Gas Engine Operation and Development Challenges in the Liberalized Energy Markets

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1. Introduction

In the liberalized energy markets different technologies and fuels are used for power production. Electricity is bought and sold on open markets based on short or longer term tenders. Other services for the power grid can be brought to markets, such as up- or downloading of production (or consumption), standby reserves with various response times, adjustment of active/reactive power etc.

Today's gas engines offer efficient power production and excellent load response possibilities with respect to the services requested (and often paid for) by the power grid companies. Gas engines are able to perform short start-up or stop time with limited impact on engine service life compared with other power or CHP prime mover technologies.

However, attention should be paid to possible increased emission and safety aspects, the latter with respect to possible concentration of unburned hydrocarbons in the exhaust system (manifold, ducting, silencer, heat recovery boiler etc.).

The paper will discuss these issues and will propose targets to be highlighted in the gas engine R&D works.

2. New electricity sales markets

2.1 New sales structures, new services requested

On the liberalized markets electricity is often sold at pools. At the Scandinavian NordPool /7/ this means day-ahead bidding requests for each 24 hours of the next day (spot market). Bidding may take place with supplementary conditions so that for example at least 3 hours of continuous operation is achieved whenever the production unit bidding is accepted.

Bidding is based on prediction of electricity consumption, likely production patterns for the next day and exact knowledge of own production costs. In countries with significant wind power installed, precise hourly wind predictions is a key player.

The power transmission grid operators may also request bidding for other services in the deregulated markets. Such power grid services can be:

1. Power balancing, this means up- or down loading of production
2. Backup capacity, this means units for short remote or manual start, often to stop shortly after again.
3. Island operation services.
4. Black start services etc.
5. Others

Services 1 and 2 are often well paid and will typically require limited (if any) plant modifications. The technical demands for power production units in these markets will often be short response time and fast up- or downloading.

Gas engine based power/CHP units have excellent performance characteristics in this respect. When up and running, full-load operation is normally preferred to obtain best shaft efficiency. However, during full load service downloading can be offered for these hours. When the units are not running (due to low sales tariffs) uploading or backup capacity can be offered.

The backup capacity market may also present a business opportunity for <u>older reliable power production units</u>. Instead of removal of such units, they may be used to generate running income in such services. Special service and engine overhaul packages may be developed to ensure availability and short start-up time instead of power efficiency optimisation at continuous full load for such units.

Operation on the liberalized energy market will <u>generally lead to more start/stops</u> for the units, possibly even with short intervals from the start request is given to full load has to be achieved.

2.2 Safety aspects, R&D challenges

As more starts and stops are to be expected on the liberalized markets, safe operation during these conditions should be addressed as a key issue.

As for all other gas appliances, incidents with natural gas fuelled engines and turbines are continuously registered and analysed when in operation in Denmark.

Based on these registrations it can be concluded that many accidents at CHP plants using gas engines as prime movers often happen during start or stop sequences. This is of importance for both manufacturers, plant entrepreneurs, operation staff and owners as the annual number of starts and stops is expected to rise in the liberalized power market.

Diagrams showing a few statistics can be found in Appendix 1. The data represented are based on the incidents known to the gas suppliers. Major mechanical breakdowns causing significant unplanned downtime are also represented. However, not all mechanical breakdowns are known/reported to the gas suppliers. Mechanical breakdowns imposing no danger to surroundings are not considered accidents.

To minimise the risk of accidents a number of measures has been launched from approx. 1998 an onwards. These measures are:

- Discussion with suppliers.
- Re-design of engines, sensors, control systems, auxiliary equipment etc. by manufacturers.
- Revision and updating of Installation Codes.
- Recommendations for installations have been made.
- Improved education of operation staff.

The measures seem to have significantly reduced incidents at these plants from a level of some 15-20 to generally less than 5 registered events per year in Denmark. A total of some 750 natural gas fuelled engines are installed for CHP, representing some 950 MW_e installed power capacity. The total hours of operation each year are estimated to approx. 4 million (4.000.000).

The re-design or modifications of engine control systems and auxiliaries for increased safety may include the following:

- Forced purging (ventilation) of exhaust system prior to start (or when stopping). This should be included in engine delivery/supply as a type-tested device. Alternatively, the control system should be prepared for such, causing minimum delay in the start process. To achieve optimum effect it is recommend that forced purging continues also during idling as high concentrations of unburned gas are often measured in the exhaust system.

- Electronic limitation of number of start attempts (possibly distinction between cold/warm start).
- Back pressure electronic detection integrated in engine surveillance system.
- Misfiring detection, not only as deviation from average cylinder bank but also within an actual absolute temperature interval for cylinders.
- Use of safety valves (spring loaded and one-off) in exhaust system and vacuum valves at the stack.

Illustrations showing examples of such improvements can be seen in Appendix 2.

Forced pre-purging will ensure that a new start after a possibly failed start attempt will be made with as little risk of combustible gasses in the exhaust system as a fresh new start. Pre-purging often becomes even more important for the large pre-chamber gas engines since purging by engine turning prior to start is usually reduced due to limited compressed air reserves for starting. It is strongly recommended that forced purging is also in action during engine idling. If hot items such as catalysts are present in the exhaust system at start, special care should generally be taken; a by-pass used during start/stop may be beneficial. Please refer to the emission chapter.

DGC has made a number of measurements of unburned hydrocarbon (UHC) fractions (FID measurements) at certain points in the exhaust systems during start and stop. The measurements show the concentration in the specific points measured and they state the amount of combustible gasses or point out actual peak (“all time high”) concentrations in the exhaust system. Please refer to Appendix 3 concerning the measured concentrations etc.

2.3 The emission R&D challenge

Gas-engine shaft efficiency has been improved steadily over the last decades leading to fuel savings and less environmental impacts, respectively. Also, emission reduction by primary measures such as improved combustion process has lead to significantly reduced NO_x and

UHC emission. The instantaneous combustion process in ICE’s (Internal Combustion Engines) with water cooled surfaces makes it basically difficult in general to achieve as low emission as some competing technologies, see examples in Appendix 4. For most countries, implementation of the Gothenburg Protocol /11/ NO_x values will lead to more stringent NO_x emission limit.

Secondary measures such as after-treatment of the exhaust may be included in engine manufacturer’s delivery to meet the emission limits required. This will secure the market for future gas engine sales. By including post-treatment equipment, where necessary, the after-sales markets for older engines may also be reached. Tailoring such equipment to meet various emission levels (various countries or utilisations) means that the base engine can have engine settings giving optimum efficiency.

The after-treatment processes can be based on catalytic cleaning and may be made as recuperative or regenerative integrated processes. Also non-catalytic regenerative or recuperative high-temperature processes can be used for oxidation of combustible flue gas products. This process may run with no additional fuel if sufficient combustible products are present in the flue gas. Non-catalytic processes may be preferential for use in biogas fuelled engines as presence of sulphur seems to significantly reduce methane reduction activity for oxidation catalysts, see ref. /3/.

Care should be taken at short interval re-start operation that hot items such as a catalyst or heavy mass non-cooled items do not act as ignition for unburned gas during the start phase. A by-pass so that the exhaust gasses are only lead to the catalyst at 30% load or higher might be a solution. Otherwise, a temperature probe in the catalyst might be needed to tell when catalyst temperature is at a safe low level for re-start.

2.4 General aspects the liberalized markets on gas engine R&D

Liberalisation of the ***gas markets*** has opened for natural gas cross border export/import quality standards. The EASEE gas organisation has launched such a standard February 2005, please refer to Appendix 5. For most countries, the values and their acceptance interval will mean the possibility of more variation in gas quality and combustion properties, respectively, such as the methane number /10/.

For improved utilisation of alternative fuels, efforts are also seen on governmental, EU and other levels. This interest includes studies etc. to utilise natural gas grids for distribution of biogas, hydrogen etc. To prepare for this future, gas engine manufacturers should prepare multiple setting/versions of the engines, advanced controls and sensors to make the engines as fuel-flexible as possible. Increased utilisation of biogases will lead to less CO_2 emission in the CO_2 accounts.

In the liberalized ***power markets*** the power producers will compete on production price, short start up and/or downloading and other services. It is possible also to include pollution aspects in market considerations. Mapping of emissions from various power suppliers has been initiated, please refer to ref. /5 & 6/ and the examples given in Appendix 4. Such average emission values or actual certified values from the specific CHP plant may be used for evaluating power offers. Therefore, continued developments in emission reduction are necessary. Primary and secondary measures (units for after-treatment of flue gasses) should be considered as part of engine developments/supply, please refer to separate chapter: Emission aspects.

The measurements presented in /5/ have lead to a rough estimate on the influence of start/stops. This estimate (based on start/stop measurements at two sites) shows the following increased emissions with one daily start/stop compared to non-interrupted operation:

- UHC: +1-10 %
- NO_x: +0,6-1,4 %
- CO: +0,8- 4 %

An ongoing study includes measurements at more plants to get more valid data on this subject.

Engines/CHP units should be prepared for remote operation. A number of services offered to the liberalized power market will be based on hour-to-hour basis (or even shorter intervals) 24 hours a day, which makes remote operation beneficial if not mandatory for certain services.

The power pools established have stated time intervals from request for start to full power is achieved. For the Nordpool this is some 15 minutes for power balancing services. Short, but still safe, start procedures will be a key competition parameter for gas engines compared to other prime movers in this business. Consideration and preparation for continuously heated lube oil and vital engine parts may be a step to short starting time with as limited impact on engine life as possible.

If the unit is generally only in service as short start reserve/backup power for the grid, special development or service packets, lube oil recommendations etc. may be developed for this specific pattern of operation

3. Future issues for gas engine R&D work

Gas is continuously increasing its global market share. In large areas of the world combined power and cooling instead of heating may be needed. Even in the colder areas of the world improved building codes, insulation standards and increased internal heat load from electric appliances have increased the need for comfort-cooling/air conditioning in increasing periods of the year (tri-generation).

Absorption cooling driven by jacket water heating may be used for this. To achieve best coefficient of performance for such units, the heat source should preferably be as hot as possible. This means that gas engines with the option of jacket water outlet temperature above 100 °C (212 °F) are beneficial. Also for industrial purposes the possibility of elevated jacket water temperatures is preferential.

4. Conclusion

The liberalized power market gives increased opportunities for energy services from gas-engine based power production. The impressive power production efficiency achieved, the excellent load and start/stop performance characteristics of gas engines make them very competitive in the power markets. However, improvements should still be made within following fields:

- Continued optimisation to the energy services requested (for new and older engines)
- Emission related R&D
- Safety related R&D
- Gas quality/fuel flexibility R&D

to keep gas-engine track records in the forefront within power and CHP business in the liberalized energy markets.

5. Acknowledgements

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6. References

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/6/ “Emission factors for CHP plants < 25 MW_e (in English)“, Nielsen, M; Illerup, J.B; Kristensen, P.G; Jensen J.K; Jacobsen, H.H; Johansen, L.P; Poster presentation 4th JOINT UNECE Task. 6. Okt. 2003.

/7/ NordPool ASA, the Nordic Power Exchange, www.nordpool.com

/8/ EASEE-gas, Paris Agreement on harmonisation of gas quality specifications for the European gas Market “Common Best Practice (CBF) 2005-001/01”, February 2005.

/9/ EASEE-gas Press Announcement: “European Gas Industry Ratifies Agreement on Gas Quality Specifications”, November 3’rd, 2005 (www.easee-gas.org).

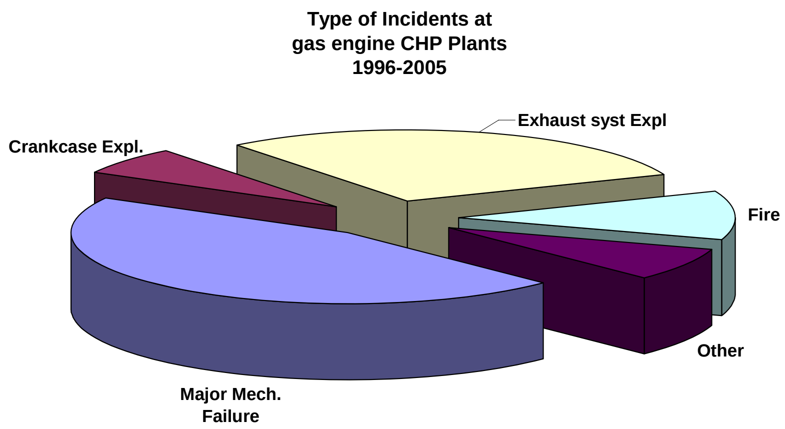
/10/ ASME 1999 Paper: “Classification methods for the knock resistance of gaseous fuels - an attempt towards unification”, Jacob Klimstra et al. ASME Conf. paper, Ann Arbor 1999.

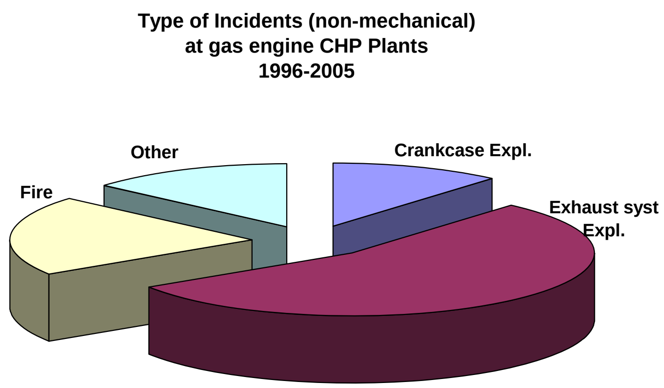
/11/ Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone” 1999 in Gothenburg, Sweden (extension to the United Nations’ 1979 Geneva Convention on Long-Range Transboundary Air Pollution).

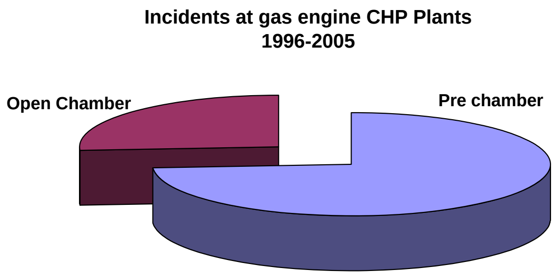
Incident statistics   Appendix 1

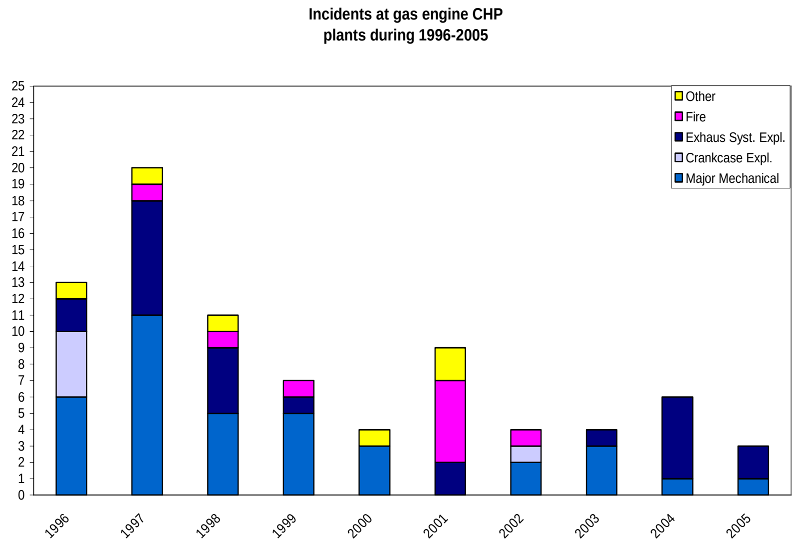
Natural gas fuelled gas engine driven CHP plant incidents analysis.

A total of 80 known incidents year 1996 to 2005 at Danish plants are included in the analysis.









A total of some 750 natural gas fuelled engines are installed for CHP, representing some 950 MW_e installed power capacity. Pre-chamber engines counts by number for some 25 %, but represents some 60 % of the installed power capacity. The total hours of operation each year is estimated at approx. 4 million (4.000.000).

Figure A.2.1: Vent for flushing the exhaust system at start or stop

Figure A.2.2: Explosion relief valve, spring type

Figure A.2.3: Explosion relief valve, outdoor one-off type

Figure A.2.4: Pressure relief valves to prevent vacuum deformation of thin plate stack tube ducting

Appendix 3

Unburned hydrocarbon (UHC) during start and stop at gas-engine based CHP plants

This appendix shows examples of measured UHC emission concentrations during start and stops at three different gas-engine based CHP plants. Emergency stop measurement was included at one plant.

The UHC concentration was measured by using FID measuring equipment (CH_4 equivalence). This concentration was recalculated assuming the UHC measured is unburned fuel (= natural gas).

Table A.3.1 gives an overview of measured maximum unburned gas concentrations in the measuring point and presents the type of engine, sample point etc.

Table A.3.1: Maximum measured unburned hydrocarbon concentration recalculated as natural gas concentration /1/

Plant No.	Engine Type	Net power kW_e	Max. gas concentration at start %	Max. gas concentration at stop %	Sample point
1	Pre-chamber	~ 3000	2,0	2,3	After heat recovery boilers
2	Pre-chamber	~ 3000	1,6	1,6	After heat recovery boilers
3	Open-chamber	~ 1300	3,0	0,9	Silencer/HT-heat recovery boiler (combined)

The highest combustible gas concentrations were measured during start of the open-chamber engine. The engine is a type that has low UHC emission during continuous operation.

At the two other engines shown in Table A.3.1 (pre-chamber units with forced purging at start) the maximum concentrations were measured during stop procedure (idling). As it can be seen in the below Figures A.3.1-A.3.4 the forced purging at (re-)start has a significant effect on flushing the exhaust system.

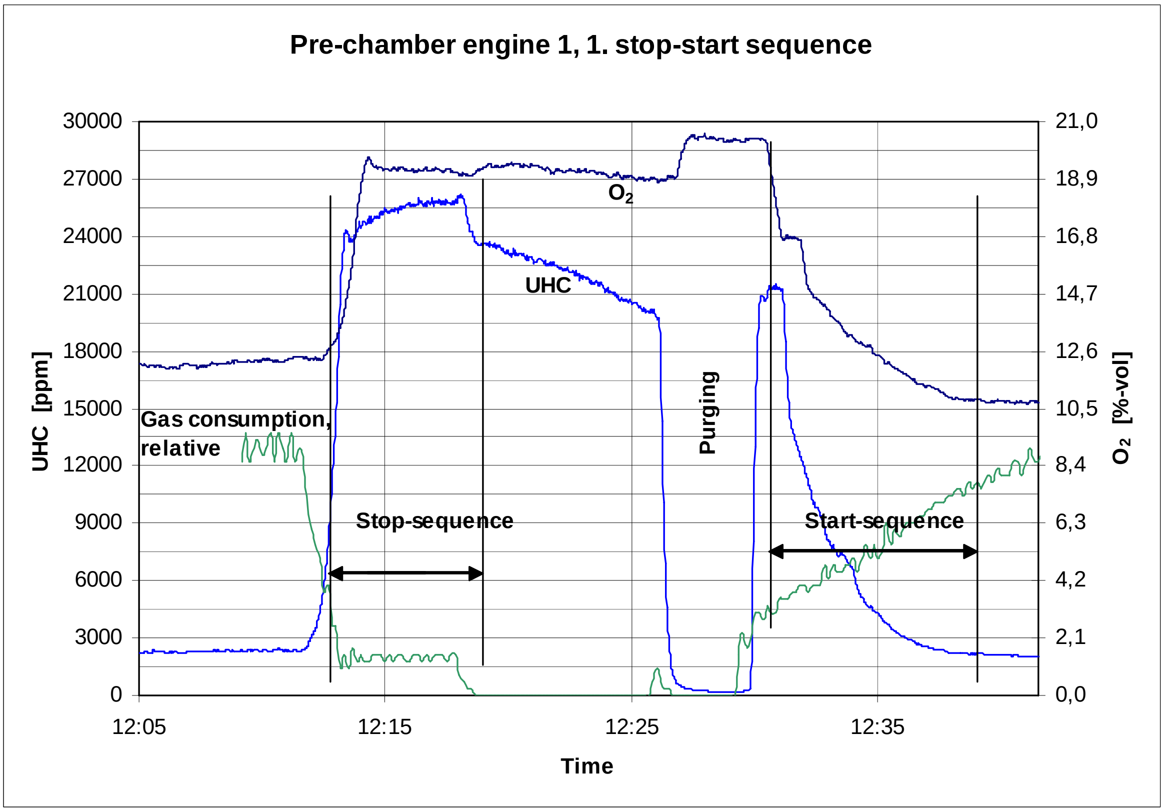


Figure A.3.1

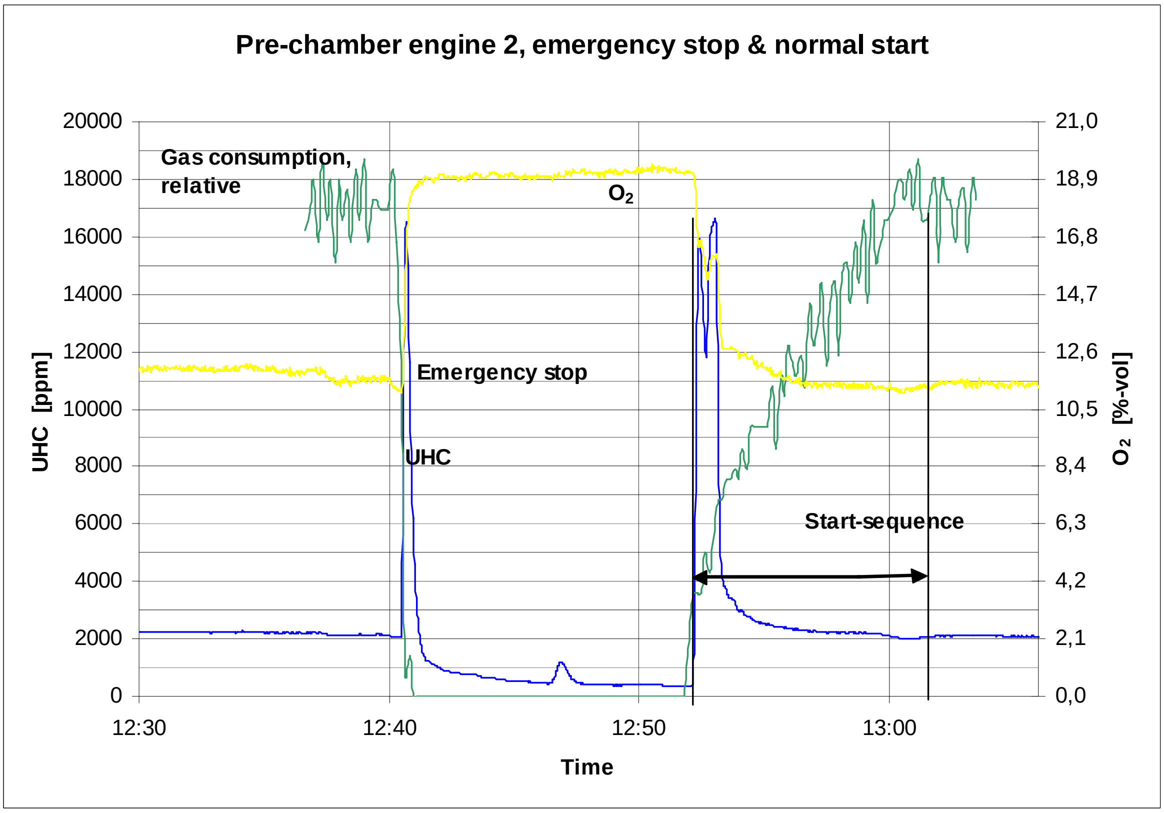


Figure A.3.2

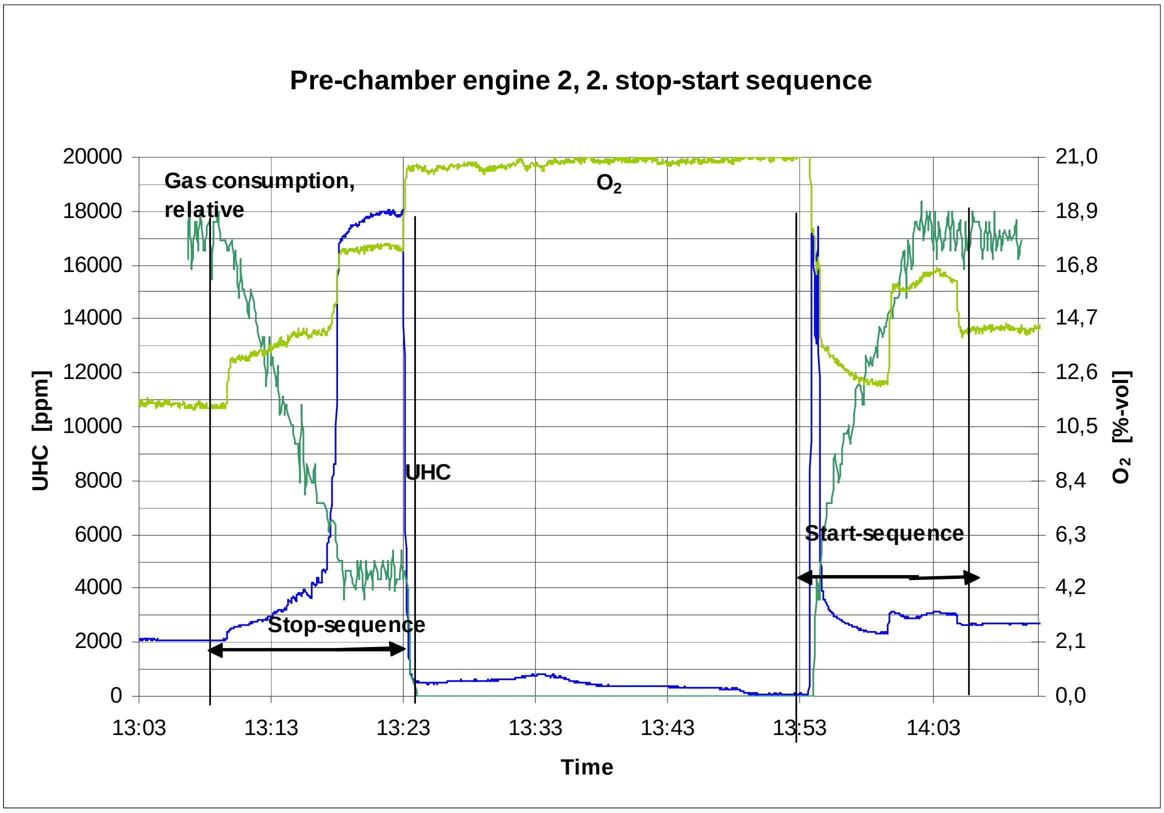


Figure A.3.3

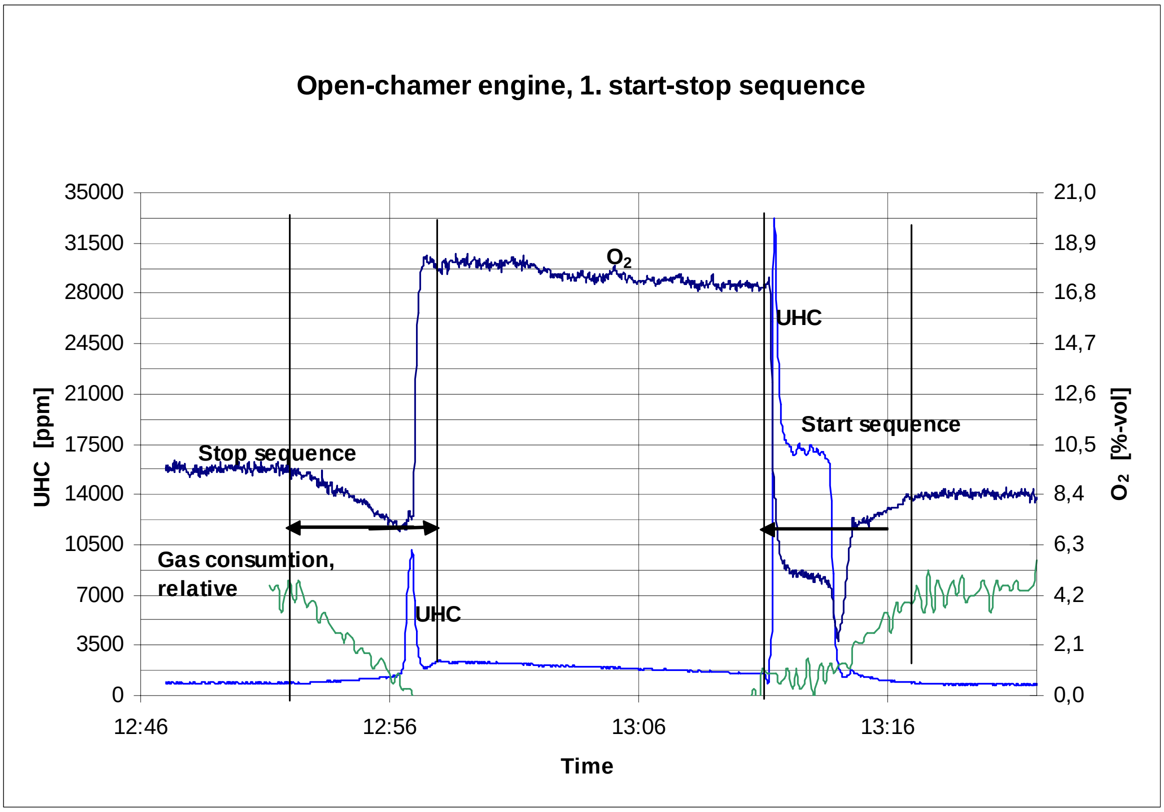


Figure A.3.4

Appendix 4

Emission mapping, CHP technologies

Table A.4.1 shows average emission factors found from measurements made at various central and decentralised CHP units fuelled by different fuels /5/ and /6/. The survey was based on measurements from 1990 and onwards for plants still in service and supplementary new series of measurements made in 2000-2003. Some 27 new measurement series were made by DGC during years 2000-2003 on natural gas and biogas fuelled units.

Most older measurements primarily deal with NO_x, CO and UHC only. The additional new sites have been chosen with respect to prime mover type, to make the measurements representative for the actual Danish CHP market situation of 2001-2003.

At some sites, additional measurements of additional components were made.

The values presented have been used for determination/declaration of emission for the distributed electricity based on knowledge of its origin and the average emission values for this origin.

Table A.4.1 Average emission factors for decentralised CHP plants in operation in Denmark

Emission	Unit	Natural gas engines	Biogas engines	Gas turbines	Municipal waste CHP	Straw CHP	Wood CHP	Dec. CHP plants	Central power plants
NO_x	g/GJ	168	540	124	124	131	69	154	133
CH_4	g/GJ	520	323	1,5	<0,6	<0,5	<2,1	248	3
NMVOC	g/GJ	117	14	1,4	<1	<0,8	<3,4	55	2
CO	g/GJ	175	>273	6	<8	63	79	98	12
N_2O	g/GJ	1,3	0,5	2,2	<1,3	1,4	<0,8	1	3
TSP	g/GJ	0,76	2,63	0,10	<2,02	3,97	7,94	1,6	3,0
PM10	mg/GJ	189	451	61	1126	133	1944	0,6	2,5
PM2,5	mg/GJ	161	206	51	1084	102	1226	0,5	2,1
PAH (Benz[a]pyrene-eq.)	mg/GJ	<0,023	<0,003	<0,005	<0,006	<0,154	<0,008	<0,020	-
- Benzo[a]-pyrene	mg/GJ	0,003	0,001	0,001	<0,0009	<0,022	<0,003	<0,003	0,020
- Benzo[b]-fluoranthene	mg/GJ	0,042	0,001	0,001	<0,002	0,157	0,002	<0,026	0,091
- Benzo[k]-fluoranthene	mg/GJ	0,024	<0,0004	<0,002	<0,0008	<0,091	<0,003	<0,015	0,018
- Indeno[1,2, 3-cd]pyrene	mg/GJ	0,006	<0,0011	<0,003	<0,0009	<0,023	<0,002	<0,004	0,030
SO_2	g/GJ	x	19	x	<24	47	<1,8	10	41
As	mg/GJ	x	x	x	<6,8	<2,1	<2,4	2,2	0,6
Cd	mg/GJ	x	x	x	<4,8	<0,8	<1	1,5	0,2
Cr	mg/GJ	x	x	x	<2,5	<1,6	<2,4	0,9	1,7
Cu	mg/GJ	x	x	x	<10,1	<1,7	<2,7	3,1	1,2
Hg	mg/GJ	x	x	x	<7,4	<0,6	<0,8	2,2	1,7
Ni	mg/GJ	x	x	x	<4,8	<1,7	<2,4	1,6	5,8
Pb	mg/GJ	x	x	x	<123	<6,2	<3,7	36,3	2,2
Dioxin	µg/GJ	x	x	x	0,157	0,022	0,001	0,047	-

A total of approx

- 430 measurement series is included from natural-gas fuelled gas engine based CHP units
- 20 measurement series from biogas fuelled gas engine plants
- some 42 natural-gas fuelled gas turbine plants

are included in the values concerning natural-gas fired plants < 25 MW_e.

It is important to notice that these measurements are performed at stack. This means that if a catalyst is used it may reduce emission components. The values shown are calculated as fuel consumption weighted average.

For details concerning the data, please refer to ref. /5/ and /6/.

Appendix 5

Gas quality variation standard for cross border interoperability

February 2005 the EASEE organisation launched a standard for gas quality variation for natural gas (high calorific gasses) at cross border entry points for gas import/export, /8/ and /9/.

The aim of this standard is to ease gas trade interoperability. The EASEE gas members have agreed on the values shown.

Table A.5.1 Values agreed and proposed implementation dates

Parameter	**Unit**	**Min**	**Max**	**Recommended implementation date**
Wobbe Index, gross (WI)	**kWh/m^3**	[13.60]	15.81	1/10/2010
Density (d)	**m^3/m^3**	0.555	0.700	1/10/2010
Total Sulphur (S)	**mg/m^3**	-	30	1/10/2006
H_2S + COS[1)] (as S)	**mg/m^3**	-	5	1/10/2006
RSH[2)] (as S)	**mg/m^3**	-	6	1/10/2006
O_2	**mol %**	-	[0.01]*	1/10/2010
CO_2	**mol %**	-	2.5	1/10/2006
H_2O dew point	**°C at 70 bar (a)**	-	- 8	See note**
HC dew point	**°C at 1- 70 bar (a)**	-	- 2	1/10/2006

* EASEE gas have organised an oxygen measurement survey, which by end of 2005 will examine the maximum feasible limit equal to or at an alternative specified value below 0.01 mol%.
**At certain cross border points, less stringent values are used than defined in this CBP. For these cross border points, these values can be maintained and the relevant producers, shippers and transporters should examine together how the CBP value can be met in the long run. At all other cross border points, this value can be adopted by 1st October 2006.

1) COS : Carbonyl sulphide
2) RSH : Mercaptans

The table shows that the recommended implementation date for some key combustion properties is October 2010, as studies and possible modifications to certain end user appliances may be needed.

Gas engines may be affected as the variation range and certain values in the table shown may lead to a broader methane number (MN) range /10/ compared to gas quality variations of today in some countries.