

**INTEGRATED BIOMASS GASIFICATION AND GAS
CLEANING FACILITY;
ECN PILOT-PLANT FOR BIOMASS RESEARCH**

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ABSTRACT: Gasification of biomass converts biomass of various shape and origin into product gas that, after cooling and cleaning, is suitable for the production of electricity, heat, chemicals and fuels. Dust, tars, and ammonia are the main components in product gas that need removal. Based on ten years experience, ECN has extended its existing test infrastructure and commissioned a complete integrated facility for research on biomass gasification, gas cooling and cleaning, and gas applications. In the last quarter of 2003 and first months of 2004, a complete operational test programme has successfully been carried out for the different units and system configurations. Results showed that the system could be optimised for each gas application.

Keywords: gasification, gas cleaning, combined heat and power generation (CHP).

1 INTRODUCTION

Gasification of biomass into product gas can convert biomass of various shapes and origins into an energy source of more constant quality, suitable for direct combustion, application in prime movers like engines, turbines, and fuel cells, or for the production of synthetic natural gas (SNG) and transportation fuels (*e.g.* Fischer-Tropsch diesel). Dust, tars, and ammonia are the main components in product gas that interfere with applications (fouling), result in waste streams (condense water), or lead to unacceptable emissions (*e.g.* NO_x). Therefore, the raw product gas from the gasifier needs to be cooled and cleaned to meet the demands of the selected application.

2 PILOT INFRASTRUCTURE

Based on ten years experience, ECN has extended its existing test infrastructure and commissioned a complete integrated biomass gasification and gas cleaning facility in 2003. The facility is available for research on all aspects of gas cooling,

cleaning, and application (Figure 1). In the next sections the system units are described in more detail. Numbers in parentheses {} refer to numbers in Figure 1.

2.1 Gasifier {1}

CN Biomass operates a 500 kW_{th} circulating fluidised bed (CFB) gasifier with a typical feed rate of 80-100 kg/h that produces approximately 200 m_n³/h of wet gas. The installation was commissioned in 1996, primarily to test the gasification behaviour of different fuels to support the design of commercial installations. A wide variety of fuels and fuel mixtures have been tested since, comprising clean wood, waste wood, straw and grassy materials, RDF, sludges, and manure [1]. The installation is equipped with two different feeding systems to allow feeding of biomass materials of different forms and properties, *e.g.* chips, pellets, fluffs, and powders. Typically, the gasifier operates at atmospheric pressure with air as gasification medium. In several tests an oxygen/steam mixture has been used. The gasification temperatures range from 750 to 950°C.

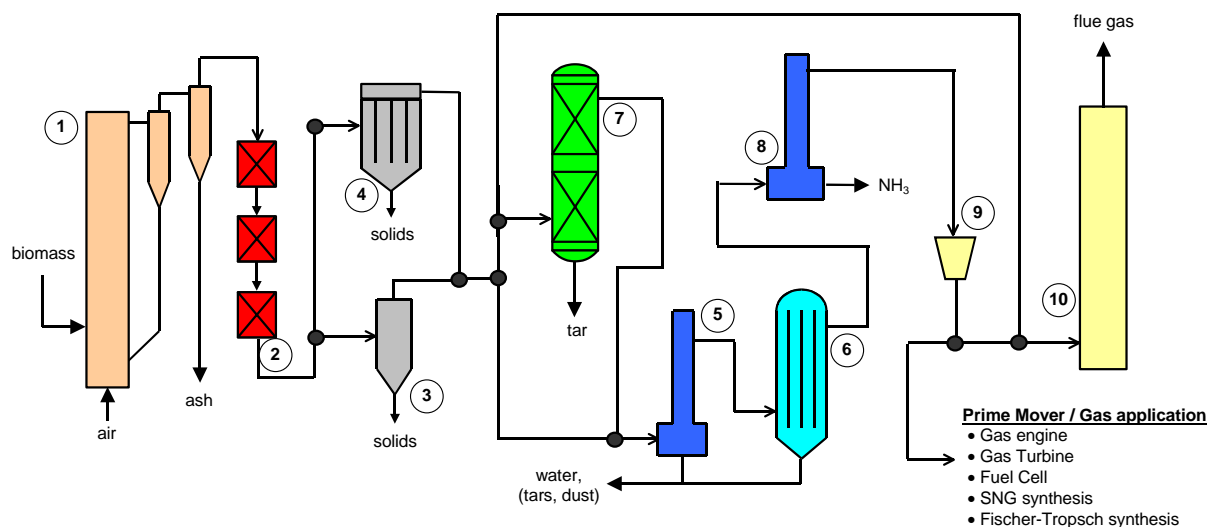


Figure 1: Complete line-up (gas-side) of integrated biomass gasification and gas cleaning facilities at ECN. Numbers are explained in the text. The black circles indicate connections and valves. *Process integrations of heat and residual streams (i.e. NH_3 and tars to gasifier) are not shown.*

2.2 Gas cooler {2}

The raw hot product gas is cooled in a three-stage double-pipe cooler with air as cooling medium. In this way the combustion air of the burner {10} is pre-heated. The three stages are connected by two 'deposition chambers' in which probes are placed to study temperature and fuel dependent deposition and fouling phenomena. The air flow rate through the three stages allows control over the gas temperature in the 'deposition chambers' and the gas outlet temperature. In normal operational mode the second (hot) cyclone is bypassed to ensure a high solids load in the gas passing the cooler. As a result, deposition in the cooler is continuously physically removed.

2.3 Dust removal {3} and {4}

Typical product gas from CFB gasification contains 6 to 20 g/m_n^3 of dust. The actual value mainly depends on the ash content of the fuel. As the second (hot) cyclone is bypassed, the gas still contains the full dust load after cooling. For dust removal two units are present: a cyclone and a hot gas filter. The cyclone {3} operates at 300°C and removes approximately 90% of the solids; the removal efficiency for small particles is lower. The hot gas filter {4} with sinter metal candles operates at 350 to 400°C and removes essentially all solids

present in the gas. The filter is periodically purged. Purge gas can be either (pre-heated) nitrogen, cleaned product gas, or a CH_4/N_2 mixture with a heating value matching the heating value of the product gas.

2.4 Water-based tar removal {5} and {6}

The water-based tar removal comprises a cooler {5} and a wet electrostatic precipitator (ESP) {6}. The cooler reduces the gas temperature to approximately 20°C by direct contact with water. The cooler effectively dries the gas and removes water soluble components like HCl and NH_3 (however NH_3 removal is limited by water saturation). If cyclone {3} is used, the water also removes most dust that has passed, furthermore, part of the condensable tars promoting the formation of tar aerosols. The condensed tars are separated from the scrubbing water in a settling tank. Excess condense water is cleaned with an active carbon filter to allow disposal to the sewer

The ESP {6} operates at the cooler outlet temperature and removes all remaining solid fines and tar aerosols from the product gas. A small water flow is applied to clean the internal surfaces of the ESP. Typically the remaining tar concentration in the gas is 1 to 3 g/m_n^3 , however, as the tar dew point of the product gas is equal to the gas temperature [2], no

downstream tar condensation will occur if the gas is not cooled any further.

2.5 OLGA tar removal unit {7}

In essence, the patented OLGA tar removal unit {7} comprises a scrubber to wash the tars from the product gas and a stripper to regenerate the washing liquid ('oil'). The gas inlet temperature of OLGA has to be higher than the tar dew point (typically $>350^{\circ}\text{C}$) to prevent tar fouling upstream the OLGA. As the current design of the OLGA unit requires a dust free gas, the hot gas filter {4} has to be used upstream of the OLGA. The gas outlet temperature is kept above the water dew point to avoid mixing of condense water and scrubbing liquid [^{3,4}].

Downstream the OLGA unit, the cooler {5} again cools the product gas to ambient temperature and simultaneously dries it.

2.6 Ammonia scrubber {8} and booster {9}

Ammonia (NH_3) removal is achieved in a counter current packed water scrubber. No acid additive is used. Overall NH_3 removal efficiency in the cooler {5} and the scrubber {8} together is $>99.5\%$.

Downstream the NH_3 scrubber a booster {9} is operated to compensate for the pressure drop over the installation and to provide the small overpressure necessary to deliver the gas to the prime movers.

2.7 Low- NO_x burner {10}

Product gas from the cyclone or the hot gas filter can be combusted in the three-staged burner, using preheated combustion air from the gas coolers {2}. The burner is placed in a flame tube boiler, in which the flue gasses are cooled down to approximately 200°C . the combustion process can be optimised to minimise the NO_x emissions, by varying the amount of primary, secondary, and tertiary airflows.

2.8 Prime-mover / Gas applications

The available downstream prime mover and gas applications at ECN comprise a gas engine, SOFC stacks, a bench-scale slurry phase synthesis reactor for Fischer-Tropsch synthesis, and a micro-flow fixed-bed reactor for *e.g.* SNG, Fischer-Tropsch, or

alcohol synthesis. In the second half of 2004, a micro gas turbine will be tested.

3 OPERATIONAL EXPERIENCE

The research facility is used to support the development of three systems for commercial relevant gas applications: (1) Direct combustion or co-firing; (2) CHP with gas engines; and (3) Advanced gas applications, like turbines, fuel cells, catalytic processes, or CHP with more stringent emission regulations.

3.1 Direct combustion or co-firing {1-2-3-10}

For co-firing in a coal boiler the product gas needs only limited cooling and dedusting with a cyclone. In most cases, this line-up is also suitable for stand-alone firing in a boiler. When stringent dust emissions apply, configuration {1-2-4-10} with hot gas filter offers a possible solution.

At ECN both configurations with the cyclone {3} and hot gas filter {4} have been tested. The low- NO_x burner {10} operates stably and the NO_x emissions can be reduced effectively by staging the combustion air. A NO_x reduction of more than 75 % is measured when switching over from the unstaged combustion mode to the staged combustion mode.

3.2 CHP with gas engine {1-2-3-5-6-8-9+}

A large market is foreseen for distributed biomass combined heat and power plants. For CHP plants with a gas engine ECN aims at plant scales up to $\sim 50 \text{ MW}_{\text{th}}$ (for the Dutch market). WECN has demonstrated that a gas engine can be operated without problems on a product gas cleaned with a water-based gas cleaning in a slightly different configuration [⁵].

If cyclone {3} was used, the gas cooler {5} removes the remaining dust (approximately 2 g/m_n^3) as well as all condensable tars. Handling and separation of the resultant mixture of water, dust, and tars is the critical step in this system. Alternatively, to remove all dust upstream of the water system and simplify the water treatment, the hot gas filter {4} can substitute the cyclone {3}.

The gas cooler {5} in combination with the ESP {6} yields a gas free of dust and condensable tars, *i.e.* the tar dew point equals the gas temperature and no tar condensation will occur if the gas is not cooled any further (although still 1 to 3 g/m³ of tars may be present in the gas of which a large part is naphthalene). The ESP has proven to be a very reliable and effective unit.

With a product gas free of solids and condensable tars the ammonia scrubber {8} operates stably and efficiently. Dissolved CO₂ provides sufficient driving force for NH₃ absorption in the water, without recourse to acid additives. Therefore, the stripper can be operated without base additives. NH₃ can be removed from the water by a combination of air and temperature increase.

3.3 Advanced gas applications {1-2-4-7-8-9+}

To allow the application of the product gas in turbines, fuel cells, or catalytic synthesis more stringent specifications must be met. In comparison to the system for CHP this especially comprises the tar concentration. Essentially complete tar removal is established in the OLGA unit {7} with upstream hot gas filter {4}. Downstream the OLGA unit only some benzene and toluene is present in the gas. The outlet gas temperature typically lies between 80 and 100°C. In the gas quench cooler {5} and NH₃ scrubber {8}. The gas cooler {5} cools the gas to ambient temperature and removes all the NH₃ and HCl.

The suitability of product gas cleaned with OLGA and a wet scrubber for advanced applications has been successfully demonstrated in several lab-scale test runs. In March 2003, a fixed-bed Fischer-Tropsch synthesis reactor was operated for 500 hours on cleaned gas and in December 2003 a similar 150 hours test run was carried out to synthesise SNG or 'green gas'. In both cases, the system additionally contained a compressor to bring the gas to the desired synthesis pressure, a ZnO filter to remove H₂S, and an active carbon filter for final catalyst protection.

4 OUTLOOK: 1000 HOURS TEST

In September-October 2004 the OLGA-based system in combination with a gas engine will be submitted to a 1000 hours test. The objective of the test is to build up operational experience with the system and the individual units. To benefit at maximum from the long operational time of the installation, spin-off R&D will be carried out during the 1000 hours test, *e.g.* by monitoring process performance, varying operational conditions, and performing experiments with product gas side streams.

ECN would like to give the opportunity to colleagues in the biomass community to take part in the 1000 hours test and carry out their R&D work at our installation. Interested parties are invited to contact us and discuss the possibilities.

5 ACKNOWLEDGEMENTS

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6 REFERENCES & NOTES

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- [²] The tar dew point is an important parameter to determine if tar related problems, like fouling, could occur; the absolute amount of tars present in a gas is a much less relevant. More information on tar dewpoints and a calculation tool can be found on: www.thersites.nl (site operated by ECN Biomass).
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