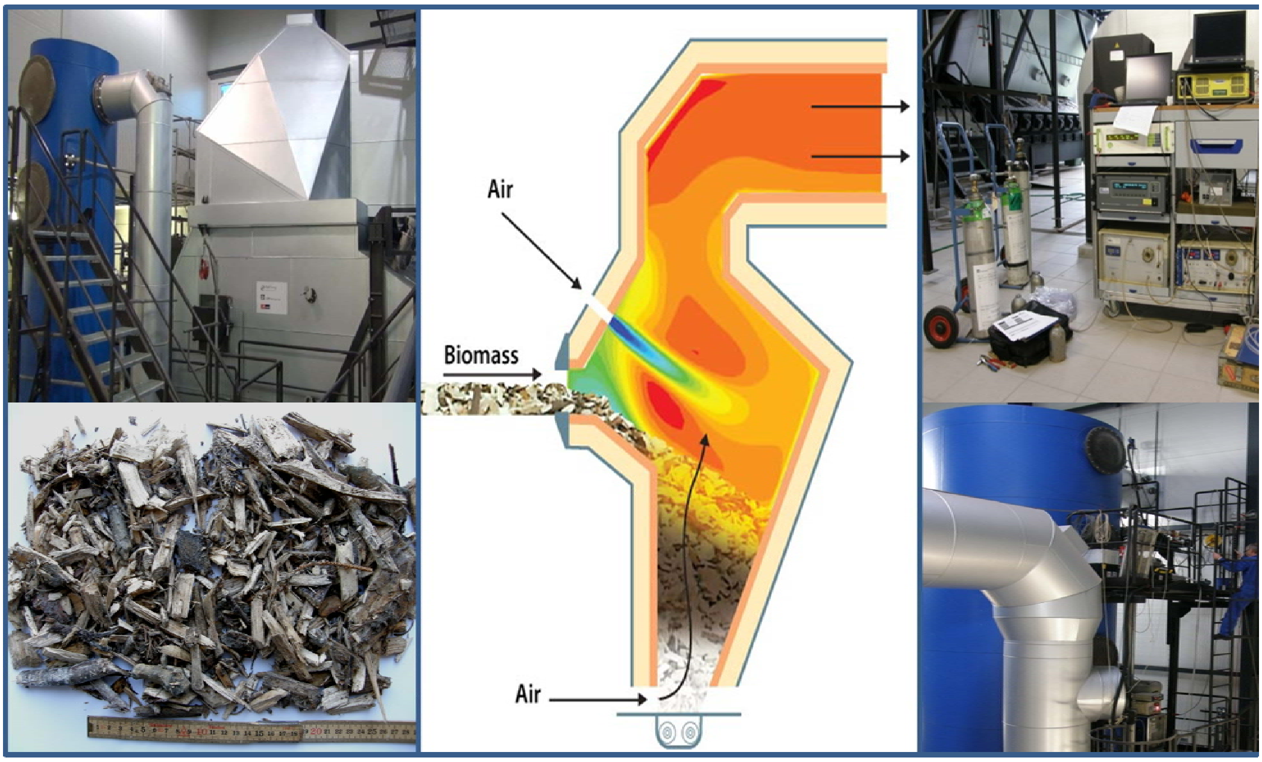
Dall Energy Biomass Furnace

Low particle, CO and NO_X emission furnace



Document	**Test Report**
Date	May 2012
Document Responsible	Ole Schleicher

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2. INTRODUCTION

This test report is the implementation of a test design developed for verification of the performance of an environmental technology following the DANETV method. See the verification protocol /1./ for details on organization and implications.

2.1. Verification protocol reference

Dall Energy Biomass Furnace, Low particle, CO and NO_X emission furnace, March 2011.

2.2. Name and contact of vendor

Dall Energy
Venlighedsvej 2
2970 Hørsholm
Denmark
Phone: +45 29 87 22 22
Contact: Jens Dall Bentzen
E-mail: info@dallenergy.com

2.3. Name of centre / test responsible

Verification Test Centre (DANETV)	Test responsible
FORCE Technology Park Allé 345	Ole Schleicher
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2.4. Technical experts

The technical expert assigned to this test and responsible for review of test plan and test report includes:
Arne Oxbøl
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3. TEST DESIGN

Emissions and operation parameters shall be measured continuously and/or manually during stable operation for the furnace at different loads, and during load changes.

3.1. Test site

The testing was conducted at the newly constructed 8 MW Dall Energy Furnace, at Andelsselskabet Bogense Fjernvarme in Denmark. The furnace was operated by the local operators, supervised by Dall Energy, which also has provided the necessary documentation and operation instructions for the tests.

3.2. Test type

The technology is the furnace, which is an integrated part of a biomass district heating plant, and consequently the test must be carried out as On-site test.

3.3. Addresses

Andelsselskabet Bogense Fjernvarme
Fynsvej 5
5400 Bogense
Denmark

3.4. Descriptions

The Dall Energy furnace is a newly invented combustion design, which in one special designed unit combines the well known updraft gasification technology with a gas combustion section above the gasification.

The technology can only work as an integrated part of a biomass combustion plant, consisting of a fuel feeding system, a system to utilize heat and a chimney. To achieve the highest energy efficiency the heat utilizing system includes a wet condensation system. Several other units, e.g. blowers, instrumentation and a process control system are necessary to operate the plant. Only the furnace is included in the ETV verification test, as all the surrounding equipment can be selected among different technologies and suppliers.

3.5. Tests

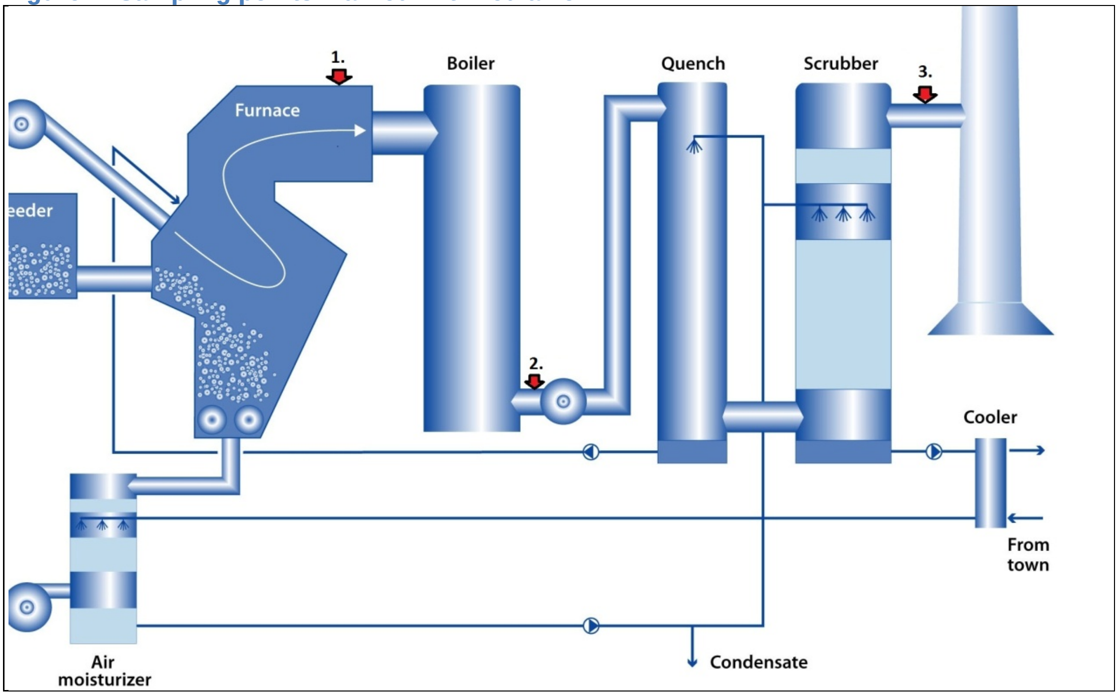
The Dall Energy biomass furnace was tested for its ability to keep the emission of CO, particles and NO_X low, during stable operation at both high and low load, as well as during load changes.

The main test parameters were the concentrations of CO, particles and NO_X but also the concentration of O_2, CO_2 and water and the flue gas temperature and flow was measured, to normalize the measured value to the reference conditions, and to verify the operational conditions during the test.

The accessible sampling points in the plant are showed in Figure 1. The sampling points are:

1. Outlet furnace
2. After the boiler
3. Stack

Figure 1. Sampling points marked with red arrow



The flue gas temperature at the outlet from the furnace, sampling point 1, is between 800 °C and 950 °C, and the concentration of particles at such high temperature, is not the same as if measured after the boiler, where the temperature is between 120 °C and 150 °C. This difference in particle concentration is due to condensable, which is salts and organic compounds on vapour form at high temperature, which condenses to form particles at lower temperature.

The concentration of particle measured after the boiler would probably be lower than the measured concentration out of the furnace, because a part of the condensable will condense on the surface of the boiler. The total particle emission including the condensable is therefore the most comprehensive measure for the load of particle and potential depositions to the boiler and the following flue gas handling units.

To verify the load of particles from the furnace to the heat recovery system, the concentration of condensable is also measured and presented.

The concentration of particles and condensable was measured manually, by isokinetic sampling of flue gas, and subsequent analysis. Because of the very high flue gas temperature, special sampling equipment med of quarts glass was needed, and also adjustments of the sampling procedure described in Appendix 3 was necessary, because the method is not intended for high temperature sampling. The sampling was consequently not precisely following the standard, and cannot be reported accredited, but all standard procedures for accredited sampling was followed.

Continuous measurement was performed for the parameters CO, O_2, NO_X and flue gas temperature in sample point 2 after the boiler where the flue gas temperature is more suitable for the measurement.

3.5.1. Test methods

The testing consists of two types of measurements: Continuous and manual measurements.

See appendix 3 for a short description of the applied accredited measurement methods, limits of detection, references and uncertainty. The design of the sampling site has an influence on the measurement uncertainty.

3.5.2. Test staff

The test staffs are:
Test responsible: Ole Schleicher (OSC)
Field responsible: Steen Meldorf (SME)
Test technician: Steen Meldorf (SME)

3.5.3. Test schedule

Table 1. Test Schedule

	Week number 2011										
Task	10	11	12	13	14	15	16	17	18	19	20
Draft Test plan	x	x									
Draft Test plan, review & QA			x	x							
	Week number 2012										
	10	11	12	13	14	15	16	17	18	19	20
Plant stability test	x	x									
Test period			x								
Analysis				x	x	x					
Data handling and calculation					x	x	x	x			
Draft Test Report, review & QA								x	x		
Final Test Report									x	x	x

3.5.4. Test equipment

Only equipment for normal emission measurement is used, except for the modified equipment for measuring particles and condensable at the furnace outlet.

3.5.5. Type and number of samples

The measurement program is listed in the following Table 2.

Table 2. Measurement program

Operation Conditions	Measuring point	Measuring principle	Measured parameters
Stable operation at 100 % load	Outlet furnace	Continuous	Flue gas temperature
		Three 1 hour samples	Particles including condensable
	After the boiler	Continuous	Temperature and the gas parameters: O_2, CO, CO_2, NO_X,
	After scrubber	Continuous	Flue gas temperature and flow
Changing from 100 % to 20 % load	Outlet furnace	Continuous	Flue gas temperature
	After the boiler	Continuous	Temperature and the gas parameters: O_2, CO, CO_2, NO_X,
	After scrubber	Continuous	Flue gas temperature and flow
Stable operation at 20 % load	Outlet furnace	Continuous	Flue gas temperature
		Three 1 hour samples	Particles - including condensable
	After the boiler	Continuous	Temperature and the gas parameters: O_2, CO, CO_2, NO_X,
	After scrubber	Continuous	Flue gas temperature and flow
Changing from 20 % to 100 % load	Outlet furnace	Continuous	Flue gas temperature
	After the boiler	Continuous	Temperature and the gas parameters: O_2, CO, CO_2, NOX,
	After scrubber	Continuous	Flue gas temperature and flow

Also subsamples of the fuel and ash were collected during the test period, and one combined sample of each was analyzed (see prescription in section 3.5.6).

Continuous measuring of flue gas temperature in furnace outlet was not possible, because only one sampling port was accessible. The furnace temperature was consequently taken from the plant monitoring system.

The continuous measurement of flue gas temperature, water content and concentration of O_2, CO, CO_2 and NO_X has run around the clock during the whole test period of 3-4 days, to be able to verify the operation and emission stability for the whole period. The sampling point for these measurements was after the boiler, where the temperature is suitable for sampling.

Manual samplings of particles and condensable was carried out in the sampling point at the outlet from the furnace.

The manual samples with the duration of one hour were taken during two periods with stable operation at 100% and 20% load respectively.

3.5.6. Fuel and ash samples

A sample of the wood chips was taken from a truck load of chips delivered to the plant on the 20th March. The wood chips used, is freshly cut and chopped mixed forest wood.

The sample is described for visual appearance, including wood types and parts of the trees, chip sizes and colour, and documented by photos. Information from the plant about origin of the fuel and possible fuel analysis is presented.

A sample of ash from the furnace was collected by the end of the sampling campaign. The ash is transported by eight screw conveyers from the bottom of the furnace to a watering trough, where the ash is soaked, to cool it, and to prevent dust problems. The ash sample was collected by collecting a subsample from each of the eight conveyers.

The ash sample was described for visual appearance, including colour and content of larger and maybe unburned particles, and documented by photo. The sample is analyzed for residual heat value.

3.5.7. Operation conditions

The test was carried out during two days, with different loads and during load changes, according to this program:

1. Stable operation at 100 % load.
2. Changing load from 100 % to 20 % load.
3. Stable operation 20 % load.
4. Changing load again up to 100 % load.

The loads for the first three items was achieved according to the plan, but the fourth changing the load from 20 % up to 100 % was divided in two steps. First the load was increased to 60 % where it stayed until next morning, where it was increased to 100%.

3.5.8. Operation measurements

During the test several operating parameters was measured and logged by the test team, and some additional parameters was delivered from the plant instrumentation and monitoring system in a data file covering the whole test period.

Many data was delivered from the plant, but mainly data for the fuel feed, the load and produced energy is presented in this report.

3.5.9. Product maintenance

No regular maintenance is required for a furnace, which normally can operate for several years without maintenance. However, the inside fireproof bricks lining should be inspected regularly for cracks and depositions, and repaired or cleaned if necessary.

3.5.10. Health, safety and wastes

The use of the product does not imply special health, safety and waste issues different from the operation of other furnaces.

The work during testing was done according to the FORCE Technology Safety Rules that are compliant with the extensive Danish rules for safe occupational health and the European regulations of work with chemicals.

4. REFERENCE ANALYSIS

4.1. Analytical laboratory

Analysis was carried out by the FORCE Technology laboratory according to DANAK accreditation no. 65.

Analysis of condensable is not covered by the accreditation, but it was performed according to well known and accepted standards and within the same QA system as the accredited analysis.

4.2. Analytical parameters

Analysis was carried out for:

- Particles collected on plane filters.
- Condensable in condensate and in water form rinsing the sampling equipment.

4.3. Analytical methods

The analytical methods are:

- Conditioning the filters to constant weight and weighing them according to EN 15284-1.
- Evaporation of liquid from the condensate samples and rinsing solution and weighing the residue according to US EPA Method 202.

4.4. Preservation and storage of samples

There are no special requirements for preservation and storage for the plane filters used for collecting particles and the absorption water used for collecting condensable, as they are not sensitive for degradation or chemical reactions, caused by normal temperature and light. The only requirements are the basics, to keep the samples in clean and sealed containers or bottles in a dark and cool place.

5. DATA MANAGEMENT

Handling of data and calculation of results is performed according to the FORCE Technology DANAK accreditation no. 51 (also for parameters not covered by the accreditation).

Calculations were performed by means of approved spread sheets and controlled spread sheet calculations.

5.1. Data storage, transfer and control

All manually read data from instruments, observations and information's about the plant operation during the test, was stored in handwritten form on paper and schemes.

All the data stored in data loggers was transferred to the FORCE Technology computer system, which is regularly backed up for data safety.

6. QUALITY ASSURANCE

All measuring, handling of data and calculation of results is performed according to the FORCE Technology DANAK accreditation no. 51 (also for parameters not covered by the accreditation).

All handwritten data and notes were present in the original forms.

Approved spread sheets for calculations of results was subjected to an intensive control, to assure correct calculations, and consequently no further control is necessary.

6.1. Test report review

The test report is subject to internal review by the verification responsible from FORCE Technology Test Centre:

Marianne Kyed Ørbæk
E-mail: mko@force.dk
Phone: +45 4326 70 62
Cell phone: +45 2269 75 65

Review of the test report will be done by the technical expert assigned to this verification (see section 2.4).

6.2. Performance control – reference analysis

One field blank sample and one laboratory blank were performed for each of the manually sampled parameters during the sampling campaign.

6.3. Data integrity check procedures

All transfer of data from handwritten form to computer, was subjected to 100 % control by another person.

New calculations in spread sheets were subjected to 100 % check of all new formulas and spot check of copies of the formulas.

7. TEST RESULTS

7.1. Test summary

The test was conducted at Andelsselskabet Bogense Fjernvarme, Denmark, on behalf of Dall Energy and coordinated by FORCE Technology.

The test plant has been in operation at app. 100 % load for several days, and has proven its ability to operate at this load for a longer period, before the test was scheduled for week 15, 2012.

The combustion plant including the furnace was operated without problems during the whole test period.

During operation, the operation conditions were recorded and sampled as mentioned in section 3.5.1 to 3.5.8

7.2. Test results

The test was started Tuesday the 20th of March, but measurement equipment was installed on Monday the 19th. The continuously operated emission measurement was running from Tuesday 8:30 until Wednesday at 10 AM.

Time and periods for the thermal loads and changes of the load is listed in Table 3.

Table 3. Time and periods for the thermal load and load changes calculated from thermal output for the test period.

Period		Load			Comments
From	To	Target %	Actual average MW	Actual %	
8:30 AM	15:00 PM	100	7.7	96	Sampling period
15:00 PM	16:30 PM	100 → 20	3.7	-	Load change
16:30 PM	20:15 PM	20	1.6	20	Sampling period
20:15 PM	21:10 PM	20 → 60	2.9	-	Load change
21:10 PM	7:00 AM	App. 60	5.3	66	Night operation
7:00 AM	7:45 AM	60 → 100	6.3	-	Load change
7:45 AM	10:00 AM	100	8	100	

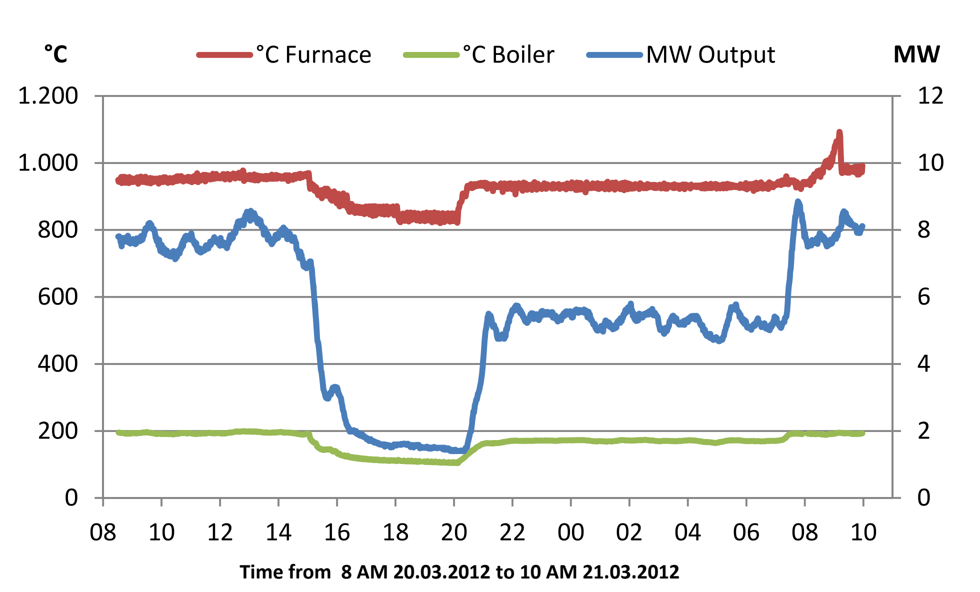
The load changed by changing fuel feed rate and the amount of primary air. When the fuel feed rate is changed the production rate of pyrolysis gases changes, and when the amount of primary air is changed the amount of gasification gas is changed. The SRO system will automatically adjust the set points for the regulation of some other parameters, e.g. the concentration of O_2, which is maintained by the feed of secondary air. The bed height of the fuel is maintained by regulating the fuel feed and the temperature in the combustion zone is maintained by the injection of water.

If the wood feed is completely stopped, the furnace can operate continually for many hours, with just a slowly decreasing output, because of the big amount of wood in the gasification part.

The flue gas temperature in the furnace and in the boiler is shown together with the thermal load in Figure 2.

The blue line in the figure is in fact the thermal output from the furnace, which is calculated from the heat recovered in the boiler part and in the scrubber/condenser. After the measurement campaign when handling data, it showed up, that the recorded plant data for “thermal input” in fact is the thermal output, which is calculated as the sum of the thermal output from the boiler and the scrubber. The thermal input is some percent lower than the output, because of the condensation in the scrubber, which increases the thermal efficiency to more than 100 %.

Figure 2. Thermal input and temperatures in furnace and boiler

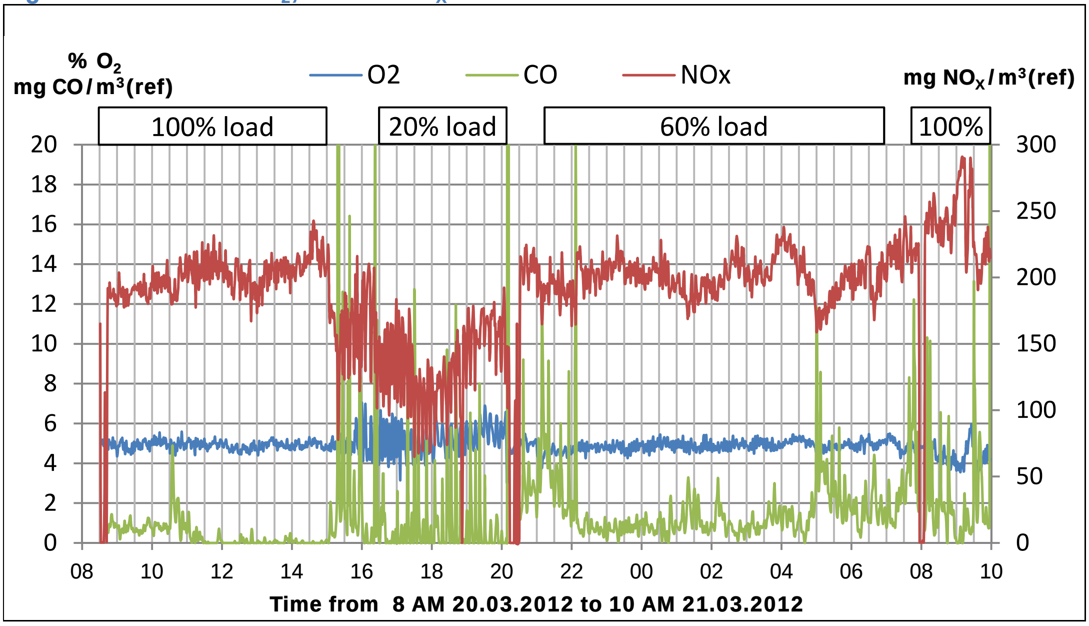


The regulation of the furnace temperature should maintain a constant temperature, which is the case at 100% load and at 60% load, but at 20 % load the temperature is decreased. At the first constant 100 % load the average furnace temperature was just around 960 °C, and it dropped down to between 860 and 835 °C, when the load was reduced to 20 %. It was anticipated that the furnace temperature would be kept constant over the load range, but it appears that the set point are automatically reduced at lower loads. The furnace temperature is regulated by the injection of water into the combustion zone.

The emission of CO was on average below the detection limit of 2 mg/m^3(ref). In short periods the concentration was above the detection limit, especially when the load was changed, but apparently also once in a while when operation at low load. See the plot in Figure 3. The two peaks above the scale at the beginning and end of the 20 % load period is one-minute average peaks reaching 134 and 140 mg/m^3(ref).

The NO_X emission depends not only on the furnace conditions, but also on the nitrogen content in the fuel. The NO_X emission is clearly somewhat lower in the 20 % load period, which is related to the furnace conditions, e.g. retention time, as the nitrogen content in the fuel is anticipated to be constant. The NO_X concentration fluctuates, but it seems to be among pretty constant values, depending on the actual load.

Figure 3. Emission of O_2, CO and NO_X



The measured emissions as hourly averages for CO, NO_X and particles from the three sampling hours at high and low load are presented in Table 4 and Table 5, and the average emission of CO and NO_X in the load change periods are seen in Table 7.

Table 4. Measurements in flue gas outlet from furnace at 100 % load.

Parameter	Unit	Sample 1	Sample 2	Sample 3	Average	ELV[1]
Date	dd-mm-yy	20-03-2012	20-03-2012	20-03-2012	20-03-2012	-
Measuring period	hh:mm	11:12 - 12:12	12:15 - 13:15	13:22 - 14:22	11:12 - 14:22	-
Operating parameters						
Temperature	°C	957	960	957	958	-
O_2	Vol % (dry)	4.9	4.8	4.9	4.9	-
CO_2	Vol % (dry)	15.4	15.6	15.4	15.5	-
H_2O	Vol %	38.0	38.2	37.7	38.0	-
Concentrations						
CO	mg/m³(s,d)[2]	< 2	< 2	< 2	< 2	-
	mg/m³(ref)[3]	< 2	< 2	< 2	< 2	625
NO_X	mg/m³(s,d)[2]	300	290	300	300	-
	mg/m³(ref)[3]	210	200	210	200	300
Particles	mg/m³(s,d)[2]	100	100	97	100	-
	mg/m³(ref)[3]	70	69	66	69	100
Condensables (rinse and condensate)	mg/m³(s,d)[2]	73	73	73	73	
	mg/m³(ref)[3]	50	49	50	50	

Table 5. Measurements in flue gas outlet from furnace at 20 % load.

Parameter	Unit	Sample 1	Sample 2	Sample 3	Average	ELV[1]
Date	dd-mm-yy	20-03-2012	20-03-2012	20-03-2012	20-03-2012	-
Measuring period	hh:mm	16:44 - 17:44	17:50 - 18:55	19:00 - 20:00	16:44 - 20:00	-
Operating parameters						
Temperature	°C	858	841	836	845	-
O_2	Vol % (dry)	4.9	5.2	5.6	5.3	-
CO_2	Vol % (dry)	15.4	15.2	14.8	15.1	-
H_2O	Vol %	32.1	32.4	32.7	32.4	-
Concentrations						
CO	mg/m³(s,d)[2]	< 2	< 2	< 2	< 2	-
	mg/m³(ref)[3]	< 2	< 2	< 2	< 2	625
NO_X	mg/m³(s,d)[2]	190	170	220	200	-
	mg/m³(ref)[3]	130	120	160	140	300
Particles	mg/m³(s,d)[2]	100	90	87	92	-
	mg/m³(ref)[3]	69	63	62	64	100
Condensable (in rinse and condensate)	mg/m³(s,d)[2]	97	97	97	97	
	mg/m³(ref)[3]	67	68	69	68	

[1] ELV: Emission Level Value (Danish)
[2] (s,d) indicates dry gas at standard conditions (0°C, 101,3 kPa)
[3] (ref) indicates dry gas at standard conditions (0°C, 101,3 kPa) at 10 % O_2

The results of the failed measuring campaign in week 44, 2011 are presented in Table 6 for comparison with the latest measuring.

Table 6. Results from the interrupted measuring campaign in November 2011

	Unit	100% load	20% load	20% load	20% load	Average
Date	dd-mm-yy	01-11-2011	01-11-2011	01-11-2011	01-11-2011	01-11-2011
Measuring period	hh:mm	13:30 - 14:07	16:37 - 17:37	17:49 - 18:49	19:33-20:33	13:30 - 20:33
Temperature	°C	940	926	918	903	922
O_2	Vol %, dry	4.9	4.6	5.6	5.3	5.8
H_2O	Vol %	35.2	35.4	32.3	33.0	34.0
CO	mg/m³(s,d)[2]	14	< 2	< 2	< 2	-
	mg/m³(ref)[3]	10	< 2	< 2	< 2	-
NO_X	mg/m³(s,d)[2]	250	250	250	260	240
	mg/m³(ref)[3]	170	170	180	180	180
Particles	mg/m³(s,d)[2]	320	69	52	59	130
	mg/m³(ref)[3]	220	46	37	42	98
Condensable (in rinse and condensate)	mg/m³(s,d)[2]	120	120	120	120	120
	mg/m³(ref)[3]	83	81	87	85	89

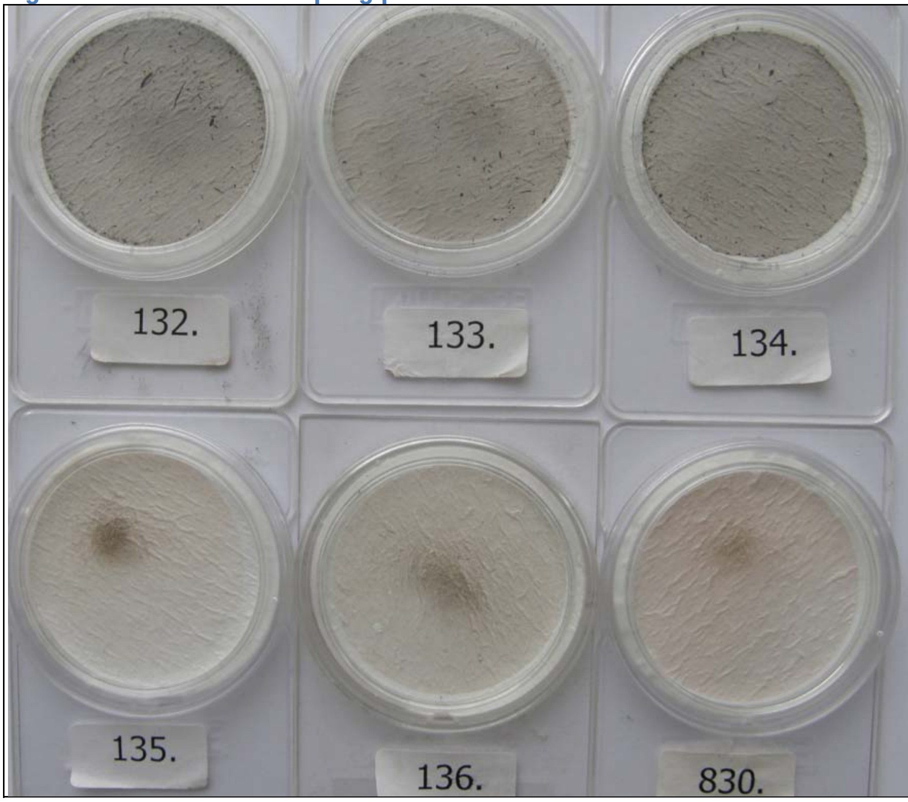
Comparing the measuring data from November 2011 (Table 6) with the new ones from week 12, 2012, Table 4 and Table 5 it is obvious, especially from the CO and particle emission from the first sample at 100 % load, that the combustion was not performing optimal. This sample was interrupted after 37 minutes of sampling. The samples at 20 % load are performing much better, and the results are in the same low level as the new samples from 2012. The emission of condensable is somewhat higher than the new results, which can be due to a higher temperature in the furnace.

Table 7. Emission of CO and NO_X during load changes

Load	Time		CO emission [mg/m³(ref)]			NO_X emission [mg/m³(ref)]		
%	From	To	Average	Max	Min.	Average	Max.	Min.
100	8:30 AM	15:00 PM	< 2	3	< 2	200	243	167
100 → 20	15:00 PM	16:30 PM	3.4	98	< 2	160	223	80
20	16:30 PM	20:15 PM	< 2	118	< 2	135	192	65
20→ 60	20:15 PM	21:10 PM	2.3	8	< 2	200	225	165
60	21:10 PM	7:00 AM	< 2	14	< 2	200	238	159
60 → 100	7:00 AM	7:45 AM	< 2	9	< 2	230	290	190
100	7:45 AM	10:00 AM	< 2	9	< 2	240	291	190

Figure 4 and Figure 5 shows photos of the filters from collecting particles.

Figure 4. Filters from sampling particles at the furnace outlet.



(photo row 1)	100 % load Sampling volume around 205 l
(photo row 2)	20 % load Sampling volume around 140 l

There is a significant visual difference in particle appearance comparing the filters: At 100 % load black particles are appearing and at the 20 % load there is no particles. As the black particles are unburned carbon, it is assumed that the difference derives from the flue gas velocity. With a reduced velocity (at 20 % load) and turbulence in the flue gas stream less particles (from the wood and ash filled gasification part in the bottom of the furnace) are carried with the flue gas.

The unburned particles can be seen more clearly in figure 5. The particles from 100 % load seem to be very different from the particles at 20 % load. The colour is darker, and there seems to be some lighter particles at the edge of the filter, where the particles at 20 % load are brownish, and they are mainly collected in a small area around the middle of the filter.

Figure 5. Close up photos of filters with particles from furnace outlet

100 % load	20 % load

Unburned carbon has a low density, and despite the colorization of the filter, the weight share of these unburned particles is probably very low. It is assumed, that the main part of the particles are condensed salts from the combustion, and that the emissions are fairly the same at both 100 % and 20 % load. Because of the higher flue gas flow at 100 % load, more and bigger unburned particles are pulled up from the wood and ash filled gasification part in the bottom of the furnace.

Nevertheless the particles on the filters indicate a considerable difference in the combustion conditions and behaviour, since the particle size, colour and distribution on the filters are very different. Some differences could also be caused by differences in the sampling conditions, where the lower temperature in the furnace, and the reduced sampling flow at the 20 % furnace load, means that the sampled flue gas will cool down faster, but there is no knowledge or evidence for such effects. However, the considerable lower temperature in the furnace at 20 % load (100 to 125 °C lower) could mean different combustion efficiency and consequently the light brownish colour could be some residual combustion by products. Despite the differences in particle appearances and colour, the emissions are the same within the uncertainty of the measurement.

7.2.1. Wood fuel

The Dall Energy Furnace is suitable to burn wood with both low and high water content, e.g. wood chips from freshly felled and chopped wood.

The wood chips are delivered by:

Skovdyrkerforeningen Fyn
Lombjergevej 1
5750 Ringe
Phone: +45 62 62 47 47

The origin of the wood is not known by the plant. They have an agreement with the company to deliver the wood, and it is not important for them to know anything about the origin of the wood, which wood sort it is, or the content of leaves, needles and fines, as long as the furnace can burn it without problems. As mentioned earlier, the water content is also not important, because more water will automatically be added in the furnace if the wood contains less water. The wood chips used are freshly felled and chopped wood, from forest areas on Fyn, probably in the vicinity of Bogense to minimize transportation.

The next two figures are photos of the actual wood fuel delivered in the test period. It seems to be a mixture of different size of branches and sort of wood, but the content of needles indicates a high proportion of spruce. The content of fines seems to be low.

Figure 6. Photos showing the fresh wood chips burned in the furnace

A combined sample of the wood chips was analysed, and the results are showed in the table below.

Table 8. Wood chips analysis

Parameter	Unit	Dry sample	Wet sample
Water	%	-	34.0
Ash	%	1.5	1
Nitrogen, N	%	0.33	0.22

The values are within the normal range for mixed forest wood chips.

7.2.2. Ash

A combined sample of the ash, from the ash screw conveyers was taken when the last sampling at 20 % load was running. From the screw conveyers the ash is humidified, by transporting it to an ash container through water filled conveyer. To avoid loss of water soluble components to the water, the samples were taken between the screw conveyers with a steel pipe through 2” pipes installed at the end of each screw conveyer.

The ash sampling point is not very suitable for representative sampling, but there were no better sampling points available. Because of the sampling point, the ash samples may be different from the ash transported in the screw conveyers.

Figure 7. Sampling ash

The ash samples were pretty moist, which is caused by the water saturated primary air added to the bottom of the gasification part of the furnace.

The ash has a grey/brownish colour, with visible unburned particles

Figure 8. Ash sample

The ash sample was analysed for the parameters in the table below.

Table 9. Ash sample analysis

Parameter	Unit	Dry sample	Wet sample
Water	%	-	24.9
Residual heat value	MJ/kg	0.27	0.20

The measured heat value is just above the analytical detection limit of 0.2 MJ/kg for dry sample. The heat value of dry wood is app. 20 MJ/kg, and assuming that the wood used consist of 1.5 % ash as measured, the residual heat value in the ash is 0.2*100/20*1.5/100=0.015 % of the heat value of the wood.

7.3. Deviations from the test plan

The test was originally planned for the beginning of May 2011 (week 18 or 19), but the commissioning of the plant was delayed and the handover to Bogense District Heating company was postponed until September 2011. Therefore the ETV-test was postponed to November 2011 (week 44).

The test was started as planned in week 44. But when the plant was put on full load, flue gas was leaking into the boiler room from the ash screw conveyer sealing's. With extra ventilation of the boiler room it was possible to start the measurements, but before the first sampling was ended, the plant was stopped because of plugging a heat exchanger in the scrubber heat recovery system. This problem was temporarily solved by cleaning the heat exchanger, but it was realised, the plant could not be operated continuously at 100 % load. It was decided to continue with the measurements at 20 % load, and see if the 100 % load could be reached the next day. The next day it was realised, that to achieve continuously 100 % load, some other things than the leaking ash screw conveyers should be fixed, and the measurements was postponed indefinitely, until all known operational problems was fixed.

After fixing the problems a new test was planned for week 12, 2012, and due to unproblematic operations of the whole plant, the test was fulfilled in 2-3 days, where all manual samplings were carried out on the second day. 3-4 days were anticipated for the test according to the Test Plan.

The method for sampling and analysing the emission of particles and condensable out of the furnace has been modified based on the experiences from the first interrupted measurements in November 2011. This is more detailed described in Appendix 3. Sampling Methods.

In the meantime the test responsible OTL has left FORCE Technology and OSC has taken over this duty. Consequently MKO has taken over from OSC the duty of being Verification responsible.

According to the Test Plan, the temperature in the furnace should be measured continuously, but due to leak of sample ports, it was not possible. Instead the plant measurement of the temperature is used. This temperature was compared to the temperature measured by FORCE, and a good correlation was found.

According to the measurement program in Table 2 the continuous measurement of CO, CO_2 and NO_X should be done with an FTIR instrument, which was originally specified by another measuring campaign which should run parallel with the ETV test. Because of the time schedule delay, the FTIR measuring was accomplished during the first measuring campaign, and the ETV test was done with normal standard instruments according to the FORCE Technology accreditation.

The fuel sample should have been collected during the test period, by collecting several samples with regular intervals during the test period, and one sub samples should have been taken for analysis, after mixing all the samples.

By a mistake the thermal heat value for the wood fuel was not analyzed, but as it is not a primary parameter, either for the ETV verification nor other parameters or calculations it was accepted to skip this parameter.

APPENDIX 1

TERMS AND DEFINITIONS

Condensable	Condensable particulate matter (CPM). CPM is organic and inorganic compounds in vapour phase at stack conditions, which forms liquid or solid particles, when cooled to below 30 °C.
Effect	The way the target is affected
ETV	Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and adequate quality assurance.
Evaluation	Evaluation of test data for a technology or product in relations to the performance and data quality
Performance claim	The effects foreseen by the vendor on the target(s) in the matrix of intended use
Performance parameters	Measurable and quantitatively documentable parameters, which is equivalent to the performance of the product, or describes the performance, and can provide all the relevant and necessary information on the performance
QA	Quality assurance
Standard	Generic document established by consensus and approved by a re-cognized standardization body that provides rules, guidelines or characteristics for tests or analysis
Test/testing	Determination of the performance of a product for parameters defined for the application
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance

APPENDIX 2

REFERENCE

/1./ DANETV: Dall Energy Biomass Furnace. Verification Protocol March 2011. www.etv-danmark.com,

APPENDIX 3

SAMPLING METHODS

In the following a short description of the applied measurement methods, limits of detection, references and uncertainty are given. The design of the sampling site has an influence on the measurement uncertainty.

The testing consists of two types of measurements: Continuous and manual measurements.

Continuous emission monitoring (monitors, thermo couples etc.):

The limit of detection is given as the normal achievable at emission measurements. For monitors it is three times the average of monitor drift in the span point at repeated field measurements. Lower limits of detection can be achieved by optimized choice of calibration gas and higher frequency in the calibrations.

The uncertainty is based on measurements performed in a homogeneous gas stream as described in EN 15259. The uncertainty is given in % of the measured value (95 % confidence level). At low concentrations between 5 and 1 time the limit of detection, the uncertainty will increase from the stated %-value (at 5 times the limit of detection) up to 100 % of the measured value at the limit of detection.

Gas temperature:

The gas temperature is measured with a NiCr/NiAl-thermocouple connected to a data logger.

Range: -40 - 600 °C
Uncertainty: 4 °C (absolute)
FORCE Technology method: EM-03-01
Reference/standard: VDI 3511 bl. 1-5, IEC 584-2, IEC 584-2 amd. 1

CO_2-concentration: In a dry partial flow of flue gas free of particles the CO_2-concentration is determined by a nondispersive infrared (NDIR) monitor.

Range: 0 - 20 Vol. %

Limit of detection: 0.5 Vol. %

Uncertainty: 5 % of measured value (95% confidence interval).

FORCE Technology method: EM-05-01

Reference/standard: USEPA M.3A, ISO 12039

O_2-concentration: In a dry partial flow of the flue gas free of particles the O2-concentration is determined by means of a paramagnetic pilot cell.

Range: 0 - 25 Vol %

Limit of detection: 1 Vol %

Uncertainty: 5 % of measured value (95% confidence interval).

FORCE Technology method: EM-06-03

Reference/standard: EN 14789

CO-concentration: In a dry partial flow of flue gas free of particles the CO-concentration is determined by a non-dispersive infra red (NDIR) monitor.

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Range: 0 - 1000 ppm

Limit of detection: 1 ppm

Uncertainty: 5 % of measured value (95% confidence interval).

FORCE Technology method: EM-07-01

Reference/standard: EN 15058

NO_X-concentration: In a dry partial flow of flue gas free of particles the NO_X-concentration is determined by a chemiluminescence monitor.

Ranges: 0 - 100, 0 - 1000, 0 - 10000, 0 - 100000 ppm

Limit of detection: 1 ppm

Uncertainty: 5 % of measured value (95% confidence interval).

FORCE Technology method: EM-10-01

Reference/standard: EN 14792

Manual methods

The limit of detection is stated as the normal achievable at 60 minutes sampling time, normal suction level and accredited analysis. In some cases the limit of detection can be either lower or higher than the stated value. The limit of detection can be improved by higher suction flow and longer sampling time. The limit of detection is defined as the average of repeated blank values plus three times the standard deviation of the same blank values.

The uncertainty is based on measurements performed in a sampling site that meets the requirements in EN 15259 for grid measurements. When the demands in EN 15259 are not fulfilled, the uncertainty rises to an unknown level. The uncertainty is given in % of the measured value (95 % confidence level). At low concentrations between 5 and 1 time the limit of detection, the uncertainty will increase from the stated %-value (at 5 times the limit of detection) up to 50-100 % of the measured value at the limit of detection.

Flow:

The gas velocity is measured by means of a pitot tube connected to an inclined tube manometer or a micro manometer, reading the dynamic pressure. The velocity is measured in a number of points in the cross section of the duct. From the velocity and the cross section area, the flow is calculated.

Range: 0 - 40 m/s
Limit of detection: 2.3 m/s
Uncertainty: 10 % of measured value (95% confidence interval).
FORCE Technology method: EM-02-01
Reference/standard: ISO 10780

Particles:

A partial gas stream is aspirated isokinetic through a planar filter and a drying column. The gas flow is aspirated by means of a pump unit consisting of a gas tight pump, a calibrated gas meter and a flow meter. Sampling can be either in-stack or out-stack (the filter in the stack at stack temperature or the filter outside the stack in an oven).

Range: 0 - 50 mg/m^3(n,t)

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Limit of detection: 0,05 mg/m³(n,t)
Uncertainty: 10 % of measured value (95% confidence interval).
FORCE Technology method: EM-01-05
Reference/standard: EN 13284-1

The method for sampling particle is modified to make the sampling in a 1000°C hot flue gas, and to include sampling of condensable, according to the US EPA Method 202[4] by means of:

5. The nozzle and probe will be made of quarts glass, which can tolerate the high temperature.
6. A cooling system with air was adapted to the probe, to cool the flue gas down to between 120 and 180 °C where it enters the filter.
7. After the filter a condensation system to collect condensable according to US EPA Method 202 was applied.

This modified particle and condensable measuring system are combining methods from well known and international accepted standards, which guarantee the applicability and quality. The only parts which are not according to any standard are the system to cool the flue gas, but this part is only critical for the results if particles are deposited in the probe. To include these possible depositions in the measurements, the probe will be washed with ultra pure water after the sampling, and the content of particles and condensable in the wash water will be measured by evaporating the water, and weighing the residue. The weight will be distributed to the samples in proportion to their sampling volume.

At the first interrupted sampling in November 2011 four samples was collected with final condensation in impinger bottles in an ice bath but only a very small volume of condensate was collected, and the content of condensable was below the limit of detection of 2 mg/sample for each sample. After sampling the glass equipment being in contact with the flue gas, was washed with ultra pure water, and the content of particles and condensable was measured by weighing the residual after evaporation of the water. A considerable amount of condensable was found her.

Based on these facts, and the risk with handling the heavy glass equipment, it was decided to skip the impinger bottles and the ice bath at the next samplings, because the water cooling appears to be efficient enough to condense all condensable.

Furthermore it was decided to measure the condensable in the condensate in combined sample for each of the two loads (100 % and 20 %), to increase the possibilities to measure something above the limit of detection. The results was measurable, where analysing each sample would on average give the result below the detection limit of 2 mg/sample for the 20 % load samples, and just above the 2 mg/sample for the three 100 % load samples (7.6 mg in combined sample = 2.5 mg/sample).

The used sampling equipment without impinger bottles are showed in Figure 9

[4] US EPA Method 202. Dry impinger method for determining condensable particulate emissions from stationary sources.

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Figure 9. Equipment used for sampling particles and condensable in the furnace outlet.