Waste wood gasification in an allothermal gasifier

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Waste wood gasification in an allothermal gasifier

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ABSTRACT: The Energy research Centre of the Netherlands (ECN) has developed a biomass gasification technology, called the MILENA technology. The MILENA gasification technology has a high cold gas efficiency and high methane yield, making it very suitable for gas engine or gas turbine application and upgrading of the gas into Substitute Natural Gas (SNG).

HVC Group (situated in Alkmaar, North Holland) is a modern public service waste and energy company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC has a large waste wood boiler in operation, which produces heat and electricity. HVC expects an important role for Bio-SNG and medium size Bio-CHP plants in the future. HVC has decided to join ECN with the development, demonstration and implementation of the MILENA technology for CHP and SNG production.

Most biomass gasification processes use clean wood as fuel, but clean wood is relatively expensive. Waste wood is an attractive fuel for gasification, because it is widely available and the price is low. Because of the pollutants in the wood (glass, nails, screws, plastic, stones, etc.) and the increased content of chloride and sulphur, this fuel behaves differently than clean wood. ECN performed an extensive test program in the 800 kW_{th} pilot scale MILENA gasifier to test if waste wood supplied by HVC is a suitable fuel for the 12 MW_{th} demonstration plant HVC and ECN are preparing. The OLGA pilot plant was used to remove tar and dust from the producer gas.

Demolition wood containing painted wood, particle board, glass particles and other pollutants were tested during a duration tests. The test results showed that demolition wood can be a suitable fuel if the bottom ash handling system is designed to discharge the accumulated pollutants like nails and screws and the bed material is refreshed enough to prevent bed agglomeration by e.g. melting glass particles. The gas cleaning should be designed in such a way that the increased level of pollutants (NH_3, HCN, H_2S, COS and HCl) can be removed.

Keywords: combined heat and power generation (CHP), allothermal conversion, biomass conversion, bio-syngas, gasification, methane.

1 INTRODUCTION

Gasification technology offers the possibility to convert a solid biomass into a gas that can be combusted in prime movers to produce heat and electricity or can be upgraded to valuable energy carriers like Fischer Tropsch diesel and Substitute Natural Gas (SNG). The production of gas from solid biomass is an attractive option to reduce CO_2 emissions and to replace declining fossil fuel reserves.

Biomass gasification technology is still under development. A limited number of demonstration plants and commercial plants is in operation. Successes with these first plants have resulted in an increasing interest for biomass gasification. Several biomass gasifiers in combination with gas engines are under construction at the moment. Most of these gasifiers use clean wood as a fuel.

ECN (Energy research Centre of the Netherlands) has developed an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Bio-SNG, but not restricted to Bio-SNG. The MILENA fluidized bed gasifier is fuel flexible. An extensive test program was done to prove that the MILENA gasifier can handle demolition wood. The data obtained from these tests was used to design a 12 MW_{th} demonstration plant that will be constructed in Alkmaar in the Netherlands.

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 [1] 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 a troublesome ash stream which contains combustible carbon. Furthermore, 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 [2]. The construction of the 30 kW_{th} MILENA installation was started in 2003. The installation was finished and taken into operation in 2004. Financing of the 800 kW_{th} 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 (or any other gas available including air) is added from below to enable bed material circulation in the bottom of the riser reactor. 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 - 7 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.

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 [3]. 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.

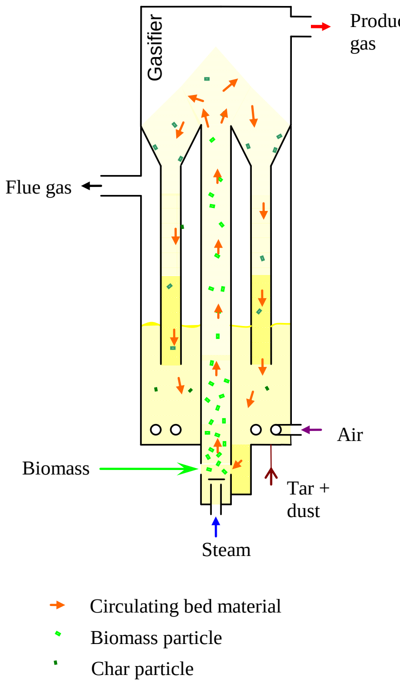

Figure 1: Simplified scheme of MILENA gasifier

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.

To produce Bio-SNG, 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 PILOT PLANT

3.1 Design of pilot plant

The MILENA pilot plant was designed to replace the 500 kW_{th} BIVKIN gasifier [1], 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 [3]. The same OLGA pilot plant as was tested behind the BIVKIN gasifier is used to clean the gas from the MILENA pilot plant.

The goal for the pilot plant is to realize an installation, which can 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 is 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 kW_{th} CBF gasifier.

A simplified scheme of the MILENA installation connected to existing gas coolers, gas cleaning and boiler is given in
Figure 2.

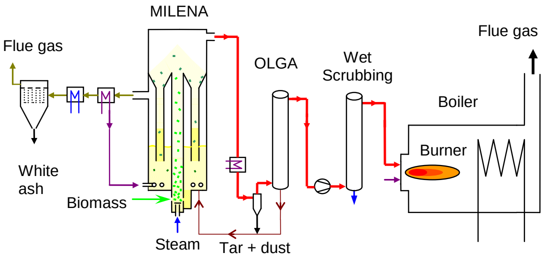

Figure 2: Schematic overview of pilot installation

Producer gas from the pilot MILENA gasifier is cooled from approximately 850°C to 400°C in a double pipe cooler [4]. 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 [5]. A booster increases the pressure of the gas to 70 mbar in the pilot plant. 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 is combusted in a gas boiler in the pilot plant at ECN.

The flue gas from the MILENA combustor is cooled to 100 - 150°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 kW_{th} to 800 kW_{th} (HHV basis). The thermal output was increased as well. Because of the increase the gas burner and boiler had to be modified.

The basic design data for the MILENA gasifier fueled with dry wood pellets is given in Table I. The tar in the producer gas and some of the benzene and toluene are removed from the gas in the OLGA gas cleaning. The tar, benzene and toluene are used as fuel in the combustor.

Table I: 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

3.2 Demolition wood tests

A duration test on demolition wood was done in the autumn of 2010 in cooperation with operators from HVC.

Figure 3 shows a photo of the demolition wood fraction that was used duing the tests. The used fraction is relatively small, because of limitations in the feeding system of the pilot plant. The fraction was sieved from a larger fraction and the sieving resulted in an accumulation of glass particles and stones in the fuel (typically 3 wt%), which ended up in the reactor. The ash discharge system was adapted to minimize accumulation of glass in the reactor.

Figure 3: Demolition wood B as tested in the MILENA pilot plant

The demolition wood used was of the so called 'B' quality according to Dutch qualification. This means that it includes painted waste wood and particle board. Table II shows the average composition of the wood used during the tests. It must be noted that the composition of the demolition wood varied strongly during the tests, some batches contained large amounts of particle board material and others contained significantly more gypsum board material than average.

In total 243 hours of operation of the entire plant were recorded during the 2010 duration test. The first half of the test was done with clean wood pellets, the second half with demolition wood. During wood pellets operation the MILENA gasifier ran without any problems. During waste wood operation the gasifier had to be shut down twice because of accumulation of glass in the riser. Most of the other shut downs were caused by fouling of the piping that connects the gasifier to the gas cleaning. The distance between the gasifier and gas cleaning is relatively long, because there was no room in the gasifier building to place the gas cleaning. This was the major cause for the clogging of the piping. For commercial plants this should not be an issue, because the gas cleaning is placed next to the gasifier.

Table II: Fuel compositions; ar: as received, daf: dry and ash-free basis

	Clean wood	Demolition wood B
Moisture [wt.% a.r.]	10.1	19.0
Ash [wt.% d.b.]	1.0	2.7
C [wt.% d.a.f.]	49.2	50.2
H [wt.% d.a.f.]	6.1	6.1
O [wt.% d.a.f.]	44.5	41.6
N [wt.% d.a.f.]	0.2	1.9
S [wt.% d.a.f.]	0.017	0.10
Cl [wt.% d.a.f.]	0.005	0.12
LHV [MJ/kg d.a.f.]	18.2	18.9
HHV [MJ/kg d.a.f.]	19.5	20.2

Table III shows the measured gas compositions directly after the gasifier. After gas cleaning the gas was fired in a bolier.

Table III: Measured gas compositions after gasifier.

Fuel		demolition wood		clean wood
Fluidization gas		Steam	Air	steam
Bed material		olivine	Olivine	olivine
CO	[vol%]	33.6	28.6	39.9
H_2	[vol%]	28.1	21.1	23.8
CO_2	[vol%]	14.0	13.7	11.1
CH_4	[vol%]	13.1	9.8	15.3
N_2	[vol%]	4.2	23.5	3.9
C_2H_2	[vol%]	0.3	0.2	0.2
C_2H_4	[vol%]	3.5	2.1	4.3
C_2H_6	[vol%]	0.2	0.1	0.3
C_6H_6	[vol%]	1.0	0.7	1.1
C_7H_8	[vol%]	0.1	0.1	0.1
H_2S	[Vppm]	403	355	-
COS	[Vppm]	14	20	-
NH_3	[Vppm]	19450	-	-
HCN	[Vppm]	-	4000	-
HCl	[Vppm]	150	-	-
Tar Total	[g/nm^3]	30	-	40

The high nitrogen concentration in the gas during the demolition wood was caused by a relative high amount of fluidization air which was used during this test. This was done to minimize the wood throughput, because the wood storage capacity at the ECN site was limited. In principal, the nitrogen content of the gas is similar to what was measured during the clean wood tests, where fluidization was achieved by adding steam. The tar concentration after the gas cleaning (not shown in the table) was low enough for gas engine application. The OLGA tar removal system was capable of handling the high tar load.

Most of the sulfur in the biomass ends up in the producer gas. If additional sulfur removal is required depends on the local emission limits. The residual ash is completely white / grey. This indicates that there is no unburned carbon left in the ash, the overall fuel conversion is almost 100%.

The flue gas from the combustor was cleaned by a bag-house filter. Emissions were below the local emission limits with the exception of HCl. Additional chloride removal is required if waste wood is used as fuel.

4 FURTHER PLANS

The basic engineering of the 12 MW_{th} demonstration plant was done by Dahlman (www.dahlman.nl) in 2010. Cost estimations are now more accurate and have shown that the combination of the MILENA gasifier and OLGA gas cleaning is an attractive configuration to produce heat and electricity in a gas engine. Investment cost for a complete plant is around 4000 €/kW_e. The project was delayed because of changes in the Dutch subsidies for green heat, electricity and gas. The changes in subsidy and the strong interest from industry in producing Bio-SNG have changed the plans. The demonstration plant will now be build to produce Bio-SNG. Several industrial companies have expressed interest in joining this demonstration program. Discussions with potential consortium parties are on gonging. A new time planning will be made public when approval with all consortium partners is reached. A new application for subsidy on green gas will be filed by HVC at the end of 2011. Figure 4 depicts the demonstartion plant. The methanation section is not shown, because selection of the technology methanation technology is an ongoing activity.

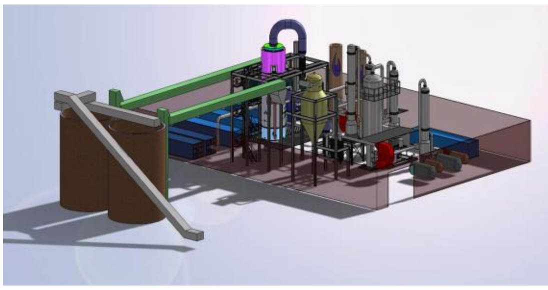

Figure 4: 12 MW_{th} MILENA demonstration plant

The MILENA demonstration plant will be part of the Biomass Gasification Expert Centre. Gas produced by the demonstration plant will be made available for testing of other new (catalytic) conversion technologies.

The MILENA development has attracted attention from other industrial companies as well. Thermax, a large boiler manufacturer from India, has selected the MILENA technology to convert local biomass waste in gas for gas engine application. An 1 MW_e demo plant is scheduled for construction in 2012.

The test done with demolition wood in the pilot plant have resulted in a interest from several companies in the application of MILENA and OLGA for gas production for gas engines. Several commercial offers are under discussion at the moment.

Further scale up (to over 100 MW_{th}) is another topic of development. Preliminary designs have shown that this is a viable option. The integrated one vessel concept makes pressurization of the process relatively simple, this is advantageous for further scale up.

5 CONCLUSIONS

Tests done in the 800 kW_{th} (150 kg/h) pilot plant showed that demolition wood is a suitable fuel, most alternative gasification technologies cannot handle polluted demolition wood. Accumulation of glass particles, that are present in the fuel, should be prevented by discharging the bottom ash. The increased concentration of pollutatants, such as H_2S, HCN and NH_3 must be taken into account when designing the gas cleaning system.

The OLGA tar removal technology is able to remove the tars making the gas suitable for (turbocharged) gas engine application. The fuel conversion is over 99%, this is significantly higher than for most biomass gasifiers. The complete fuel conversion benefits the efficiency.

6 ACKNOWLEDGEMENTS

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