GASIFICATION IN A CFB-REACTOR – A SIMPLE AND ECONOMIC WAY OF CO-FIRING RENEWABLE FUELS IN EXISTING POWER PLANTS

by

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In 1997 AE Energietechnik implemented in the course of a EU-THERMIE funded demonstration project, together with some partners, a biomass gasifier in Zeltweg, Austria. This plant operates as a Circulating Fluidised Bed Reactor with a hot low-calorific product gas produced and transported into an existing coal-fired boiler. The thermal capacity (fuel input) is up to 20 MW_{th} *(design 10* MW_{th}*), compared to a thermal capacity of 344* MW_{th} *of the PC-boiler, a coal substitution of approximately 5%. The plant started commercial operation in December 1997 and, after a large measuring program, very promising operational records are available. In addition, some gasification tests with alternative fuels (waste wood, different plastics) were carried out. They have also produced some interesting results and proved the plant's suitability for such a purpose. This concept can be seen as a very economic way to increase the share of renewable fuels in fossil-fired power plants where the equipment is originally not designed for such fuels.*

Introduction

Biomass has considerable potential for future energy supply, offering substantial advantages for environmental protection and much shorter CO_2-circuits compared to fossil fuels. But due to the low specific volumetric energy density and the consequently high transport and handling volume, biomass is not suitable as main fuel in large biomass fired power plants. On the other hand, decentralised small power plants with biomass as main fuel have much higher specific investment and operational costs and therefore a poor economic prospect. Therefore the co-firing of biomass in existing coal-fired thermal power plants is a possible solution.

The capacity of the co-firing installations can be ideally adapted to the local biomass availability, which is mainly limited by the transport distance.

A significant advantage of this co-firing concept is the benefit of an existing plant: The share of many parts can keep the investment costs low. This way, small amounts of biomass can also be converted into electricity at high efficiencies.

EU-demonstration project at Zeltweg power plant

BioCoComb concept

Under the title *BioCoComb* – preparation of *bio*fuel for *Co-Comb*ustion – a biomass gasifier for bark, wood chips and sawdust was installed at the Zeltweg power plant. The project has been realised by Verbund as project leader (and owner of the power plant) and AE Energietechnik as main supplier, together with four partners – EnBW/Germany, ELECTRABEL/Belgium, ENEL/Italy and ESB/Ireland. The Technical University of Graz provided scientific advice.

In this reactor the biomass with a maximum particle size of 50 mm is converted into a low-calorific-value (LCV) gas, also containing fine char particles. This ”biogas” can be easily burned in the coal boiler as additional fuel. The energy of the fuel is transported to the coal boiler in three different forms via sensible heat, LCV-gas and fine combustible char particles. Due to the very low heat losses, the efficiency of the biomass conversion into electricity is almost as high as of the coal-fired unit.

In the gasification process the biomass is combusted in a substoichiometric atmosphere. That means, that only the first steps of the combustion process – drying of the fuel, pyrolysis and (partial) gasification of the char – take place in the gasifier. So the heat required for the biomass gasification is produced from the fuel itself (autothermal method). The final burnout of the produced syngas is performed in the main coal boiler. This way, the gasifier can be considered as a ”thermal mill” for biomass fuels. Figure 1 shows the principle flow sheet of the plant.

The main features of the Zeltweg-concept are the following:

- Adiabatic system: gasifier, cyclone, product-gas duct completely refractory-lined
- Primary/gasification air is taken from the secondary air system of the coal boiler (preheated air, therefore giving better gas quality and better efficiency),
- Burnout of the syngas with the available excess air in the coal boiler, and no separate air supply. Adjustment of excess air by slight changes of the coal/air ratio of the coal burners (automatically via correction of coal heating value),
- Start-up burners installed directly in the combustion chamber of the gasifier, and
- Changeover from combustion to gasification by increasing the fuel input, causing a sudden change of the thermal heat input.

Gasification is realised in a separate, circulating fluidised bed reactor. The CFB is characterised by the intensive motion of the bed material. Therefore all the well-known advantages of the CFB in combustion technology, such as fuel flexibility, moderate and smooth temperatures over the reactor *etc.,* are also valid for the use of this reactor in gasification processes.

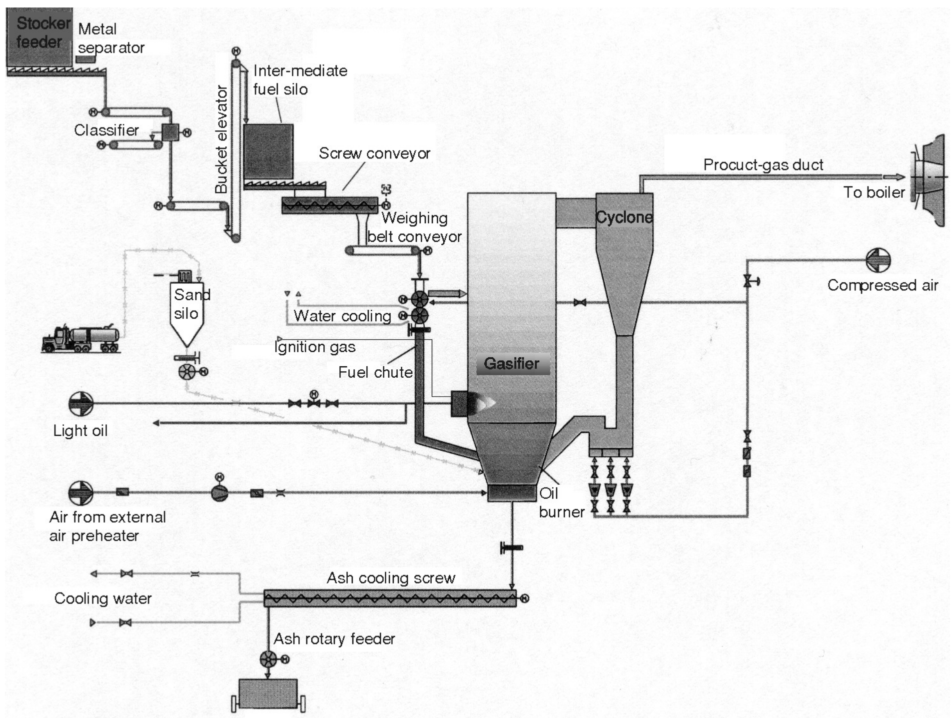

Figure 1. Flow diagram of *BioCoComb*-process

The only modification at the existing boiler was the installation of an opening for biogas-injection. Also no adaptations concerning control and instrumentation equipment were required. The coal boiler can still be operated with the gasification plant shut down. Figures 2 and 3 show the arrangement of the gasifier.

A gasifier with a small hot gas duct, which results from the reduced gas volume compared to the combustion process, offers high flexibility in integrating the main components into existing plants. The gasification unit does not need to be located in the immediate vicinity of the combustion chamber of the coal boiler. In the demonstration project at Zeltweg, the gasifier is installed outside the boiler house, approximately 22 m from the boiler.

Innovative features of BioCoComb concept

- CFB also as gasification reactor is very flexible for a wide range of fuel types.
- No preparation of the biomass is required as the poor gas quality is sufficient for co-firing in a stable coal flame.

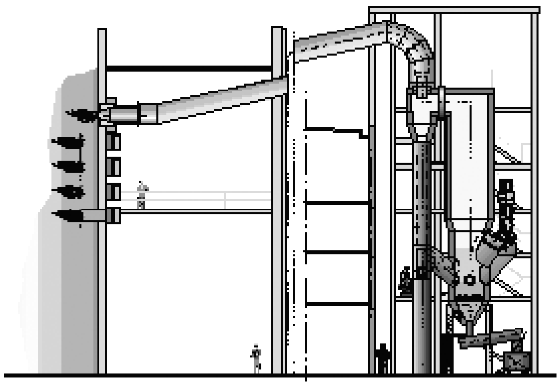

Figure 2. ***BioCoComb*** **gasifier and its connection to the boiler**

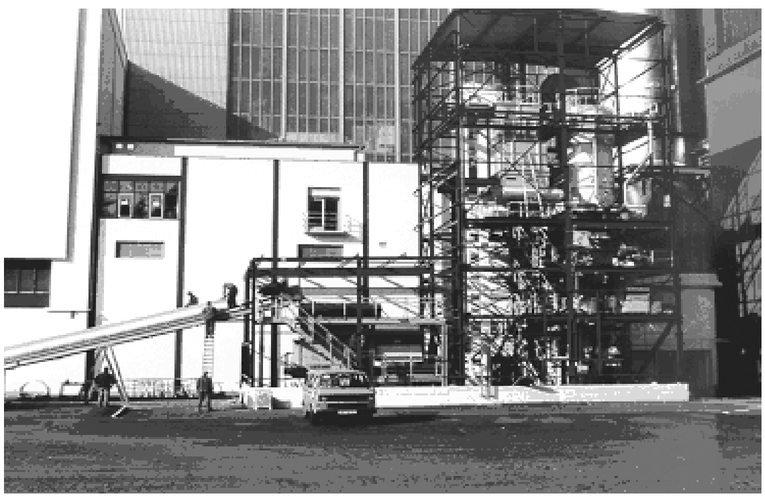

Figure 3. CFB gasifier during final stage of erection

- Partial gasification of the biomass is sufficient and even desirable. The fine char particles carried out with the gas are burned in the coal boiler. The maximum particle size of the char particles is limited by the retention cyclone. Therefore burnout is guaranteed.
- Partial gasification requires a shorter residence time, which leads to a smaller gasifier design.
- No gas cooling and cleaning. Problems due to tar condensation are avoided.
- Relatively low and even temperatures in the gasifier prevent slagging. The produced gas can be burned at higher temperatures in the furnace of the coal boiler.
- "Reburning effect" of the syngas in the coal boiler. As a result additive consumption (NH_3) in the SNCR plant decreased by around 20%.

- The efficiency of the conversion of the biomass into electricity is almost as high as for the coal in a coal-fired unit.
- Only minor modifications of the existing coal fired boiler are necessary.

Fuels

During the first operating period (1997/98) mainly biomass (bark, chopped wood, saw dust, see Table 1) was used as fuel.

Table 1. Characteristic data of biomass fuels

	Humidity % by wt	LHV MJ/kg	Spec. weight kg/m³
Spruce bark	50–60	6.2–8.2	280–380
Chopped larch wood	35	10.9	300
Larch sawdust	40–50	8.2–10.5	250–320

Accompanied by a very extensive measuring program, in the second operating period (1999) additional fuels were fired together with biomass up to a maximum mixing ratio of 50%. These make-up fuels (see Table 2) mainly comprised railway sleepers, waste wood, plastic materials (PVC free), sewage sludge, and sorted residues from electronic shredder material (*e. g.* plastics and casings).

Table 2. Characteristic data of all fuel mixtures

	Humidity % by wt	LHV MJ/kg	Spec. weight kg/m³
Bark, chopped wood	56	6.8	360
Bark, chopped wood, railway sleepers	48	9.2	320
Bark, chopped wood, waste wood	48	8.3	320
Bark, chopped wood, plastics (PVC-free)	58	6.4	310
Bark, chopped wood, sewage sludge	46	8.5	350
Bark, chopped wood, electr. scrap material	48	8.8	310
Bark, chopped wood, mixture of all fuels	57	6.5	330

Within the measuring program, the following measurements were made:

- Pressure and temperature profiles in the gasifier (see Fig.4),
- Analysis of the bed and siphon materials of the gasifier,
- Composition of the product gas,

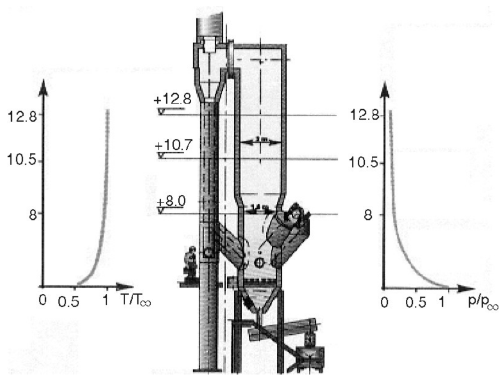

Figure 4. Temperature and pressure at different levels of the reactor

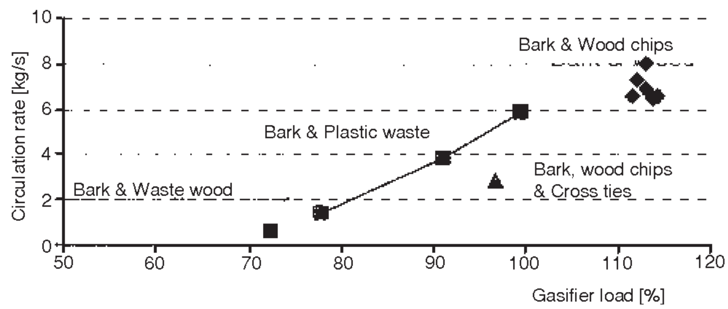

Figure 5. Circulation rate

- Velocity profiles within the gasifier, and
- Determination of the recirculation rates within the gasifier (see Fig. 5).

Scale-up

The 10 MW_{th} Zeltweg gasifier was designed as a small demonstration unit for biomass fuels. To widen the range of fuels (esp. high calorific fuels) as well as for the implementation of bigger units, some modifications may be necessary to allow safe, stable and comfortable operation.

These modifications in comparison to the original Zeltweg design and also the advantages that can be achieved are listed as follows:

- Installation of the *start-up burners* in a *separate combustion chamber*:
- No burners inside the gasifier itself (except eventual bed lances)

Advantages:

- Less openings in the reactor (potential escape of hot, explosive syngas).
- No input of cooling air into the gasifier necessary (which leads to poor gas quality, temperature peaks,…).
- No pollution and associated disturbances of the burners.
- ”Self-inertisation” possible (creation of ”Flue gas”).

Installation of a *separate combustion air supply* at the syngas injection point at the coal boiler:

- Taking the combustion air from the secondary air system of the coal boiler.
- Quantity of this ”burnout air” is calculated as equal to the total combustion air necessary for the actual fuel input (resulting from combustion calculation) minus the actual air flow directly into the gasifier.

Advantages:

- Sufficient air supply for complete burnout of the biomass is ensured, both in combustion as well as in the gasification mode, independent of the excess air provided by the coal flame in the main boiler (O_2-content in the flue gas of the coal boiler is secured)
- No changes of the fuel/air ratio of the coal burners necessary to make excess air available for the syngas burnout (important for Low-NO_x-burners).
- Changeover from combustion to gasification only by ”shifting” the feeding point of the burnout air from the gasifier to the syngas nozzle at the coal boiler (and vice versa).

Installation of a *flue gas recirculation system* (with recirculated flue gas from the main boiler directly into the windbox of the gasifier):

- Installation of a separate small flue gas fan or – alternatively – a control damper in the suction duct of the gasification air fan for control of the ratio of air and recirculated flue gas (during normal operation only air supply is necessary).

Advantages:

- Constant operation in cases of low oxygen demand (very low load and/or high calorific value fuels) is possible. Thus the required minimum fluidisation of the bed material is ensured by replacing part of the air with recirculated flue gas.
- Changeover from combustion to gasification mode can be accomplished by decreasing the oxygen input into the gasifier (and replacing the air with recirculated flue gas if necessary) at constant fuel flow rates. This avoids sudden changes of thermal heat input into the main boiler (especially when firing high-calorific-value fuels with great differences concerning the required fuel/air ratio between combustion and gasification modes).
- Full load range of gasifier, also for high calorific value fuels.

Economy

The economy of the *BioCoComb* process can be demonstrated by showing the electric power production cost depending on the cost of the biomass and the annual operating hours. For this calculation a gasifier with a thermal capacity of 50 MW together with the following frame conditions is assumed:

- Plant lifetime 10 years
- Interest rate 6% p. a.
- Power plant efficiency 40% net
- Cost of revisions per year 1.5% of the investment cost (based on 8000 h/yr.)
- Ash disposal cost 75 € per ton
- Fuel Biomass mixture with average humidity of 40%

The investment cost comprises the complete gasification plant from the internal fuel system up to the openings in the membrane wall of the boiler, the field instrumentation and the tie-in to the power plant control system. The construction of the biomass storage facilities is not considered.

For operation of the plant, an additional personnel cost of 3 men (1 man per shift, 3-shift operation) is assumed in this calculation. However, experience at the demonstration project of Zeltweg has shown that the power plant staff, without additional personnel, can operate the gasification plant as well.

The specific investment cost for a *BioCoComb* plant of a thermal capacity of 50 MW amounts to approx. 400 to 500 €/kWh_{el}, which is clearly less than the target value of the European Commission. The electric power production costs are illustrated in Fig. 6. If waste wood and residual wood were fired, it can be assumed that there will not be any fuel cost, so that the actual electric power production cost would be lower than 0.02 €/kWh.

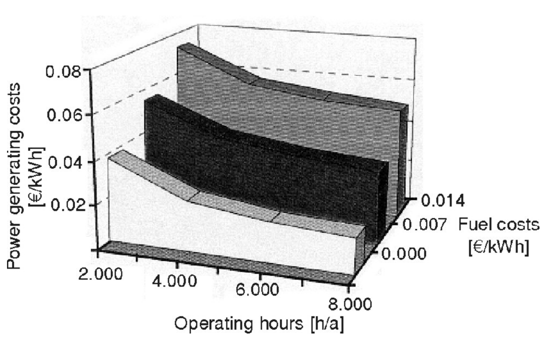

Figure 6. Electric power production cost depending on price of biomass and on annual operating hours for a gasification plant of capacity 50 MW_{th}

Conclusion

In 1997, a gasifier of a thermal capacity of 10 MW firing bark, chopped wood, sawdust, *etc.* was installed at the 137 MW_{el} PC boiler of Zeltweg power plant, Austria. This *BioCoComb*-demonstration plant succesfully prepares biomass for co-combustion as an additional fuel, replacing 3% of the total input of hard coal.

Based on the experience with this application and with an appropriate scale-up, it is possible to increase considerably the share of biomass in the production of electricity in existing power plants fired with fossil fuels.

Parallel to the further optimisation and research into the gasification process, the combination with a gas engine or a gas turbine sometimes seems to be an attractive alternative. However, this is more expensive than the *BioCoComb*-concept concerning investment and operation costs and still affords many research activities especially in the cleaning and cooling of the biogas or the dimensioning and adaptation of the gas turbine.

The ready-to-use *BioCoComb*-concept ensures the conversion of biomass to electricity at high efficiencies, but also tolerable investment and operating costs without major modifications of the present equipment.

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