Technical and Financial Guidance for Emission Limit Values of Stationary Engines

BEES-B Netherlands

Euromot Non-Paper

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EUROMOT

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of Internal Combustion
Engine Manufacturers

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ENGINES IN SOCIETY

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1 BACKGROUND

Euromot was asked in the meeting on May 30, 2008 by the Dutch Environmental Ministry (VROM) of the Netherlands to define technical areas with regard to gas and liquid (conventional and bio-fuels) fired engines that would need further investigation, research and testing in the light of a possible introduction of the strict BEES-B limits in the future. Ideas how to proceed in the mean-time was also asked for. This paper includes the Euromot response to the request.

2 INTRODUCTION

In the meeting between VROM and Euromot on May 30, 2008 in den Haag Euromot showed that the proposed limits (NOx, THC and particulate) are not BAT due to technical and cost feasibility aspects.

The intention of this paper is to discuss items which need further R&D actions. Also some general fundament for establishing a research, development, demonstration and commercial application program to promote and speed up the research of needed appropriate technologies for NOx-, total hydrocarbons (THC) – and particulate reduction technologies is discussed. Certain technology gaps need to be filled and technological hurdles studied. Some of the needed techniques are very advanced. It has been seen that in absence of a coordinated program the technical progress is slow due to economical and technical constraints of the single companies. In a coordinated program granting funds and enabling a broad cooperation between universities, research foundations and private companies the development is faster and the achieved results can be shared in a more cost-effective way.

However the interest of the industry to participate in such a possible R&D program is to be investigated when the first proposal is made by the state and all conditions (time span, cost-sharing, etc.) are known.

Below, the different research topics: THC, NOx and particulates are divided into separate sections while fund needs and a time table are proposed.

3 SUMMARY

NOx	Emissions	total R&D costs / total development time / comment
Proposed NOx emission for natural gas engines and gas engines fired with renewable-/biogas [g/GJ]	30	-
Proposed NOx emission for liquid fuel fired Diesel engines [g/GJ]	40	-
Euromot NOx proposal for natural gas fired gas engines **ONLY** [g/GJ]	**140** 80 possible, but with negative consequences: - higher maintenance costs - 2-3% more fuel consumption, and thus more CO2 - bad running stability of the engine - more THC and other emissions of "unburned" gases - low NOx will cause lower flue gas temperatures and thus negative impacts on CHP installations	Under special conditions SCR is possible but only if rentability is given (e.g. greenhouses). Otherwise too expensive and not accepted by the market (killing of decentralised power market (CHP) for natural gas fired stationary engines)!!!
Euromot NOx proposal for gas engines fired with renewable-/biogas [g/GJ]	**140**	SCR is not state-of-the-art 20 million € / 5 years research program for secondary measures (catalyst)
Euromot NOx proposal for Diesel engines fired with Diesel fuel / liquid biofuel [g/GJ]	**400** (including efficiency factor bonus η/30) **SCR experience has to be gathered**	20 million € / 5 years research program for secondary measures (catalyst)
THC		
Proposed THC emission for gas engines [C mg/Nm3 at 3% O2]	1200	-
Euromot THC proposal for natural gas fired gas engines [C mg/Nm3 at 3% O2]	**1690 * η/30** (current Danish limit) at steady full MCR load (for example: a natural gas fired engine with an efficiency of 40% would have then a limit of ≈ 2250 mg/Nm3) New innovative technologies have to be developed in order to achieve lower limits in the future	25 million € / 5 years research program for engine internal measures 30 million € / 5 years research program for secondary measures (catalyst) eventually in cooperation with TNO and other Dutch institutes
PM		
Proposed PM emission for existing Diesel engines [mg/Nm3 at 3% O2]	50	-
Proposed PM emission for new Diesel engines [mg/Nm3 at 3% O2]	30	-
Euromot PM proposal for existing Diesel engines [mg/Nm3 **at 15% O2**]	**50** at steady full MCR load (measured with ISO 9096) (=150 @ 3% O2)	-
Euromot PM proposal for "new" Diesel engines [mg/Nm3 at 15% O2] fired with biofuel	**30** at steady full MCR load (measured with ISO 9096) (=90 @ 3% O2) **Experience has to be gathered with existing secondary techniques. Possible new techniques has to be developed in order to achieve stricter limits in the future**	15 million € / 5 years research program

4 HYDROCARBON EMISSION LIMITS

4.1. General:

VROM proposes a THC limit of 1200 mg C/m3 (3% O_2), which equals about 2.3% fuel slip, while:

1. Data from a manufacturer well represented in the market show for six (6) different engines a scatter between 1100 and 2200 mg C/m^3 (3% O_2), where only one engine complies with the proposed limit;
2. The current Danish limit (based on measurements) for new engines equals 1690 mg C/m^3 (3% O_2) times an efficiency correction of $\eta_{shaft}/30$; apparently, this limit takes into account the scatter mentioned under (1).

The Danish limit caused already some engine types to be excluded from the market, so it is not a limit that causes no restrictions.

Hydrocarbon emissions from reciprocating engines originate from the fuel. Crevices in the combustion chamber (top-land crevice + cavities at the valves and cylinder head gaskets) as well as inhomogeneous combustion under cold combustion conditions are the major causes.

The scatter in THC emissions measured for a particular engine type is caused by:

- differences in gas composition;
- differences in process conditions;
- the state of wear of an engine within a specified maintenance interval.

Typically, Groningen gas contains much nitrogen (an inert gas) that allows engines to run somewhat richer than with standard natural gases which have a higher calorific value. That might result in relatively low THC emissions for a given temperature level inside the engine. There is a tendency to use more Russian and other imported gases (LNG) also in The Netherlands, which will affect the THC emissions.

The engine sector strongly opposes the introduction of a THC limit for existing engines, unless a breakthrough technology will be developed. Existing engines generally cannot be modified to accommodate new developments and the integrated cogeneration design prohibits the retrofit of any exhaust gas treatment systems. Therefore existing engines should preferably be grandfathered.

4.2 Research carried out on THC so far

The engine industry as well as the fuel supply companies (e.g. N.V. Nederlandse Gasunie) has been working on these issues during many years already. Euromot wants to point out, that a reduction of THC emissions has a significant impact on engine efficiency and so it has already been one of the main design goals for a gas engine development since many years. Therefore R&D programs within the individual technology departments of the members have been ongoing and are still continuing in order to maximise efficiency and minimize THC emissions. So the current combustion chamber design reflects regarding THC emission already the best possible compromise between engine emission, engine performance, durability and efficiency.

The route via exhaust catalysts has been very disappointing, notwithstanding promising stories of catalyst suppliers. During tests at laboratory, at several sites of an engine manufacturer amongst all following occurred: an expensive catalyst broke down at one site and the turbocharger was damaged, turbochargers overspeeded during transient behaviour of the engines, etc. It was also learned that the temperature level of the exhaust gas of modern gas engines is too low to make platinum-palladium based catalysts effective. Increasing the exhaust temperature with external heating would substantially reduce the fuel efficiency of the systems thus removing the incentive for cogeneration. Heat recuperation systems proved to be slowly reacting and therefore unfit for the dynamic operation of cogeneration plants. Moreover, the costs and sizes were prohibitive. Currently, tests are being carried out with plasma assisted catalysts and syngas-based oxidation catalyst systems at a research foundation premises.

Some manufacturers of prechamber engines have been successful in reducing hydrocarbon emissions by decreasing the size of the prechambers and improving their ignition stability. With a more stable combustion system, the engine process can operate closer to the knock limit without needing an excessively lean mixture of fuel and air.

Each internal and external measure require a long time of testing (at least one year) before the technology can be released as proven. If during the test period modifications have to be carried out, the durability testing has to start again from the beginning. A successful development program easily takes three years to complete, while with some common drawbacks, five years is a reasonable time span for an innovation project.

4.3 Research proposal for THC

The engine industry proposes the following:

1) A **five year** intensified program on engine internal measures, aimed at further stabilisation of the combustion process and the reduction of crevice volumes. This can include spark ignition, laser-induced ignition as well as prechamber and diesel pilot systems. The associated costs are estimated at **25 million €.**

2) A **five year program** to develop and evaluate catalyst systems (plasma assisted, heat recuperation catalysts, etc., syngas swing regeneration). TNO and the NL universities can play an active role in this. The associated costs are estimated **at 30 million €.**

5 EMISSIONS OF NOX

5.1 State of the art NOx from gas engines

During the last decade, it became clear that for lean-burn spark-ignited gas engines, an engine-out NOx level of 140 g/GJ equalling 500 mg/m^3 at 5% O_2 (i.e. the current TA-Luft limit) is an optimum (lowest fuel consumption, “unburned emission species”, etc.) from an engine performance point of view. The associated air-to-fuel ratio allows for a high mean effective pressure (bmep) and a proper knock margin. With most new lean-burn spark-ignited gas engine types a lower NOx level of “half TA-Luft” (equal to about 80 g/GJ NOx) can also be reached by internal measures but the consequences are: higher maintenance costs, a penalty in fuel efficiency (up to an about 2 .. 3 % higher fuel consumption and thus higher CO_2 emissions) and running stability, also causing additional THC and other “unburned” gaseous (such as CO, etc.) emissions. Furthermore the lower NOx value (80 g/GJ) will cause lower flue gas temperatures of the engine which will have a negative impact on CHP (**C**ombined **H**eat and **P**ower) installations. Thus the total efficiency of CHP installations will decrease.

Additional aspects for biogas fuel and all other renewable gases are: These gas types include typical conterminations (such as volatile organic silica compounds, siloxanes, silanes, etc.). That has an indirect impact on the combustion process and so on the combustion chamber as these fuel impurities will cause fouling processes which will influence the combustion chamber dramatically within few operation hours (by creation of deposits in the combustion chamber). Therefore for these fuels the optimal NOx-level is 140 g/GJ.

The NOx level of 30 g/GJ as proposed by the NL authorities can only be reached with an additional SCR system. For natural gas as a fuel, such SCR-systems are state-of-the art; for fuels of biological origin insufficient experience has been gained with catalysts; certain components in the bio fuel appear to deteriorate catalysts up to a factor 5 …10 faster than for natural gas. Recently carried out research with biomass combustion systems have shown an identically rapid deterioration of which the causes are not clear.

An issue with new and existing gas engines is the costs of SCR systems. Although an NOx reduction from 140 g/GJ down to 30 g/GJ is achievable with pipeline quality gas (= 80 % reduction), and the costs per tonne of NOx removed seem acceptable by the NL authorities, the installation owner has to take profitability into account. Therefore, for the operator only the costs per MWh are relevant (the authorities mistakenly referred to costs per MW). The profit level of cogeneration systems is so low that a 5% increase in costs per MWh will remove all reasonable profitability. Therefore, the engine sector implores the authorities to use €/MWh as the reference costs for NOx removal besides Euro/per removed kg NOx unit.

In existing installations, the heat recovery system is fully integrated with the engine and no space is available for adding an SCR system in between the engine and the heat recovery boiler. This is especially the case in container based systems. Installing an SCR system would mean a complete rebuild of the installation which is extremely costly, estimated at about 40% of the total installation costs (€/MW).

5.2 State of the art NOx from diesel engines

The diffusion-type combustion process in a diesel engine makes that the specific NOx production (g/kWh) is about a factor 10 higher than that in a lean-burn gas engine. Stationary diesel engines will normally always run close to maximum power output, which is completely different from vehicle engines. With an SCR catalyst with 90% reduction, a NOx level of 140 g/GJ can be achieved. The level of 40 g/GJ as indicated by the authorities would require an SCR effectiveness of approximately 97 .. 98 %, which is excessive and not state-of-the art.

In order to keep the catalyst layer exchange frequency level reasonable when operating diesel engines on liquid biofuels (field experience has shown fast deterioration of SCR elements when Diesel engines with SCR are operated with liquid biofuels) we propose to maintain the current Dutch NO_x limit value of 400 g/GJ with efficiency bonuses for the time being.

In practice, only stationary diesel engines running on renewable fuels will be used in The Netherlands. Such fuels contain certain minerals (e.g. phosphorus) that deteriorate catalyst rapidly. Long-term experience has to be gained on the effect of such minerals on catalysts and how to remedy the problem.

5.3 Research proposal for NOx reduction with catalysts for engines running on renewable fuels

SCR catalysts for gas engines running on fuels of biological origin are not state of the art. Long-term tests have to be carried out on the influence of typical components in the gas on catalyst life and performance. This has to be done in close co-operation between catalyst developers, gas pre-treatment specialists and the engine sector. The initially estimated costs are **20 million €** in a time span of **five years.**

SCR catalysts for diesel engines running on renewable fuels have to be evaluated for a performance with more than 90% reduction. Issues are ammonia storage on the catalysts, homogeneity achievement before the catalyst, optimum catalyst configuration (number of rows, replacement strategy, control strategy). Next to that, experience has to be gained on the effect of elements naturally present in renewable liquid fuels on catalyst life and performance. The estimated costs of this research **is 20 million € in a time span of 5 years.**

6 PARTICULATE EMISSION LIMITS

6.1 State of the art with particulates

The NL authorities propose a particulate limit of 30 **mg/Nm^3 (3% O_2) (=10 mg/Nm^3 (15 % O_2))** for new diesel engines and **50 mg/Nm^3 (3% O_2) (= abt. 16.7 mg/Nm^3 (15 % O_2))** for existing diesel engines. These are very low limits, in the EU BREF BAT document at

http://www.jrc.es/pub/english.cgi/d1254325/19%20Reference%20Document%20on%20Best%20Available%20Techniques%20for%20Large%20Combustion%20Plants%20%28adopted%20July%202006%29%20-%2022%20Mb (page 405)

A particulate emission level of **30 mg/Nm^3** (**15 %** O_2) (= **90** mg/Nm^3 (**3 %** O_2), **note also** particulate emission measurement method and load range: ISO 9096 steady state 85 .. 100 % MCR load of engine !) is considered BAT for bigger diesel engines operated on distillates (light fuel oil) and for smaller high speed engines (< 1.3 MWth unit size) **20** mg/Nm^3 (**15 % O_2**) (= **60** mg/Nm^3 (**3 % O_2**)). Proposed limits would set very demanding operation demands on the secondary abatement equipment, because it works at "actual conditions", an emission concentration at 3 vol-% O_2 is for a bigger engine far from "actual conditions". An emission concentration reference point of 15 vol-% O_2 is more representative, see Euromot document for more information at

http://www.euromot.org/download/news/positions/stationary_engines/O2_Refpoint_oct02.pdf .

We propose a particulate level of 30 mg/Nm^3 at 15% O_2 (90 mg/Nm^3 at 3% O_2) for new stationary Diesel installations and 50 mg/Nm^3 at 15% O_2 (150 mg/Nm^3 at 3% O_2) for existing stationary Diesel installations. These values can be achieve with low sulphur ash liquid biofuels. These emission limits should be achieved at steady 100% MCR load (measured with ISO 9096).

In reciprocating engines, particulates originate from incomplete combustion, from minerals and sulphur present in the fuel as well as from additives in the lubricating oil. In practice, this limit will only apply for engines running on bio fuels since sulphur emission limitations prohibit the use of heavy fuel oil (HFO) and light fuel oils are too costly for purposes other than emergency power.

The problem with unrefined bio fuels (refined bio fuels are uneconomic for stationary power plants) is that the mineral content can vary depending upon the nature of the fuel and even the batch. Insufficient experience has been gained with such fuels. In addition, while electrostatic precipitators have shown their technical feasibility with e.g. coal-based power plants, their performance (especially the electrical properties of the particulate) is still unknown with installations running on bio fuels. Also cloth filter (in case with bag filters) performance with engines running at 100% load on bio fuels is unknown. In a plant with a semidry flue gas desulphurization diesel engine plant operating on heavy fuel oil it was seen that the particulate reduction of the bag filter was lower than expected due to the thin cake formed on the bag surface. Special pre-coated filter bags had also to be used. In the plant excessive wear on the bags were detected especially in the seams.

The engine sector believes that local power plants running on unrefined liquid bio fuels will play an important role as a back-up generator for wind and solar power. Therefore, ultimately, the emission level has to be low, however, the sector needs time to develop and evaluate cleaning methodologies.

6.2 Research proposal for particulate emission levels:

In close cooperation with the authorities, research has to be carried out on the relationship between the nature of the minerals present in bio fuels and their expected negative impact on air quality and health. Elements such as sodium and magnesium might have different effects than others.

Moreover, performance of ESP systems as well as cloth filters has to be investigated over a time span of about **five (5) years. A first costs estimation is 15 million €.**

7 CONCLUSION

Above, the reasons why further R&D is needed in order to enable introduction of stricter emission limits in the future have shortly been described.

Please note that the above proposed time tables and costs have a preliminary character. The time tables and costs have to be updated in regular time steps: when the proposed R&D program is known and when the first results of this program are available.

R&D is costly and big resources are tied up for the single companies (the “risk” in R&D work should not be forgotten) if proceeding alone which could be used for other needed development. The requirements on a reciprocating power plant are in today's world very fragmented and engine industry has therefore to make priority choices in their R&D work. By introducing a combined integrated program more companies could be involved in the work and then the needed resources by each participant could be more reasonable.

Some of the needed techniques do at the moment not exist and the expertise from Universities and research foundations are therefore needed in this work. R&D work should be done in partnerships between the different entities. The State of Netherlands could by stimulating this R&D program promote products needed in the climate change abatement work, in promotion of clean decentralized power production, etc.

In the meantime apply following emission limits:

- THC: the Danish limit (see above text).
- NOx: for spark ignited lean-burn conventional and bio-gas fired engines the current TA-LUFT limit (see above text). For liquid fired (especially) bio-fuel engines maintain the current Dutch limit of 400 g/GJ with efficiency bonuses.
- Particulate: For bigger and smaller ones the EU BREF BAT levels (see above text).

When the results of the multi-year testing program have been evaluated, adjust the **BAT-achievable future emission limits, if needed**. Existing sources need a separate treatment which should be based on site-specific analysis investigating their individual BAT-levels.

As pointed out above the interest of the industry to participate in such a possible R&D program is to be investigated when the first proposal is made by the state and all conditions (time span, cost-sharing, etc.) are known.

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