND WASTE

The torrefaction behaviour of agricultural residues, such as straw, is comparable to woody feedstocks. A significant factor in determining yields at a given set of reaction conditions (residence time, temperature) is the hemicellulose content. This is illustrated graphically in Figure 2. Grass seed hay and bagasse have the highest hemicellulose content, and lowest lignin fraction, while the situation is reversed for pine and spruce. Trockenstabilat and RDF are two waste derived products that are also plotted in Figure 2. Due to their plastic and ash contents, however, their hemicellulose content is not a meaningful indicator.

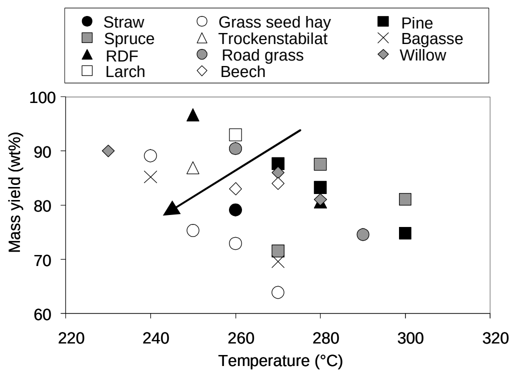

Figure 2: Torrefaction mass yields as a function of feedstock and temperature, generally increased hemicellulose content in direction of arrow

The improvement in grinding behaviour is likewise of a comparable nature for agricultural residues and the studied waste derived fuels. This is illustrated in Figure 3. However, untreated straw and hay are already easier to grind than wood, while untreated trockenstabilat and RDF could not be ground at all. Grinding of untreated trockenstabilat and RDF only proved possible after cryogenic treatment with liquid nitrogen, or after torrefaction.

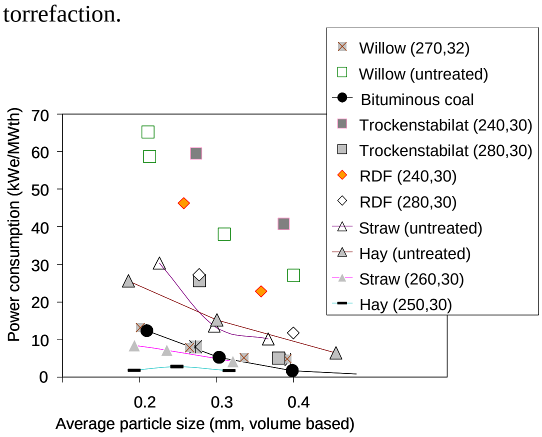

Figure 3: Grinding behaviour of a range of feedstocks, including agricultural residues and waste derived fuels

4 BO_2-TECHNOLOGY

BO_2-technology consists of three main process steps, viz. drying, torrefaction and pelletisation. Drying and pelletisation are considered to be conventional steps, for which commercially available technology can be applied. The innovative part in the technology is the torrefaction step. The applied torrefaction technology concept is aimed at achieving high energy efficiency at low cost. The central element in this step is a directly heated moving bed torrefaction reactor in which biomass is heated using recycled torrefaction gases (torgas). The recycle consists of re-pressurization of the torgas to compensate for the pressure drop in the recycle-loop and of the heating of the recycle gas to deliver the required heat demand in the torrefaction reactor. A generalized process flow diagram of the BO_2-technology process is presented in Figure 4.

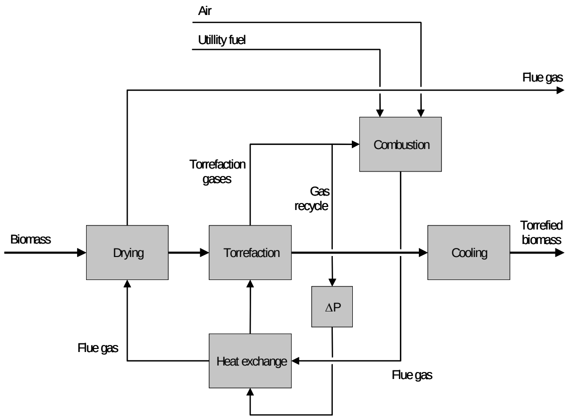

Figure 4: Process flow diagram of BO_2-technology. Only the integrated drying-torrefaction part of the process is shown (not size reduction and pelletisation).

For biomass feedstock wetter than 15-20% moisture content, an external dryer is required. This lowers the heat requirement of the torrefaction process, reduces the recycle flow rate, and permits the combustion of the torgas that otherwise would be too wet. The heat generated by combustion of the torgas is used for both torrefaction and drying of the biomass. A support fuel is employed to balance the process thermally and to provide stability and control of the combustion process.

The moving bed reactor has been selected for the torrefaction unit as it provides a low cost option, as well as high heating and feed rates. Consequently, it is also very compact. The reactor has several innovative aspects to allow for feedstock flexibility, good temperature control and to make the integral process feasible. The reactor design enables the use of state-of-the-art technology for all other operations than torrefaction. This minimises both the investment costs and the technological risks.

The typical commercial scale of operation is expected to be 60-100 ktonne/a of product, which is on energy basis comparable to the typical production scale of pelletisation (80-130 ktonne/a).

5 PELLETISATION BEHAVIOUR

Process design in combination with flow sheet simulations reveals that the overall efficiency (based on lower heating value (LHV), as received) is improved when pelletisation is combined with torrefaction (compared to pelletisation alone). The efficiency is estimated in the range of 88% to 92% for wood pellets and is estimated to be in the range from 92% to 96% for BO_2pellets. The higher overall energetic efficiency of the BO_2-technology is the result of producing very dry pellets with high calorific value, while consuming less electricity for size reduction and pelletisation.

An illustration of BO_2pellets is given in Figure 5. The energetic density of BO_2pellets is approximately 13-17 GJ/m^3, which is an increase of 30-80% compared to that of wood pellets. Such a high energy density is the result of a low moisture content (typically 1 to 5% on mass basis), high calorific value and higher mass density that can be established during densification (under similar pressure conditions).

Figure 5: BO_2pellets

Tests on the mechanical strength of conventional and BO_2pellets reveal that pellets produced from torrefied wood can be twice as strong compared to those produced from untreated wood. It is expected that the relatively high lignin content of torrefied biomass is responsible for this increase. In a preliminary evaluation the hygroscopic nature of the pellets was estimated by immersing pellets for long periods in water (viz. 15 hours). BO_2pellets showed only little swelling (no disintegration) due to water uptake, whilst conventional pellets swelled and disintegrated rapidly (within minutes). The ASTM D3201-94(2003) standard test method for hygroscopic properties of fire-retardant wood and wood based products has also been applied and likewise shows substantially reduced moisture uptake by BO_2pellets.

Pelletisation tests on a bench-scale unit at California Pellet Mill (CPM) have provided similar results as for the smaller-scale tests performed at ECN, indicating that good quality pellets can be produced on an industrial scale.

The best pelletisation behaviour was found with material torrefied between 240 °C and 280 °C for 15 to 30 minutes. Approaching charcoal has a deleterious effect on pelletisation behaviour based on these tests. A summary of BO_2pellet properties is given in Table I.

Table I: Overview of BO_2pellet properties

Properties (typical values)	Wood chips	Torref. Wood	Wood pellets	BO_2 pellets
Moisture wt%	35	0	10	3
LHV kJ/kg				
Dry	17.7	20.4	17.7	20.4
As received	10.5	20.4	15.6	19.9
Bulk density				
kg/m^3	475	230	650	750
GJ/m^3	5.0	4.7	10.1	14.9

6 PILOT PLANT TESTS

The pilot plant at ECN, illustrated in Figures 6 and 8, has been built to demonstrate the torrefaction step of the BO_2-technology, including the innovative moving bed reactor, the torgas recycle loop and the accompanying heat integration.

Figure 6: Biomass being fed to the top section of the pilot plant (Photo Jasper Lensselink)

Over 75 hours of operation have now been accumulated with recycle torgas temperatures varied between 220 and 280 °C, recycle flows varied by a factor three, and a throughput of approx. 60 kg/h (input basis). Analysis of these first test runs indicates that 100 kg/h will be easily achievable without any design changes. The feedstock used for these initial pilot-plant tests was a mixture of soft and hardwoods with a large content of bark and small branches and some needles. An illustration of the torrefied product is shown in Figure 7.

Figure 7: Torrefied biomass

In general, the plant showed smooth operation. Due to the modestly exothermic nature of the process, the temperature in the reactor is slightly elevated over the recycle torgas inlet temperature. The good temperature control of the process is clearly vital, as otherwise a thermal runaway towards 350 °C with charcoal production and, consequently, low product yields would result, as was proven in some initial testing in batch mode.

Figure 8: Bottom section of the pilot plant (Photo Jasper Lensselink)

In addition to providing good temperature control and gas distribution together with a modest pressure drop, the reactor concept also allows incoming biomass to act as a filter, which very effectively removes virtually all dust formed in the moving bed from the gas stream exiting the reactor. Together with innovative gas inlet and outlet designs, the load on the cyclones has therefore been reduced to virtually zero.

The torrefied material from the pilot plant has been subjected to bench-scale and semi-industrial scale pelletisation tests making use of the facilities of CPM in Amsterdam, the Netherlands. Despite the very heterogeneous nature of the biomass feedstock and the preliminary nature of the torrefaction tests, good quality pellets could be produced. Pellet quality appears to be clearly influenced by the torrefaction conditions. At too extreme conditions, pelletisation becomes more difficult, as it was found as well in earlier pelletisation tests with material from bench-scale torrefaction tests. This appears to be related to degradation of the lignin fraction in the biomass.

Following this initial pilot-scale testing, attention is now focused on optimising torrefaction operation, in combination with subsequent pelletisation, and on determining long-duration performance of the plant. During the second half of 2008, it is foreseen to broaden the scope to include other feedstocks, such as agricultural residues. In addition, extensive pellet quality assessment and optimisation will be conducted. Relevant pellet parameters to be assessed are, e.g., grindability, hygroscopic behaviour, strength, biological degradation and combustion/ gasification performance.

7 MARKET INTRODUCTION

BO_2-technology has the potential to make a large contribution to reaching policy goals concerning the application of biomass to reduce CO_2 emissions and increase the share of Renewable Energy Sources (RES) in the energy mix. BO_2-technology aims at processing a wide range of lignocellulosic feedstocks, avoiding competition with food and feed. Major end-use options for BO_2pellets involve direct co-firing (outdoor storage, co-milling with existing coal mills), transportation fuels production via entrained-flow gasification and small-scale combustion (pellet boilers and stoves).

Moreover, BO_2pellets have large advantages over the original biomass feedstock, but also over conventional pellets, with respect to storage, handling and (long-distance) transportation [8,9]. They have the potential of becoming a major commodity fuel, allowing trading schemes similar to coal.

The following examples may illustrate the large potential impact of the technology:

- 10% biomass co-firing of all coal-fired plants in the EU-27 requires 70 Mtonne/a dry biomass. BO_2pellets do not require special investments for biomass co-firing; BO_2pellets can be stored on the coal yard and milled and fed to the boiler together with the coal. 70 Mtonne/a requires 700 BO_2-plants with a plant-size of 100 ktonne/a biomass input.
- 10% biofuels to be introduced in the EU-27 in 2010 corresponds to ≅ 1300 PJ/a or approx. 110 Mtonne/a dry biomass (@ 60% conversion efficiency). BO_2-technology is an enabling technology for 2nd generation biofuels produced via high-temperature gasification (e.g. Fischer-Tropsch diesel).
- In the EU-15, there is 43 Mtonne/a dry biomass (agro-residues) available for energy purposes. BO_2-technology can play a major role in increasing the efficiency and reducing the cost of the overall biomass-to-energy chain for this type of biomass.

To bring BO_2-technology to the market, ECN has teamed up with two Dutch industrial parties, viz. Econcern and Chemfo. Together, they have established BO_2GO, aiming at realising the first commercial plant. This plant with a capacity of 70 ktonnes/a BO_2pellets will be located in Delfzijl, in the northern part of the Netherlands. Currently, the permitting procedure has started and the performance data of the pilot-plant at ECN are being used to support the design of the BO_2GO plant. Initial start-up of the BO_2GO plant is scheduled for late 2009.

In addition, the three parties will establish BO_2Unlimited, a company aiming at the engineering and supply of the technology for interested third parties. It is envisaged that future commercial BO_2 plants will be located predominantly at biomass source locations, to benefit to a maximum extent from the advantageous logistic properties of BO_2pellets.

8 CONCLUSION AND OUTLOOK

The combination of torrefaction and densification offers the opportunity to produce high-quality 2^{nd} generation fuel pellets from a wide range of biomass feedstocks. Due to their high energy density, hygroscopic nature and easy grindability, BO_2pellets have the potential to become a major commodity fuel with excellent properties for co-firing applications, for biofuels production via high-temperature gasification and for small-scale combustion applications. Moreover, the hygroscopic nature makes the pellets highly resistant to biological degradation and spontaneous heating, which leads to large advantages in transport, handling and storage.

ECN BO_2-technology is expected to allow the production of BO_2pellets against attractive production costs. Significant cost savings can be achieved throughout the biomass-to-energy chain when compared to state-of-the-art wood pellets.

Currently, pilot-scale testing of this technology is underway and initial results are very promising in validating ECN's innovative moving bed reactor concept.

Also the scope for application is being broadened to a wide range of biomass feedstocks, including various types of wood, straw, hay and bagasse. Furthermore, a co-operation with two industrial parties (Econcern and Chemfo) has been set up to realise the first commercial plant at a scale of approx. 70 ktonne/a BO_2pellets. In addition, this partnership will establish an engineering and equipment supply company for bringing this technology on the market.

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