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Small craft — Reciprocating internal combustion engines exhaust emission measurement — Test-bed measurement of gaseous and particulate exhaust emissions

Petits navires — Moteurs alternatifs à combustion interne mesurage des émissions de gaz d'échappement — Mesurage des émissions de gaz et de particules au banc

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Contents

Page

Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 188, *Small craft*, SC 2, *Engines and propulsion systems.*

Introduction

This International Standard is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of reciprocating internal combustion (RIC) engines for marine use in small craft. Its purpose is to provide a map of an engine's emissions characteristics which, through use of the proper weighting factors, can be used as an indication of that engine's emission levels under various applications. The emission results are expressed in units of grams per kilowatt-hour and represent the mass rate of emissions per unit of work accomplished.

Although this International Standard is designed for marine engines, it shares many principles with particulate and gaseous emission measurements that have been in use for many years for on-road engines. One test procedure that shares many of these principles is the process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis (full-flow dilution method) as currently specified for certification of 1985 and later heavy-duty truck engines in the USA. Another is the procedure for direct measurement of the gaseous emissions in the undiluted exhaust gas, as currently specified for the certification of heavy-duty truck engines in Japan and Europe.

NOTE It is common in many full-flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter (see Figure 19).

Many of the procedures described in this International Standard are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

Small craft — Reciprocating internal combustion engines exhaust emission measurement — Test-bed measurement of gaseous and particulate exhaust emissions

1 Scope

This International Standard specifies the measurement and evaluation methods for gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines under steady-state conditions on a test bed, necessary for determining one weighted value for each exhaust gas pollutant. Various combinations of engine load and speed reflect different engine applications.

This International Standard is applicable to RIC marine engines intended to be installed in small craft up to 24 m length of hull.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 8178-1:2006, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

ISO 8178-6:2000, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Report of measuring results and test*

ISO 8666, *Small craft — Principal data*

ISO 14396, *Reciprocating internal combustion engines — Determination and method for the measurement of engine power — Additional requirements for exhaust emission tests in accordance with ISO 8178*

ISO 15550:2002, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8666 and the following apply.

3.1
particulates
material collected on a specified filter medium after diluting exhaust gases with clean, filtered air to a temperature greater than 315 K (42 °C) and less than or equal to 325 K (52 °C), as measured at a point immediately upstream of the primary filter

Note 1 to entry: Particulates consist primarily of carbon, condensed hydrocarbons, and sulfates and associated water.

Note 2 to entry: Particulates defined in this International Standard are substantially different in composition and weight from particulates or dust sampled directly from the undiluted exhaust gas using a hot filter method. Particulates measurement as described in this International Standard is conclusively proven to be effective for fuel sulfur levels up to 0,8 %.

[SOURCE: ISO 8178-1:2006, 3.1, without Note 3 to entry]

3.2
partial-flow dilution system
system using a process of separating a part of the raw exhaust from the total exhaust flow, then mixing with an appropriate amount of dilution air prior to passing through the particulate sampling filter

Note 1 to entry: See 18.2.1, Figures 10 to 18.

3.3
full-flow dilution system
system using a process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis

Note 1 to entry: It is common in many full-flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter (see Figure 19).

3.4
isokinetic sampling
process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the probe equal to the exhaust stream mean velocity

[SOURCE: ISO 8178-1:2006, 3.4]

3.5
multiple-filter method
process of using one filter for each of the individual test cycle modes

Note 1 to entry: The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

[SOURCE: ISO 8178-1:2006, 3.6]

3.6
single-filter method
process of using one filter for all test cycle modes

Note 1 to entry: Modal weighting factors must be accounted for during the particulate sampling phase of the test cycle by adjusting sample flow rate and/or sampling time. This method dictates that particular attention be given to sampling duration and flow rates.

[SOURCE: ISO 8178-1:2006, 3.7]

3.7
specific emissions
mass emissions expressed in grams per kilowatt-hour

[SOURCE: ISO 8178-1:2006, 3.8—modified]

3.8
span gas
purified gas mixture used to span gas analyzers

Note 1 to entry: Calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

3.9
zero gas
gas that yields a zero response in an analyzer

Note 1 to entry: This may either be purified nitrogen, purified air, or a combination of purified air and purified nitrogen.

3.10
calibration
process of setting a measurement system's response so that its output agrees with a range of reference signals

3.11
verification
means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance

4 Symbols and abbreviations

4.1 General symbols

Symbol	Term	Unit
A/F_{st}	Stoichiometric air-to-fuel ratio	—
A_p	Cross-sectional area of the isokinetic sampling probe	m^2
A_r	Atomic mass	G
A_x	Cross-sectional area of the exhaust pipe	m^2
c_c	Background corrected concentration	ppm % (V/V)
c_d	Concentration in the dilution air	ppm % (V/V)
c_x	Concentration in the exhaust (with suffix of the component nominating)	ppm % (V/V)
D	Dilution factor	—
E_{CO2}	CO_2 quench of NO_x analyser	%
E_E	Ethane efficiency	%
E_{H2O}	Water quench of NO_x analyser	%
E_M	Methane efficiency	%
E_{NOx}	Efficiency of NO_x converter	%
e_{PT}	Particulate emission	g/kW·h
e_x	Gas emission (with subscript denoting compound)	g/kW·h
λ	Excess air factor ([kg dry air]/([kg fuel] * [A/F_{st}]))	—
λ_{Ref}	Excess air factor at reference conditions	—
f_a	Laboratory atmospheric factor	—
f_c	Carbon factor	—
f_{fd}	Fuel specific factor for exhaust flow calculation on dry basis	—
f_{fh}	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	—
f_{fw}	Fuel specific factor for exhaust flow calculation on wet basis	—
H_a	Absolute humidity of the intake air (g water/kg dry air)	g/kg
H_d	Absolute humidity of the dilution air (g water/kg dry air)	g/kg

Symbol	Term	Unit
i	Subscript denoting an individual mode	—
k_f	Fuel specific factor for the carbon balance calculation	—
k_{hd}	Humidity correction factor for NO_x for diesel engines	—
k_{hp}	Humidity correction factor for NO_x for gasoline (petrol) engines	—
k_p	Humidity correction factor for particulates	—
k_{wa}	Dry to wet correction factor for the intake air	—
k_{wd}	Dry to wet correction factor for the dilution air	—
k_{we}	Dry to wet correction factor for the diluted exhaust gas	—
k_{wr}	Dry to wet correction factor for the raw exhaust gas	—
M	Percent torque related to the maximum torque for the test engine speed	%
M_r	Molecular mass	g
m_d	Mass of the dilution air sample passed through the particulate sampling filters	kg
$m_{f,d}$	Particulate sample mass of the dilution air collected	mg
m_f	Particulate sample mass collected	mg
m_{sep}	Mass of the diluted exhaust sample passed through the particulate sampling filters	kg
P_A	Absolute outlet pressure at pump outlet	kPa
p_a	Saturation vapour pressure of the engine intake air	kPa
p_b	Total barometric pressure	kPa
p_d	Saturation vapour pressure of the dilution air	kPa
p_r	Water vapour pressure after cooler	kPa
p_s	Dry atmospheric pressure	kPa
P	Uncorrected brake power	kW
P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by ISO 14396	kW
P_m	Maximum measured or declared power at the test engine speed under test conditions (see 13.5)	kW
q_{mad}	Intake air mass flow rate on dry basis	kg/h
q_{maw}	Intake air mass flow rate on wet basis	kg/h
q_{mdw}	Dilution air mass flow rate on wet basis	kg/h
q_{medf}	Equivalent diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mew}	Exhaust gas mass flow rate on wet basis	kg/h
q_{mf}	Fuel mass flow rate	kg/h
q_{mdew}	Diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mgas}	Emission mass flow rate of individual gas	g/h
q_{mPT}	Particle mass flow rate	g/h
r_d	Dilution ratio	—
r_a	Ratio of cross-sectional areas of isokinetic probe and exhaust pipe	—
R_a	Relative humidity of the intake air	%
R_d	Relative humidity of the dilution air	%
r_h	FID response factor	—
r_m	FID response factor for methanol	—
r_x	Ratio of the SSV throat to inlet absolute, static pressure	—

Symbol	Term	Unit
r_y	Ratio of the SSV throat diameter, *d*, to the inlet pipe inner diameter	—
ρ	Density	kg/m^3
S	Dynamometer setting	kW
T_a	Absolute temperature of the intake air	K
T_d	Absolute dewpoint temperature	K
T_{ref}	Absolute reference temperature (of combustion air: 298 K)	K
T_c	Absolute temperature of the intercooled air	K
T_{cref}	Absolute intercooled air reference temperature	K
V_m	Molar volume	L
W_f	Weighting factor	—
W_{fe}	Effective weighting factor	—

4.2 Symbols for fuel composition

w_{ALF} H content of fuel, % mass

w_{BET} C content of fuel, % mass

w_{GAM} S content of fuel, % mass

w_{DEL} N content of fuel, % mass

w_{EPS} O content of fuel, % mass

α molar ratio (H/C)

β molar ratio (C/C)

γ molar ratio (S/C)

δ molar ratio (N/C)

ε molar ratio (O/C)

NOTE The conversion between mass content and molar ratio is given in ISO 8178-1:2006, Formulae A.3 to A.12.

4.3 Symbols and abbreviations for the chemical components

ACN acetonitrile

C1 carbon 1 equivalent hydrocarbon

CH_4 methane

C_2H_6 ethane

C_3H_8 propane

CH_3OH methanol

CO carbon monoxide

CO_2 carbon dioxide

DNPH	dinitrophenyl hydrazine
DOP	dioctyl phthalate
HC	hydrocarbons
HCHO	formaldehyde
H_2O	water
NH_3	ammonia
NMHC	non-methane hydrocarbons
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
N_2O	dinitrogen oxide
O_2	oxygen
RME	rapeseed oil methylester
SO_2	sulfur dioxide
SO_3	sulfur trioxide

4.4 Abbreviations

CFV	critical flow venturi
CLD	chemiluminescent detector
CVS	constant volume sample
EP	exhaust pipe
ECS	electrochemical sensor
FID	flame ionization detector
FTIR	Fourier transform infrared analyser
GC	gas chromatograph
HCLD	heated chemiluminescent detector
HFID	heated flame ionization detector
HPLC	high-pressure liquid chromatograph
NDIR	non-dispersive infrared analyser
NMC	non-methane cutter
PDP	positive displacement pump
PMD	paramagnetic detector

PT particulates

RH relative humidity

UVD ultraviolet detector

ZRDO zirconium dioxide sensor

5 Test conditions

5.1 Engine test conditions

5.1.1 Test condition parameter

The absolute temperature, T_a, of the engine intake air expressed in Kelvin, and the dry atmospheric pressure, p_s, expressed in kilopascals shall be measured, and the parameter, f_a, shall be determined according to the following provisions.

a) Compression-ignition engines

Naturally aspirated and mechanically pressure-charged engines:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0,7} \quad (1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,5} \quad (2)$$

b) Spark-ignition engines

$$f_a = \left(\frac{99}{p_s}\right)^{1,2} \times \left(\frac{T_a}{298}\right)^{0,6} \quad (3)$$

NOTE Formulae (1) to (3) are identical with the exhaust emissions legislation from ECE, EEC, and EPA, but different from the ISO power correction formulae.

5.1.2 Test validity

For a test to be recognized as valid, the parameter, f_a, shall be such that:

$$0,93 < f_a < 1,07 \quad (4)$$

Tests should preferably be conducted with the parameter, f_a, between 0,96 and 1,06.

5.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared rated power and full load, within ±5 K of the maximum charge air temperature specified by the manufacturer. The temperature of the cooling medium shall be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature shall be set to within ±5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared rated power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle.