Biomass gasification and use of syngas as an alternative fuel
in a Belgian coal-fired boiler

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Abstract

As partner of EU-Thermie BioCoComb Project [1,2] in Austria (1996-1998), Electrabel and subsidiary research centre Laborelec have gained much experience concerning biomass gasification in a separate, external Circulating Fluidised Bed (CFB) reactor and co-firing of the gas in the coal boiler. Conversion of biomass into electricity is ensured with the same efficiency as a large coal fired unit with a minimum of requirements for the preparation of the biomass. Electrabel has upscaled this technology within one of his coal power plant located in Belgium. The gasifier has been delivered by Foster Wheeler and has been commissioned by December 2002. It is since then operated daily. The concept of the process guarantees a complete combustion of the syngas in the coal boiler. A low gas quality is quite sufficient and therefore no pre-drying or milling of the biomass and no hot gas (850°C) cleaning or gas cooling is necessary. This reduces the costs and the risks dramatically compared to other concepts, needing a clean, dust and tarfree high quality gas for the use in gas engines or gas turbines.

Nominal capacity of the gasifier is 50 MWth with an average moisture content of 50% in the used biomass mixture. With an efficiency of about 34% the corresponding electrical output is 17 MW. This means that about 9% of the coal is substituted by syngas on a nominal basis. On yearly basis 120 GWh will be produced, and this is, for Belgium and Flanders Region a significant increase of the electricity produced from renewable energy sources. By using biomass instead of coal the CO2 output from fossil fuels will be reduced by 120.000 ton/year. The plant has operated 2650 hours in 2003 with an averaged power level of 22 MW.

Keywords: co-gasification, circulating fluidised bed (CFB), wood chips.

1. Background and planning

Process is based on a Circulating Fluidised Bed (CFB) reactor for the thermal degradation of biomass and mechanical attrition of the created char to a particle size, which guarantees a complete combustion of the syngas in a coal boiler. For this concept a low gas quality is quite sufficient and therefore no pre-drying or milling nor hot gas (850°C) cleaning and cooling is necessary. This reduces the costs dramatically compared to all other concepts, which need a clean, dust and tar free high quality gas for the use in gas engines or -turbines (like I.C.C.G.). This makes the project competitive compared to other renewables like wind farms. The use of an existing infrastructure is cost effective and avoids additional visual impact.

From the variety of solid biomass sources only clean fractions like untreated wood chips, bark and uncontaminated residues of hard- and soft-board are used to avoid other negative environmental impacts.

According to EU guidelines, electricity generation from renewable energy sources (RES) is due to increase between 1997 and 2010 from 6% to 12% in the E.U; and from 1% to 6% in Belgium.

The potential of all possible RES is quite limited in Belgium: besides existing small hydro power plants (0,39 TWh/year), mainly wind (5,4 TWh/year) and biomass (about 3,5 TWh) offer a significant potential in Belgium estimated to be 10 TWh by 2020 (less than 10%) [3,4].

Belgian regional governments have set up a renewable obligation for the power suppliers under the form of green certificates. Quota of 6% green power by 2010 will be imposed gradually and accompanied by a penalty of up to 12,5 c€ per kWh in Flanders.

Biomass gasifier has been commissioned by the end of 2002 and has started commercial operation by January 2003.

2. Historical site data

Ruien plant is located in West Flanders along the Scheldt River, near the French border (Fig. 1). It is the largest fossil fuel-fired power plant in Belgium, with a total installed capacity of 900 MWe via 4 operating units:
- Unit 3: started in 1967, 130 MWe, coal & fuel oil,
- Unit 4: started in 1966, 125 MWe, coal & fuel oil,
- Unit 5: started in 1973, 190 MWe on coal, 300 MWe on gas or fuel oil, Gas turbine (1997): 40 MWe direct and 12 MWe through unit 5 steam cycle,
- Unit 6: started in1979, 300 MWe gas and fuel oil.

Figure 1: Electrabel Ruien power station

Unit 5 originally fired heavy-fuel oil, and was retrofitted for coal firing in 1986. Steam data are: HP: 540°C/180 bar; MP: 540°C/40 bar. Maximum thermal power level with coal is limited to 530 MWh. The boiler operates about 6 500 hours per year.

In 1997, the plant was repowered with a gas turbine connected to the pre-heater for the boiler feed water. Maximum electrical output of this gas turbine is 49 MWe, for a reference outside temperature of -25°C.
The boiler fires 500,000 tons coal per year. It makes use of primary measures (over-fire air) for NOx removal and is expected to be equipped with a flue gas desulphurisation (FGD) system by 2006.

3. ATMOSPHERIC CFB GASIFICATION SYSTEM

Gasification and co-firing (i.e. co-gasification) is one of the most appropriate technologies, because of the high energetic efficiency of the steam cycle. Biomass is converted into a low calorific value (LCV) gas by partial gasification in a separate reactor, working on the principle of an atmospheric circulating fluidised bed (CFB). Operating reactor temperature range is 800-1000°C depending on the load and fuel composition. Inert circulating bed material serves as a heat carrier and stabilises the temperatures in the process. [5].

CFB gasification principle is simple. The gasifier has been manufactured by Foster Wheeler Oy. It works as a thermo-mechanical mill for fuel preparation in the sense that thermal conversion and mechanical attrition deliver a char particle size that guarantees complete combustion in a pulverised coal boiler.

The system consists in a reactor where gasification takes place, a cyclone to separate the bed material from the gas, and a pipe to return the circulating material to the bottom part of the gasifier. All of the above mentioned components are entirely refractory lined (Fig. 2).

![Diagram of a Foster Wheeler CFB gasifier](image)

Figure 2: Lay-out of the Foster Wheeler CFB gasifier.

In the uniflow-type cyclone, gas and circulating solid material flow in the same direction downwards. Both hot product synthesis gas and char particles are extracted from the bottom, in contrast with conventional cyclones.

After the cyclone, syngas flows into the air preheater, which is located below. A distribution grid feeds gasification air to the bottom of the reactor. Air is blown with a high-pressure fan and enters the gasifier below the dense bed such that gas velocity is high enough to fluidise the particles in the bed. At this stage, the bed expands and all particles move rapidly. Gas velocity is so high that many particles are conveyed out of the reactor to the cyclone. As partial gasification is sufficient, residence time of the fuel is shorter, and a relatively small and thus cheap gasifier can thus be used.

Incoming bio-fuel is fed into the lower part of the gasifier above the air distribution grid. Water content is typically 20-60% (dry basis) while ash content is 1-2%. The coarse ash accumulates and is removed from the gasifier with a water-cooled bottom ash screw.

Some mechanical changes have been made to accommodate to the special nature of the fuel components to be used in the gasifier. The air distribution grid and the bottom ash extraction system have been designed in a different way to accumulate the various types of solid impurities in the feedstock (nails, screws, metal wires, concrete).

4. FUEL HANDLING

Wood supply system has been delivered by Roxon. Bio-fuel is transported by trucks in arrange of 20 km (walking floors and tipping trucks). From the unloading pit an underground conveyor lifts the fuels to a belt conveyor, which has a magnetic separator above it. The belt conveyor transports the fuel onto a disk screen. The coarse fuel fractions fall from the disk screen into a crusher, while a chain conveyor transport the fine fractions from the screen and the crushed bio-fuel to the fuel storage building.

A silo with a storage capacity of 8000 m³ insures 4 to 5 days autonomy and adequate homogenisation of the fuel mixture before it is fed into the gasifier. The discharger (screw reclaimer) of the silo has variable speed control. Supply chain is a crucial step of the process.

CFD gasification accepts a wide range of moisture content (from 20% up to 60%) and particle dimensions (length + width +height) up to 15 cm. On a yearly basis up to 10 to 15% of the coal consumption i.e. 50,000 tons can be avoided (depending on wood low heating value).

5. FUEL CHARACTERISATION

The gasifier uses either wood chips originating from forestry or recycled (cleaned) wood residues from the wood manufacturing industry (Table 1).

Table 1: Available local bio-fuels on yearly basis

<table>
<thead>
<tr>
<th>Bio-fuel</th>
<th>Ratio %</th>
<th>Moisture content (% mass dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saw dust</td>
<td>10</td>
<td>45-55</td>
</tr>
<tr>
<td>Wood residues (bark, wood chips.)</td>
<td>40</td>
<td>45-55</td>
</tr>
<tr>
<td>Dry wood residues</td>
<td>50</td>
<td>10-20</td>
</tr>
</tbody>
</table>

| Industry (plywood, particle board, cuttings, metal wires, concrete). |

Enough dry recycled wood bio-fuel is available in the surroundings of the plant, significant quantities originating from the local prosperous chipboard industry. Those residues are ideal for energetic efficiency since they are dry.

Nevertheless recycled wood is sometimes too dry resulting in too high operating temperatures since primary air flow cannot be reduced under a minimal value. This necessitates the addition of wet wood chips.

It turned out also that recycled wood contained much non-ferrous material (aluminium) that was not filtered by the magnetic separator, resulting in high concentrations in the ashes and slagging of the reactor. This issue has been
recently solved by the installation of a Foucault eddy-current separator. Eddy-current systems are ideal to separate valuable non-ferrous metals such as aluminium, copper and similar from non-metallic recycling products and recover thus a clean bio-fuel.

6. CO-FIRING SYNGAS INTO COAL BOILER

Fluidisation air of the gasifier is heated up via a co-current concentric pipe: the syngas flows from the cyclone into the inner part and the fresh air into the outer part, resulting in air pre-heating up to 300°C and syngas cooling to about 750°C. This means that one does not need a tubular heat exchanger and has no fouling nor leakages. The syngas duct is an externally-insulated, high-alloy pipe section along the concentric air-heating part and is refractory lined after the concentric exchanger.

Syngas is led at 750°C to two dedicated burners, which are located within the pulverised coal boiler below the coal burners (Fig.3).

![Figure 3: Lay-out of the Foster Wheeler co-gasification system at Ruien power plant.](image)

The design of the syngas inlet is unique and heavily based on computational fluid dynamics (CFD). Modelling work performed by Laborelec used the code developed at Stuttgart University (IVD). Special attention has been given to the layout of the syngas duct, which has an outside diameter of about 2 meters (Fig. 4).

![Figure 4: Lay-out of syngas duct.](image)

From the process point of view, the major difference compared to the gasifiers in the mid-80’s [6,7] is that fuel will not be dried in this application although its moisture content can be up to 60% (dry basis). For this concept a low gas quality is quite sufficient and therefore no pre-drying or milling of the biomass and no hot gas cleaning or gas cooling is necessary. This reduces the costs dramatically compared to all other concepts, which need a clean, dust and tar-free high quality gas for the use in gas engines or –turbines (Fig. 5).

![Figure 5: No pre-drying nor gas cleaning is required (Courtesy Verbund/Andreas Mory).](image)

7. CONTROL AND INSTRUMENTATION

In normal operation, the fuel feed rate defines the output level of the gasifier and the air feed rate controls temperature. Nominal temperature level is 850°C.

The sophisticated C&I system allow manual or automatic operation and manages the complicated switch from combustion to gasification mode (or reverse). The gasifier starts in combustion mode. The problem during the switching period to the gasification mode is the enormous change of the specific air demand and the high temperature transient that is related to it. So the biomass flow has to be controlled to keep the system in safe conditions. Further on the control logic is reverse in the two operation modes and has to be changed from airflow to fuel flow control. Standard control system of the boiler manages coal flow according to syngas generation rate.

7. PERFORMANCES

Overall efficiency is about 34%, resulting from the combined efficiencies of the existing boiler (about 36%) and the gasifier (about 98%).

Generated renewable power depends strongly on the moisture content, ranging from 38 MWth with 60% moisture (dry basis) up to 86 MWth with a moisture content of 20% Energetic content of the syngas takes three different forms: sensible heat (flue gas), latent heat (fuel gas) and fine char particles. When the fuel is wet, low heating value of the gas is very poor. Typically, when the fuel moisture is about 60% the calorific value is only about 2 MJ/Nm³ and latent heat and sensible heat are approximately equal. Ratio between latent heat and sensible heat increases when moisture content decreases, sensible heat being only 20% of latent heat with a moisture content of 20%.

Nominal capacity is 50 MWth with a moisture content of 50%, resulting in net nominal electrical power of 17 MW and, in expected yearly generation, of about 120 GWh green power. This is for Belgium and Flanders Region, a significant increase of the power produced from renewable energy sources. By using biomass instead of coal, about 9% of the coal is substituted by syngas on a yearly basis and fossil CO₂ output is reduced by 120,000 ton/year.
The gasifier has operated 2650 hours in 2003 with an averaged power level of 22 MW. The plant is the first source of green certificates in Flanders in the year 2003. Technical problems were mainly encountered when firing recycled wood instead of fresh wood and can be summarised as follows:
- due to faulty design, leakage in concentric primary air pre-heater resulting in fire in the syngas channel;
- degradation of refractories inside the reactor;
- two times congestion of cyclone and return leg that could be caused by faulty design or excessive lime injection for sulphur reduction;
- blockage of ash screw due to slagging related to non ferrous metals within feedstock;
- congestion of steam ejectors at the top of the gasifier (this is a required safety equipment in the case of emergency shutdown of the gasifier);
- fouling of the syngas burners in the coal boiler;
- mechanical breakages in the wood supply system;
- fire in the dust filter of the wood supply system;
- faulty working of some measurements.

8. ENVIRONMENTAL IMPACT

8.1. Gaseous emissions

It turns out that co-gasification has a very positive environmental impact. From calculations and reference pilots [8], following conclusions can be drawn.
- \( \text{SO}_x \)-emissions decrease because of the low sulphur content of the wood compared to coal.
- \( \text{NO}_x \)-emissions decrease by 10 to 20% due to the lower temperature of the syngas compared to the boiler (in this particular case no reburning effect since syngas is injected in the oxidation zone of the boiler below).
- Dust emissions will remain at the same level or will decrease due to the low ash content of the wood and the fact that most ash will stay in the gasifier after separation by the cyclone.
- CO-emissions will not be affected and can be controlled easily.
- A slight increase of some heavy metals emissions might occur when firing recycled wood, but the base level remains low.

8.2. Waste Residues

The gasifier bottom ash contains less than 3% unburned carbon, with typical values below 0.5%. The bottom ash consists in bed material (sand and limestone) and inert material from the gasified biomass feedstock. Due to its composition this bottom ash can be used in the cement or construction industry as raw material.

Due to the low percentage of ash in the syngas no changes in the main boiler fly ashes characteristics was noticed and they remain re-usable in the cement industry.

9. CONCLUSIONS

Bio-fuels have many environmental benefits compared to fossil fuels and co-gasification is one of the most appropriate conversion technologies and one of the less risky processes for green power generation.

Electrabel has participated to the demonstration of co-gasification and has implemented the technology at a large industrial scale. It leads to significant reduction of coal consumption and offers substantial advantages in view of European and Belgian environmental objectives (reduction of fossil \( \text{CO}_2 \) and acid gases emissions in the air).

A simple technical concept with re-use of existing power station infrastructure and gasifier of small size yield low investment and operating costs.

Key-advantages of co-gasification are recalled below.
- No milling of the biomass is necessary.
- No pre-drying of the biomass (40 to 75% water content), because high gas quality is not required for co-firing in a stable coal flame.
- Partial gasification with residual fine char particles requires a shorter residence time, what leads to a small gasifier design.
- No gas cooling is needed: producer gas is led at high temperature to the boiler and no condensation of hydrocarbons is possible.
- No hot gas dust removal equipment for the syngas is required, residual char dust particles are small enough for complete combustion.
- Reduction of NOx emissions is obtained by reburning effect or temperature cooling effect in the main coal boiler.
- Sulphur content of wood is low and so are \( \text{SO}_x \) emissions controlled by lime injection
- Efficiency of the biomass conversion is almost as high as of a coal-fired unit (34%).

10. REFERENCES