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STANDARDS AND METHODS FOR SAMPLING AND ANALYSING EMISSION COMPONENTS IN NON-AUTOMATIVE DIESEL AND GAS ENGINE EXHAUST GASES - MARINE AND LAND BASED POWER PLANT SOURCES

The International Council on Combustion Engines

Conseil International des Machines à Combustion

CIMAC is an international organisation, founded in 1950 by a French initiative to promote technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines). This is achieved by the organisation of congresses and working groups.

It is supported by engine manufacturers, engine users, technical universitites, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Member Associations (NMAs), National Member Groups (NMGs) and Corporate Members (CMs) as well as previous CIMAC Recommendations are listed in the back of this publication.

This document has been elaborated by the CIMAC Working Group „Exhaust Emissions Control“ and approved by CIMAC in January 2005.

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FOREWORD BY THE PRESIDENT

Exhaust emissions control is a very important factor for the engine industry and the importance will further increase in coming years as environmental regulations become tighter.

The present Recommendation on “Standards and methods for sampling and analysing emission components in non-automotive diesel and gas engine exhaust gases – marine and land based power plant sources” was elaborated by the CIMAC Working Group “Exhaust Emissions Control”.

Exhaust emissions from diesel and gas engines are being measured with a number of different methods for each exhaust component. These methods had originally been developed for on-road and off-road high speed diesel and gasoline automotive engines. In this Recommendation a number of emission measurement methods and standards for marine and land based power plant diesel and gas engines are presented and covered in an excellent manner.

I am sure that this document will be very effective in passing on the message about measurement methods which should be implemented and widely used by the non-automotive engine industry, engine users, scientists and classification societies.

My best thanks to all those members of the Working Group who have put in so much effort to produce this CIMAC Recommendation.

Matti Kleimola, President
February 2005

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CIMAC is an international organisation which represents the non-automotive engine industry including manufacturers, users, component suppliers, oil companies, scientists, classification societies and others.

CIMAC RECOMMENDATION - STANDARDS AND METHODS FOR SAMPLING AND ANALYSING EMISSION COMPONENTS IN NON-AUTOMOTIVE DIESEL AND GAS ENGINE EXHAUST GASES – MARINE AND LAND BASED POWER PLANT SOURCES

Issued in 2005 by:
CIMAC WORKING GROUP ON EXHAUST EMISSIONS

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1. Introduction

Exhaust emissions from diesel and gas non-automotive reciprocating engines are currently being measured with a number of different measurement methods for each exhaust component. Many of these methods are originally developed and aimed to be used for other types of exhaust sources and fuel qualities and consequently not always suitable for use together with non-automotive diesel and gas engine exhaust and cleaning systems.

In this paper a list of emission measurement methods and standards appropriate for use together with non-automotive reciprocating engines are presented. Marine and land based power plant diesel and gas engines are covered. The exhaust gases from big diesel and gas engines have some specific features, which if not considered may result in incorrect measurement results. Attention is drawn to some critical issues, which experience has shown may cause problems.

Correct and repeatable measurement data is crucial for many different reasons:

- Setting emission limits involves evaluating the emission performance of various techniques. Based on this information, it is possible to set emission limits that will give optimal environmental performance, but still recognise technical limitations as well as economical realities. If the emission limits are based on incorrect measurement data the risk is that the emission limits are either too loose or make the compliance with the emission limits technically impossible or economically unjustifiable.

- Verifying emission compliance naturally also requires measurement methods that yield correct and repeatable emission levels. Ultimate consequences of erroneous measurements may include the prolonged operation of facilities at elevated emission levels or unjustified shutting down of facilities that in reality comply with the emission limit.

- Furthermore, the tuning of a process towards good environmental performance relies on the availability of reliable measurement data of emission

2. CIMAC recommended measurement methods and standards

Appendix 1: CIMAC Recommended Emission Measurement Methods and Standards for Marine Diesel Engines
Measurement of: NOx, CO, THC, SO_2, O_2, PM, PM_{10}, $PM_{2.5}$, Smoke (Filter Smoke Number, Smoke Density, Ringelmann and Bacharach)

Appendix 2: CIMAC Recommended Emission Measurement Methods and Standards for Land Based Diesel Power Plants
Measurement of: NOx, CO, THC, SO_2, O_2, PM, PM_{10}, $PM_{2.5}$, Smoke (Smoke Density, Ringelmann and Bacharach)

Appendix 3: CIMAC Recommended Emission Measurement Methods and Standards for Gas Engines – Marine Engines and Land based Power Plants
Measurement of: NOx, CO, NMHC, VOC, HCOH, O_2, PM, PM_{10}, $PM_{2.5}$, Smoke (Smoke Density, Ringelmann and Bacharach)

Appendix 4: Some aspects on the use of Continuous Emission Monitoring (CEMS)

Appendix 1.

CIMAC RECOMMENDED EMISSION MEASUREMENT METHODS AND STANDARDS FOR MARINE DIESEL ENGINES

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8. Smoke – Smoke Density, Ringelmann and Bacharach
9. Assessment of measurement uncertainties and acceptance

1. Nitrogen oxides (NO_X)

Recommended methods:

- **ISO 8178-1 Chapter 7.4.3.6:** *Oxides of nitrogen (NO_X) analysis*
- **EPA Method 7E (USA):** *Determination of nitrogen oxides from stationary sources (Instrumental analyser procedure)*.
- **VDI 2456 Blatt 5 and 7 (Germany)**

Recommendation:

- Methods based on chemiluminescense are recommended
- Non-Dispersive InfraRed (NDIR) absorption methods can be used for measurement of the NO part of NO_x. The NO_2 part of NO_x cannot be measured with NDIR since NO_2 is soluble in water and the sample must be supplied cold and dry
- Methods based on Zirconia sensors can be used at on-board measurements provided that good correlation with the chemiluminescense method can be documented

Warning:

- Electrochemical cells are sometimes used for measuring NO_x emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations[1]. Experience from the field indicates that chemical cells should be avoided

2. Carbon monoxide (CO)

Recommended methods:

- **ISO 8178-1 Chapter 7.4.3.1:** *Carbon monoxide (CO) analysis*
- **EPA Method 10 (USA)**: *Determination of carbon monoxide emissions from stationary sources.*
- **VDI 2459 Blatt 6 (Germany)**: *Gaseous Emission Measurement; Measurement of carbon monoxide concentration; non-dispersive infrared absorption method.*

Recommendation:

- Methods based on Non-Dispersive InfraRed (NDIR) absorption are recommended

Warning:

- Electrochemical cells are sometimes used for measuring CO emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided

3. Total Hydrocarbons (THC)

Recommended methods:

- **ISO 8178-1 Chapter 7.4.3.4:** *Hydrocarbon (HC) analysis*
- **EPA Method 25A (USA):** *Determination of total gaseous organic concentration using Flame Ionisation Analyser*

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[1] EPA CTM-022: Determination of nitric oxide, nitrogen dioxide and NO_X emissions from stationary combustion sources by electrochemical analyser.

- **VDI 3481 Blatt 1 (Germany):** *Gaseous emission measurement; determination of hydrocarbon concentration; flame-ionization-detector (FID)*

Recommendations:
- Methods based on Flame-Ionization-Detection (FID) are recommended
- THC is to be calculated and reported as methane (ppmv-C1). The calibration of the instrument can be based on methane (C1) or propane (C3). If C3 is used then the factor for result conversion to C1 should be 3

Warning:
- Electrochemical cells are sometimes used for measuring hydrocarbon emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided
- Non-Dispersive InfraRed (NDIR) absorption methods should be avoided, because instruments yield different response for different hydrocarbon species

4. Sulphur dioxide (SO_2)

4.1 Sulphur dioxide (SO_2) after engine

Recommended method:
- **ISO 8178-1 Chapter 7.4.3.7:** *Sulphur Dioxide (SO_2) analysis.*
  - According to ISO 8178-1, the SO_2 concentration shall be calculated from the sulphur content of the fuel, since experience has shown that using direct measurement method for SO_2 does not give more precise results. It is further noted that SO_2 measurement is a difficult task and has not been fully demonstrated for exhaust measurements.

4.2 Sulphur dioxide (SO_2) after flue gas desulphurisation (FGD)

Recommended method:
- **EPA Method 6C (USA):** *Determination of sulphur dioxide emissions from stationary sources (Instrumental analyser method)*

Recommendations for both methods above:
- SO_x is to be measured, calculated and reported as sulphur dioxide (SO_2). Typically only about 2-4% of SO_x is SO_3 after the engine and after the FGD the percentage is even lower. Consequently, the contribution of SO_3 to SO_x can be disregarded.

5. Oxygen (O_2)

Recommended methods:
- **ISO 8178-1 Chapter 7.4.3.3:** *Oxygen (O_2) analysis*

- **EPA Method 3A (USA):** *Determination of oxygen and carbon dioxide emissions from stationary sources (Instrumentation analyser procedure)*

Recommendation:
- ParaMagnetic Detector (PMD) method is preferred

6. Particulate Matter (PM)

Particulate Matter from marine sources can be measured according to two completely different measurement methods i.e. the dilution method and the direct measurement method (dry dust method).

Warning and recommendation!
- The dilution method should only be used with low sulphur fuels ($S<0.05\%$) whereas the direct measurement method (dry dust method) can be used when operating on any fuel quality
- The particulate measurement result differs a lot for the two measurement methods – the results are not comparable. The root cause of the difference in results is the behaviour of sulphur compounds in sampled exhaust gas. Simultaneous measurements from the same engine exhaust duct with both measurement methods has shown that a fuel sulphur content exceeding 0.05%-weight is resulting in big difference in results between the methods
- The direct measurement method (dry dust method) is used for measuring particulates from land based stationary sources. Consequently, CIMAC is recommending the use of this method for big marine and land based diesel engines operating on any fuel quality in order to enable comparison to other sources

6.1 Particulate Matter with the dilution method – maximum fuel sulphur content is 0.05%-weight

Recommended method:
- ISO 8178: *Reciprocating internal combustion engines – Exhaust emission measurement*

Note:
The ISO 8178-1 states that the maximum fuel sulphur content with this method is 0.8%-weight. The CIMAC recommendation for maximum fuel sulphur content with this method is though 0.05%-weight. See the explanation above.

6.2 Particulate Matter with the direct measurement method (dry dust method) – all fuel qualities - measurement after engine and before heat recovery boiler, before flue gas cleaning system, etc

Recommended methods:
- **ISO 9096: 2003:** *Stationary source emissions – Manual determination of mass concentration of particulate matter.* In-stack filtration

- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.* In-stack filtration.
- **VDI 2066 Blatt 1 (Germany)**: *Particulate matter measurement. Measuring of particulate matter in flowing gases. Gravimetric determination of dust load.*
- **EPA Method 17 (USA)**: *Determination of particulate emissions from stationary sources*
- **JIS Z8808 (Japan)**: *Methods of measuring dust concentration in flue gases*

Note:
Particulate matter is a function of temperature and pressure. Many direct emission measurement methods (dry dust) specify a sampling temperature, which for a diesel engine means that the exhaust gas has to be cooled very dramatically. The cooling of the exhaust gas cannot be considered a controlled process and will not yield reproducible sampling. The main reason for this is the uncontrolled condensation of semi-volatile components from the exhaust gas on the cold surfaces needed to cool the gas. According to ISO 9096[2] and EN 13284-1[3], more reproducible results are achieved if volatile compounds are not trapped during sampling or further evaporated during sample drying. Considering the above issues it is concluded that to yield repeatable particulate matter measurement data from the hot exhaust gas of a diesel engine, the particulate sampling has to be performed at exhaust gas temperature, i.e. using in-stack sampling.

6.3 Particulate Matter – measurement after heat recovery boiler (flue gas temperature <160°C) or low temperature flue gas cleaning system (flue gas temperature <160°C)

Recommended methods:

- **ISO 9096:2003**: *Stationary source emissions – Manual determination of mass concentration of particulate matter.* Out-stack filtration
- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.* Out-stack filtration.
- **EPA Method 5B (USA)**: *Determination of nonsulfuric acid particulate matter emissions from stationary sources.*
- **JIS Z8808 (Japan):** *Methods of measuring dust concentration in exhaust gases*

Note:
The out-stack filtration is recommended, because this arrangement enables heating of the filter holder to a temperature close to 160ºC for avoiding any risk of condensation and absorption of sulphur compounds, water, etc on the sampling filter. If the temperature of the exhaust gas is high enough (close to

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[2] ISO 9096: Stationary source emissions: Manual determination of mass concentration of particulate matter.
[3] ISO 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.

160ºC) for ensuring that no condensation or absorption could take place then the in-stack filtration can be used

6.4 Filterable PM_{10} or $PM_{2.5}$

Recommended method:

- **EPA Method 201A (USA):** *Determination of PM_{10} emissions constant sampling rate procedure.* In-stack filter method with sizing device – in-stack cyclone, cut-off: 10μm or 2.5μm.

Note – for all particulate measurements:
Quartz fibre filter material should be used.
Glass fibre filter material may react with acidic compounds in the exhaust gas originating from sulphur compounds present in fuel and lube oil, leading to an increase of the filter mass[2] – the use of glass fibre filter paper material should be avoided
Teflon coated glass fibre filter material can be used together with the dilution method (ISO 8178)

7. Smoke - Filter Smoke Number

Recommended methods:

- **ISO 8178-3:** *Reciprocating internal combustion engines –exhaust emission measurement, method 2: Smoke measurement by a filter-type smoke meter*

- **ISO 10054:** *Internal combustion compression ignition engines – measurement apparatus for smoke from engines operating under steady-state conditions – filter type smoke meter*

Warning!

- Simultaneous measurements from the same engine exhaust duct with several various smoke meter types and configurations, all in line with the requirements in the FSN measurement standards above, have shown big differences in Filter Smoke Number, especially when operating on high sulphur and high ash fuel qualities. Consequently, the precise smoke meter configuration is affecting the Filter Smoke Number result and has to be taken into account when evaluating FSN test results.

7.1 Requirements for achieving reproducible Filter Smoke Number results

Although the used smoke meter type and configuration are fulfilling the measurement standards ISO 10054 and ISO 8178-3 following additional requirements must be met in order to achieve reproducible FSN smoke results and enabling comparison of FSN results between engines:

- Exact the same type of sample probe has to be used
- Exact the same type and length of sample tube has to be used
- Same type of instrument has to be used

  - If the results from a “heated system” is intended to be compared to results received with a “non-heated system” the heating has to be switched off (instrument and sample line)
- Same sampling volume and same sampling time are to be used
- Same filter paper quality is to be used

7.2 Requirements for achieving comparable results to the “one stroke Bosch scale”

- In case a “heated system” is used the heating should be switched off (instrument and sample line)
- “Bosch hand pump” type of sample probe with cap screwed on has to be used
- Sample line type to be used: Viton material, Unheated Non-insulated tube
- Sample line length is to be minimized
- Standard filter paper has to be used
- Reference sample volume is 0.33 litre/stroke and the number of strokes is 1.

Comparison of the FSN smoke value to the “one stroke Bosch value” is not possible to do, unless these requirements (above) are met. The FSN corresponds approximately 1:1 to the “one stroke Bosch value” provided that the requirements above are fulfilled.

Note – for all Filter Smoke Number measurements:
Information of the precise Smoke Meter type (heating switched on/off), sample probe type (cap screwed on/off) and sample line type (heated/not heated; insulated/non-insulated tube; tube material and length) should always be included into the test report.

8. Smoke – Smoke Density, Ringelmann and Bacharach

Recommended methods for Smoke Density (Opacity):
- **ISO 8178-3:** *Reciprocating internal combustion engines – exhaust emission measurement, method 1: Smoke measurement by an opacimeter*
- **ISO 11614:** *Reciprocating internal combustion compression ignition engines – apparatus for measurement of the opacity and for determination of the light absorption coefficient of the exhaust gas*

Ringelmann

- Ringelmann is a smoke measurement method based on visual assessment of the smoke appearance. Visual Ringelmann testing should be avoided, because many uncontrollable factors will affect the subjective smoke appearance value, such as weather conditions (cloudy, bright day, etc), position of sun, stack diameter and height, etc

- ASTM D3211-79 “Standard Test Method for Relative Density of Black Smoke (Ringelmann Method) can be used for specifying the relationship between Ringelmann Number and Smoke density (Opacity). Opacity of 20% corresponds to Ringelmann 1, etc.

Bacharach

- Bacharach method should be avoided due to low reproducibility of results

9. Assessment of measurement uncertainties and acceptance

Recommended guideline:
- **VDI 2048 Section 6.2:** *Uncertainties of the measurement during acceptable tests on energy-conversion and power plants*

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Appendix 2.

CIMAC RECOMMENDED EMISSION MEASUREMENT METHODS AND STANDARDS FOR LAND BASED DIESEL POWER PLANTS

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5. Oxygen (O_2)
6. Particulate Matter (PM)
    - 6.1 Particulate Matter – measurement after engine and before heat recovery boiler, before flue gas cleaning system, etc
    - 6.2 Particulate Matter – measurement after heat recovery boiler (flue gas temperature <160ºC) or low temperature flue gas cleaning system (flue gas temperature <160ºC)
    - 6.3 Filterable PM_{10} and $PM_{2.5}$
7. Smoke – Smoke Density, Ringelmann and Bacharach
8. Assessment of measurement uncertainties and acceptance

1. Nitrogen oxides (NO_x)

Recommended methods:
- **EPA Method 7E (USA):** *Determination of nitrogen oxides from stationary sources (Instrumental analyser procedure)*.
- **ISO 8178-1 Chapter 7.4.3.6:** *Oxides of nitrogen (NO_X) analysis*
- **VDI 2456 Blatt 5 and 7 (Germany)**

Recommendation:
- Methods based on chemiluminescense are recommended
- Non-Dispersive InfraRed (NDIR) absorption methods can be used for measurement of the NO part of NO_x. The NO_2 part of NO_x cannot be measured with NDIR since NO_2 is soluble in water and the sample must be supplied cold and dry

Warning:

- Electrochemical cells are sometimes used for measuring NOx emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations[1]. Experience from the field indicates that chemical cells should be avoided

2. Carbon monoxide (CO)

Recommended methods:

- **EPA Method 10 (USA)**: *Determination of carbon monoxide emissions from stationary sources.*
- **VDI 2459 Blatt 6 (Germany)**: *Gaseous Emission Measurement; Measurement of carbon monoxide concentration; non-dispersive infrared absorption method.*
- **ISO 8178-1 Chapter 7.4.3.1:** *Carbon monoxide (CO) analysis*

Recommendation:

- Methods based on Non-Dispersive InfraRed (NDIR) absorption are recommended

Warning:

- Electrochemical cells are sometimes used for measuring CO emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided

3. Total Hydrocarbons (THC)

Recommended methods:

- **EPA Method 25A (USA):** *Determination of total gaseous organic concentration using Flame Ionisation Analyser*
- **VDI 3481 Blatt 1 (Germany):** *Gaseous emission measurement; determination of hydrocarbon concentration; flame-ionization-detector (FID)*
- **ISO 8178-1 Chapter 7.4.3.4:** *Hydrocarbon (HC) analysis*

Recommendations:

- Methods based on Flame-Ionization-Detection (FID) are recommended
- THC is to be calculated and reported as methane (ppmv-C1). The calibration of the instrument can be based on methane (C1) or propane (C3). If C3 is used then the factor for result conversion to C1 should be 3

Warning:

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[1] EPA CTM-022: Determination of nitric oxide, nitrogen dioxide and NO_X emissions from stationary combustion sources by electrochemical analyser.

- Electrochemical cells are sometimes used for measuring hydrocarbon emissions after diesel engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided
- Non-Dispersive InfraRed (NDIR) absorption methods should be avoided, because instruments yield different response for different hydrocarbon species

4. Sulphur dioxide (SO_2)

4.1 Sulphur dioxide (SO_2) after engine

Recommended method:

- **ISO 8178-1 Chapter 7.4.3.7:** *Sulphur Dioxide (SO_2) analysis.*
  - According to ISO 8178-1, the SO_2 concentration shall be calculated from the sulphur content of the fuel, since experience has shown that using direct measurement method for SO_2 does not give more precise results. It is further noted that SO_2 measurement is a difficult task and has not been fully demonstrated for exhaust measurements.

4.2 Sulphur dioxide (SO_2) after flue gas desulphurisation (FGD)

Recommended method:

- **EPA Method 6C (USA):** *Determination of sulphur dioxide emissions from stationary sources (Instrumental analyser method)*

Recommendations for both methods above:

- SO_x is to be measured, calculated and reported as sulphur dioxide (SO_2). Typically only about 2-4% of SO_x is SO_3 after the engine and after the FGD the percentage is even lower. Consequently, the contribution of SO_3 to SO_x can be disregarded.

5. Oxygen (O_2)

Recommended methods:

- **EPA Method 3A (USA):** *Determination of oxygen and carbon dioxide emissions from stationary sources (Instrumentation analyser procedure)*
- **ISO 8178-1 Chapter 7.4.3.3:** *Oxygen (O_2) analysis*

Recommendation:

- ParaMagnetic Detector (PMD) method is preferred

6. Particulate Matter (PM)

6.1 Particulate Matter – measurement after engine and before heat recovery boiler, before flue gas cleaning system, etc

Recommended methods:

- **ISO 9096:2003**: *Stationary source emissions – Manual determination of mass concentration of particulate matter.* In-stack filtration
- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.* In-stack filtration.
- **VDI 2066 Blatt 1 (Germany)**: *Particulate matter measurement. Measuring of particulate matter in flowing gases. Gravimetric determination of dust load.*
- **EPA Method 17 (USA)**: *Determination of particulate emissions from stationary sources*
- **JIS Z8808 (Japan):** *Methods of measuring dust concentration in flue gases*

Note:

Particulate matter is a function of temperature and pressure. Many direct emission measurement methods (dry dust) specify a sampling temperature, which for a diesel engine means that the exhaust gas has to be cooled very dramatically. The cooling of the exhaust gas cannot be considered a controlled process and will not yield reproducible sampling. The main reason for this is the uncontrolled condensation of semi-volatile components from the exhaust gas on the cold surfaces needed to cool the gas. According to ISO 9096[2] and EN 13284-1[3], more reproducible results are achieved if volatile compounds are not trapped during sampling or further evaporated during sample drying. Considering the above issues it is concluded that to yield repeatable particulate matter measurement data from the hot exhaust gas of a diesel engine, the particulate sampling has to be performed at exhaust gas temperature, i.e. using in-stack sampling.

6.2 Particulate Matter – measurement after heat recovery boiler (flue gas temperature <160°C) or low temperature flue gas cleaning system (flue gas temperature <160°C)

Recommended methods:

- **ISO 9096:2003**: *Stationary source emissions – Manual determination of mass concentration of particulate matter.* Out-stack filtration
- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concetration of dust – Part 1: Manual Gravimetric method.* Out-stack filtration.
- **EPA Method 5B (USA)**: *Determination of nonsulfuric acid particulate matter emissions from stationary sources.*
- **JIS Z8808 (Japan):** *Methods of measuring dust concentration in flue gases*

Note:

The out-stack filtration is recommended, because this arrangement enables heating of the filter holder to a temperature close to 160ºC for avoiding any risk of condensation and absorption of sulphur compounds, water, etc on the

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[2] ISO 9096: Stationary source emissions: Manual determination of mass concentration of particulate matter.

[3] ISO 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.

sampling filter. If the temperature of the exhaust gas is high enough (close to 160ºC) for ensuring that no condensation or absorption could take place then the in-stack filtration can be used.

6.3 Filterable PM_{10} or $PM_{2.5}$

Recommended method:

- **EPA Method 201A (USA):** *Determination of PM_{10} emissions constant sampling rate procedure.* In-stack filter method with sizing device – in-stack cyclone, cut-off: 10μm or 2.5μm.

Note – for all particulate measurements:
Quartz fibre filter material should be used.
Glass fibre filter material may react with acidic compounds in the exhaust gas originating from sulphur compounds present in fuel and lube oil, leading to an increase of the filter mass[2] – the use of glass fibre filter paper material should be avoided

7. Smoke – Smoke Density, Ringelmann and Bacharach

Recommended methods for Smoke Density (Opacity):

- **ISO 8178-3:** *Reciprocating internal combustion engines – exhaust emission measurement, method 1: Smoke measurement by an opacimeter*
- **ISO 11614:** *Reciprocating internal combustion compression ignition engines – apparatus for measurement of the opacity and for determination of the light absorption coefficient of the exhaust gas*

Ringelmann

- Ringelmann is a smoke measurement method based on visual assessment of the smoke appearance. Visual Ringelmann testing should be avoided, because many uncontrollable factors will affect the subjective smoke appearance value, such as weather conditions (cloudy, bright day, etc), position of sun, stack diameter and height, etc
- ASTM D3211-79 "Standard Test Method for Relative Density of Black Smoke (Ringelmann Method) can be used for specifying the relationship between Ringelmann Number and Smoke density (Opacity). Opacity of 20% corresponds to Ringelmann 1, etc.

Bacharach

- Bacharach method should be avoided due to low reproducibility of results

8. Assessment of measurement uncertainties and acceptance

Recommended guideline:

- **VDI 2048 Section 6.2:** *Uncertainties of the measurement during acceptable tests on energy-conversion and power plants*

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Appendix 3.

CIMAC RECOMMENDED EMISSION MEASUREMENT METHODS AND STANDARDS FOR GAS ENGINES - MARINE ENGINES AND LAND BASED POWER PLANTS

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6. Oxygen (O_2)
7. Particulate Matter (PM)
    - 7.1 Particulate Matter – measurement after engine and before heat recovery boiler, before flue gas cleaning system, etc
    - 7.2 Particulate Matter – measurement after heat recovery boiler (flue gas temperature <160ºC) or low temperature flue gas cleaning system (flue gas temperature <160ºC)
    - 7.3 Filterable PM_{10} and $PM_{2.5}$
8. Smoke – Filter Smoke Number
    - 7.1 Requirements for achieving reproducible Filter Smoke Number results
    - 7.2 Requirements for achieving comparable results to the “one stroke Bosch scale”
9. Smoke – Smoke Density, Ringelmann and Bacharach
10. Assessment of measurement uncertainties and acceptance

1. Nitrogen oxides (NO_x)

Recommended methods:

- **EPA Method 7E (USA):** *Determination of nitrogen oxides from stationary sources (Instrumental analyser procedure)*.
- **ISO 8178-1 Chapter 7.4.3.6:** *Oxides of nitrogen (NO_X) analysis*
- **VDI 2456 Blatt 5 and 7 (Germany)**

Recommendation:
- Methods based on chemiluminescense are recommended
- Non-Dispersive InfraRed (NDIR) absorption methods can be used for measurement of the NO part of NO_x. The NO_2 part of NO_x cannot be measured with NDIR since NO_2 is soluble in water and the sample must be supplied cold and dry
- Methods based on Zirconia sensors can be used at on-board measurements provided that good correlation with the chemiluminescense method can be documented

Warning:
- Electrochemical cells are sometimes used for measuring NOx emissions after gas engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations[1]. Experience from the field indicates that chemical cells should be avoided

2. Carbon monoxide (CO)

Recommended methods:
- **EPA Method 10 (USA)**: *Determination of carbon monoxide emissions from stationary sources.*
- **VDI 2459 Blatt 6 (Germany)**: *Gaseous Emission Measurement; Measurement of carbon monoxide concentration; non-dispersive infrared absorption method.*
- **ISO 8178-1 Chapter 7.4.3.1:** *Carbon monoxide (CO) analysis*

Recommendation:
- Methods based on Non-Dispersive InfraRed (NDIR) absorption are recommended

Warning:
- Electrochemical cells are sometimes used for measuring CO emissions after gas engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided

3. Non-Methane Hydro Carbons (NMHC)

Non-Methane Hydro Carbons (NMHC) are defined as total hydrocarbons (THC) excluding methane.

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[1] EPA CTM-022: Determination of nitric oxide, nitrogen dioxide and NO_X emissions from stationary combustion sources by electrochemical analyser.

3.1 NMHC - measurement after engine with no oxidation catalyst installed

Recommended methods:

- **EPA Method 25A (USA)**: *Determination of total gaseous organic concentration using a flame ionisation analyser.*
- **VDI 3481 Blatt 1 (Germany):** *Gaseous emission measurement; determination of hydrocarbon concentration; flame-ionization-detector (FID)*
- **ISO 8178-1 Chapter 7.4.3.4:** *Hydrocarbon (HC) analysis*

Calculation of NMHC:

- NMHC = Total Hydrocarbons (THC) – methane
- The methane concentration in the exhaust gas is calculated based on the fuel analysis. The ratio of methane to THC in the fuel gas is considered to remain constant in the exhaust gas.
- NMHC is to be calculated and reported as methane (ppmv-C1). The calibration of the FID instrument can be based on methane (C1) or propane (C3). If C3 is used then the factor for result conversion to C1 should be 3

Recommendation:

- Methods based on Flame-Ionization-Detection (FID) are recommended

Warning:

- Electrochemical cells are sometimes used for measuring hydrocarbon emissions after gas engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided
- Non-Dispersive InfraRed (NDIR) absorption methods should be avoided, because instruments yield different response for different hydrocarbon species

3.2 NMHC measurement after an oxidation catalyst

Recommended methods:

- **EPA Method 18 (USA)**: *Measurement of gaseous organic compound emissions by gas chromatography.*
  - Measured Non-Methane Hydrocarbons components are C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10} and C_6H_{12}. Formaldehyde concentration is negligible after a catalyst. If required this can be verified with method EPA Method 323 (USA).
- **EPA Method 320 (USA)**: *Measurement of vapor phase organic and inorganic emissions by extractive Fourier Transform Infrared (FTIR) spectroscopy.*

- Measured Non-Methane Hydrocarbons components are C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10} and C_6H_{12}. Formaldehyde concentration is negligible after a catalyst.

4. Volatile Organic Compounds (VOC) or Non-Methane/Non-Ethane Hydro Carbons (NM/NEHC)

Volatile Organic Compounds (VOC) and/or Non-Methane Non-Ethane Hydrocarbons are defined as total hydrocarbons (THC) excluding methane and ethane.

4.1 VOC (NM/NEHC) – measurement after engine with no catalyst installed

Recommended methods:
- **EPA Method 25A (USA)**: *Determination of total gaseous organic concentration using a flame ionisation analyser.*
- **VDI 3481 Blatt 1 (Germany):** *Gaseous emission measurement; determination of hydrocarbon concentration; flame-ionization-detector (FID)*
- **ISO 8178-1 Chapter 7.4.3.4:** *Hydrocarbon (HC) analysis*

Calculation of VOC (NM/NEHC):
- VOC (NM/NEHC) = Total Hydrocarbons (THC) – methane - ethane
- The methane and ethane concentrations in the exhaust gas are calculated based on the fuel analysis. The ratio of methane and ethane to THC in the fuel gas is considered to remain constant in the exhaust gas.
- VOC (NM/NEHC) is to be calculated and reported as methane (ppmv-C1). The calibration of the FID instrument can be based on methane (C1) or propane (C3). If C3 is used then the factor for result conversion to C1 should be 3

Recommendation:
- Methods based on Flame-Ionization-Detection (FID) are recooмended

Warning:
- Electrochemical cells are sometimes used for measuring hydrocarbon emissions after gas engines. Electrochemical sensor technology can be prone to cross interference, noise, short term drift at low concentrations, and overloading or saturation at high concentrations. Experience from the field indicates that chemical cells should be avoided
- Non-Dispersive InfraRed (NDIR) absorption methods should be avoided, because instruments yield different response for different hydrocarbon species

4.2 VOC (NM/NEHC) measurement after an oxidation catalyst

Recommended methods:

- **EPA Method 18 (USA)**: *Measurement of gaseous organic compound emissions by gas chromatography.*
  - VOC is defined as Non Methane Non Ethane Hydrocarbons. Measured components are C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10} and C_6H_{12}. Formaldehyde concentration is negligible after a catalyst. If required this can be verified with EPA Method 323 (USA).
- **EPA Method 320 (USA)**: *Measurement of vapour phase organic and inorganic emissions by extractive Fourier Transform Infrared (FTIR) spectroscopy.*
  - VOC is defined as Non Methane Non Ethane Hydrocarbons. Measured components are C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10} and C_6H_{12}. Formaldehyde concentration is negligible after a catalyst

5. Formaldehyde (HCOH)

Recommended methods:

- **EPA Method 320 (USA)**: *Measurement of vapor phase organic and inorganic emissions by extractive Fourier Transform Infrared (FTIR) spectroscopy.*
- **EPA Method 323 (USA):** *Measurement of formaldehyde emissions from natural gas-fired stationary sources-acetyl acetone derivitization method.*
- **VDI 3862, Blatt 2 (1999):** *Gaseous emission measurement - Measurement of aliphatic and aromatic aldeydes and ketones by DNPH method - Impinger method*
- **VDI 3862, Blatt 3 (1999):** *Gaseous emission measurement - Measurement of aliphatic and aromatic aldehydes and ketones by DNPH method - Cartridges method*

6. Oxygen (O_2)

Recommended methods:

- **EPA Method 3A (USA):** *Determination of oxygen and carbon dioxide emissions from stationary sources (Instrumentation analyser procedure)*
- **ISO 8178-1 Chapter 7.4.3.3:** *Oxygen (O_2) analysis*

Recommendation:

- ParaMagnetic Detector (PMD) method is preferred

7. Particulate Matter (PM)

7.1 Particulate Matter – measurement after engine and before heat recovery boiler, before flue gas cleaning system, etc

Recommended methods:

- **ISO 9096:2003:** *Stationary source emissions – Manual determination of mass concentration of particulate matter.* In-stack filtration
- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.* In-stack filtration.

- **VDI 2066 Blatt 1 (Germany)**: *Particulate matter measurement. Measuring of particulate matter in flowing gases. Gravimetric determination of dust load.*
- **EPA Method 17 (USA)**: *Determination of particulate emissions from stationary sources*
- **JIS Z8808 (Japan):** *Methods of measuring dust concentration in flue gases*

Note:
Particulate matter is a function of temperature and pressure. Many direct emission measurement methods (dry dust) specify a sampling temperature, which for a diesel engine means that the exhaust gas has to be cooled very dramatically. The cooling of the exhaust gas cannot be considered a controlled process and will not yield reproducible sampling. The main reason for this is the uncontrolled condensation of semi-volatile components from the exhaust gas on the cold surfaces needed to cool the gas. According to ISO 9096[2] and EN 13284-1[3], more reproducible results are achieved if volatile compounds are not trapped during sampling or further evaporated during sample drying. Considering the above issues it is concluded that to yield repeatable particulate matter measurement data from the hot exhaust gas of a diesel engine, the particulate sampling has to be performed at exhaust gas temperature, i.e. using in-stack sampling.

7.2 Particulate Matter – measurement after heat recovery boiler (flue gas temperature <160°C) or low temperature flue gas cleaning system (flue gas temperature <160°C)

Recommended methods:
- **ISO 9096:2003**: *Stationary source emissions – Manual determination of mass concentration of particulate matter.* Out-stack filtration
- **EN 13284-1:** *Stationary source emissions – Determination of low range mass concetration of dust – Part 1: Manual Gravimetric method.* Out-stack filtration.
- **EPA Method 5B (USA)**: *Determination of nonsulfuric acid particulate matter emissions from stationary sources.*
- **JIS Z8808 (Japan):** *Methods of measuring dust concentration in flue gases*

Note:
The out-stack filtration is recommended, because this arrangement enables heating of the filter holder to a temperature close to 160ºC for avoiding any risk of condensation and absorption of sulphur compounds, water, etc on the sampling filter. If the temperature of the exhaust gas is high enough (close to 160ºC) for ensuring that no condensation or absorption could take place then the in-stack filtration can be used.

7.3 Filterable PM_{10} or $PM_{2.5}$

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[2] ISO 9096: Stationary source emissions: Manual determination of mass concentration of particulate matter.
[3] ISO 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual Gravimetric method.

Recommended method:

- **EPA Method 201A (USA):** *Determination of PM_{10} emissions constant sampling rate procedure.* In-stack filter method with sizing device – in-stack cyclone, cut-off: 10μm or 2.5μm.

Note – for all particulate measurements:
Quartz fibre filter material should be used.
Glass fibre filter material may react with acidic compounds in the exhaust gas leading to an increase of the filter mass[2] – the use of glass fibre filter paper material should be avoided

8. Smoke - Filter Smoke Number

Recommended methods:

- **ISO 8178-3:** *Reciprocating internal combustion engines –exhaust emission measurement, method 2: Smoke measurement by a filter-type smoke meter*

- **ISO 10054:** *Internal combustion compression ignition engines – measurement apparatus for smoke from engines operating under steady-state conditions – filter type smoke meter*

Warning!

- Simultaneous measurements from the same engine exhaust duct with several various smoke meter types and configurations, all in line with the requirements in the FSN measurement standards above, have shown big differences in Filter Smoke Number, especially when operating on high sulphur and high ash fuel qualities. Consequently, the precise smoke meter configuration is affecting the Filter Smoke Number result and has to be taken into account when evaluating FSN test results.

8.1 Requirements for achieving reproducible Filter Smoke Number results

Although the used smoke meter type and configuration are fulfilling the measurement standards ISO 10054 and ISO 8178-3 following additional requirements must be met in order to achieve reproducible FSN smoke results and enabling comparison of FSN results between engines:

- Exact the same type of sample probe has to be used
- Exact the same type and length of sample tube has to be used
- Same type of instrument has to be used
    - o If the results from a “heated system” is intended to be compared to results received with a “non-heated system” the heating has to be switched off (instrument and sample line)
- Same sampling volume and same sampling time are to be used
- Same filter paper quality is to be used

8.2 Requirements for achieving comparable results to the "one stroke Bosch scale"

- In case a "heated system" is used the heating should be switched off (instrument and sample line)
- "Bosch hand pump" type of sample probe with cap screwed on has to be used
- Sample line type to be used: Viton material, Unheated Non-insulated tube
- Sample line length is to be minimized
- Standard filter paper has to be used
- Reference sample volume is 0.33 liter/stroke and the number of strokes is 1.

Comparison of the FSN smoke value to the "one stroke Bosch value" is not possible to do, unless these requirements (above) are met. The FSN corresponds approximately 1:1 to the "one stroke Bosch value" provided that the requirements above are fulfilled.

Note – for all Filter Smoke Number measurements:
Information of the precise Smoke Meter type (heating switched on/off), sample probe type (cap screwed on/off) and sample line type (heated/not heated; insulated/non-insulated tube; tube material and length) should always be included into the test report.

9. Smoke – Smoke Density, Ringelmann and Bacharach

Recommended methods for Smoke Density (Opacity):

- **ISO 8178-3:** *Reciprocating internal combustion engines – exhaust emission measurement, method 1: Smoke measurement by an opacimeter*
- **ISO 11614:** *Reciprocating internal combustion compression ignition engines – apparatus for measurement of the opacity and for determination of the light absorption coefficient of the exhaust gas*

Ringelmann

- Ringelmann is a smoke measurement method based on visual assessment of the smoke appearance. Visual Ringelmann testing should be avoided, because many uncontrollable factors will affect the subjective smoke appearance value, such as weather conditions (cloudy, bright day, etc), position of sun, stack diameter and height, etc
- ASTM D3211-79 "Standard Test Method for Relative Density of Black Smoke (Ringelmann Method) can be used for specifying the relationship between Ringelmann Number and Smoke density (Opacity). Opacity of 20% corresponds to Ringelmann 1, etc.

Bacharach

- Bacharach method should be avoided due to low reproducibility of results

10. Assessment of measurement uncertainties and acceptance

Recommended guideline:

- **VDI 2048 Section 6.2:** *Uncertainties of the measurement during acceptable tests on energy-conversion and power plants*

Appendix 4.

SOME ASPECTS ON THE USE OF CONTINUOUS EMISSION MONITORING (CEM)

Table of contents:

1. Background
2. CEMS challenges
3. Alternative approach to CEMS
4. Recommendations

1. Background

When choosing between different approaches for emission monitoring there must be a balance between the availability of the method, reliability, level of confidence, costs and the environmental benefits[1]. Continuous Emission Monitoring (from here on referred to as CEM) systems are more and more frequently being proposed as a means of monitoring emission performance. A working CEM enables continuous emission compliance monitoring and also continuous follow up of a process to ensure that it is operating in an environmentally "optimal" window.

The current type of reciprocating engine can be considered a stable process. Once the engine has been tuned, there will be only small changes in the emission levels. This means that discrete measurements (e.g. every second/third year) of emissions will give a good indication of the emissions also between the measurements. A stable process has a low monitoring frequency need and measurements can be done on discontinuous basis[2]. From the stability of the process and comparatively small plant size follow also that any possible breach of emission limits will be small and the environmental consequences small.

Considering environmental, technical as well as economical factors, CEM type systems are not feasible in small installations. For example the EU Directive 2001/80/EC, Annex VIII[3] requires CEM only for big > 100 MW

[1] Europen Commission: Integrated Pollution Prevention and Control (IPPC) – Reference document on the general principles of monitoring.
[2] Europen Commission: Integrated Pollution Prevention and Control (IPPC) – Reference document on the general principles of monitoring.
[3] DIRECTIVE 2001/80/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

thermal input boiler and gas turbine power plants. Continuous measurements are also exempted in following EU cases:

- For SO_2 and dust from gas burning boilers or from gas turbines burning natural gas[4]
- For SO_2 from gas turbines or boilers firing oil with known sulphur content in cases no desulphurization equipment (FGD) is used[5]

2. CEMS challenges

Many technical challenges still have to be resolved before CEM systems for engine applications can be considered a feasible way of collecting reliable measurement data. Problems when measuring from engine exhaust gas include but are not limited to:

- High exhaust gas temperature
- High and fluctuating pressure may lead to problems with exhaust gas entering sensitive parts of the measurement equipment.
- The dust after a diesel engine is sticky, which may cause problems especially with optical systems.
- A prerequisite for a working CEM system is the availability of a developed service network and of trained personnel for maintaining the system in good shape. Hence, continuous systems are not feasible in small remotely located installations.

The small unit size means that the cost of monitoring per produced power will be high in engine driven power plants compared to power plants consisting of bigger units. Using extractive systems with a common analyser may reduce the costs in plants with multiple units. Experience has however shown that especially if the engine is running on HFO, the sampling system may be prone to problems, such as clogging and corrosion.

Systems based on exhaust gas optical properties are used frequently used for evaluating particle emissions. The relationship between the measured parameter and the “mass-related” particle emissions depend on particle properties such as size, colour, shape, etc. Normally, the monitoring system is calibrated against discrete measurements. The problem with using this technique for measuring particle emissions after a diesel engine is that when the emission level changes, the particle properties also change. Therefore, monitoring parameters such as exhaust gas opacity can in the case of diesel engines not be seen as a means of monitoring the “mass-related” particle emissions.

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of 23 October 2001 – on the limitation of emissions of certain pollutants into the air from large combustion plants

[4] European Commission: Integrated Pollution Prevention and Control (IPPC) – Reference document on the general principles of monitoring.

[5] DIRECTIVE 2001/80/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2001 – on the limitation of emissions of certain pollutants into the air from large combustion plants

3. Alternative approach to CEMS

For particulate and SO_2 emissions, monitoring the fuel quality will give a good indication of possible variations in emissions between discrete measurements. The SO_2 emission is directly proportional to the fuel sulphur content and monitoring the ash and sulphur content of the fuel will give good indications about the particle emissions. For a given engine the NO_x emission level can be verified by controlling that the combustion pressure (with discrete measurements) and scavenge air temperature are within certain limits based on reference tests on a similar type of engine. Another important parameter affecting NO_X emissions is intake air humidity and monitoring the intake air humidity will give good indications about variations in NO_X emissions. World Bank guidelines for thermal power[6] suggest the use of surrogate performance monitoring as an alternative to continuous emissions monitoring.

4. Recommendations

Based on the above discussion, it is recommended that in engine driven applications as far as possible avoid continuous emission monitoring systems. If continuous monitoring is required, surrogate monitoring of parameters such as fuel quality and intake air humidity may in many cases yield superior results compared to CEM systems. Discrete measurements of the concentration of emissions (e.g. every second/third year) can be used to validate the surrogate monitoring results.

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[6] World Bank: Pollution Prevention and Abatement Handbook – Part III "Thermal Power – Guidelines for New Plants – Monitoring"

Other CIMAC Recommendations

(all available in the CIMAC Technical Paper Database)

No. 1 Recommendations for Diesel Engine Acceptance Tests, 1968

No. 2 Recommendations for Gas Turbine Acceptance Test, 1968

No. 3 Recommendations of Measurement for the Overall Noise of Reciprocating Engines, 1970

No. 4 Recommendations for SI Units for Diesel Engines and Gas Turbines, 1975

No. 5 Recommendations for Supercharged Diesel Engines, 1971
Part I: Engine De-rating on Account of Ambient Conditions
Part II: Engine Acceptance Tests

No. 6 Lexicon on Combustion Engines, Technical Terms of the IC Engine and Gas Turbine Industries, 1977

No. 7 Recommendations regarding Liability - Assured Properties, Publications and Fuels for Diesel Engines, 1985

No. 8 Recommendations regarding Requirements for Heavy Fuels for Diesel Engines, 1986 (superseded by No. 11)

No. 9 Recommendations concerning the Design of Heavy Fuel Treatment Plants for Diesel Engines, 1987

No. 10 Recommendations regarding Liability - Assured Properties, Publications and Fuels for Gas Turbines, 1985

No. 11 Recommendations regarding Fuel Requirements for Diesel Engines, 1990

No. 12 Exhaust Emission Measurement - Recommendations for Reciprocating Engines and Gas Turbines, 1991

No. 13 Guidelines for the Lubrication of Medium Speed Diesel Engines, 1994

No. 14 Standard Method for the Determination of Structure Borne Noise from Engines, 1994

No. 15 Guidelines for the Lubrication of two-stroke Crosshead Diesel Engines, 1997

No. 16 Guidelines for operation and/or maintenance contracts, 1999

No. 17 Guidelines for Diesel Engines lubrication - Oil consumption of Medium Speed Diesel Engines

No. 18 Guidelines for diesel engines lubrication - Impact of Fuel on Lubrication, 2000

No. 19 Recommendations for the lubrication of gas engines

No. 20 Guidelines for diesel engines lubrication – Lubrication of large high speed diesel engines, 2002

No. 21 Recommendations regarding fuel quality for diesel engines, 2003

No. 22 Guidelines for diesel engines lubrication – Oil degradation, 2004

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