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Presented at the 16th European Biomass Conference, 2-6 June 2008, Valencia, Spain

ECN-M--08-054 June 2008

THE 800 KWTH ALLOTHERMAL BIOMASS GASIFIER MILENA

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ABSTRACT: ECN is developing an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Substitute Natural Gas (SNG). The MILENA gasification technology has a high cold gas efficiency and high methane yield, making this technology extremely suitable for SNG production.
A lab-scale MILENA gasifier has been in operation since 2004. The lab-scale installation is connected to the lab-scale gas cleaning section and methanation section. Several duration tests were done with good results. The lab-scale MILENA gasifier was extended with an automated biomass feeding system, which makes it possible to do tests without operators. The gasifier is now ready for long duration Bio-SNG production tests.
The MILENA gasification technology is scaled up from 30 kWth to 800 kWth. The construction of the MILENA pilot plant is finished. The first functional tests showed that some minor adjustments to the installation (flue gas cooler) and start up procedure are required. The functional and operational tests will be continued in the summer of 2008.
Keywords: see allothermal conversion, biomass conversion, bio-syngas, gasification, methane.

1 INTRODUCTION

The production of Substitute Natural Gas from biomass (Bio-SNG, Bio-CNG or Bio-Methane) is an attractive option to reduce CO_2 emissions and replace declining natural gas reserves. The production of Bio-SNG via digestion has been developed and implemented on a small scale. The limited amount of suitable digestible feed stock demands for development of a technology which can convert a wider range of bio-fuels, like wood residue, into Bio-SNG. Gasification is such a route.

ECN (Energy research Centre of the Netherlands) is developing an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Bio-SNG. The gasification technology can also be used to produce gas for a natural gas boiler, fuel cell, gas engine or gas turbine. Cleaned producer gas from the MILENA gasifier can be upgraded into Bio-SNG by a catalytic process.

For the efficient production of SNG, a producer gas with a high concentration of hydrocarbons is ideal. This requires a gasification process at low temperature (below 1000°C). A low temperature air blown allothermal gasification process can produce SNG from biomass with an overall efficiency of more than 70% [1].

Most low temperature gasifiers produce a considerable amount of tar. The tar content in the producer gas can be reduced by a catalyst in or after the gasifier. In general these catalysts require addition of extra steam to the gasifier to prevent the formation of soot and to enhance the steam reforming reactions. The additional steam reduces the overall efficiency of the process. ECN has chosen not to reduce the tar content catalytically, but to remove the tar from the gas and to use the tar as fuel for the combustion section of the gasifier. The selected tar removal technology is the OLGA technology [2] which was jointly developed by ECN and Technisch Bureau Dahlman and currently commercially available.

For the further development and scale up of the MILENA gasification technology experimental data is required. Here, we present results from experiments carried out in the lab-scale MILENA gasifier and we give an update on the status of the 800 kWth MILENA pilot plant gasifier.

2 MILENA GASIFICATION TECHNOLOGY

ECN started to work on gasification in 1987. A downdraft gasifier was constructed and operated to produce gas for gas cleaning (H_2S removal) tests. This downdraft gasifier was later used for biomass gasification research. In 1996 the 500 kWth Circulating Fluidized Bed (CFB) gasifier BIVKIN [3] was constructed and was taken into operation. The BIVKIN installation was tested on wood pellets, wood chip, demolition wood, sewage sludge, sunflower husks, wheat straw, chicken manure, pig manure and paper sludge. The limited fuel conversion of a CFB gasifier, typical between 90 and 98%, was seen as a major drawback of this technology. Incomplete fuel conversion results in a loss of efficiency and an ash stream which contains combustible carbon. The producer gas from an air blown Bubbling Fluidized Bed (BFB) or CFB gasifier has a relatively low calorific value (< 7 MJ/m_n^3) this makes the application of the gas in a gas engine or gas turbine more problematic. The experience gained by running the BIVKIN gasifier was used to develop the MILENA process.

The first design of the MILENA gasifier was made in 1999. The first cold flow, for hydrodynamic testing, was built in 2000. Financing a lab-scale installation appeared to be problematic, because there was no interest in a new gasification technology at that time. This changed when SNG was identified as a promising bio-fuel. Allothermal gasification was identified as a promising technology for production of SNG [4]. The construction of the 30 kWth MILENA installation was started in 2003. The installation was finished and taken into operation in 2004. Financing of the 800 kWth MILENA pilot plant was approved in 2006 and the construction was finished in 2008.

The MILENA gasifier contains separate sections for gasification and combustion. Figure 1 shows a simplified scheme of the MILENA process. The gasification section consists of three parts: riser, settling chamber and downcomer. The combustion section contains two parts, the bubbling fluidized bed combustor and the sand transport zone. The arrows in Figure 1 represent the circulating bed material. The processes in the gasification section will be explained first.

Biomass (e.g. wood) is fed into the riser. A small amount of superheated steam is added from below. Hot bed material (typically 925°C sand or olivine of 0.2 – 0.3 mm) enters the riser from the combustor through a hole in the riser (opposite and just above of the biomass feeding point). The bed material heats the biomass to 850°C. The heated biomass particles degasify; they are converted into gas, tar and char. The volume created by the gas from the biomass results in a vertical velocity of approximately 6 m/s, creating a "turbulent fluidization" regime in the riser and carrying over of the bed material together with the degasified biomass particles (char). The vertical velocity of the gas is reduced in the settling chamber, causing the larger solids (bed material and char) to separate from the gas and fall down into the downcomer. The producer gas leaves the reactor from the top and is sent to the cooling and gas cleaning section. Typical residence time of the gas is several seconds.

The combustor operates as a bubbling fluidized bed (BFB). The downcomer transports bed material and char from the gasification section into the combustor. Tar and dust, separated from the producer gas, are also returned to the combustor. Char, tar and dust are burned with air to heat the bed material to approximately 925°C. Flue gas leaves the reactor to be cooled, de-dusted and emitted. The heated bed material leaves the bottom of the combustor through a hole into the riser. No additional heat input is required; all heat required for the gasification process is produced by the combustion of the char, tar and dust in the combustor.

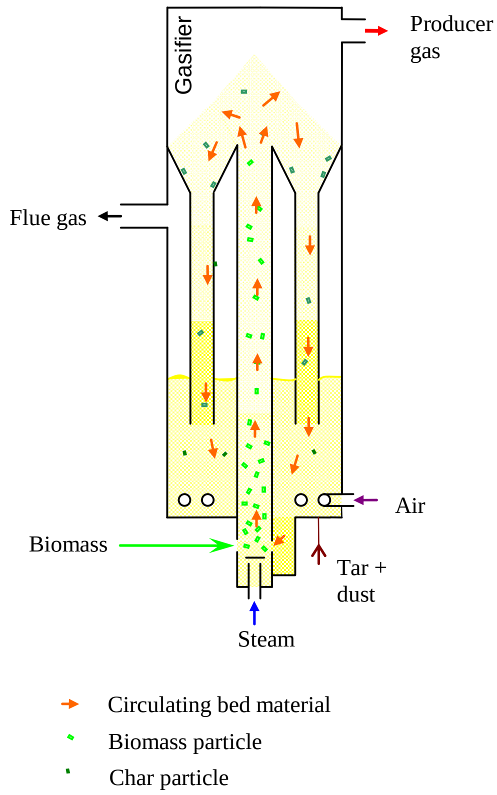

Figure 1: Simplified scheme of MILENA gasifier

The flue gas leaving the MILENA installation is cooled down to approximately 100°C and is cleaned in a bag house filter. If clean wood is used as a fuel no additional flue gas cleaning is required.

The hot producer gas from the gasifier contains several contaminants such as dust, tar, chloride and sulfur, which have to be removed before the catalytic conversion of the gas into Bio-SNG. All fluidized bed gasifiers produce gas which contains some tar. Tar compounds condense when the gas is cooled, which makes the gas very difficult to handle, especially in combination with dust. The producer gas is cooled in a heat exchanger, designed to treat gas which contains tar and dust. The heat is used to pre-heat combustion air. Tar and dust are removed from the gas in the OLGA gas cleaning section [2]. The OLGA gas cleaning technology is based on scrubbing with liquid oil. Dust and tar removed from the producer gas are sent to the combustor of the MILENA gasifier. The cleaned producer gas, containing mainly CO, CO_2, H_2, CH_4, C_2H_4 and C_6H_6 can be used in gas boilers, gas engines, gas turbines or fuel cells.

The overall theoretical cold gas efficiency of the gasification process including tar removal is 78% on LHV basis and 76% on HHV basis when wood chips with 25wt% moisture are used as fuel. Efficiency can be improved by using low temperature heat for biomass drying.

Further conversion of the cleaned producer gas into a mixture of CH_4, CO_2 and H_2O is done in catalytic reactors. After compression and removal of the H_2O and CO_2 the Bio-SNG is ready for gas grid injection or can be used as transport fuel (Bio-CNG).

3 LAB-SCALE EXPERIMENTS

3.1 Lab-scale set-up

ECN realized a 30 kWth lab-scale MILENA gasifier in 2004, capable of producing approximately 8 m_n^3/h methane-rich medium calorific gas with high efficiency. The installation has been used for nearly 1000 hours as bubbling fluidized bed gasifier and allothermal gasifier.

The installation consumes approximately 6 kg/h of biomass. In general dry beech wood particles between 0.75 and 3 mm are used as fuel, but also sewage sludge and grass were tested.

The internal diameter of the riser (gasifier) is 36 mm. The internal diameter of the combustor is 250 mm. The lab-scale installation is made of stainless steel (grade 253MA). Heat loss from the process is compensated by high temperature electrical trace heating and external insulation.

The riser is fluidized with steam. The amount of fluidization steam varies between 0.1 and 2 kg/h. The amount of steam required to fluidize the riser is low (0.1 kg/h), but additional steam is used to increase the water content of the producer gas, because the biomass used for lab-scale experiments is relatively dry (10 wt% moisture), the fuel foreseen for commercial applications contains more moisture (25 wt%).

3.2 Lab-scale experiments

The MILENA lab-scale installation has been used for nearly 1000 hours as bubbling fluidized bed gasifier and allothermal gasifier. During the first test sand was used as bed material. Later olivine from Norway was used as bed material. The results were not as expected. Later the bed material was replaced by olivine from Austria, similar to the olivine used in the Güssing gasifier [5]. This bed material is now used as a standard bed material, because olivine reduces the amount of heavy tars in the gas, this makes operation of the gas splitter easier. During test with sand as bed material the gas splitter was clogged several times. The gas splitter is required because producer gas from the MILENA gasifier is divided into two streams. Approximately 70% of the gas is sent directly to the afterburner and 30% is sent to the lab scale OLGA gas cleaning.

Table I shows the main gas composition for different bed materials. The fuel was beech wood for all three temperatures. Operating temperature of the gasifier varied between 850 and 900°C.

Table I: Example of measured gas compositions for three different bed materials.

		Sand	Norwegian Olivine	Austrian Olivine
CO	[vol% dr.]	39.3	33.4	27.5
H_2	[vol% dr.]	21.4	25.3	27.3
CO_2	[vol% dr.]	13.9	20.3	24.8
CH_4	[vol% dr.]	12.8	12.4	9.5
C_6H_6	[Vppm dr.]	12179	11012	9551
C_7H_8	[Vppm dr.]	1303	1108	944
Measured tar concentrations				
Class 2	[mg/m_n^3 dr.]	1462	863	982
Class 3	[mg/m_n^3 dr.]	275	523	197
Class 4	[mg/m_n^3 dr.]	18579	17262	11406
Class 5	[mg/m_n^3 dr.]	5010	3437	2147
Unknowns	[mg/m_n^3 dr.]	6556	6238	3642
Total tar	[mg/m_n^3 dr.]	31882	28322	18374

The selection of bed material influences the tar concentration, the CO shift equilibrium and the amount of oxygen which is transported from the combustor to the gasifier. Oxygen transport is caused by reduction and oxidation of the iron in the olivine. Oxygen transport from the combustor to the gasifiers increases the CO_2 concentration in the producer gas and decreases the temperature difference between combustor and gasifier.

The N_2 concentration in the producer gas from the gasifier has to be minimized, because this N_2 will end up in the final product. Nitrogen is an inert gas which lowers the heating value of the gas and increases the compression duty. For instance, a N_2 concentration of 5 vol% in the dry producer gas from the gasifier will result in a SNG N_2 concentration of 19%. Inert gases (including CO_2) in natural gas are limited to 5% according the Swedish standard for biogas as vehicle fuel. The amount of CO_2 in the final SNG can easily be reduced to approximately 1.5% by conventional CO2 removal processes, so the maximum allowable N_2 concentration, next to CO_2, in the producer gas from the gasifier is approximately 1%.

Tests were done to minimize the N_2 concentration in the gas from the MILENA gasifier. The N_2 concentration was reduced to 1% by purging the fuel bunkers with CO_2 and injecting CO_2 in the sand transport zone between the combustion and gasifier section of the MILENA gasifier.

The lab-scale MILENA gasifier is extended with an automated feeding system, which makes it possible to do tests without operators. Figure 2 shows the raw gas composition of the MILENA producer gas during automatic operation of the fuel bunker and switching between bunkers. The fuel bunker was refilled every 5 hours; the influence of the filling of the bunker on gas composition is limited.

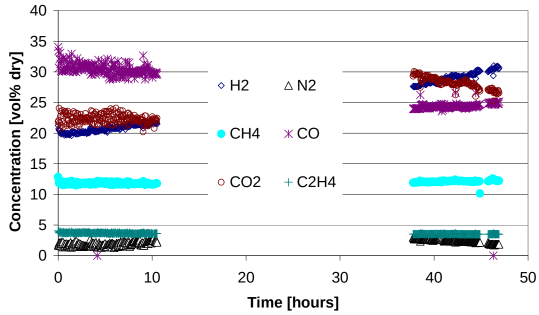

Figure 2: MILENA raw gas composition

The feeding system was tested for 50 hours. During the test part of the gas was sent to the lab-scale OLGA gas cleaning facility and methanation unit. No MILENA gas composition was measured, between hours 11 and 38, because the analyzers were used to measure the gas composition at several locations in the complete SNG line-up. Figure 2 shows that the methane concentration was stable during the testing period. The hydrogen concentration increased over time. This increase is probably caused by an increase of CO shift activity of the bed material over time. Previous tests showed the same increase in hydrogen concentration over time. The nitrogen concentration varied between 1.4 and 3 vol% on dry basis. This variation is caused by variations in pressure difference between the combustor and the gasifier. The CO_2 concentration varied during the test, because the amount of CO_2 used to purge the feeding system was varied.

4 PILOT PLANT

4.1 Design of pilot plant

The MILENA pilot plant was designed to replace the 500 kWth BIVKIN gasifier [3], which was used for ten years. The BIVKIN gasifier was extensively used to develop and test several new gas cleaning technologies. This resulted in the OLGA tar removal technology [2]. The same OLGA pilot plant as was tested behind the BIVKIN gasifier will be used to clean the gas from the MILENA pilot plant.

The goal for the pilot plant was to realize an installation which could be used to do experiments under realistic 'commercial' conditions. This means no external heat supply to the reactor and an increase in fuel particle size from 1 – 3 mm for the lab scale installation to <15 mm for the pilot plant. The lab scale installation was limited in fuel particle size because of the size of the feeding screw and riser reactor. For the pilot plant an upper size limit of 15 x 15 mm was selected based on experiments with the 500 kWth CBF gasifier.

A simplified scheme of the MILENA installation connected to existing gas coolers, gas cleaning and boiler is given in Figure 3.

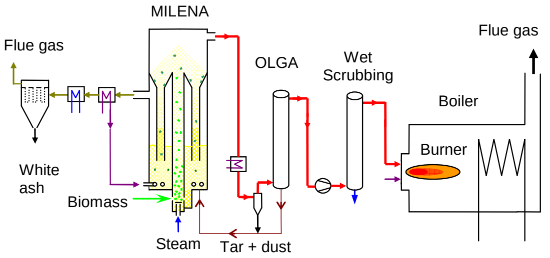

Figure 3: Schematic overview of pilot installation

Producer gas from the MILENA gasifier is cooled from approximately 850°C to 400°C in a double pipe cooler [7]. Most of the dust in the gas is removed by a cyclone. This dust stream contains ash, small bed material particles and char. This stream will be recycled to the MILENA combustor in the future. Tar and the remaining dust are removed from the producer gas in the OLGA gas cleaning section. Heavy tars and dust will be pumped to the MILENA combustor. The light tars are stripped with air from the OLGA absorption fluid (oil) and are used as combustion air. Ammonia, chlorides and water can be removed from the gas by the existing wet cleaning system [8]. A booster increases the pressure of the gas to 70 mbar. The gas pressure was required in the past to use the producer gas as fuel for a gas engine. No gas engine tests are planned for the future, because tests have shown that gas engine operation is straightforward as long as the tar dew point temperature is above the lowest temperature in the gas engine gas supply system. The cleaned producer gas will be combusted in a gas boiler.

The flue gas from the MILENA combustor is cooled to 200°C. Part of the heat is used to pre-heat the combustion air. The flue gas is cleaned in a bag house filter before the flue gas is sent to the stack.

The scale of the installation was determined by the existing BIVKIN gasifier. The volume flow of gas produced in the MILENA gasifier is chosen to be slightly smaller than the volume flow from the BIVKIN gasifier (190 m_n^3/h). Because of the higher heating value of producer gas from an indirect gasifier the thermal input of the MILENA gasifier increased from 500 kWth to 800 kWth (HHV basis). The thermal output was increased as well. Because of the increase the gas burner and boiler had to be replaced.

The basic design data for the MILENA gasifier fueled with dry wood pellets is given in Table II.

Table II: Basic design data MILENA pilot plant

Thermal input (HHV basis)	[kW]	797
Biomass mass flow	[kg/h]	158
Steam to gasifier	[kg/h]	19
Riser diameter	[m]	0.2
Combustor diameter	[m]	0.8
Overall reactor height	[m]	8
Circulation rate bed material	[kg/h]	6300
Producer gas volume flow wet	[m_n^3/h]	174
Tar and BTX to combustor	[kW]	55
HHV gas wet basis excl. tar	[MJ/m_n^3]	13.1
HHV gas dry basis excl. tar	[MJ/m_n^3]	18.0

The tar in the producer gas and some of the benzene and toluene are going to be removed from the gas in the OLGA gas cleaning. The tar, benzene and toluene are going to be used as fuel in the combustor. In the first phase of operation of the pilot plant the recycle of tar will be simulated by adding natural gas to the combustor.

4.2 Construction of the pilot plant

The engineering of the MILENA pilot plant was started in 2005. Financing was approved at the end of 2006. The detailed engineering was done by the Engineering and Services department of ECN in the beginning of 2007. The construction of the reactor vessel was done by HoSt BV, together with Klaas Zijlstra Metaalbewerking BV. The reactor vessel was delivered to ECN at the end of November 2007 (see Figure 4).

Figure 4: Delivery of the MILENA reactor to ECN

The construction and connection of the installation to the existing infrastructure was finished at the end of April 2008. Pressure testing and the required fixing of leakages caused some delays. Figure 5 shows the installation without external insulation.

Figure 5: MILENA pilot nearly finished

Installation of all the required sensors, wiring and piping was finished at the end of April 2008.

4.3 Results from first tests

Functional testing was started at the beginning of May 2008. Tests of the feeding system, using wood pellets, showed that this system functioned as expected. Stable feeding of 160 kg/h of wood pellets was possible.

The natural gas burners in the freeboard of the combustor were used to heat up the installation. The installation was heated up at a rate of 50°C/h. This limit is set by the refractory used in the vessel. The second section of the flue gas cooler did not perform as expected. It was not possible to cool down the flue gas to 200°C as required for the bag house filter. The problem is now identified and the cooler will be modified. The first flue gas coolers seem to perform according design.

First fluidization tests using olive particles of 0.08 to 0.26 mm and heated air showed that the pressure drop over the air nozzles increased after a stop of the installation. This was caused by a back flow of bed particles into the air nozzles. The backflow was probably caused by pressure pulses coming from the bag house filter. In the future purging of the bag house filter will stop when the combustion air fan is not running.

The next tests are scheduled for the end of June 2008.

5 FURTHER PLANS

The MILENA OLGA – Methanation lab scale will be extended with a CO_2 removal unit and gas compressor to bring the final gas quality up to natural gas specification. A demonstration is planned where gas from the MILENA lab scale gasifier will be upgraded to natural gas quality and will be used to fuel a conventional commercial available natural gas vehicle such as the Opel Zafira CNG.

Preparations are underway to realize a 10 MWth demonstration plant, based on ECN MILENA and OLGA technology.

ECN plans to license the MILENA gasification technology to interested industrial parties when the pilot plant has proved that the technology is suitable for the next scale up step. The foreseen scale for commercial CHP units based on MILENA – OLGA technology is around 10 MWth. The scale foreseen for a commercial single-train Bio-SNG production facility is between 50 and 500 MWth.

6 CONCLUSIONS

The lab-scale MILENA gasifier has been in operation since 2004 and is running very well. The standard bed material for the lab-scale installation was changed from sand to olivine. This resulted in a decrease in tar concentration in the producer gas and lesser problems with fouling of piping before the gas cleaning. Further (OLGA) tar removal is required for applications such as gas engines or gas turbines. Sand is still considered to be a suitable bed material if a high tar concentration is acceptable.

The lab-scale installation was connected to the lab-scale gas cleaning unit and methanation unit. Several duration tests were done with good results. The lab-scale MILENA gasifier was extended with an automated feeding system, which makes it possible to do long duration tests without operators. This system was tested in the beginning of 2008. The gasifier is now available for long duration Bio-SNG production tests.

The construction of the MILENA pilot plant is finished. The first functional tests showed that some minor adjustment to the installation (flue gas cooler) and start up procedure are required. The functional and operational tests will be continued in the summer of 2008.

6 ACKNOWLEDGEMENTS

A large part of the work described here is financed by the Dutch SenterNovem agency. Their financial support is greatly acknowledged.

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