Methane Oxidation Catalyst for Gas Engines

Project Report

February 2005

Methane Oxidation Catalyst for Gas Engines

Jan de Wit, Ianina Mofid

Danish Gas Technology Centre
Hørsholm 2005

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Enclosures

1 Summary and Conclusion

An oxidation catalyst has been tested at the laboratory of Danish Gas Technology Centre (DGC) to see if it had sufficient methane reduction capacity at typical exhaust temperatures for gas engines for combined heat and power production.

Significant reductions were seen at low temperatures for this catalyst in an earlier project with natural gas fired burners for a different purpose /7/.

A test was arranged in the DGC laboratory with flue gasses from the lean-burn test gas engine permanently installed. Ducting was made so both cooling and supplementary firing could be used to achieve the temperatures needed for the tests.

A test program was decided upon with the catalyst supplier. The aim of this programme was to test reduction efficiency at various flue gas temperatures (500, 450 and 400 °C) and at three different flow rates (space velocities). Between the measurement series the catalyst was heated to 550 °C to regenerate its performance. Before the test the complete duct system was flushed with 550 °C gas engine exhaust. Fresh certified lube oil was used at the engine.

As a start, measurements were made at 500 °C. The catalyst had only minor reduction (most likely higher hydrocarbons than methane) of hydrocarbons at this temperature. Even at 550 °C only very little UHC reduction was seen. At lower temperatures even less reduction is to be expected; less reduction is also to be expected at long-term operation as the catalyst will suffer from degradation or toxification.

Supplementary tests at approx. 500 °C were made with an increased amount of active catalyst and reduced flow. Also at these supplementary tests only minor UHC reduction was seen. Most likely only hydrocarbons higher than methane are reduced.

The test series was stopped as the results with the fresh catalyst obtained so far had no relevance in relation to actual working conditions of gas engines in practical operation and methane reductions requested.

Efficient catalytic long-term reduction of methane has until now mostly been seen with combinations of catalyst and techniques to obtain increased flue gas temperature. This has been demonstrated through oxidation catalysts with integrated recuperative or regenerative heat exchangers /5/, /6/, by temperature increase via supplementary firing /2/ or by using incineration devices to temperatures of approx. 800-900 °C /6/.

2 Background

Gas engines have become widely used for decentralised combined heat and power production (CHP) in Denmark. Almost 800 engines representing some 1000 MW_e installed power are in use, most of these fuelled by natural gas.

Developments within the gas engine technology have resulted in a significant rise in shaft efficiency and less pollution during the last 10 years. However, compared to gas turbines gas engines still have relatively higher content of unburned hydrocarbons(UHC) in the exhaust. This is mainly due to the non-continuous combustion in reciprocating engines, crevices in the combustion chamber, cold walls, and a possible carry over from intake valve to exhaust valve during scavenging.

By improvement of combustion chamber design this emission has been reduced. But as the combustion process is non-continuous in the engine there will be a limit how far you can go with these primary measures. After-treatment of the flue gasses is necessary for this.

Oxidation catalysts have been successfully used for CO reduction purposes. A number of tests have also been carried out for using oxidation catalysts for reduction of the unburned hydrocarbons, especially methane, as this has a relatively large greenhouse gas potential.

Earlier tests have shown that oxidation catalysts can reduce unburned hydrocarbons. However, as gas engines have become more efficient and the combustion leaner, the exhaust temperatures are too low to ensure good and continuous reduction. Earlier catalyst tests have shown this /8/.

A test at DGC with a tube combustor for other purposes than CHP showed that the Catator catalyst did reduce unburned hydrocarbons at flue gas temperatures similar to exhaust temperatures from gas engines /7/.

The combustor test mentioned above was the reason for setting up the gas engine test rig to test catalyst UHC reduction under controlled real-life conditions. The test should be performed under stationary conditions at various temperatures and various exhaust gas flows.

The catalyst has been supplied by the Swedish company Catator Ltd. Catator (www.catator.se) has also supplied housing and the fitting made for installation in the DGC test rig. Mr. Tihamer Hargitai has been in charge for this at Catator Ltd. Catator has experience in catalyst for natural gas combustion due to works for the Swedish Gas Technology Centre. Catator Ltd. is located in the innovation centre IDEON at the Lund University.

2.1 Organisation

The test work at DGC has been carried out by the following staff:

- Jan de Wit (Project Manager)
- Ianina Mofid
- Johan G. Larsen
- Lars Jacobsen
- Steen D. Andersen
- Leo van Gruijthuijsen
- Lotte Sarbæk Salling

Henrik Andersen, DGC, has made the Q/A works.

The work at DGC has been financed by the Danish gas companies' Technical Committee for Gas Utilisation and Installations.

Hørsholm, February 2005

Jan de Wit
Project Manager
Dept. of Energy Technology and Safety

Bjarne Spiegelhauer
Vice President
Dept. of Energy Technology and Safety

3 Gas engines, emission etc.

3.1 General

A total of approx. 800 stationary gas engines are installed in Denmark. The installed capacity is approx 1000 MW_e.

Almost all gas engines are lean burn spark ignited engines; some 200 engines (600 MW_e) of these are pre-chamber engines. With exception of a few smaller engines (<150 kW_e) all engines are turbocharged.

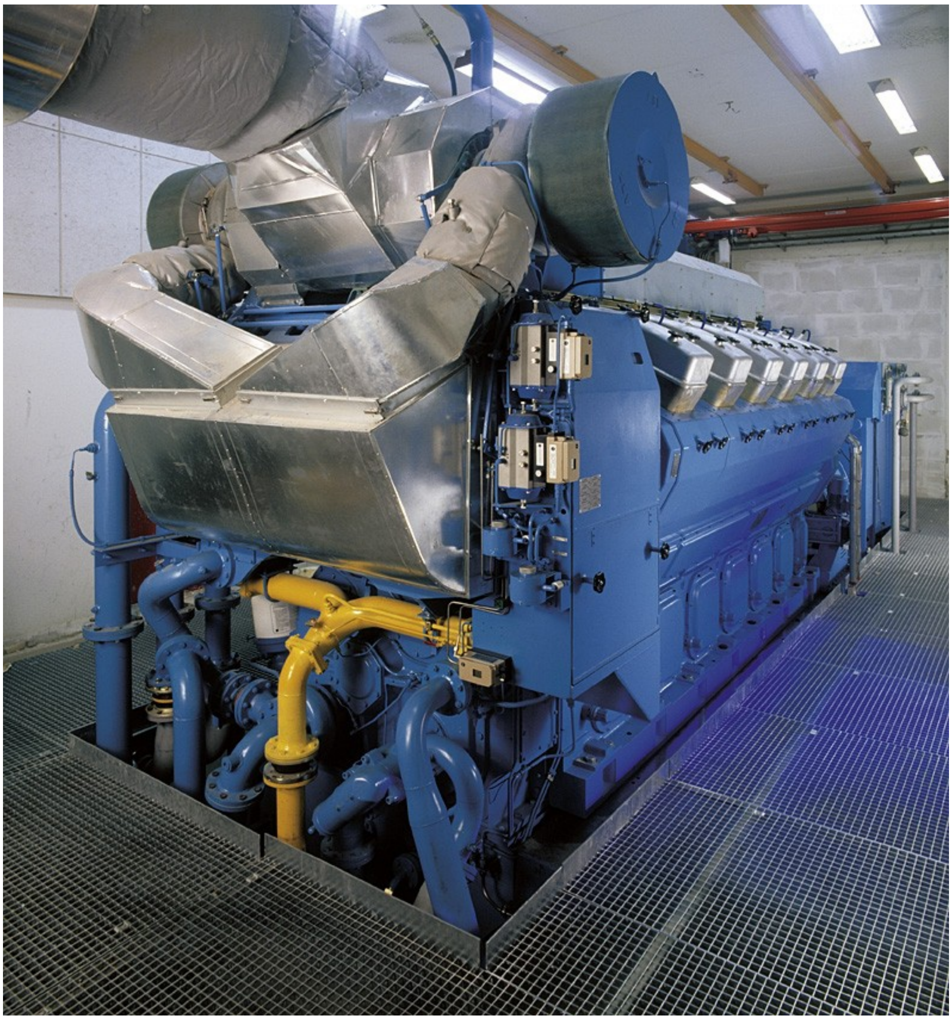


Figure 1 A 5 MW_e gas turbocharged V-configuration lean-burn gas engine

The engines typically operate full-load to achieve the best electrical efficiency and to produce most during the hours of the day when electricity is paid best. Surplus heat production is most often stored in heat storage (water tank).

The medium size and large gas engine manufacturers represented are the following:

- Rolls-Royce (Bergen)
- Caterpillar
- Wärtsilä
- GE-Jenbacher
- MAN-B&W
- Niigata
- Deutz/MWM
- Waukesha
- MAN-Rollo
- Guascor
- Dorman
- Perkins

Also, a number of smaller engines from Valmet, FIAT, SACHS, and VW are represented in the lowest power range (5-20 kW_e).

To a large extent the gas engines listed above are the same that can be seen used for stationary purposes throughout Europe. A few engines may not be represented in specific countries due to lack of sales agent/service providers etc.

3.2 Emission

In Table 1 typical emissions from lean burn spark ignited gas engines can be found. NO_x emissions have been reduced significantly during the last 10 years as a result of lean burn combustion techniques and improved combustion chamber design.

Table 1 State of art gas engine concentrations of pollutant flue gas components

Year	O2 [%]	CO [ppm]	NOx [ppm]	UHC [ppm]	ηe [%]
1989	6,7	450	3500	?	34
1997	11,8	350	150	1250	40
2003	11,5	415*)	50	1400	43

Please refer to Enclosure 6 to see the current Danish legislation concerning flue-gas emission for stationary gas engines for CHP production.

3.3 Exhaust temperature

Table 2 shows typical full-load exhaust temperatures before and after turbocharger.

Table 2 Typical full-load gas-engine exhaust temperature

	Exhaust temperature before turbocharger	Exhaust temperature after turbocharger
	[°C]	[°C]
Open-chamber engines	540..600	450..500
Pre-chamber engines	430..575	350..440

Catalysts are installed downstream (after) the turbocharger to avoid risks of damaging this costly high speed engine component. As it can be seen in Table 2 the catalyst should at this point be able to reduce methane at temperatures down to 350 °C to cover all engines in the market.

4 Test set up

4.1 The catalyst

The catalyst was supplied as solid state metal nets (Figure 2) on which the active material has been applied. DGC received a number of these corrugated nets and some distance layers (metal rings) to ensure good contact between flue gas and the active catalyst material. In Figure 3 the catalyst nets placed in the catalyst housing can be seen.

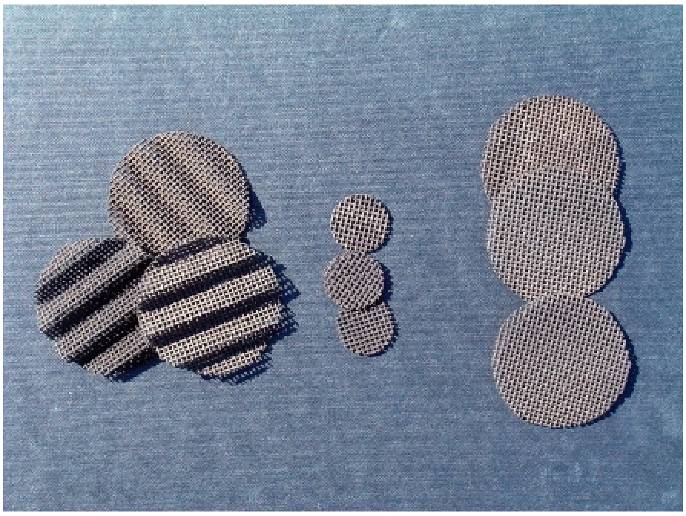


Figure 2 The catalyst nets

Some supplementary test with 20 nets (10 corrugated and 10 flat nets) where also made. During these tests the housing shown in Figure 3 and Figure 4 were filled with catalyst nets. Supplementary information about the catalyst nets can be found in Enclosure 4.

Figure 3 Corrugated metal nets with the active catalytic material (4 nets)

Catator Ltd. also supplied the catalyst housing, which can be seen in Figure 4. The catalyst was installed in a side stream to the main flue-gas flow to enable test at various flows through the catalyst, thus still operating the engine full load, please refer to Section 4.2.

Figure 4 Catalyst housing

4.2 Test rig

The gas engine exhaust is led outside the damper box. Here a cooling loop facility is established, which enables cooling of the exhaust as shown at Figure 5. Also, connections are made for injection of LPG/air as an afterburner to increase the temperature if needed.

The catalyst is placed in a side stream to the exhaust. By doing this it is possible to keep the engine at full and stable load by using dampers to adjust the flue-gas flow through the catalyst according to test programme (see Section 4.3)

As shown on the test set up diagram (Figure 5), emissions upstream of the catalyst can be measured in point 3, emissions after the catalyst in point 4, and concentrations in the mixed stream (flue gas via catalyst and by-passed flue gas) can be measured in point 5.

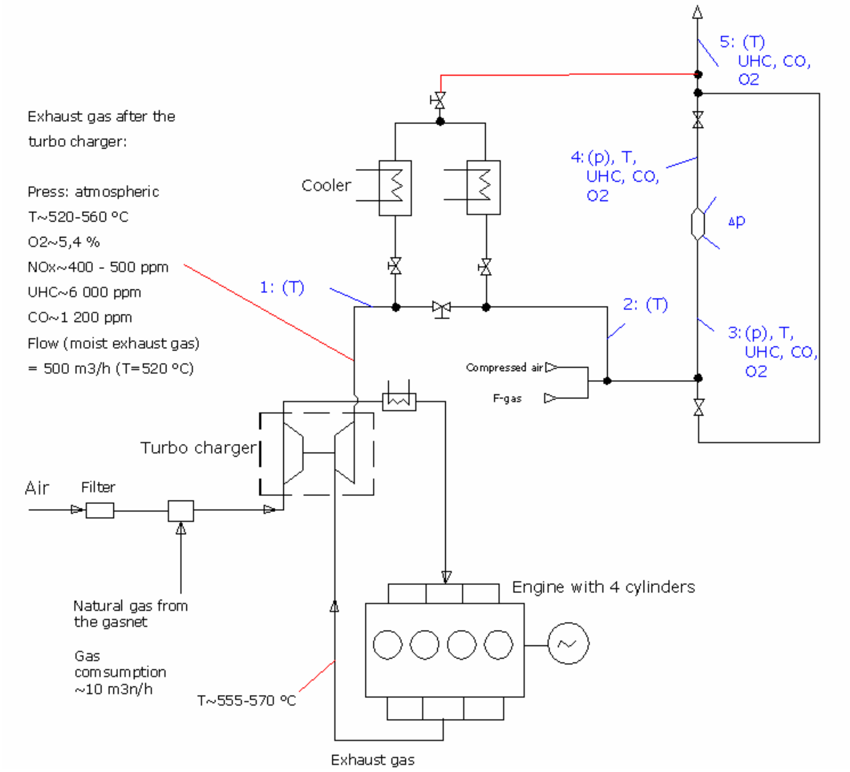


Figure 5 Test set up, the catalyst housing can be seen at delta p indication

Figure 6 Picture of the test rig, the gas engine is located in the damper box

4.3 Test programme

The test programme shown below was agreed upon prior to tests by DGC and Catator.

4.3.1 Preparations

- Analysis of engine lube oil in DGC fresh oil tank was made. The analysis contained the species listed below.
  - Insolubles
  - Total Acid Number
  - Total Base Number
  - Viscosity at 40 °C
  - Viscosity at 100 °C
  - Water content
  - Ash content
  - Sulphur content
  - Metal wear/metal from additives (21 metals)

  Please refer to Enclosure 2.

- Oil change to this fresh oil was made.

- The engine was operated for at least 7½ hours without catalyst housing/catalyst.

- Catalyst housing and catalyst (nets) were installed.

- Used oil analysis was made through the test programme

4.3.2 Tests

General remarks
During test the engine will be operated at full load. Limitations in flue-gas flow to catalyst will be made by adjusting valves/dampers for by-passing the catalyst, see Figure 5.

Determination of flue gas to catalysts will be made by mass balance as follows: Total flue-gas amount from gas engine will be determined by measuring gas flow and oxygen content in exhaust. The fraction of the flow that goes to the catalyst will be determined by measuring concentration of CO before and after catalyst, and CO concentration in the flue gas after the flue gas streams are mixed again downstream the catalyst. Supplementary pressure drop measurements over the catalyst will also be made.

In the catalyst housing 3-4 pieces of flat catalyst net will be placed at flue-gas entrance end. These flat nets will then be followed by corrugated/profiled nets. In general, the total number of catalyst plates (nets) in the housing will depend on achieving a reasonable UHC reduction effect. However, the number of nets used should be unchanged through measurements at the three temperature sets and preferably also at the three flow series outlined below.

Test programme
Initial burn in of catalyst for some 5-7 hours at temperature higher than 500 °C.

Then for max. catalyst flow rate (preferably some 50-70 m^3n/h):

Operation for one hour at 550 °C, then measurement during steady state at 500 °C
Operation for one hour at 550 °C, then measurement during steady state at 450 °C
Operation for one hour at 550 °C, then measurement during steady state at 400 °C

Measurements are made at steady state conditions after at least 30 minute continuous operation with the new flow.

The above procedure is repeated for two other flow rates (60 % and 35 % of max. flow).

Description of the emission test equipment used can be found in Enclosure 5.
The hydrocarbon composition in the exhaust is intended to be analysed three times (upstream and downstream the catalyst) during the test series stated above. DGC supposes, based on numerous tests like that /4/, /8/, that the upstream hydrocarbon distribution to a very large extent is similar to the

fuel gas. Downstream of the catalyst, most of the higher hydrocarbons (higher than methane) have been oxidised.

Depending on the results obtained via the above measurements a further test programme concerning long term testing can be made at a later stage.

5 Test results

Table 3 shows the measurement results from the first measuring series according to the test plan outlined in Section 4.3.2.

Table 3 Test results, measuring series 1 (4 catalyst nets)

Flue gas temperature (through cat.)	536/538 °C			
Flow (through cat.)	50	**m^3n/h**		
Space Velocity SV	$7 \cdot 10^6$	**$m^3n/(m^3 \cdot h)$**		
		Before catalyst	**After catalyst**	**Reduction (%)**
O_2	**% (vol, dry)**	6,1	6,1	(-)
CO	**ppm (vol, dry)**	1020	555	46
UHC *)	**ppm (vol, dry)**	2750	2525	8

**) Total hydrocarbons expressed as CH_4 equivalence*

After this first measurement series the flue gas temperature was raised (according to plan).

In between the planned measurement series an extra measurement series was made at this elevated temperature level. The results can be seen in Table 4. Please note that the flow through catalyst is increased in this "intermediate" extra test.

Table 4 Test results, extra measuring series (4 catalyst nets)

Flue gas temperature (through cat.)	546/548 °C			
Flow (through cat.)	90	**m^3n/h**		
Space Velocity SV	$12{,}5 \cdot 10^6$	**$m^3n/(m^3 \cdot h)$**		
		Before catalyst	**After catalyst**	**Reduction (%)**
O_2	**% (vol, dry)**	6,3	6,1	
CO	**ppm (vol, dry)**	1040	650	38
UHC *)	**ppm (vol, dry)**	2810	2560	9

**) Total hydrocarbons expressed as CH_4 equivalence*

As shown in Table 3 and Table 4 the UHC reduction is not significant at these relatively high exhaust temperatures having in mind the catalyst is still fresh.

After the test shown in Table 3 and 4 a few supplementary tests with 20 catalyst nets was made at high temperature(>500 °C) and at 3 different flows. First initial burn in for some hours 3½-4 hours at temperatures >500 °C was made.

Table 5 Test results, extra measuring series (X1-20 catalyst nets)

Flue gas temperature (through cat.)	503/506 °C			
Flow (through cat.)	6	**m^3n/h**		
Space Velocity SV	190.000	**$m^3n/(m^3 \cdot h)$**		
		Before catalyst	**After catalyst**	**Reduction (%)**
O_2	**% (vol, dry)**	6,7	6,6	(-)
CO	**ppm (vol, dry)**	682	33	95
UHC *)	**ppm (vol, dry)**	3654	3095	15

**) Total hydrocarbons expressed as CH_4 equivalence*

Table 6 Test results, extra measuring series (X2- 20 catalyst nets)

Flue gas temperature (through cat.)	518/525 °C			
Flow (through cat.)	17	**m^3n/h**		
Space Velocity SV	550.000	**$m^3n/(m^3 \cdot h)$**		
		Before catalyst	**After catalyst**	**Reduction (%)**
O_2	**% (vol, dry)**	6,6	6,3	(-)
CO	**ppm (vol, dry)**	710	57	92
UHC *)	**ppm (vol, dry)**	3529	2882	18

Table 7 Test results, extra measuring series (X3- 20 catalyst nets)

Flue gas temperature (through cat.)	530/536 °C			
Flow (through cat.)	26	**m^3n/h**		
Space Velocity SV	830.000	**m^3n/(m^3 · h)**		
		Before catalyst	**After catalyst**	**Reduction (%)**
O_2	**% (vol, dry)**	6,6	6,3	(-)
CO	**ppm (vol, dry)**	748	83	89
UHC *)	**ppm (vol, dry)**	3494	3061	12

All tests have shown relatively small UHC reduction despite the high flue gas temperature. It is likely, that the UHC reduction seen mostly is due to reduction of hydrocarbons higher than CH_4. The fuel used contains some 12-13 % (vol.) higher hydrocarbons than methane.

Based on the small UHC reduction the test was stopped.

6 References

1. "Various Parameters influencing Efficiency of and Emission from High-Efficient Gas Engines". Jan de Wit, Ole Christensen. International Gas Research Conference Cannes, 1995

2. "Catalytic Emission Control with respect to CH_4 and CO for highly Efficient Gas Fuelled Decentralised Heat and Power Production". Jan de Wit, Keld Johansen, Poul L. Hansen, Helle Rossen, Niels B. Rasmussen. INFUB Conference Porto, 2000

3. " Metanreduktion i katalysatorer för naturgasmotorer-en statusrapport". Helena Bomann. Vattenfall Energisystem AB, 1993

4. Kortlægning af emissioner fra decentrale kraftvarmeværker". ELTRA PSO project, 2002

5. Rekuperativ katalytisk udstødsreaktor til stationære gasmotorer. Lone M. Schmidt, Niels Bjarne K. Rasmussen. DGC, February 2004, R0401

6. www.reccat.dk

7. "Gasfyret væskeopvarmning til industrielle processer", EFP-1999, J.nr. 1223/99-0002. Lotte Sarbæk Salling, Michael Andersen, DGC. Final report expected early 2005

8. "Katalysatorteknologi til lean-burn gasmotorer", DGC, Haldor Topsøe, NESA & SGC. 1996

Enclosures

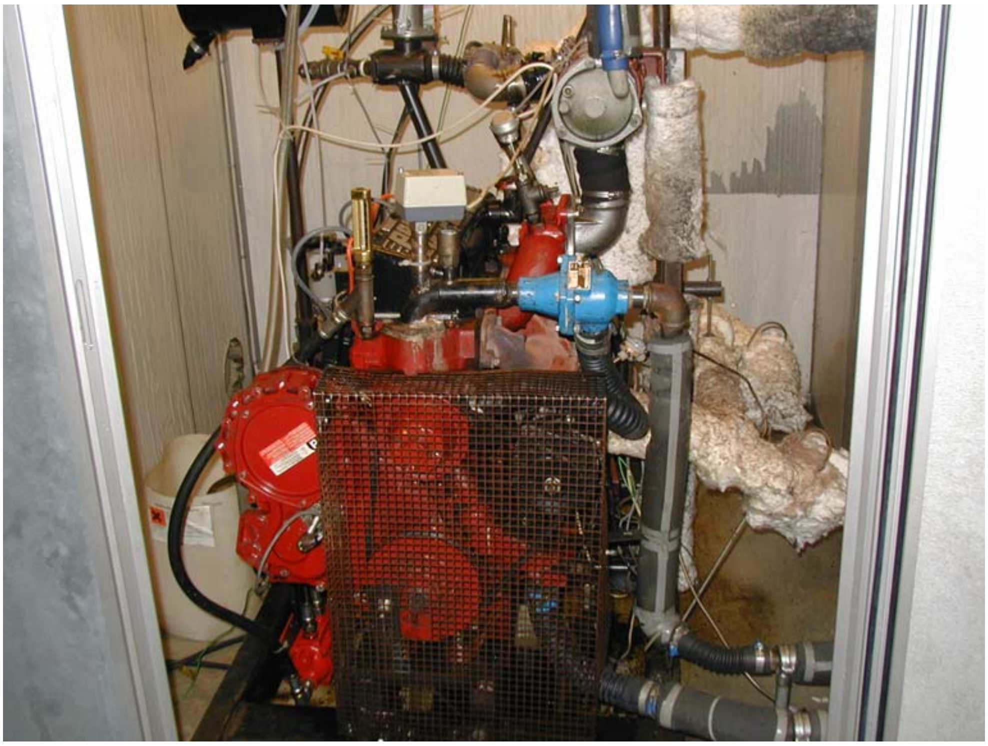
1. Short description of the gas engine and emission
2. Results of the lube oil analysis
3. Typical gas analysis, Danish natural gas
4. The catalyst used, short description
5. Measuring equipment used
6. Danish legislation concerning flue gas emission from gas engines for CHP

Enclosure 1

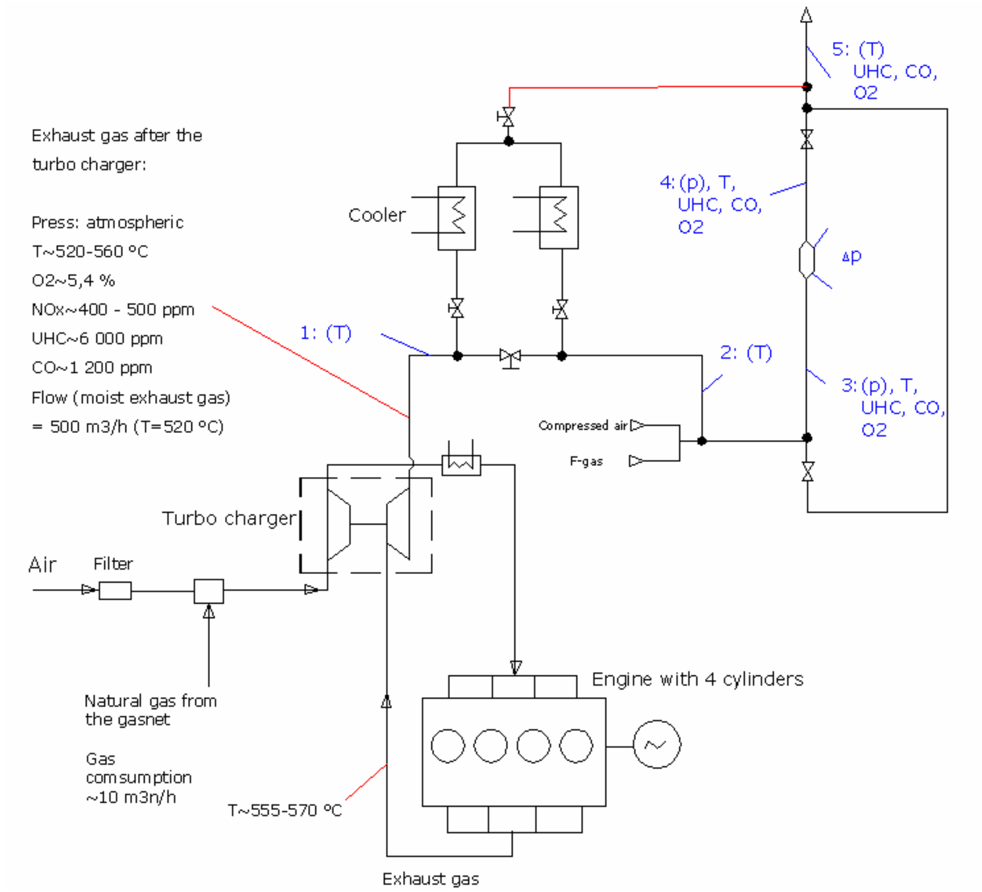
Short description of the DGC gas engine

The gas engine is a Ford Power Torque industrial engine. It is a 4 in-line cylinder water cooled engine. It is originally a diesel engine but has been modified to natural gas firing. It has been equipped with a turbo charger and has been in operation in the DGC laboratory for approx. 4500 hours total.

The continuous full-load output from the generator is approx. 35 kW_e. Jacket cooling water temperature is approx. 90 °C and gas/air mixture after intercooler approx. 36 °C.



The gas engine in its damper box.



Principle drawing showing typical emission values etc. at full-load test engine operation.

Enclosure 2

Results of the lube oil analysis

Analysis results concerning the lube oil can be found on the next pages. The first analysis is with the oil already in the engine prior to the test set up. This analysis can be seen as a typical example of used lube oil.

The next analysis is from the fresh oil filled on the engine just before start of burn-in and tests. This engine is of the same make, type, viscosity and batch as the engine mentioned in the paragraph above.

14/10 2004 08:54 FAX SAYBOLT LAB COPENHAGEN 001

Dansk Gasteknisk Center a/s
Ianina Mofid

Analysis Report no. : 102/11518/04 **Sample No.:** 1518

Saybolt
A CORE LABORATORIES COMPANY
FAST TO THE POINT.

Sample submitted as : Lube Oil
Received : From Client on 07-10-04
Marked : "Gammel Olie"
:
Location :
Date of Sampling :
Sample Sealed : Unsealed

Test	*Method*	*Result*	*Unit*
Ash	ASTM D 482	0.026	% wt
Base number (TBN)	ASTM D 2896	0.43	mg KOH/g
Sulphur	ASTM D 4294	1.02	% wt
Viscosity, kinematic at 40°C	ASTM D 445	164.2	cSt
Viscosity, kinematic at 100°C	ASTM D 445	15.83	cSt
Water by karl Fisher	ASTM D 1744	0.021	% wt
Acid number	ASTM D 664	4.76	mg KOH/g
Insolubles by Millipore filtration	ASTM D 4055	0.378	% wt
Determination of metals from additives	ASTM D 5185		
Barium Content (Ba)		<1	mg/kg
Calcium Content (Ca)		41	mg/kg
Magnesium Content (Mg)		2	mg/kg
Phosphorous Content		464	mg/kg
Zinc Content (Zn)		27	mg/kg
Determination of wear metals	ASTM D 5185		
Aluminium Content (Al)		4	mg/kg
Boron Content (B)		3	mg/kg
Chromium Content (Cr)		26	mg/kg
Copper Content (Cu)		20	mg/kg
Iron Content (Fe)		85	mg/kg
Lead Content (Pb)		1	mg/kg
Mangan Content (Mn)		2	mg/kg
Molybdenum Content (Mo)		<1	mg/kg
Nickel Content (Ni)		<1	mg/kg
Silicon Content (Si)		2	mg/kg
Sodium Content (Na)		<1	mg/kg

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Precision parameters apply in the evaluation of the results listed above. Please also refer to ASTM D3244 (except for analysis of RFG), IP 367 and appendix E of IP standard methods for analysis testing with repect to the utilization of test data to determine conformance specifications.

SAYBOLT DANMARK A/S
Fyrtårnvej 11, 2300 København S, Danmark
Tel. +45 3295 3132, Fax +45 3295 3134
Internet: www.saybolt.dk
E-mail: say_dan_cph@saybolt.dk

14/10 2004 08:57 FAX SAYBOLT LAB COPENHAGEN 002/002

Dansk Gasteknisk Center a/s
Ianina Mofid

Analysis Report no. : 102/11518/04 **Sample No.: 1518**

Saybolt
A CORE LABORATORIES COMPANY
FAST TO THE POINT.

Sample submitted as : Lube Oil
Received : From Client on 07-10-04
Marked : "Gammel Olie"
:
Location :
Date of Sampling :
Sample Sealed : Unsealed

Test	*Method*	*Result*	*Unit*
Tin Content (Sn)		3	mg/kg
Vanadium Content (V)		<1	mg/kg

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Precision parameters apply in the evaluation of the test specified above. Please also refer to ASTM D3244 (except for analysis of RFG). IP 367 and appendix E of IP standard methods for analysis testing with repect to the utilization of test data to determine conformance specifications.

SAYBOLT DANMARK A/S
Fyrtårnvej 11, 2300 København S, Danmark
Tel. +45 3295 3132, Fax +45 3295 3134
Internet: www.saybolt.dk
E-mail: say_dan_cph@saybolt.dk

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Ianina Mofid

Saybolt
A CORE LABORATORIES COMPANY
FAST TO THE POINT.

Analysis Report no. : 102/11521/04 **Sample No.:** 1521

Sample submitted as : Lube Oil
Received : From Client on 08-10-04
Marked : "Ren Olie"
:
Location :
Date of Sampling :
Sample Sealed : Unsealed

Test	*Method*	*Result*	*Unit*
Ash	ASTM D 482	0.028	% wt
Base number (TBN)	ASTM D 2896	2.75	mg KOH/g
Sulphur	ASTM D 4294	1.113	% wt
Viscosity, kinematic at 40°C	ASTM D 445	13.61	cSt
Viscosity, kinematic at 100°C	ASTM D 445	132.0	cSt
Water by karl Fisher	ASTM D 1744	67.8	% wt
Acid number	ASTM D 664	1.16	mg KOH/g
Insolubles by Millipore filtration	ASTM D 4055	0.15	% wt
Determination of metals from additives	ASTM D 5185		
Barium Content (Ba)		<1	mg/kg
Calcium Content (Ca)		8	mg/kg
Magnesium Content (Mg)		<1	mg/kg
Phosphorous Content		549	mg/kg
Zinc Content (Zn)		3	mg/kg
Determination of wear metals	ASTM D 5185		
Aluminium Content (Al)		<1	mg/kg
Boron Content (B)		7	mg/kg
Chromium Content (Cr)		<1	mg/kg
Copper Content (Cu)		<1	mg/kg
Iron Content (Fe)		<1	mg/kg
Lead Content (Pb)		<1	mg/kg
Mangan Content (Mn)		<1	mg/kg
Molybdenum Content (Mo)		<1	mg/kg
Nickel Content (Ni)		<1	mg/kg
Silicon Content (Si)		<1	mg/kg
Sodium Content (Na)		<1	mg/kg

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Precision parameters apply in the evaluation of the test specified above. Please also refer to ASTM D3244 (except for analysis of RFG), IP 367 and appendix E of IP standard methods for analysis testing with repect to the utilization of test data to determine conformance specifications.

SAYBOLT DANMARK A/S
Fyrtårnvej 11, 2300 København S, Danmark
Tel. +45 3295 3132, Fax +45 3295 3134
Internet: www.saybolt.dk
E-mail: say_dan_cph@saybolt.dk

14/10 2004 08:55 FAX SAYBOLT LAB COPENHAGEN 003

Dansk Gasteknisk Center a/s
Ianina Mofid

Saybolt
A CORE LABORATORIES COMPANY
FAST TO THE POINT.

Analysis Report no. : 102/11521/04 **Sample No.: 1521**

Sample submitted as : Lube Oil
Received : From Client on 08-10-04
Marked : "Ren Olie"
:
Location :
Date of Sampling :
Sample Sealed : Unsealed

Test	*Method*	*Result*	*Unit*
Tin Content (Sn)		<1	mg/kg
Vanadium Content (V)		<1	mg/kg

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Georges Svartstein

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Precision parameters apply in the evaluation of the test specified above. Please also refer to ASTM D3244 (except for analysis of RFG), IP 367 and appendix E of IP standard methods for analysis testing with repect to the utilization of test data to determine conformance specifications.

SAYBOLT DANMARK A/S
Fyrtårnvej 11, 2300 København S, Danmark
Tel. +45 3295 3132, Fax +45 3295 3134
Internet: www.saybolt.dk
E-mail: say_dan_cph@saybolt.dk

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Enclosure 3

Typical example of Danish natural gas

A typical example of the major components and characteristics etc. for Danish natural gas can be seen below.

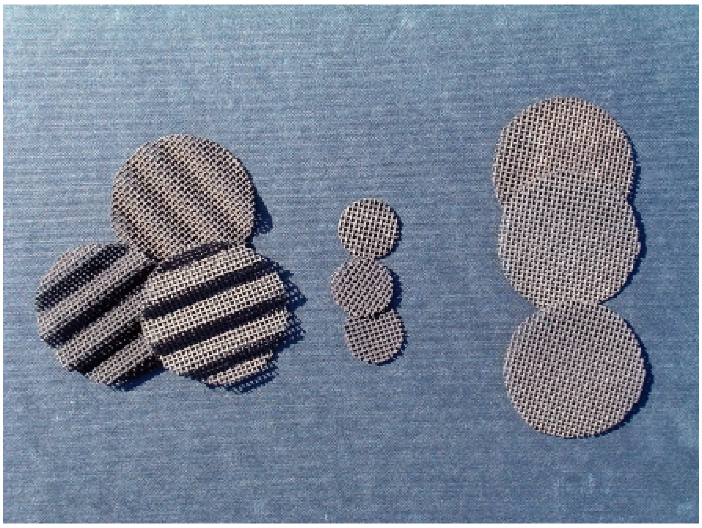
Methane	Mol %	88,9
Ethane	Mol %	6,1
Propane	Mol %	2,5
I-Butane	Mol %	0,4
N-Butane	Mol %	0,6
I-Pentane	Mol %	0,1
N-Pentane	Mol %	0,09
Hexane+	Mol %	0,06
Nitrogen	Mol %	0,3
Carbondioxide	Mol %	1
H_2S	mg/m^3n	2,9
Calorific value, upper	MJ/m^3n	43,8
Calorific value, lower	MJ/m^3n	39,7
Wobbe index	MJ/m^3n	54,8
Normal Density	kg/m^3n	0,827
Relative density	(-)	0,64

THT is added as odorant in an amount of approx. 10-15 mg/m^3n. It contains some 35 % (weight) Sulphur.

Enclosure 4

The catalyst used, short description

Catator has supplied 30 pieces of wire mesh catalysts with a diameter of 48 mm (see photo below). The mesh was manufactured of Kanthal AF high-temperature steel material with mesh number 16. The meshes were prepared according to Catator's patented method to produce efficient catalytic layers on meshes. The catalyst formulation was based on a mixture of Pd/Metal oxide.



The nets were based on wires Ø0.8 mm. Due to crossing of the wires the net thickness was 1.6 mm.

The Catator nets had 28x28 wires in each net. The corrugated nets had 28x34 wires. The flow area was approx. 50 %, according to Catator information.

Enclosure 5

Measuring equipment used

Flue gas conditioning

The flue gas is conditioned according to processes described below, before flue gas is led to the separate analysers.

- condensation in glass bottle at ambient temperature
- the flue gas is cooled in a cooling dryer; dew point 2 ± 1°C – capacity 0-10 l/min
- filtering in fine filter with an efficiency >99.9% for particles 0.3 µm
- distribution by means of flowmeters to separate analysers
- DGC-No.: 01702 / User instruction B-01701

Oxygen and carbon monoxide in the flue gas

The content of oxygen in the dry flue gas is measured with a paramagnetic oxygen analyser. The data for the analyser are:

Manufacturer:	SERVOMEX O_2/CO-ANALYSATOR
Model:	04900 C1
Range:	O_2: 0-5 and 0-25 %-vol.
	CO: 0-200 and 0-3000 ppm
Repeatability:	O_2: <0,05 % vol.
	CO: 1% of reading
Linearity:	O_2: <0,05 % vol.
	CO: 1% of reading
Calibration:	Ambient air, N_2, and 1010 ppm
DGC-No.:	00207/ User instruction B-00207

Hydrocarbons in the flue gas

The content of unburned hydrocarbons in dry flue gas is measured with an analyser using a flame ionisation detector. The data for the analyser are:

Manufacturer:	Signal THC-analysator
Model:	3000 HM
Ranges:	0 - 10000 ppm in 8 ranges
Range used:	0-10000 ppm
Repeatability:	± 1 % of range
Linearity:	± 0,5 % of range or ± 2% of reading
Calibration:	N_2 and calibration gas containing 2000 ppm CH_4 in N_2
DGC-No.:	00602 / User instruction B-00602

Composition of UHC

UHC composition is at DGC measured by means of a gas chromatograph with flame ionisation detector.

Manufacturer:	Chrompack
Model:	Natural Gas Analyzer
Detection limit:	0.8 ppm CH_4 equivalent
Accuracy:	± 20% for concentrations < 20 ppm 10% 10-100ppm 5% > 100 ppm
Calibration:	CH_4/N_2 and synthetic natural gas mixtures
DGC-No:	03301 / User instruction B-03301

Enclosure 6

Danish legislation concerning flue gas emission from gas engines for CHP production

Current Danish emission limits for gas engines

	CO	NO_x	UHC	Formaldehyde
Existing plants (erected before 17.10.1998) After 17.10.2006 all plants must comply with rules for "New plants"	650 mg/m^3n	650 mg/m^3n	No legislation	No legislation
New plants Gas engines	500 mg/m^3n **)	500 mg/m^3n **)	1500 mg/m^3n *) expressed as mg C	10 mg/m^3n ***)

*) reference: 5 % O_2, η_e 30 %

**) reference: 5 % O_2

***) for gas engine CHP > 5 MW natural gas consumption erected later than 01.07.2003, recommendation