Stationary Engines Emissions Abatement
With a view to German TA LUFT 2002

The Euromot Position

October 2002

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EUROMOT
Engine-in-Society

Euromot is the **European Association of Internal Combustion Engine Manufacturers**.

We represent the leading manufacturers of internal combustion engines used in a broad range of nonroad, marine and power plant applications (construction, mining and material handling equipment, trucks and buses, agricultural and forestry equipment, commercial marine and seagoing vessels, workboats and pleasure boats, rail traction, lawn/garden and recreational equipment, power generation).

Euromot has been working for many years with international regulatory bodies, eg European Union, the UN International Maritime Organizations (IMO) and the Central Commission for the Navigation on the Rhine (CCNR). In addition, we are seeking an open and fair dialogue with national governments to provide reliable know-how on advanced internal combustion engine technologies in general and, in particular, on the feasibility of environmental as well as cost-effective product regulations. To achieve a pro-active engagement of all stakeholders in international harmonisation of regulations affecting engines and equipment, we coordinate our activities worldwide with trade associations of the non-road, power and marine industry sector.

For further information about our Association please refer to our Annual Report 2001 or pay us a virtual visit at **http://www.euromot.org** – your bookmark for engine power worldwide.

The Role of Emission Regulations

Emission regulations serve on the protection of the general public and the neighbourhood against harmful effects on the environment due to pollutants, as well as the precaution against harmful effects on the environment due to air pollutants (as stated in German TA-LUFT). Since measures useful for local protection may be detremental to the public, requirements should consider both.

On condition that sufficient protection based on respectable examinations is guaranteed an emission legislation should give the whole power industry a chance to comply and be in line with available proven technique of today. Unfortunately in this respect the new TA-LUFT 2002 legislation does not satisfy for bigger liquid fired stationary engine driven plants.

The intention of this document is to draw your attention to the engine manufacturer's main concerns on TA-LUFT 2002 for bigger liquid fired stationary engine driven plants, as they are:

1. Stipulated particulate limit is technically not achievable.

2. Stipulated SO_2 limit is stricter for engine driven plants than for oil fired boilers, although SO_2 depends predominantly on the fuel used.

3. Stipulated very strict NO_x limit is solely driven by available technology regardless of cost-impact.

4. No efficiency bonus is granted to the engine driven power plant although higher efficiency results in both lower consumption of fossil or renewable fuels and lower emission of greenhouse gases

The reasoning for our concerns are explained herebelow.

General Aspects

Some decades ago engine driven power plants were mostly used for short time running applications like emergency & peaking and small scale power production, but today, however, reciprocating engines become widely popular especially for continuous power generation. Both, large base load engine driven power plants with an output up to 150 MW electricity and dezentralized smaller combined heat and power (CHP) production plants are common today.

An engine driven plant has many advantages such as:

- a compact size,
- short construction time,
- flexible fuel choice,
- water preservation,
- high thermal efficiency (low fuel consumption),
- optimal matching at different load demands,
- fast load response and good load following characteristics,
- easy maintenance, and
- a robust design.

1 TA-LUFT 2002: Non-achievable Particulate Limit

TA Luft 2002 stipulates for stationary liquid fired engines a limit of 20mg/Nm^3 (corrected to 5 vol-% O_2). This limit equals to about 7,5mg/Nm^3 (15 vol-% O_2). This limit is very strict and can not be fulfilled with technology of today for bigger liquid fired engines.

A big stationary engine usually fulfills following particulate values by primary/internal methods:

- in Heavy Fuel Oil (HFO) operation (< 0.04 wt-% ash, max. 1 wt-% S): 50 mg/Nm^3 (15 vol-% O_2) = about 130 mg/Nm^3 (5 vol-% O_2)
- in Light Fuel Oil (LFO) operation (< 0.01 … 0.02 wt-% ash): 20 … 30 mg/Nm^3 (15 vol-% O_2) = about 50 … 80 mg/Nm^3 (5 vol-% O_2).

Secondary reduction methods (traps/filters) are still not state-of-the-art for big engines, as described below in 1.2 to 1.4.

First a comparison is made between particulate limits stipulated by **EU for oil fired boilers** and by UK and Germany for engines. The European Union (EU) new Large Combustion Plant Directive (LCPD) 2001/80/EC stipulates the following particulate emission limits for liquid fired boilers:

- 30 mg/Nm^3 (3 % O_2) for > 100 MW_{th} units.
- 50 mg/Nm^3 (3 % O_2) for 50 … 100 MW_{th} units

Typical “real conditions” of the boiler flue gas are: temperature about 170 °C and 2 … 5 vol-% O_2. This means that an exhaust gas secondary cleaning system has to clean the flue gas of particulate down to about **18 mg/m^3** (**actual conditions**) resp. **31 mg/m^3** depending on plant size.

Typical “real condition” ranges of the bigger **liquid fired stationary engine** flue gas are: temperature 300 … 400 °C, O_2 concentration 13 … 15 vol-%, dependent on engine type. For the following considerations 350 °C and 13 vol-% O_2 are assumed.

- In UK[1)] the particulate emission limit (oil firing) is 50 mg/Nm^3 (dry, 15 vol-% O_2). A secondary exhaust gas cleaning system would thus have to clean the flue gas down to an **actual** particulate concentration of about **29 mg/m^3**.
- German TA Luft 2002 particulate limit is 20 mg/Nm^3 (5% O_2) (equals to an about 7,5 mg/Nm^3 (15 vol-% O_2)). This means that a secondary cleaning system is to clean the flue gas down to an **actual** particulate concentration of about **4 mg/m^3**.

The secondary cleaning equipment “sees” the pollutant at the “actual” concentration (at both real flue gas temperature and oxygen content). From above figures it can be concluded that the German TA-LUFT 2002 particulate limit value for a bigger liquid fired stationary engine is almost 8 times stricter than the EU stipulated particulate limit value for a “big” (50 … 100 MW_{th}) oil fired boiler plant. The TA-LUFT 2002 particulate limit for bigger liquid fired engines is beyond the BAT (Best Available Technique) approach. The actual particulate concentration values in oil firing mode to be reached according to the UK > 50 MW_{th} compression ignition engine plant norm and the EU “big” boiler plant limit are about the same. In UK BAT technique is to be used in > 50 MW_{th} engine

1) (Achievable Releases to Air), HM Inspectorate of Pollution: Processes Subject to Integrated Pollution Control, Chief Inspector’s Guidance Note, Series 2 (S2). S2 1.03 Combustion Processes: Compression Ignition Engines 50 MW_{th} and Over (September 1995)

driven plants and the BATNEEC (Best Available Techniques Not Entailing Excessive Costs) principle is followed for smaller ones.

Conclusion: The TA–LUFT 2002 particulate limit value does not represent the cost-effective state-of the art technology.

1.1 Particulate Emission: General Aspects

All prime movers such as boilers, gas turbines and engines emit small particulate when burning oil or gas. Also the different running profile; steady state high loads, part loads, transient conditions; is largely affecting the particulate emission. At part loads and transient conditions (with less efficient fuel combustion) the particulate emission is higher than at steady state full load.

Stationary power plants are normally operated in a steady state high load mode (boilers, gas turbines and engine driven plants), thus the situation of particulate emissions is different from that of automotive engines operating at transient conditions. The technique of stationary bigger stationary engines used in power plants differ from that of smaller engines used in trucks, off-road applications, etc. A big stationary engine has much higher combustion temperatures and pressures in the cylinders compared to the truck engines. High temperatures and pressures improve the combustion quality and consequently lowers the particulate emissions.

Conclusion: Emissions from a stationary power plant versus automotive engines are not comparable.

1.2 Particulate Traps

This technology is developed for **small** diesel engines (exhaust gas flow typically up to 3600 Nm^3/h), i.e. automotive diesel engines, off-road applications, small utility and electric power generators which will be burning an ultra fine diesel oil (fuel to be virtually sulphur free, typically 0,001 … 0,005 wt-% S). Otherwise deactivation of the catalyst, clogging, sulphate formation might occur.

Experiences show that well over 90 % of the solid particulate emitted by small diesel engines consist of elementary carbon/organic fraction, which is largely burned away during the regeneration phase of the filter. Bigger stationary engines are usually operating on fuels containing various amounts of ash and sulphur. The biggest contributor to the particulate flow of bigger engines in heavy fuel oil mode is the ash content of both the burnt fuel and the lube oil: ash can not be burnt.

Conclusion: Particulate traps are technically not available for bigger engines.

1.3 Electrostatic Precipitator (ESP) and Bag Filter

An **ESP** has many advantages:

- low pressure drop,
- withstands high temperatures (no cooling of the flue gas is needed),
- erases particulate in a concentrated form (no "protection" agent is needed).

Of disadvantage is the big size due to the needed low flue gas speed of about 1 m/s in the ESP in order to avoid re-entrainment in the flue gas of erased particulate.

Based on both extensive discussions with many ESP manufacturers and pilot and demo testing in the field, following can be concluded: ESP is relatively new in the stationary engine driven power plant field, not a well-proven technology as in boiler based power plants. The electrical properties of the particulate in the engine flue gas differ due to the high temperature and the composition of the flue gas from those of a boiler. Due to the different electrical properties of the particulate and the low inlet dust mass concentration (compared to a coal fired boiler plant) the reduction rate of the ESP expressed in % is much lower than values presented in the literature for boilers. With high ash and high sulphur heavy fuel oils or orimulsion typical particulate values from the the engine are up to 75 ... 150 mg/Nm^3 (15 vol-% O_2) and a BAT-value (Best Available technique) for the ESP technology is today about 30 … 50 mg/Nm^3 (15 vol-% O_2) resp. about 80 … 130 mg/Nm^3 (5 vol-% O_2). The level of 30 … 50 mg/Nm^3 (15 vol-% O_2) corresponds to about 29 … 17 mg/"actual" m^3. These "actual" concentration values are similar to those of an oil fired boiler regulated by the "Large Combustion Plant Directive (LCPD) 2001/80/EC".

Bag filters are usually an integrated part of a Flue Gas Desulphurization (FGD) system for simultaneous both SO_2 and particulate removal. No "solely pure" particulate bag filter for stationary engine particulate removal has been found from the literature.

Disadvantages of a bag filter are:

- high pressure drop (a fan is needed in order to compensate for the pressure drop),
- a "protection reagent" ("pre-coating" of the filter) is needed when burning fuel oil otherwise the filter will clog due to "sticky" diesel particulates,
- flue gas cooling is needed in front of the filter. A typically maximum allowed inlet temperature is up to 200 °C (resp. 250 °C with special materials). Flue gas temperature of a big liquid fired engine flue gas is typically 300 … 400°C,
- huge size (could be three times bigger than the diesel engine) due to needed very low air to cloth ratio in the order of 0,6 m/min,
- bag filters are expensive.

The particulate removal capacity of the bag filter is heavily dependent on the formed "cake" on the filter surface. **It has been seen in long term field operation of bag filters that when burning fuel oil the formed filter cake is thin and the particulate reduction is not good: in order of 40 mg/Nm^3 ("actual" O_2) (= about 30 mg/Nm^3 (15 vol-% O_2)) on the clean gas side is reached. Prerequisite is that the bag filter material is "plastic coated"; otherwise the particulate reduction is even lower.**

<u>Conclusion</u>: TA Luft 2002 particulate limit for liquid fired bigger stationary engines can not be fulfilled with bag filters nor ESP.

1.4 Other Techniques

Ceramic and metal filters can withstand high temperatures but have a high pressure drop typically up to 3 kPa. The long-term durability and cracking risk (mainly during cleaning) of the elements are critical. The pressure drop is high and gradually increasing due to clogging of the pores, fracturing and difficulties in removing the filter cake off the surface.

Fabric bag filters (high temperature resistant) are ceramic, metallic or glass fibre based fabrics. The fabrics are fragile, require care in handling and installation and must be supported by a special cage that adds significantly to the cost of the filter assembly. A glass bag (max. 480 °C inlet flue gas temperature) is a relative new product on the market. The dust cake on the surface is removed by periodic reverse pulsing of air.

These filters presently are used only in some special applications: mostly in IGCC (Integrated Gasification Combined Cycle) plants for cleaning the fuel gas before the gas turbine; in the chemical and metal industry they are more popular and have reached a commercial level in some applications, but the operating conditions differ considerably (nature of particulates, exhaust gas composition and temperature, etc.) from those of a compression ignition engine power plant.

To note is that diesel particulates are sticky and might clog the filter and the pressure fluctuations in the engine flue gas could contribute to possible crackings on the ceramic filter. Comprehensive testing of the filter system is needed in order to optimise the filter system design and to verify the filter performance for a stationary engine driven power plant. The size of the filter system might be about three times larger than that of the engine and investment cost is very high. A fan is needed in order to compensate for the big filter pressure drop (increases the parasitic electrical consumption in the power plant).

Conclusion: These techniques are not state-of-the-art technology today for stationary engine plants. A lot of comprehensive testing is needed before any commercialisation may take place.

2 TA-LUFT 2002: Stricter Sulphur Dioxide Limit for Engine Plants than for Boilers

According to TA Luft 2002 regulation, a liquid fired stationary engine is to burn a light fuel oil according to DIN 51603 Part 1(March 1998) containing max. 0,2 wt.-% sulphur and with a lower heating value $\geq$ 42,6 MJ/kg or to reach an equivalent SO_2-limit by installing a FGD (Flue Gas Desulphurization Unit). This means that the SO_2 limit is about 110 mg/Nm^3 (15 % vol-O_2) = approx. 300 mg/Nm^3 (5 vol-% O_2).

According to TA Luft 2002 a 5 … 50 MW_{th} boiler plant burning oil has a sulphur dioxide limit of 850 mg/Nm^3 (3 vol-% O_2) = about 750 mg/ Nm^3 (5 vol-% O_2) which equals to usage of an about 0,5 wt-% sulphur fuel oil.

To be noted is that SO_2 is a fuel related emission. The reciprocating internal combustion engine with a better fuel efficiency has lower specific SO_2 emission per produced electrical power (g/kWh_e) than a boiler process even if the same SO_2-emission concentration limit should be stipulated for both prime mover types.

<u>Conclusion</u>: TA LUFT 2002 stipulated SO_2-emission limit for an engine driven plant is much stricter compared to an oil fired boiler as can be seen from above comparison.

3 TA-LUFT 2002: Very Strict Nitrogen Oxides Limit

For bigger liquid fired diesel engines ($\geq$ 3 MW_{th}), in order to reach the strict NO_x limit as of TA Luft 2002 of 500 mg/Nm^3 (5 vol-% O_2), equils to about 190 mg/Nm^3 (15 vol-% O_2), a very efficient exhaust gas after treatment technique such as a SCR (Selective Catalytic Reduction) is needed whereas many other competing prime movers can meet the stipulated NO_x limits largely by use of primary methods.
In TA Luft e.g. a gas turbine is granted an efficiency bonus corrrection for the NO_x-limit, engines do not get any similar benefit.

SCR is a commercial technique, but it should be noted:

- SCR is an expensive and sensitive method: a certain minimum temperature of the exhaust gas is needed in order to avoid salt formation on the catalyst element surface (SO_2 sensitivity). Some trace metals which might be present in the fuel oil act as “catalyst poisons” and deactivate the catalyst.

- SCR has an upper technical reduction limit of approx. 85 … 90 %, if excessive ammonia slip is to be avoided. At high reduction rates the control system is critical due to operation within a narrow window. Also the size of the SCR reactor increases and more complicated premixing and reagent injection systems are needed. Consequently the investment costs for SCR increase further.

Bigger stationary oil fired stationary engines, i.e. engines with piston diameters above approx. 200 mm are typically used for power plants. The speed may be 1500 rpm or even much less. Bigger stationary diesel engines have a high thermal efficiency, due to the high combustion temperature and pressure in the cylinder. As a consequence the oil fired engine equipped with the latest engine internal NO_x reduction measures (primary methods) has a NO_x emission up to 2000 mg/Nm^3 (15 vol-% O_2) = about 5300 mg/Nm^3 (5 vol-% O_2). This is higher than for engines (with a higher fuel consumption) typically used in on-road or non-road mobile applications, resulting mostly from the lower speed (more time to form NO_x).

World Bank 1998[2)] has a NO_x-limit of 2000 mg/Nm^3 (15 vol-% O_2) when granting subsidies for engine driven power plants in “Third World” countries, considering that exhaust gas after treatment is rarely possible (due to existing infrastructure: fuel availability, water and reagent supplies, etc.). National industrial country standards with focus on existing infrastructure and on cost-effective primary abatement methods are for instance the UK 20 .. 50 MW_{th} engine plant standard[3)] and the Japanese diesel engine norm (nation wide general limits). Above three examples are driven by the environmental quality need and are based on the BATNEEC principle.

Improved internal measures are under development but probably only resulting in further NO_x reductions from the engine of approximately 30 % in some years time.

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2) Thermal Power – Guidelines for New Plants”, in resultant “non-degraded” areas
3) The Environmental Protection Act 1990, Part 1 (1995 Revision)), PG1/5(95): Secretary of State´s Guidance-Compression Ignition Engines, 20-50 MW Net Rated Thermal Input

<u>Conclusion</u>: TA Luft 2002 in setting new NO_x-limits seems not to be driven by a balanced analysis of air quality needs and sensitive emission inventories but primarily by available technology (regardless costs). The only available abatement technique sufficient enough is the Selective Catalytic Reaction (SCR).

This approach should be compared to the requirements of the EU Council Directive 96/61/EC concerning integrated pollution prevention and control, which sets out an integrated approach to pollution prevention and control in which all the aspects of an installation's environmental performance are considered in an integrated manner; combustion installations with a rated thermal input <u>exceeding 50 MW</u> are included within the scope of the Directive. This Directive asks for use of BAT techniques, the aim is also <u>to avoid distortion of competition</u>, and taking into account the <u>balance between benefits and cost of action</u>.

4 No efficiency bonus is granted to the engine driven power plant

CO_2 emissions today are in focus due to the Kyoto Protocol. These emissions can be reduced by increasing the total efficiency of the plant and/or by using oil instead of coal and natural gas or gases from renewable sources instead of oil. Other measures to reduce the CO_2 emissions are increased combined heat and power (CHP) production in dezentralized efficient power plants and replacing old inefficient power stations with new efficient solutions.

Single cycle application

The reciprocating engines are used in single cycle as well as in cogeneration applications. Single cycle applications are benefiting from the high electrical efficiency (at alternator terminal), ranging from about 40 % for the smaller engines up to about 50 % for the big engines (calculated on their fuel lower heating value). High efficiency results in low emissions of CO_2, the most important “greenhouse gas”. A comparison between technologies in terms of single cycle CO_2 emissions is given in figure 1.

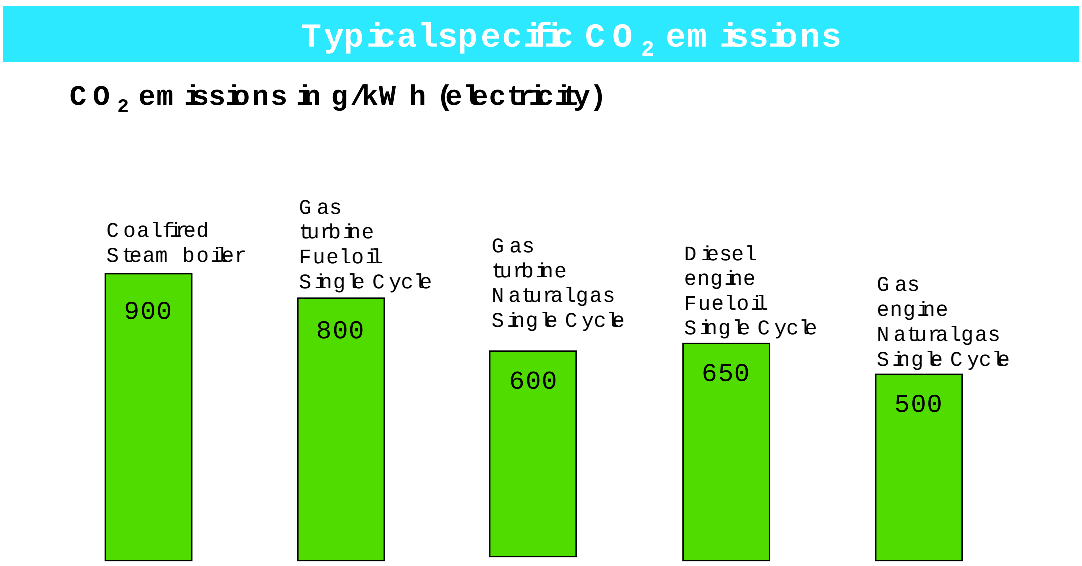

Fig 1: Typical CO_2 emissions for different prime movers (single cycle)

Combined heat and power (CHP)

One practical way to decrease CO_2 emissions is to increase the total efficiency of the power plant, for instance by increased combined heat and power (CHP) production of simultaneous electricity and heat. These CHP plants can be in urban locations or industrial areas close to the heat and electricity consumers, thus the need for transmission lines is reduced and associated energy losses and land need can be minimized.

In the EU CHP is in focus, e.g. in Directive 2001/80/EC it is stated:

"The Community is committed to a reduction of carbon dioxide emissions. Where it is feasible the combined production of heat and electricity represents a valuable opportunity for significantly improving overall efficiency in fuel use".

Reciprocating engines are well suited for cogeneration (CHP) e.g. for hot water production, steam generation (sometimes with an additional steam turbine for enhanced electrical efficiency), desalination of sea water, district cooling systems and for "heating" air. The total fuel efficiency of this kind of installation is high, up to 90 % in some applications. The heat to power ratios for the engine CHP-applications are typically from 0,5 to 1,3. As an example, specific CO_2 emission for cogeneration (CHP) plants producing electricity and recoverable heat is 370 g/kWh when operating on HFO (heavy fuel oil) at a total plant efficiency of about 80 %.

TA LUFT deals only with at-site emissions of "regulated pollutants" for engine driven plants not considering non-regulated emissions like the green house gas CO_2. Other regulations consider additionally both the at-site emission of such unregulated gases and that emissions occur also during fuel production and distribution: lower fuel consumption leads to lower environmental burden that may be taken into consideration e.g. by an efficiency bonus. In the UK legislation[4)] for 20 ... 50 MW_{th} engine plants an efficiency correction of the stipulated emission limits is granted. In TA-LUFT 2002 stationary engine driven plants are not granted any efficiency "bonus", which is on the contrary the case for the gas-turbine (on the NO_x emission limit).

Emissions from a thermal power plant are to a high degree dependent on the existing fuel infrastructure in the specific country. If natural gas is available, emissions of SO_2 and particulate are very low. Also in this respect, NO_x, emissions are lower compared to use of e.g. oil as fuel. Natural gas is today generally available in Germany and TA Luft 2002 prescribed limits for gas fired engines are in line with available techniques.

<u>Conclusion</u>: Beneficial environmental impacts of a low fuel consumption on CO_2 emissions have not been considered for reciprocating engines.

Final conclusion

Reduction of man-made environmental deterioration is an on-going process. Consequently emissions regulations become more and more stringent. But the speed of this process should be dependent on demonstrable environmental necessities considering technical and commercial possibilities. Of overriding importance is that all

4) The Environmental Protection Act 1990, Part 1 (1995 Revision), PG1/5(95): Secretary of State´s Guidance-Compression Ignition Engines, 20-50 MW Net Rated Thermal Input

effects are taken into consideration, as far as possible, not only local effects. German TA-LUFT 2002, seems unfortunately not to be driven by such considerations.

Euromot finds it especially problematic, if other countries with less comfortable conditions (with a different existing infrastructure: natural gas not generally available, etc.) would adopt TA-LUFT 2002 as done with the former 1986 version of TA LUFT. Some of the prescribed limits in TA-LUFT 2002 for bigger stationary liquid fired engines are either technically **not achievable** (such as the particulate), **set very low** (such as SO_2) in comparison with competing prime movers like boilers or **a high effeciency secondary cleaning equipment** is to be used (such as for NO_x) while competing techniques manage largely with primary methods.

Particularly when considering secondary cleaning equipment the reference conditions for limits are important. Such equipment “sees” the pollutant at the “actual” concentration (at both real flue gas temperature and real oxygen content, i.e. at actual flue gas excess air range). Although it is possible to correct a concentration to each reference condition mathematically it is not possible to do this for the equipment. **By expressing the emission limit reference point close to actual conditions the real performance of the secondary cleaning device is best described.**

In TA-LUFT the emission limit reference point for the engine driven plant is stated at 5 vol-% O_2 which is far away from the real condition for a bigger liquid fired engine (typically 13 … 15 vol-% O_2 in the flue gas). In other regulations and guidelines as in UK, Japan, World Bank, etc. the reference conditions of the emission limits are near to the real conditions.