

## 700 HOURS DURATION TEST WITH INTEGRAL 500KW BIOMASS GASIFICATION SYSTEM

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**ABSTRACT:** In this paper an overview is given of the results of a duration test with the wood pellet fired Integral Biomass Gasification Unit at ECN, the Energy research Centre of the Netherlands. The gasification unit consists of a 500 kW CFB gasifier with producer gas cooler, an "Olga" tar removal system, a GASREIP wet gas cleaning system, a gas engine/generator set with grid connection and a gas burner/hot-water boiler. The gas burner combusts either the excess of producer gas during gas engine operation or the total producer gas flow when the gas engine is not in operation.

The aim of the duration test is to get insight into the performance and reliability of all the components of an integral biomass gasification unit. Further, the test is the first duration test on a 500kW scale with the Olga tar removal system.

During the test an accurate registration was made of the functioning of the installation. At relevant locations in the installation pressures, temperatures, quantities and gas compositions were measured. The measured values were recorded and stored every five minutes. Thus, a complete set of data was generated, showing the actual process values during the total period. The results show, that the different parts of the system operated reliably. The proper functioning of the most innovative part of the installation, the Olga tar removal system, was demonstrated convincingly. The gas engine operated trouble free on this virtually clean product gas.

With this test, valuable information on performance and reliability of a biomass gasification unit is generated.

Keywords: gasification, operating experience, tar removal

### 1 INTRODUCTION

A biomass gasification system consists of a large number of sub-systems. Some sub-systems are thoroughly tested, other systems are tested only for a short time during small scale lab tests. This makes it difficult for system suppliers to give performance guarantees. And performance guarantees are crucial for building a commercial installation. Without guarantees, a project on industrial scale is not ordered. Therefore, the main purpose of this duration test is to generate reliability data of the different sub-systems in an integral biomass gasification unit.

### 2 THE PILOT INSTALLATION

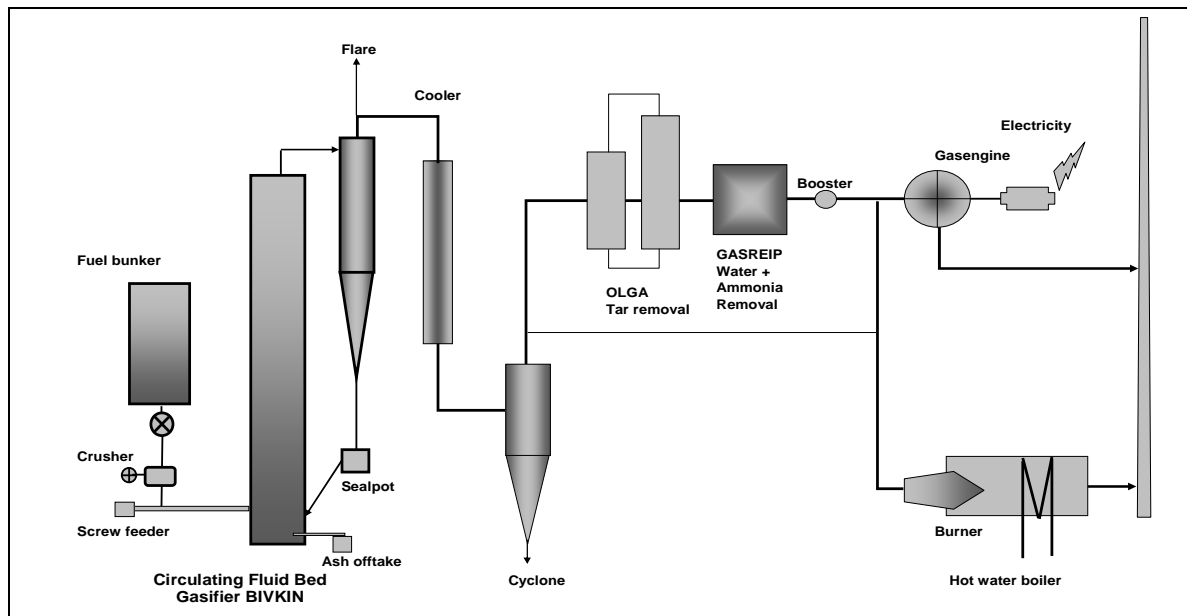
The duration test is performed with the integral Bivkin gasification system located at ECN, the Energy research Centre of the Netherlands. The gasifier itself was build there in 1996, but for this test the gasifier was extended with a producer gas cooler, a novel Olga tar removal system and a gas engine. In Figure 1 the main components of the installation are shown.

- The facility consists of the following sub-systems:
- A 500 kW<sub>th</sub> Circulating Fluidized Bed Gasifier.
  - A producer gas cooler and a cyclone. In the cooler the producer gas is cooled to < 400 °C, in the cyclone most of the dust is removed from the gas.
  - An Advanced Olga tar removal system. In Olga the gas is cooled further and the tar is removed from the gas with scrubbing oil in a collector and an absorber-stripper loop. Olga will be described in

more detail in chapter 6.4. Since Olga operates above the water dew point, tar and water are extracted from the system in separate streams. Tars are removed in Olga. Water and ammonia are removed in Gasreip.

- In Gasreip the producer gas stream is quenched with water. After the quench, ammonia is removed from the gas with water in a NH<sub>3</sub> washer/stripper loop. After this treatment the producer gas has the quality to be used in a gas engine or gas turbine. Gasreip will be described in more detail in chapter 6.5.
- Behind Gasreip, a booster is located, which regulates the pressure at the Gasreip inlet. A control valve in the burner gas line regulates the pressure before the gas engine.
- A gas engine. The gas engine is modified to suit the handling of producer gas. The gas engine drives the generator. The generator delivers a maximum of 45 kW<sub>e</sub> to the grid.
- The excess of producer gas is supplied to a burner, with which hot water is produced in a hot water boiler.

Before the start of the duration test the Gasifier had operated for several hundred hours with various biomass fuels. The same counts for Gasreip and the burner/boiler combination. With the cooler and Olga only very limited experience was generated before the start of the duration test and the gas engine was started up for the first time during the test.



**Figure 1:** Scheme of the test facility

### 3 OPERATING MODES

The installation is designed such, that certain sub-systems can be in operation, whilst other systems are not in operation. Due to this, the following operating modes can occur:

- Flare operation: Only the gasifier is in operation and the producer gas is flared. This configuration arises when there are problems with for instance the burner and is undesired with respect to emissions and odors.
- Burner operation without gas cleaning. In that case Olga and Gasreip are switched off and only the gasifier, the cooler, the cyclone and the burner are in operation. This configuration occurs when there is a malfunction in the gas cleaning. In that case the gasifier can be in operation whilst the failure of the gas cleaning is solved.
- Burner operation with gas cleaning. This configuration occurs when the gas engine is not available. In that case all the producer gas is cleaned and combusted in the hot water boiler.
- Gas engine operation. During gas engine operation all the subsystems are in operation, electricity is delivered to the grid and heat is produced in the boiler. During gas engine operation roughly half the amount of product gas goes to the gas engine, the rest goes to the burner. In this case the gas burner operates at an oxygen level in the flue gas of more than 10%. When the gas engine stops, all the producer gas can go to the burner without the need of changing the air quantity to the burner. In that case, the oxygen content in the flue gas drops to 2%.

Due to the fact that the installation can run under various operating modes, the operating time of the different sub systems are not necessarily the same during the duration test. Therefore the operating time of the various sub-systems is registered separately.

#### 3.1 Fuel

The duration test is performed with two types of clean white wood pellets and one type of "brown" wood pellets.

Since pellets can generate agglomeration in a (relatively) small circulating fluidized bed gasifier, a hammer mill was placed in the fuel feed. In this hammer mill the wood pellets are crushed to 1 mm "saw dust" particles. In this way the advantages of easy handling of pellets is combined with the superior gasification characteristics of sawdust.

An average composition of the wood pellets is given in table 1:

Fuel Type Period	Wood pellets			
	White 1 16/1/06 - 5/2/06	Brown 5/2/06 - 8/2/06	White 2 16/2/06 - 10/3/06	
LHV	kJ/kg	19,600	-	20,400
Ash (550)	%	0.3	2.4	0.3
Moisture	%	7.3	10.4	9.2
Volatiles	%	83.2	77.3	82.4
C	%	50.9	48.9	50.1
H	%	6.0	6.2	6.1
N	%	0.02	1.19	0.08
O	%	44.5	43.2	43.5

**Table 1:** average composition of the fuels used

With brown pellets the test period was very short. Even with a hammer mill in the feed line agglomeration in the gasifier occurred with brown pellets and the test was interrupted. Therefore a second white pellet was used during the last testing period.

### 4 COURSE OF THE DURATION TEST

The duration test started on January 15, 2006. The first day the gasifier operated in combustion mode, to preheat the gasifier, the cooler, the ducting and the boiler. On January 16th the gasifier was switched over to gasifying mode and Olga and Gasreip were switched on. The gas engine was taken into operation January 18th. From that moment on the installation was in full operation and electricity was delivered to the grid.

The test installation was originally built to perform

short "proof of concept" test runs with newly developed equipment. It had never been the intention to operate the installation uninterrupted for longer time periods. Therefore it was anticipated that during the test interruptions would occur. An important goal of the duration test was to analyze the system failures and check whether the cause of the failure is fundamental or incidental.

#### 4.1 Operating time

In figure 2 an overview is given of the operating hours of the different sub-systems of the installation. The figure shows that the total testing period, including all stops and interruptions took 1275 hours. Two main stops, during which the shift-work was interrupted, took 320

hours. The reasons for these stops were:

- The fuel supplier could not deliver enough white pellets, causing an interruption of the fuel supply. The period during which no fuel was available was used to relocate the cyclone. The long and winding duct between the cooler and the cyclone caused blockages. By shortening and straightening this duct the number of blockages could be minimized (stop time 198 hours).
- A foreign ceramic object in an oil circuit ruined the oil pump. This pump had to be replaced (delivery time 122 hours).

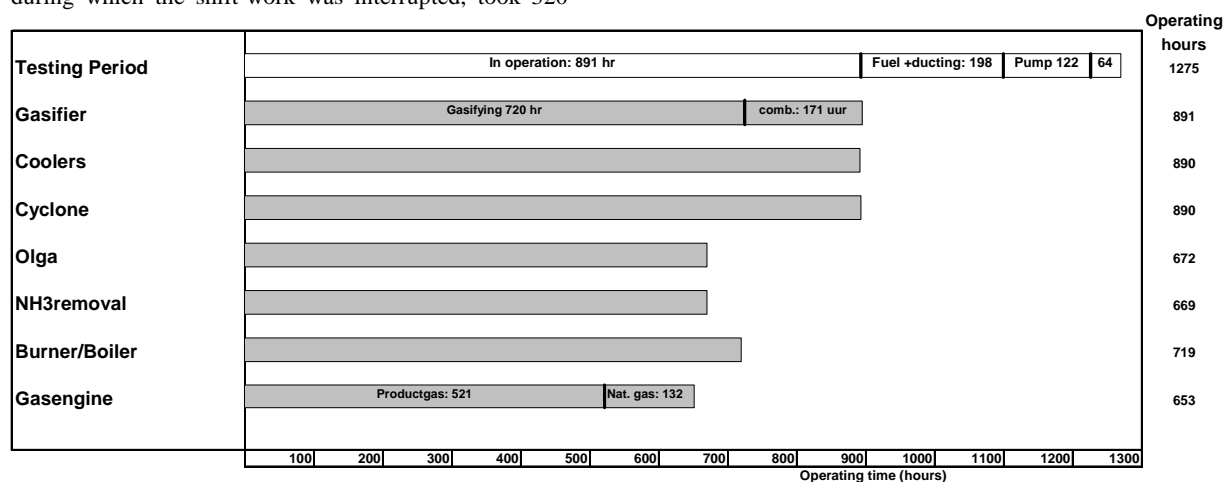


Figure 2: Overview of operating times of the different subsystems

The Bivkin gasifier has operated for 891 hours in total: 720 hours in gasifying mode, 171 hours in combustion mode. This means that (apart from the two main stops) Bivkin was not in operation for 64 hours to do maintenance work.

As soon as Bivkin is in operation, the cooler and the cyclone are in operation as well. The flare was used for less than one hour.

With respect to the burner, only the operating time was counted when Bivkin was gasifying and producer gas entered the burner. The burner operated for 719 hours, which means that the burner and the boiler operated trouble-free.

Olga as well as Gasreip are in operation only when Bivkin produces producer gas. Olga operated for 672 hours, Gasreip 669 hours. Compared with the 720 hours of Bivkin gasifying time, one can conclude that approximately 50 hours are lost, mainly during periods just before an outage or after a restart. One time Olga was out of operation for a longer period of time. Whilst changing an oil filter, the oil level in the collector became too high. Finding the cause of the problem took a few hours.

The gas engine operated for 653 hours, of which 521 on product gas and 132 on natural gas. Comparing the 521 hours with the 672 hours that Olga produced clean product gas shows that 151 hours are lost. This loss of operating hours can be explained mainly due to two causes:

1. The gas engine was first started 50 hours after the start of the duration test and
2. After a shutdown, the gas engine was taken in

operation after some stabilizing time of Olga and Gasreip.

Further, operating hours were lost due to inspections of spark plugs, valves, pistons and motor oil. Some hours were lost during tests with a micro gas turbine.

## 5 ANALYSES OF THE INTERRUPTIONS

The causes of the interruptions during the duration test can be summarized as follows:

Due to Bivkin:

- Leakage of old gaskets in the first cyclone
- Availability of wood pellets
- Agglomeration in sealpot and riser

Due to ducting:

- Dust accumulation, in particular in the duct between the second cyclone and Olga.

Due to Olga:

- Circulation problem in the scrubbing oil circuit
- Foreign object in the oil pump
- Inspection of the electrostatic precipitator

Gas engine not in operation due to:

- Temperature sensibility of the electronic equipment
- producer gas too wet (wrong setting of Gasreip)
- Inspections and tests with micro gas turbine

No interruptions were caused by the producer gas cooler, the cyclone, Gasreip, the burner or the hot water boiler. Analyzing the nature of the interruptions shows that only three process related interruptions were

encountered:

- Clogging of ducting
- agglomeration in Bivkin
- Interruption of the scrubbing oil circulation in Olga

The last cause could be prevented by adjusting the operating mode of Olga. Agglomeration in Bivkin could be minimized by using good quality wood pellets and the periodic refreshment of bed material.

Agglomeration could be detected and prevented in an early stage by using the newly developed EARS "Early Agglomeration Recognition System". With this system agglomeration in the riser is detected in an early stage, giving the opportunity to prevent problems by adding fresh sand to the bed.

A persistent problem was clogging of the producer gas duct between the cyclone and Olga. This problem is mainly caused by the lay-out of this duct. Bends, contractions, and expansion joints form obstacles where blockages can occur rapidly. In a commercial design this duct must be designed with care. It must be kept strait, short and wide.

The test facility was originally not designed to operate for longer periods of time. With this in mind one can conclude from the findings described above, that the various sub-systems have operated reliably. The coolers, the cyclone, Gasreip and the burner have operated trouble free. The proper functioning of the Olga tar removal system is demonstrated convincingly. The producer gas has the quality to operate the gas engine and the burner reliably.

## 6 RESULTS OF MEASUREMENTS

During the entire test all the measured values are stored every second in the ECN data acquisition system Wizcon. This is done to get insight into changes of the process during operation. Further, every 5 minutes the data are permanently stored to analyze trends. The figures in this article are generated with this data base.

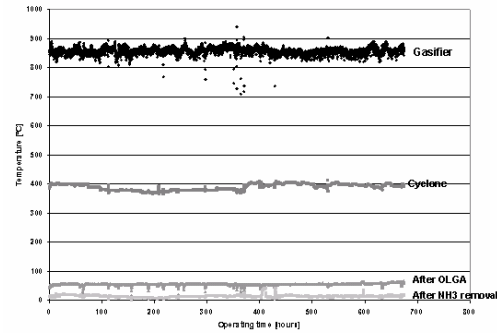
To increase the readability of the figures all data generated during outages, starts and stops are removed. This implies that on the horizontal axis the operating time is given without intermediate stops. Due to this the operating time runs from 0 to 670 hours, which corresponds with the time Olga was in Operation.

### 6.1 Process temperatures and pressures

In figure 3 four important process temperatures are given during the course of the duration test.

These temperatures are:

- The temperature in the riser of the gasifier. This temperature is the same as the temperature of the producer gas entering the producer gas cooler. The graph shows a stable producer gas temperature of 850 °C.



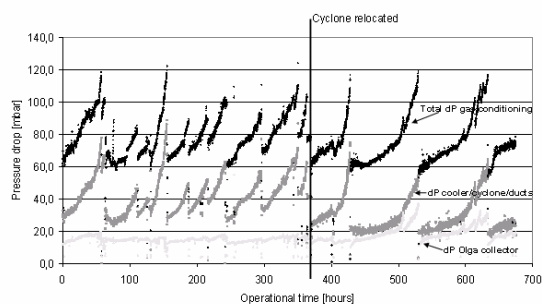
**Figure 3:** Overview of four process temperatures during the duration test.

- The cyclone temperature. The producer gas cooler cools the producer gas. At the exit of the cooler the gas enters the cyclone, so the cyclone temperature is (roughly) the same as the gas temperature at the exit of the producer gas cooler. The figure shows a cyclone temperature of 370 - 400 °C. This means that the cooler operates stable during the entire test.
- Temperature after Olga. After the cyclone the Olga tar removal system is located. The producer gas enters Olga with the cyclone temperature, being 370 - 400 °C. After Olga the temperature is reduced to 70 °C. At that temperature the tars are removed, but moisture is still in the gas phase.
- Temperature after NH<sub>3</sub> removal. The water is removed in conjunction with the ammonia removal in Gasreip. After Gasreip the temperature is at room temperature. With that temperature the producer gas enters the gas engine.

Figure 3 shows that during the test hardly any changes were made with respect to temperature levels. At the entrance of the gas engine the producer gas is at room temperature.

In figure 4 the pressure in the system is given over time. In this figure the total pressure drop over the gas conditioning is given during the entire duration test, together with the pressure drop over the cooler/cyclone/ducts and the pressure drop over the Olga collector. The graph shows:

- The pressure drop over the system increases periodically to 120 mbar. Then, the pressure drop decreases to approximately 60 mbar and increases again. The reason for this is the following: The pressure in the gasifier equals the pressure drop over the gas conditioning. The maximum allowable pressure in the gasifier is 120 mbar. As soon as that pressure level is reached, the installation is taken out of operation and the obstruction is removed.



**Figure 4:** pressure drops during the test period

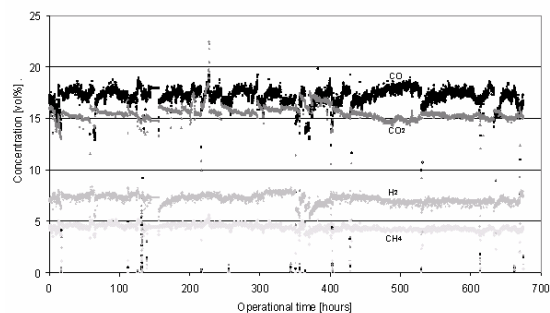
- The increase of the pressure in the system is partly caused by an increased pressure drop in the cooler/cyclone/ducting part of the system (dark grey line) and partly by an increased pressure drop in Olga (light grey line). Inspections showed that the increase in pressure drop in the cooler/cyclone/duct part of the system was solely located in the duct part after the cyclone. The cooler and cyclone were clean, but in the duct between the cyclone and the Olga collector a gradual buildup of dust and carbon was encountered. After removal of this material the pressure drop decreased, as shown in figure 4.
- After 380 operating hours, the cyclone was relocated. Due to this, the length of the ducting between the cooler and the Olga collector was more than halved and many bends were removed. This change is clearly visible in the figure: before the modification the duct had to be cleaned approximately every 40 hours, after the modification every 100 hours. Although this was a significant step forward, the problem was not entirely solved. Therefore, in a commercial unit, this part of the duct must be designed with great care.
- The light grey line in figure 6 shows an increase in pressure drop in Olga. Inspections show that this blockage emerge entirely in the entrance part of the collector. After a shut-down, this part was cleaned, together with the duct.

From figure 4 one can conclude, that apart from the duct between the cyclone and the Olga collector and the collector inlet, no blockages were found in the system. By carefully designing these parts, these blockages can be prevented in a commercial installation.

## 6.2 Bivkin gasifier

Bivkin produced producer gas for 720 hours. The composition of the producer gas is given in figure 5.

The figure shows that the composition of the gas does not change much over time. The sharp downward peaks are artificial, caused by (a.o.) filter changes in the gas analyses. On average, the gas contains roughly 17% CO, 15% CO<sub>2</sub>, 7% H<sub>2</sub> and 4.5% CH<sub>4</sub> (all on volume, dry basis). The rest is mainly N<sub>2</sub>. There is not much difference between the different fuels. Taken into account the small differences in composition of the fuels, large differences in gas compositions were not to be expected.



**Figure 5:** Composition of the producer gas leaving the gasifier.

On two days during the campaign a more extensive producer gas composition was determined, as given in table 2.

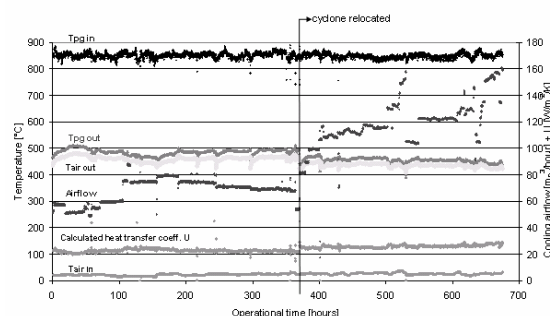
From the producer gas composition the heating value of the producer gas is calculated. The LCV is approximately 6 MJ/m<sup>3</sup>. No big changes over time are present.

Component	Feb.1, 2006	Feb.28, 2006
CH <sub>4</sub> (vol% dry)	4.68	4.16
CO (vol% dry)	17.69	17.82
CO <sub>2</sub> (vol% dry)	15.55	14.83
H <sub>2</sub> (vol% dry)	7.25	6.95
C <sub>2</sub> H <sub>2</sub> (vol% dry)	0.225	0.220
C <sub>2</sub> H <sub>4</sub> (vol% dry)	1.927	1.790
C <sub>2</sub> H <sub>6</sub> (vol% dry)	0.098	0.103
C <sub>6</sub> H <sub>6</sub> (vol% dry)	0.351	0.329
C <sub>7</sub> H <sub>8</sub> (vol% dry)	0.045	0.044
N <sub>2</sub> (vol% dry)	51.59	52.15
H <sub>2</sub> O (vol% dry)	14.8	16.5
Tar (g/m <sup>3</sup> dry)	15	18

**Table 2:** 24 hr average Composition of the producer gas after the gasifier.

## 6.3 Producer gas cooler

In figure 6, the process values of the producer gas cooler are given over time.



**Figure 6:** Process values of the producer gas cooler

Figure 6 shows stable temperatures over time. Clearly the relocation of the cyclone is visible in the graph. Due to the shorter ducts, the heat losses to the environment were much lower after the relocation of the cyclone. To maintain the desired process temperatures, much more cooling air had to be supplied to the cooler after the modification.

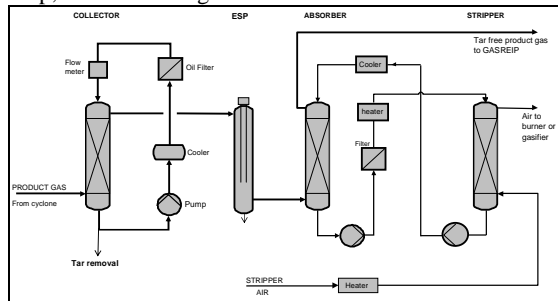
Further, in figure 6 the calculated heat transfer

coefficient  $U$  is given over time. No decrease in  $U$  is detected, showing that the cooler stays clean. The calculated heat transfer coefficient varies between 20 and 30  $W/m^2/K$ . After the cyclone modification  $U$  is higher, due to the higher air velocity in the cooler.

Before as well as after the cyclone relocation, the temperature of the cyclone is maintained 400 °C. In the duct between the cooler and the cyclone the temperature before the relocation of the cyclone dropped around 70 °C, after the relocation the temperature drop was around 30 °C. This explains the temperature difference of the producer gas temperature out ( $T_{pgout}$ ) as well as the air temperature out ( $T_{air out}$ ) before and after the relocation of the cyclone.

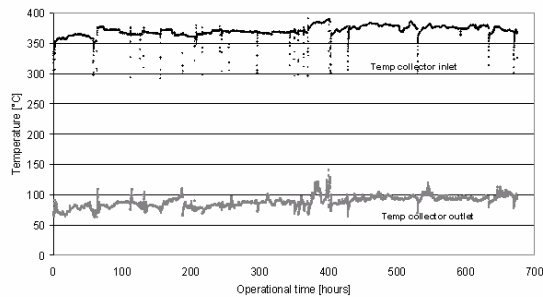
#### 6.4 Olga tar removal system

The Olga tar removal system consists of a collector, an electrostatic precipitator ESP and an absorber stripper loop, as shown in figure 7.



**Figure 7:** Flow scheme of Olga tar removal system

In figure 8 the in- and outlet temperatures of the collector are given during the entire test.

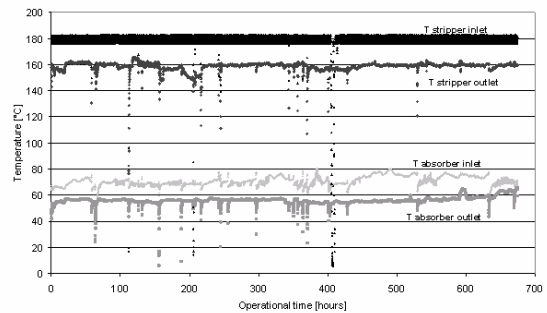


**Figure 8:** Producer gas temperatures at the Olga collector in- and outlet

In the collector the temperature of the producer gas is decreased from 360 - 390°C to 70 - 100°C. When the producer gas leaves the collector the heavy tars are removed from the gas and taken up by the scrubbing oil. However, a small part of the heavy tars are condensed on the dust that is still present in the producer gas. These tars will leave the collector in the form of aerosols. These aerosols are collected in the electrostatic precipitator located after the collector. After the ESP 5  $mg/m_n^3$  of dust/tar aerosols are measured. By than, the gas is clean enough to enter the absorber/stripper loop.

In the absorber the producer gas gets in close contact with thermal oil and the light tars dissolve in the oil. The oil is drained off, increased in temperature and introduced into the stripper where the light tars evaporate and removed by an air stream. This air is used as combustion air in the burner. In figure 9 the temperatures

of the producer gas in the absorber and the air in the stripper are given.



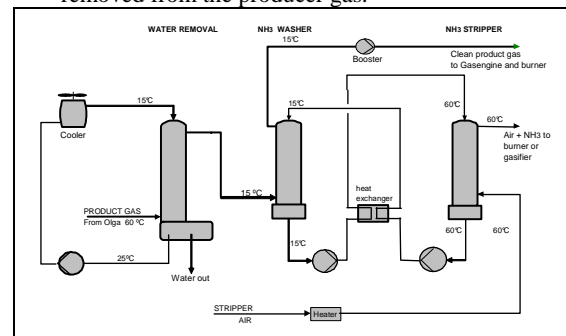
**Figure 9:** In/outlet temperatures of the producer gas in the Olga absorber and of the air in the Olga stripper.

The absorber and the stripper operated at a temperature level of approximately 65 °C and 180 °C respectively. These temperatures vary little over time.

#### 6.5 Gasreip

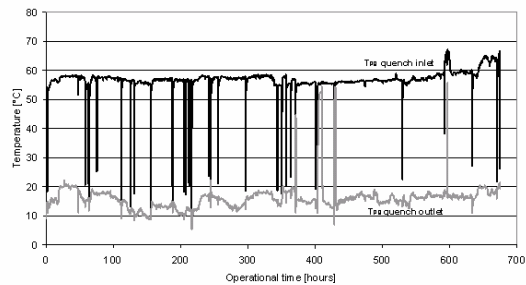
Gasreip consists of two parts, as shown in figure 10:

1. a water quench, in which the producer gas temperature is reduced by means of water injection and in which the moisture in the producer gas condenses and
2. A  $NH_3$  washer/stripper loop in which the  $NH_3$  is removed from the producer gas.



**Figure 10:** Flow scheme of Gasreip water- and  $NH_3$  removal

In figure 11 the water quench in- and outlet temperatures of the producer gas are given during the entire test.



**Figure 11:** Producer gas in- and outlet temperatures of the Gasreip water quench.

In the Gasreip water quench the producer gas temperature decreases from 55°C to 10 - 20°C, The

moisture in the producer gas condenses and is periodically drained. Although this water is not an "oil/water mixture" it is not allowed to drain this water in the ECN drainage system. It is carried off as "refuse water".

In the absorber 10-20°C water is injected in which the ammonia dissolves. By means of a heat exchanger the water temperature is increased to 60°C. This 60°C water goes to the stripper. Here the ammonia evaporates in 60°C air, which flows to the burner. In the burner the ammonia is burned. The water leaving the stripper is cooled in a heat exchanger and reintroduced into the absorber.

### 6.6 Gas engine

The cleaned producer gas is partly used in a gas engine and partly in a hot water boiler.

In table 3 an overview of the composition of the producer gas is given at two locations, before and after the gas cleaning.

		Raw producer gas	Before Gas engine
H <sub>2</sub>	vol%dry	7.2	7.4
CO	vol%dry	17.4	17.4
CH <sub>4</sub>	vol%dry	4.6	4.6
CO <sub>2</sub>	vol%dry	15.5	15.5
C <sub>2</sub> H <sub>2</sub>	vol%dry	0.2	0.2
C <sub>2</sub> H <sub>4</sub>	vol%dry	2.0	1.9
C <sub>2</sub> H <sub>6</sub>	vol%dry	0.1	0.1
N <sub>2</sub>	vol%dry	51.3	52.0
H <sub>2</sub> O	vol%	14.6	1.9
Benzene	ppmv dry	3511	2424
Toluene	ppmv dry	448	158
NH <sub>3</sub>	ppmv	160	10
H <sub>2</sub> S	ppmv	10	10
Total tar <sup>1</sup>	mg/m <sub>3</sub> dry	16855	91
Naphtalene	mg/m <sub>3</sub> dry	4023	35
Phenol	mg/m <sub>3</sub> dry	386	<2.5
Tar aerosols (incl. dust)	mg/m <sub>3</sub> dry	-	<5
Tar dewpoint (measured)	°C	-	-1 ±1
Tar dewpoint (calculated)	°C	-	2
Tar dewpoint @ 2.5 bar (calc.)	°C	-	14

<sup>1</sup>accuracy +/- 200 mg/m<sub>3</sub>

**Table 3:** Composition of the producer gas before and after the gas cleaning

In the column "raw producer gas" the average composition of the producer gas after the gasifier is given. As can be seen in the table, this gas contains a lot of tars, moisture and ammonia. The next column shows the composition of the producer gas upon entering the gas engine. Here, the producer gas has passed Olga and Gasreip and almost 99.5% of the tars, 87% of the water and 94% of the ammonia are removed from the producer gas. This gas is clean enough to enter the gas engine without causing problems.

The gas engine operated very well on this gas. Periodic inspections of spark plugs, valves and pistons proved that the engine remains clean during operation and the motor oil remains of good quality.

During operation the engine delivered on average 39 kW<sub>e</sub> to the grid. In total 20.000 kWh of electricity was produced during producer gas operation and 5000 kWh on natural gas operation.

The emissions of the gas engine are measured periodically. The results are given in table 4.

		Producer gas	Natural gas
O <sub>2</sub>	vol%	3-4	8
C <sub>x</sub> H <sub>y</sub>	ppm	375-475	>1000

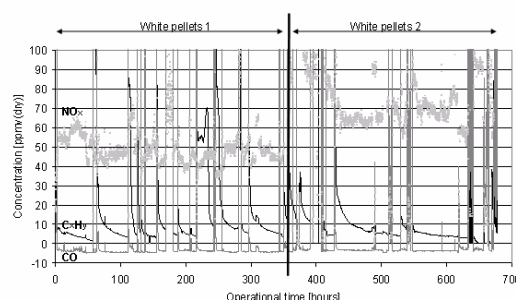
CO	ppm	1200-1600	500
NO <sub>x</sub>	ppm	80-120	40

**Table 4:** Stack emissions of the gas engine running on producer gas and on natural gas

The difference in the oxygen content of the flue gas brings about that the efficiency of the gas engine on natural gas is almost equal to the efficiency of the engine on producer gas.

### 6.7 Gas burner and hot water boiler

The producer gas which is not used in the gas engine is combusted in the hot water boiler. In figure 12 the stack emissions of the boiler are given during the duration test. The values are "as measured", so no corrections have been made for oxygen content.



**Figure 12:** Stack emissions from the hot water boiler

The figure shows a fluctuating C<sub>x</sub>H<sub>y</sub> level in the flue gas. After a boiler outage, this emission is around 90 ppmv(dry), after hours of operation the emission stabilizes on a very low level of less than 10 ppmv(dry). The stabilizing time is long: after 50 hours the trend is still decreasing. So, long test runs are required to produce accurate C<sub>x</sub>H<sub>y</sub> levels.

The CO emission is negligible (the negative value of -4 ppm is a calibration inaccuracy). Short peaks in CO emission occur during startup of the burner.

The NO<sub>x</sub> emission during the first part of the test is lower than during the second part of the test: 50 versus 75 ppmv(dry) on average. This can be explained by the higher nitrogen content of the pellets during the second part of the test. However, both values are very low for wood firing and comparable with the emissions during natural gas firing.

### 6.8 Energy balance

During the test data are collected, to determine the mass and energy balance of the system. For two periods of 24 hours the balances are elaborated. On the basis of this work it was concluded that the cold gas efficiency of the gasifier system was 65%. However, in this 65% the heating value of the tars is not included. Since the tars could be returned as a fuel to the gasifier, one can include the heating value of the tars in the balance. In that case, the cold gas efficiency increases to 71%.

Further, the electrical efficiency of the gas engine was determined. On February 1, 69 m<sub>n</sub><sup>3</sup>/hr cleaned and dried producer gas with a heating value of 440 MJ/hr was fed to the gas engine. With this gas 37 kW of electricity was generated. On February 28, 79 m<sub>n</sub><sup>3</sup>/hr producer gas with a heating value of 481 MJ/hr generated 42.5 kW. From these figures it was concluded that the electrical

efficiency of the gas engine was on average 31%.

## 6 CONCLUSIONS

The duration test with the integral 500 kW biomass gasification system was very successful. During the 891 hours of operation the reliable functioning of the gasifier, the cooler, the Olga tar removal system and the Gasreip water and ammonia removal system was demonstrated convincingly. A persistent problem was clogging in a duct between the cyclone and Olga. This problem was mainly caused by the lay-out of this duct. An adequate design of this duct is required for commercial installations.

Olga removed 99.5% of the tars and Gasreip removed 87% water and 94% ammonia from the producer gas. One can reliably operate a gas engine and a burner/hot water boiler on this clean producer gas. With wood pellet gasification the stack emissions of the gas engine and the boiler were comparable to the emissions when firing natural gas. Including tars the cold gas efficiency of the gasifier was 71%. The electrical efficiency of the gas engine was 31%.

## 7 REMARKS

During the preparations of the duration test the supplier of the Olga tar removal system, Technisch Bureau Dahlman B.V., received the order from Eneria to design and deliver an Olga for a 4 MWth biomass gasifier unit with a 1.1 MWe gas engine generator set. All the lessons learned during the duration test could be utilized in the design of this Eneria unit. Partly due to this, the 4 MWth unit was commissioned successfully in the summer of 2006. The installation, build in Moissane, France, is the first industrial demonstration of the Olga tar removal system.