COGENERATION FROM BIOMASS GASIFICATION BY PRODUCER GAS-DRIVEN BLOCK HEAT AND POWER PLANTS

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ABSTRACT: Highly efficient bioenergy plants based on gasification and IC-engines are considered to be very profitable for industrial combined heat and power generation (CHP) in the range of 5 - 20 MW fuel input capacity. Fraunhofer UMSICHT has developed a process characterized by air blown CFB-gasification, catalytic gas upgrading and producer gas utilization in a block heat and power plant (BHPP) with internal combustion engine (IC-engine). The process has been successfully tested at a pilot-scale plant with 0.5 MW fuel input capacity. Partner for the gas engine BHPP is G.A.S. Energietechnologie GmbH, D-Krefeld (see V3.21). In this paper up-to-date performance data of the pilot plant are presented and successful solutions for major operational problems such as tar reduction in the gasification part are disclosed. Since R&D-work at pilot-scale is nearly finished today, the next step in technology development will be the construction of a pre-commercial demonstration plant of about 5 MW fuel input capacity. That is why the final section of this paper deals with the very promising economic prospects of this technology.
Keywords: gasification, tar removal, economic aspects

1 INTRODUCTION

World wide huge scientific effort is being spent to develop processes for highly efficient combined heat and power generation (CHP) from solid biomass. A promising option in the lower to medium power range could be the operation of gas engines on producer gas from solid biomass gasification.

Several processes based on this concept have already been realised and investigated in pilot plant scale. However, commercialisation has not been reached so far. A common technical hurdle are tar components within the product gas that condense upstream and inside the engine.

2 THE FRAUNHOFER UMSICHT PROCESS

During the past 8 years Fraunhofer UMSICHT and G.A.S. Energietechnologie GmbH have conjointly developed an innovative process for highly efficient co-generation from solid biomass in the medium power range. As figure 1 shows, the process is characterised by atmospheric air blown circulating fluidised bed- (CFB-) gasification, catalytic producer gas upgrading, and producer gas utilisation in a block heat and power plant (BHPP) with internal combustion engine (IC-engine).

The chosen technique of gasification in a circulating fluidized bed (CFB) enables the transformation of a wide range of solid biofuels into flammable gas. At the same time, the CFB-gasifier operates very reliable and regularly.

The envisaged power range for a future commercial application of this process will be about 10 – 15 MW fuel input capacity, i.e. approx. 15,000 – 22,000 t/a of biomass (dry conditions). With this input 3.0 - 5.0 MW electrical power will be generated at a total electrical efficiency of 30 - 33 % which is considerably higher than the typical efficiency of a common combustion plant with steam boiler in the same range of performance.

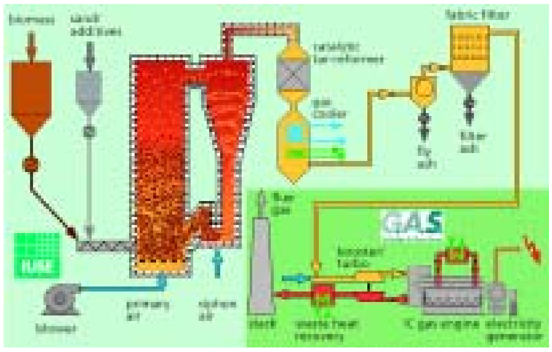

Figure 1: Process scheme: CFB gasifier with catalytic gas treatment and block heat & power plant (BHPP) with IC-engine

2.1 The Pilot Plant in Oberhausen

The past development work has been carried out at a pilot plant of 0.5 MW fuel input capacity which corresponds to a biomass consumption of about 80 - 120 kg/h. The produced gas can be burnt in a combustion chamber with a natural gas incinerator or be fed into an IC-engine. Figure 2 shows a photograph of the whole plant, figure 3 gives a partial view inside. The pilot plant is already automated to a great extent and conforms to industrial standards respecting its technical equipment.

The plant's goal was and still is to demonstrate the technical feasibility of the whole process including tar reduction and to optimise its operation. In the past years, the whole system - from biomass gasification to product gas burning in the IC-engine - has been tested successfully. Until April 2002 the pilot plant ran for about 1600 h in gasification mode and for 250 h as complete process with gas engine-BHPP application. The longest period of continuous operation with electricity supply to the grid lasted 150 h. It was only limited by logistic boundary conditions and monetary reasons. There was no indications for any problems arising at longer operational periods.

Throughout the whole test the CFB-gasifier allowed a very stable gasification with only little variations in gas composition. Operating average temperatures right downstream the CFBG reactor were about 915°C. Downstream the reformer producer gas temperature decreased to about 880°C due to endothermic reactions inside the reactor.

The composition of the produced gas showed 32 - 35 % of the volume to consist of combustible components namely carbon monoxide, methane and hydrogen. The yielded heating value was approx. 4.5 – 5 MJ/m^3 (s.T.p. wet, see fig. 3).

Figure 2: 0.5 MW-pilot plant in Oberhausen; left side: gasifier building, right side: drying plant and BHPP with gas engine

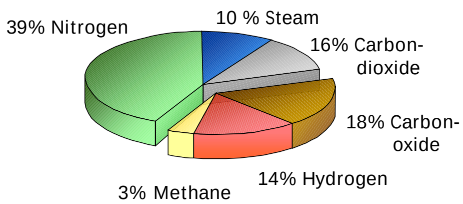

Figure 3: Main components of the producer gas generated in the pilot plant at UMSICHT

2.2 Tar Reduction

Tar reduction was one of the key technical challenges during the past project work. Hence, development of the gasification process was particularly focussed on the production of a tar-free producer gas suitable for a combustion engine.

After having tested several measures it turned out that the key to success is a catalytic decomposition (reforming) of the emerging tars. It makes wet scrubbing dispensable and the calorific value of the tars applicable to an engine. By choosing an accurate setting and operation mode for the fluidized bed in the gasifier and by using a downstream catalytic tar converter (fig. 4) a high quality-fuel gas can be generated which can be continuously burned in an IC-engine trouble-free after it has passed a fabric filter.

The maximum acceptable concentration of tars (defined as: hydrocarbons > Xylene) has been set to 50 mg/Nm^3 by the engine manufacturer. This limit could be under-run permanently by the combination of thoroughly selected bed materials, hot gas reforming, and fabric filtering of the producer gas during test operations (fig. 5).

No deactivation of the catalyst was observed over many hundred hours (time on-stream). As an indicator for the successful tar removal the fabric filter's operation was trouble-free all the time. Its cleaning cycles stayed constant during the whole 150 h test run (fig. 6).

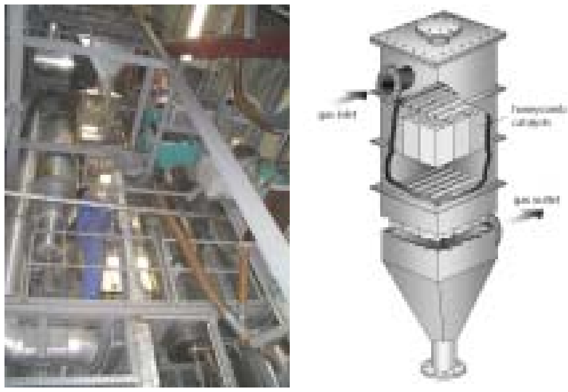

Figure 4: Left side: inside view of the gasification plant; right side: catalytic reformer for tar removal

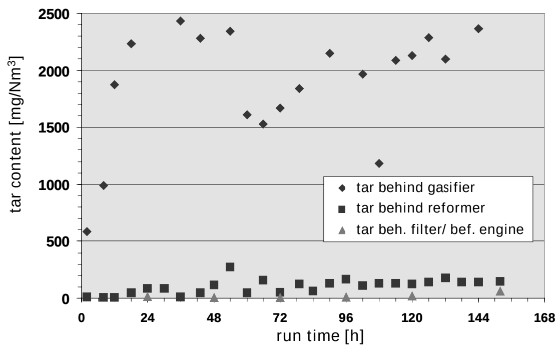

Figure 5: Tar content at gasifier exit, at reformer outlet, and after dust removal vs. time

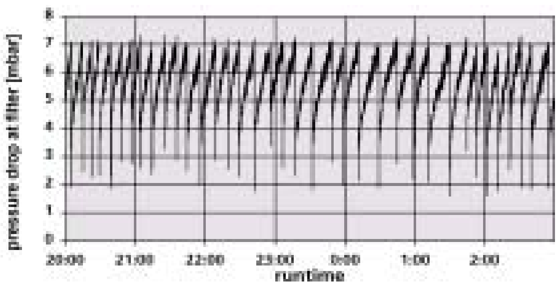

Figure 6: The regular cleaning cycles of the fabric filter are proof for a tar-free producer gas

2.2 Engine Performance

The pilot plant is equipped with a turbo-charged 6-cylinder 4-stroke gas engine (type Deutz MWM) delivered by G.A.S. Energietechnologie GmbH (see fig. 7 and contribution V3.21). For operation on producer gas from wood gasification, gas train, turbocharger, and operating conditions of the engine (lambda, time of ignition) were changed.

During the non-stop test run of 150 hours, approximately half the producer gas was fed into the engine, whereas the other half of the gas was fed into the combustion chamber of a biomass belt dryer. In future commercial plant feedstock drying will be realised with waste heat.

With this gas input an electrical output of 40 kW was achieved which means an engine derating of 20 % compared to natural gas. The emissions of CO and NOx were 1000 and 200 mg/Nm^3, respectively (at 5 % O_2). This means that the NOx-limit of the German TA Luft of 500 mg/Nm^3 was met, whereas the CO-limit of 650 mg/Nm^3 was exceeded.

Based on the many experiences gained with the pilot plant so far it can well be summarised - at least for the utilisation of non-contaminated forest wood chips - the gas engine is running without problems on the producer gas generated by CFB-gasification and hot gas tar reduction. The main expectations concerning performance and efficiency can be met.

Figure 7: The BHPP-container and the belt dryer for biomass feedstock at the pilot plant in Oberhausen (top view)

3 FURTHER DEVELOPMENT AND FUTURE PROSPECTS OF THE TECHNOLOGY

Since the development has successfully reached the pilot scale the next step is a pre-commercial demonstration plant (fig. 8). With a fuel capacity of 5.0 MW, i.e. 1.5 MW_{el} respectively, it will represent an intermediate stage between a commercial size and the already existing pilot plant.

From the present point of view the construction of the demonstration plant will start in the end of 2002, so that the further commercialization of the technology can begin in 2004. The process will primarily be applied to unpolluted biomass such as wood chips, bark, coarse lumber shavings or sawdust.

Economical analyses show that plants of a commercial scale of 10 – 15 MW fuel input enable rather attractive fuel prizes after the initial start up phase. Figure 8 depicts the expected decrease of the specific investment due to scale up and due to the increase in the number of constructed plants. The corresponding biomass price which is tolerable due to usual profit expectations is depicted for several szenarios.

Figure 8: Design of a pre-commercial scale demonstration plant; capacity: 5.0 MW_{th} fuel input (approx. 1000 kg_{dry}/h), i.e. 1.5 MW_{el}

Currently it is considered that the demonstration plant will cost about 3,900 €/kW_{el}. At these costs no economic operation will be possible. That is why the demonstration plant vitally requires public funding.

However, with the experience gained by the operation of a demonstration plant we will be able to engineer and erect a first standard plant of 12.5 MW fuel input capacity. Due to up-scaling effects on the one hand and technical simplifications on the other hand, cost reductions down to about 2,750 €/kW_{el} for the first standard plant seem to be realistic. From that time on, every doubling of the number of standard plants built could reduce the specific investment costs by 10 percent (see figure 9). This is a conservative assumption.

With that background, the system is considered to be very profitable for combined heat and power production in the range of 5 - 20 MW fuel input capacity in the long term. Due to the high process efficiency (net electric efficiency is considered to be about 26 to 29 %) fossil fuel substitution will be maximised whereas specific investment costs will be kept rather low. In combination with a fixed 9.25 Cent/kWh_{el} reimbursement for electrical energy production from renewables (guaranteed by German law since April 2000) this will make the process economically very interesting and less vulnerable against rising biofuel costs in comparison to conventional steam plant technology (see figure 9).

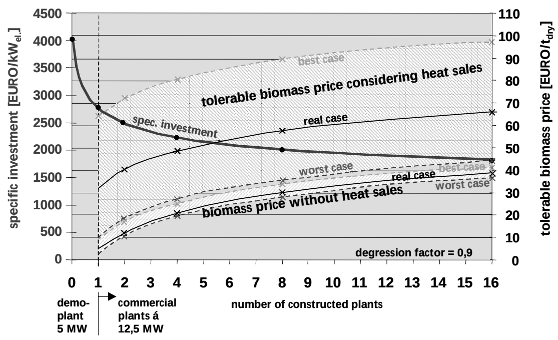

Figure 9: Expected decrease of spec. investment and increase of tolerable feedstock price with increasing number of constructed plants

The tolerable fuel prizes rise further if there are significant revenues from selling heat besides the legally assured revenues for green power (for feedstock drying or for district heating purposes e.g.). Besides, utilisation of waste heat from co-generation maximises energy efficiency and positive ecological side effects of bioenergy application

After the successful launch of the process into demonstration phase a competitive technology will be available which matches the present demands for sustainable bio-energy plants to a great extent.

4 CONCLUSION

Fraunhofer UMSICHT's efforts to develop a highly efficient process for bioenergy conversion based on gasification have been successful. Current pilot-scale investigations will come to an end in the near future and a pre-commercial demonstration project is to be launched soon. Economic prospects for further commercialisation in the 3.0 - 5.0 $MW_{el.}$ power range are very promising.

5 SPONSORS

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