



Energy research Centre of the Netherlands

BO₂-technology for biomass upgrading into solid fuel - an enabling technology for IGCC and gasification-based BtL

Presented at 4th International Conference on Clean Coal Technologies
in conjunction with the 3rd International Freiberg Conference on IGCC
& XtL Technologies, Dresden 18-21 May 2009

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BO₂-technology for biomass upgrading into solid fuel - an enabling technology for IGCC and gasification-based BtL

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Abstract

BO₂-technology is a new technology for biomass upgrading into commodity solid fuel. It consists of an innovative torrefaction technology concept (mild temperature treatment between 200 and 300 °C) in combination with pre-drying (if needed) and 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 resistant nature (eliminating/reducing biological degradation and spontaneous heating, enabling outdoor storage). BO₂pelletsTM 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 50-100 kg/h pilot plant and has teamed up with industrial partner Econcern to bring BO₂-technology to the market.

Keywords: Torrefaction, biomass upgrading, entrained-flow gasification, IGCC, BtL, biomass co-firing, pilot-scale testing, demonstration

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. Furthermore, they do not allow fulfilling the stringent requirements of (the feeding systems of) dry-feed entrained-flow gasifiers. Torrefaction is a promising biomass upgrading technology that can be applied to further enhance pellet quality by addressing these issues. This paper presents the development status of ECN's technology concept of torrefaction in combination with pelletisation; a process referred to as BO₂-technology.

Torrefaction - basic principles

Torrefaction is a thermo-chemical treatment at a temperature level of 250 to 300 °C, at near atmospheric pressure in the absence of oxygen. During torrefaction, the biomass partly decomposes releasing part of the volatiles. 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

and which can be used to produce heat for torrefaction and pre-drying if a proper process concept is applied. In addition, changes occur in the biomass structure. Looking at the three main building blocks of lignocellulosic biomass, the hemicellulose largely decomposes, depolymerisation occurs in the cellulose leading to shorter fibres, while the lignin fraction remains largely unaltered. As a consequence, the solid product becomes much more brittle, which substantially improves the grindability. The resulting reduction in power consumption is illustrated in Figure 1 for woody biomass 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.

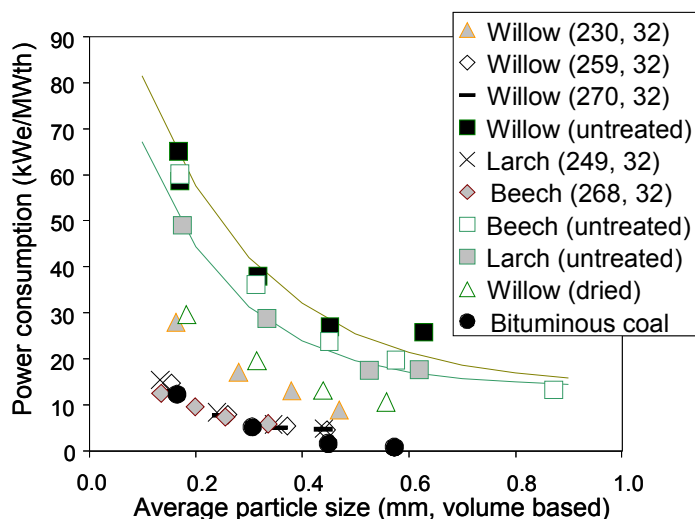


Figure 1: Power consumption as a function of final particle size (torrefaction conditions in brackets, temperature in °C, residence time in minutes)

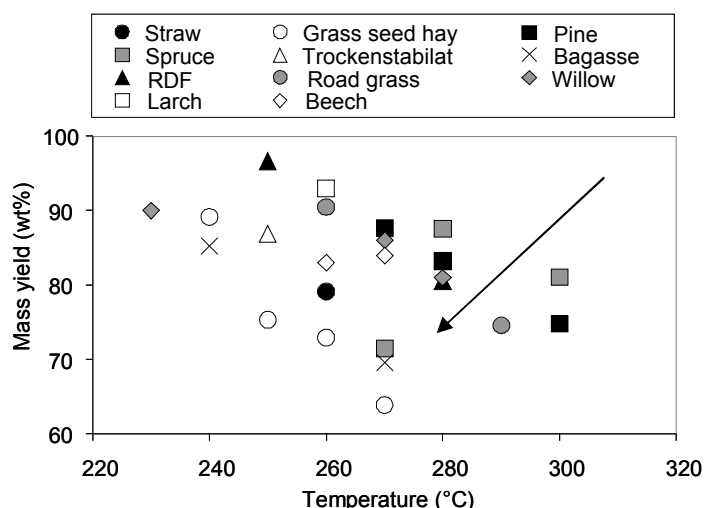


Figure 2: Torrefaction mass yields as a function of feedstock and temperature, generally increased hemicellulose content in direction of arrow

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. The improvement in grinding behaviour is likewise of a comparable nature for agricultural residues and the studied waste derived fuels.

The above findings have been gained during over six years of extensive bench-scale testing at ECN. Practical experience and detailed understanding of the chemical principles behind torrefaction have been obtained from 2 bench-scale torrefaction reactors (see Figure 3) and in depth research into torrefied product and torrefaction gas characteristics. On the basis of these experiments, ECN has developed an innovative process and reactor concept, as described in the next section. The hydrodynamic behaviour of the reactor has been tested in a cold flow reactor. For more details on the results of the smaller scale experiments, it is referred to several previous publications [1-6].



Figure 3: Equipment for bench-scale testing: 5 liter batch reactor (left), 5 kg/h Auger (screw) reactor (middle) and cold flow reactor (right)

BO₂-technology

ECN's BO₂-technology consists of three main process steps, viz. drying, torrefaction and pelletisation. Drying and pelletisation basically are 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-pressurisation 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 generalised process flow diagram of the BO₂-technology process is presented in Figure 4.

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.

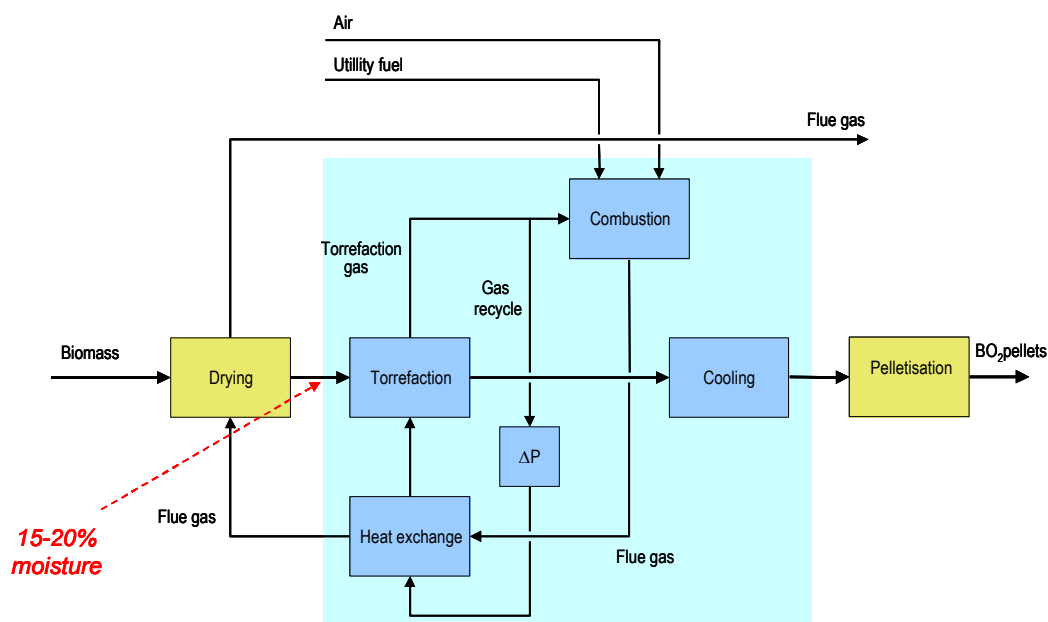


Figure 4: Process flow diagram of BO₂-technology; only the integrated drying-torrefaction part of the process is shown (not size reduction and pelletisation)

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 very compact. The reactor has several innovative aspects to allow for feedstock flexibility, good temperature control and to make the integral process feasible. Furthermore, the reactor design enables the use of state-of-the-art technology for all other operations, which 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).

Pelletisation

For the pelletisation step, a conventional pellet mill can be used, with the operating conditions tuned to the special properties of torrefied biomass. An illustration of BO₂pellets is given in Figure 5. For woody feedstocks, the energetic density of BO₂pellets is approximately 13-17 GJ/m³, 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). A summary of typical BO₂pellet properties is given in Table 1.



Figure 5: BO₂pellets

Table 1: Overview of BO₂pellet properties

Properties (typical values)	Wood chips	Torrefied 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

Pilot-scale testing

Following the extensive smaller-scale testing for a wide range of biomass feedstocks, a 50-100 kg/h torrefaction pilot-plant has been erected to validate the dedicated reactor and process design. The pilot-plant includes the innovative moving bed reactor, the torgas recycle loop and the accompanying heat integration.

To date (March 2009), this pilot-plant has been operated successfully in day shifts of 8-19 hours and in several 50 hour runs, with a total operating time of over 300 hours. The feedstocks used for these tests were poplar chips, several agricultural residues and a mixture of soft and hardwoods with a large content of bark and small branches and some needles. The first runs revealed that several adjustments had to be made, including:

- New discharge system for the torrefied product to allow for continuous discharge
- Replacement of some valves, flow meters, pipework giving excessive pressure drop
- Changes to the afterburner to reduce emissions and enable better balance

- Installation of additional measurement points for temperature, pressure and torgas analysis



Figure 6 Biomass being fed to the top section of the pilot plant (left) and bottom section of the pilot-plant (right) (Photos Jasper Lensselink)

Following these adjustments, the plant showed smooth operation. The reactor showed a high feedstock flexibility, only limited pressure drops and given a proper sizing of the feedstock, no problems with bridging were encountered. The emissions from the afterburner appeared to be comparable to natural gas burning (0-50 ppmv CO and 20-70 ppmv NO_x). Mass and energy balances over the plant appeared to be in line with results from previous smaller-scale work. 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 400 °C with charcoal production and, consequently, low product yields would result, as was proven in some initial testing in batch mode.

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. Furthermore, 1-5 tonne test batches are being produced for various interested external parties, which want to evaluate the BO₂-technology for their particular biomass or their end-use application.

In addition to the pilot-scale torrefaction tests, extensive pellet quality assessment and optimisation is being conducted. Relevant pellet parameters to be assessed are, e.g., grindability, hygroscopic behaviour, strength, biological degradation and combustion and (entrained-flow) gasification performance.

Market potential

BO₂-technology has the potential to make a large contribution to reaching policy goals concerning the application of biomass to reduce CO₂ emissions and increase the share of Renewable Energy Sources (RES) in the energy mix. BO₂-technology aims at processing a wide range of lignocellulosic feedstocks, avoiding competition with food and feed. Major end-use options for BO₂pellets involve direct co-firing (outdoor storage, co-milling with existing coal mills), power and transportation fuels production via entrained-flow gasification and small-scale combustion (pellet boilers and stoves).

Moreover, BO₂pellets have large advantages over the original biomass feedstock, but also over conventional pellets, with respect to storage, handling and (long-distance) transportation [7]. 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. BO₂pellets do not require special investments for biomass co-firing; BO₂pellets can be stored on the coal yard and milled and fed to the boiler together with the coal. 70 Mtonne/a requires 700 BO₂-plants with a plant-size of 100 ktonne/a biomass input.
- 10% biofuels to be introduced in the EU-27 in 2010 corresponds to \cong 1300 PJ/a or approx. 110 Mtonne/a dry biomass (@ 60% conversion efficiency). BO₂-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. BO₂-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.

Demonstration and market implementation

To demonstrate BO₂-technology and bring it to the market, ECN has teamed up with Econcern, a Netherlands-based company dedicated to providing innovative products and services for a sustainable energy supply. Moreover, in the first half of 2009, the consortium will be extended with an international technology provider. The first aim is to realise a first (commercial) demonstration plant. This BO₂GO plant with a capacity of 70 ktonnes/a BO₂pellets will be located in Delfzijl, in the northern part of the Netherlands. It will be built next to BioMCN, a biomethanol plant with a capacity of 1 Mtonnes (see Figure 7). This plant is currently working on building a 200 ktonnes crude glycerine pretreatment plant to convert

it into a gas that can be fed directly into the bio-methanol plant. As a feedstock diversification strategy, the development of an entrained flow gasifier of about 250 MW_{th} has been started, in order to produce syngas to fuel the biomethanol plant, aside from the crude glycerine gas. This is the first stage of the gasification project, with an ultimate goal of increasing the gasification capacity up to 1000 MW_{th}. This first gasifier requires about 400 ktonnes of torrefied pellets as an input, which will be supplied partly by the BO₂GO plant.



Figure 7: The BioMCN biomethanol plant in Delfzijl, the Netherlands

Currently, the permitting procedure for the BO₂GO plant is underway. Performance data of the pilot-plant at ECN and Computational Fluid Dynamics calculations are being used to support the detailed design. Initial start-up of the BO₂GO plant is scheduled for 2010.

In addition, the parties will establish a company aiming at the engineering and supply of the technology for interested third parties. It is envisaged that future commercial BO₂ plants will be located predominantly at biomass source locations, to benefit to a maximum extent from the advantageous logistic properties of BO₂pellets.

Conclusion

The main conclusion of the work so far is that BO₂-technology offers large technical and economic potential to improve a range of biomass-to-energy chains. For the short term, this will involve mainly biomass co-firing in pulverised-coal boilers, but for the medium-to-long term, entrained-flow gasification-based IGCC and BtL, together with small-scale combustion in pellet boilers and stoves, have been identified as major application areas.

Acknowledgement

The R&D work has been sponsored partly by SenterNovem through the Dutch Long-Term Energy Research Strategy programme (EOSLT).

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