

ANNEX 5**IMO measurement protocol for Black Carbon determination****1. Engine design parameters (to be completed before measurement)**

1.1 Engine	Production year:	<u>2016</u>		
	Location:	<input checked="" type="checkbox"/> Testbed <input type="checkbox"/> Ship		
1.2 Engine freshly manufactured	<input checked="" type="checkbox"/> yes <input type="checkbox"/> no			
	If no: Documentation of relevant maintenance provided	<input type="checkbox"/> yes		
1.3 Engine total running hours	<u>100</u>	[h]		
1.4 Regular maintenance interval	<u>-</u>	[h]		
1.5 Hours since last regular maintenance	<u>-</u>	[h]		
1.6 Engine category	<input type="checkbox"/> 4-stroke <input checked="" type="checkbox"/> 2-stroke			
1.7 Engine fuel type	<input type="checkbox"/> Diesel <input type="checkbox"/> Gas <input checked="" type="checkbox"/> Dual fuel			
1.8 Engine max. rated power	<u>13450</u>	[kW]		
1.9 Mean effective pressure at rated power	<u>17.3</u>	[bar]		
1.10 Engine speed	<input checked="" type="checkbox"/> Less than 130 rpm <input type="checkbox"/> 130 or more but less than 2000 rpm <input type="checkbox"/> 2000 rpm or more			
1.11 Method of air aspiration	<input type="checkbox"/> Naturally aspirated <input checked="" type="checkbox"/> Pressure-charged single stage <input type="checkbox"/> Pressure-charged multi stage			
1.12 Injection system	<input type="checkbox"/> Conventional <input checked="" type="checkbox"/> Common rail			
1.13 Applicable emission limit	<input type="checkbox"/> IMO Tier I <input type="checkbox"/> IMO Tier II <input checked="" type="checkbox"/> IMO Tier III <input type="checkbox"/> Others: _____			
1.14 Applicable test cycle	<input type="checkbox"/> C1 <input type="checkbox"/> D2 <input type="checkbox"/> E2 <input checked="" type="checkbox"/> E3 <input type="checkbox"/> Others: _____			
<hr/>				
1.15.1 Specific lubrication oil consumption	SLOC:	<u>-</u>	[g/kWh]	
	Breaking-in period:	<input type="checkbox"/> finished <input type="checkbox"/> not finished		

☐ not applicable

1.15.2 Cylinder liner lubrication

☐ none

☒ yes, active at

☒ 100%

Feed rate:

18830

☒ 75%

Feed rate:

14405

☒ 50%

Feed rate:

9980

☒ 25%

Feed rate:

5733

☒ 10%

Feed rate:

2932

Breaking-in period:

☒ finished

☐ not finished

☐ not applicable

1.15.3 Inlet valve seat lubrication

☒ none

☐ yes, active at

☐ 100%

Feed rate:

☐ 75%

Feed rate:

☐ 50%

Feed rate:

☐ 25%

Feed rate:

☐ 10%

Feed rate:

1.16 Exhaust gas treatment device

☒ none

☐ yes

☐ SCR

☐ Scrubber

☐ EGR

☐ Water injection

☐ Others: _____

2. Fuel

2.1 Fuel in use

☐ ULSD

☐ DMX

☐ DMA

☐ DMZ

☐ DMB

☐ RMA

☐ RMB

☐ RMD

☐ RME

☐ RMG

☐ Other: _____

acc. standard: _____

☒ Natural Gas

☐ Other gases acc. IGF: _____

☐ Liquid to gas fuel ratio as certified at mode point:

100% _____

75% _____

50% _____

25% _____

10% _____

Fuel properties and composition (in use during testing)

2.2 Gas

Please fill in as far as possible
most important marked with *)

Property	Unit / Standard	Actual value
Methane number*)	[-] / DIN EN 16726	76.5
Lower calorific value*)	[MJ/kg] / ISO 6976	49.472
Higher calorific value	[MJ/kg] / ISO 6976	-
Wobbe Indices Ws / Wi	[MJ/m ³] / ISO 6976	-
Density*)	[kg/m ³] / ISO 6976	0.789

Methane*)	wt.-% [kg/kg] / ISO 6974 or DIN 51894	92.7
Ethane*)	wt.-% [kg/kg] / ISO 6974 or DIN 51894	4.87
Propane*)	wt.-% [kg/kg] / DIN 51894	1.55
Isobutane*)	wt.-% [kg/kg] / DIN 51894	0.34
N-Butane*)	wt.-% [kg/kg] / DIN 51894	0.39
Pentane	wt.-% [kg/kg] / DIN 51894	0.01/0.02
Hexane	wt.-% [kg/kg] / DIN 51894	0
Heptane	wt.-% [kg/kg] / DIN 51894	
Nitrogen	wt.-% [kg/kg] / ISO 6974	0.12
Sulfur*)	wt.-% [kg/kg] / ISO 6326-5	
Hydrogen sulfide	wt.-% [kg/kg] / ISO 8819	
Carbon dioxide	wt.-% [kg/kg] / ISO 6974	0
Hydrogen	wt.-% [kg/kg] / DIN 51894	
Others		

2.3 Liquid fuel

Please fill in as far as possible
most important marked with *)
mandatory **)

Property	Unit / Standard	Actual value
Kind of fuel	Grade / ISO 8217	DMX
Flash point*)	[°C] / ISO 2719	-
Viscosity @ 40/50°C **)	[mm ² /s] / ISO 3104	5.7
Density @ 15°C *)	[kg/m ³] / ISO 3675 or 12185	0.8966
Net calorific value (Hu) *)	[J/g] / DIN 51900	42.07
Sulfur content*)	ppm [mg/kg] / ISO 8754 or 14596	2200
Ash content*)	ppm [mg/kg] / ISO 6245	-
Water content*)	ppm [mg/kg] / ISO 3733	490
Carbon content*)	wt.-% [kg/kg] / ASTM D5291	87.76
Hydrogen content*)	wt.-% [kg/kg] / ASTM D5291	11.42
Nitrogen content*)	wt.-% [kg/kg] / DIN 51444	0.03
Oxygen content*)	wt.-% [kg/kg] / DIN 51732	0.57
Cetane index*)	ISO 4264	-
CCAI*)		-
FAME content*)	wt.-% [kg/kg] / EN 14078	-
Mono aromatic compounds*)	wt.-% [kg/kg] / EN 12916	-
Poly aromatic compounds*)	wt.-% [kg/kg] / EN 12916	
Di aromatic compounds	wt.-% [kg/kg] / EN 12916	
Tri aromatic compounds	wt.-% [kg/kg] / EN 12916	
Inorganic constituents (V)	ppm [mg/kg] / ISO 14597 or 8691	
Inorganic constituents (Ni)	ICP	
Carbon residues*)	wt.-% [kg/kg] / ASTM D4530	0.9
Others		

3. Lube oil properties and composition (in use during testing; Producers specification can be used

3.1 Circulation lubrication oil

Please fill in as far as possible

Property	Unit / Standard	Actual value
Lube oil	Brand / Type	SK Supermar AS
Grade	multi / mono	
BN	mg KOH/g / ISO 3771	7.36
Ash content	wt.-% [kg/kg] / ISO 6245	
Viscosity	[mm ² /s] / ASTM D7042	12.03
Sulfur content	wt.-% [kg/kg] / ISO 20884	

3.2 Cylinder oil

Property	Unit / Standard	Actual value
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Please fill in as far as possible

Please fill in if applicable

Lube oil	Brand / Type	Mobilgard 525
Grade	multi / mono	
BN	mg KOH/g / ISO 3771	24.7
Ash content	wt.-% [kg/kg] / ISO 6245	
Viscosity	[mm ² /s] / ASTM D7042	20.2
Sulfur content	wt.-% [kg/kg] / ISO 20884	

3.3 Valve seat lubrication oil

Please fill in as far as possible

Please fill in if applicable

Property	Unit / Standard	Actual value
Lube oil	Brand / Type	
Grade	multi / mono	
BN	mg KOH/g / ISO 3771	
Ash content	wt.-% [kg/kg] / ISO 6245	
Viscosity	[mm ² /s] / ASTM D7042	
Sulfur content	wt.-% [kg/kg] / ISO 20884	

4. Measurement equipment information (to be completed before measurement) and parameters

Measurement instrument

4.1 BC measurement instrument information

Make:

AVL

Model: 415S

4.2 Measurement principle

☐ LII

☒ FSN

☐ PAS

☐ MAAP

☐ Others: _____

4.3 Values reported as

☐ EC (thermal)

Protocol acc.: _____

☐ rBC

☐ eBC

☒ FSN

☐ Others: _____

4.4 Values reported in unit

- ☐ mg/m_n^3 (wet basis; act. O_2 -concentration)
☐ mg/m_n^3 (dry basis; act. O_2 -concentration)
☐ mg/m_n^3 (dry basis; Ref. O_2 -concentration)
☐ mg/kWh refer to 5.
☒ FSN
☐ mg/kg fuel refer to 5.
☐ Others: _____

H_2O -conc.: _____

O_2 -conc.: _____

4.5 Reference conditions

(only if 4.4 is referred to Norm-cubic meters [m_n^3])

Norm temperature: _____ [$^{\circ}\text{C}$]

Norm pressure: _____ [mbar]

4.6 Sampling time / -number

Sampling time of each measurement: _____ 18 [s]

If mean values are reported: Number of consecutive measurements at each mode point: _____ 3 [-]

Acc. manufacturer specification: ☒ yes ☐ no

4.7 BC instrument parameter

Temperature inside measuring cell: _____ 70 [$^{\circ}\text{C}$]

Pressure inside measuring cell: _____ ambient [mbar]

Wavelength(s) used: _____ 550 [nm]

Mass absorption cross section(s) used: _____ 2 [m^2/g]

Conversion equation(s) used: _____ -

Repeatability of the instrument used: $\leq 0.005 \text{ FSN} + 3\%$ of measured value

Reproducibility of the instrument used: $\leq 0.005 \text{ FSN} + 6\%$ of measured value

Acc. manufacturer specification: ☒ yes ☐ no

Other parameters which could influence the measured values:

Parameter / Correction	Unit

4.8 BC Instrument Calibration

Date of last calibration: _____ - _____ (dd.mm.yyyy)

Calibration procedure according manufacturer specification:

☐ yes ☐ no ☐ Others: _____

Calibration including zero point: ☐ yes ☐ no

Used medium for zero point calibration: _____

Used calibration standard: ☐ Synthetic flame soot

☐ Printex-U

☐ Graphite spark aerosol generator GfG soot

☐ Soot with inorganic coatings

☐ Soot without inorganic coatings

☐ Reflectance standards

☐ Others: _____

Remark: _____

Leakage test performed before or after calibration: ☐ yes ☐ no ☐ not applicable

4.9 Sample gas pre-treatment

Please fill in if applicable

Exhaust gas dilution: ☐ yes ☒ no

If yes, dilution ratio (1:x) _____ at mode point: _____

Dilution medium: ☐ Ambient air ☐ Exhaust gas
☐ Others: _____

Filtration of the dilution medium before dilution: ☐ yes

Temperature of the dilution medium: _____ [°C]

Temperature of the diluted exhaust gas: _____ [°C]

Evaporation tube ☐ yes ☒ no

Temperature _____ [°C] acc. manufacturer spec. ☐ yes

Catalytic stripper ☐ yes ☒ no

Temperature _____ [°C] acc. manufacturer spec. ☐ yes

Thermo-denuder ☐ yes ☒ no

Temperature _____ [°C] acc. manufacturer spec. ☐ yes

Others: _____

4.10 Sample flow rate/volume

Acc. manufacturer specification: ☒ yes ☐ no

Sample flow rate of the raw exhaust gas: _____ 10

Sample flow rate of the diluted exhaust gas: _____

Sample volume of the raw exhaust gas: _____

Sample volume of the diluted exhaust gas: _____

☐ subkinetic ☐ isokinetic ☐ superkinetic ☐ not applicable

Sample line and probe

4.11 Sample/transfer line

Please fill in if applicable

Use of a sample line: ☒ yes ☐ no (in situ,...)

Acc. manufacturer specification: ☒ yes ☐ no

Length of the sample line: _____ 7 [m]

Heated sample line: ☒ yes ☐ no Temperature: _____ 200

Sample line material: _____ Viton

Inner diameter of the sample line: _____ 4 [mm]

Isolated or heated connections between sample line, measurement instrument and probe: ☒ yes ☐ no

Electrical conductive (sample line material): ☐ yes ☒ no

Grounded: ☐ yes ☒ no

Grounding method: _____

Backflushing sample line between measurements: ☒ yes

4.12 Sample probe

Please fill in if applicable

Use of sample probe: ☒ yes ☐ no (in situ,...)

Acc. manufacturer specification: ☒ yes ☐ no

Material: ☒ Stainless steel ☐ Others: _____

Type/design:

☐ Probe with single hole at the end (pipe)

☒ Probe with single hole at the end (45° beveled)

☐ Multi-hole

☐ L-shaped pipe with single hole, opening shielded with preclassifier (e.g. hat)

☐ Others: _____

Direction of the probe opening relative to the exhaust gas flow:

☐ With flow ☒ Against flow

☐ Others: _____

Effective cross section of sample hole opening(s) _____ 17.8

Backflushing sample probe between measurements: ☒ yes

Sampling point and probe location

4.13 Sample point and probe location

☒ Engine Outlet

☐ Downstream of heat exchanger

☐ Downstream of exhaust gas treatment device

Treatment device active during measurement ☐ yes

☐ Others: _____

Distance between engine outlet and sampling point: approx. 8m

Diameter of the exhaust gas pipe: 1.54 [m]

Type of exhaust gas pipe where the sample probe is located:

☒ straight part of the exhaust gas pipe

☐ bent part of the exhaust gas pipe

Immersion depth of the sample probe: approx. 0.2m [m]

Orientation of the exhaust gas pipe where the sample probe is located:

☒ horizontal ☐ vertical ☐ Others: _____

Length of straight part of the exhaust gas pipe,
if sample probe is located at straight part of the exhaust gas pipe:

upstream sample probe: approx. 2m [m]

downstream sample probe: approx. 2m [m]

Exhaust gas pulsation at the sampling point during measurement:

☒ no ☐ yes _____ [mbar]

5. Determination of engine load, exhaust gas flow, exhaust water content, fuel mass flow, O₂ and (if applicable)

5.1 Determination of values, instrument performance and calibration shall be in accordance with the requirements of NO_x Technical Code 2008 (NTC 2008) and its applicable appendices

5.2.1 Method of load determination

Electrical WB Signal 4-20mA

5.2.2 Estimated accuracy of engine load determination

+/- 1 [%] of reading

5.3.1 Method of exhaust gas flow determination

Calculation

5.3.2 Estimated accuracy of exhaust gas flow determination

+/- 1 [%] of reading

5.4.1 Method of exhaust water content determination

Calculation

5.4.2 Estimated accuracy of exhaust water content determination

+/- 1 [%] of reading

5.5.1 Method of fuel mass flow determination

Endress & Hauser Promass F

5.5.2 Estimated accuracy of fuel mass flow determination

+/- < 1% [%] of reading

5.6.1 Method of O₂ and CO₂ determination

Horiba PG 250/350

5.6.2 Estimated accuracy of O₂ and CO₂ determination

+/- < 2 [%] of reading

6. Measured values for BC determination (to be completed during measurement; measured values)

Date of measurement (dd.mm.yyyy)	02/03/2016	02/03/2016	02/03/2016	02/03/2016	02/03/2016
Measurement at mode points:	100 ↓	90 ↓	75 ↓	50 ↓	25 ↓
6.1 Stabilized mode point					
Actual Speed	97.6	93.9	88.6	77	61.3
Speed variation during measuring	1	1	1	1	1
Actual Load	13516	12165	10134	6785	3374
Load variation during measuring	1	1	1	1	1
6.2 Charge air temperature	33.3	30.3	30.2	28	34.1
6.3 Charge air pressure	3408	3062	2412	1509	548
6.4 Exhaust gas temp. at engine outlet	199	192	199	208	227
6.5 Exh. gas temp. at sampling point					
(only if there is a significant difference to the exhaust gas temperature at the engine outlet)					
6.6 Exhaust gas back pressure	28.3	21.5	14.3	06-Jan	1.4
6.7 Exhaust gas mass flow	106648	100060	86013	63714	36048
Ambient conditions					
6.8 Ambient temp. at engine inlet	15	15	17	17	16
6.9 Ambient pressure at engine inlet	1024.6	1025	1022.6	1022.4	1022.3
6.10 Absolute humidity of ambient air	~3.0	~3.0	~3.0	~3.0	~3.0

Black Carbon

Reported as (see 4.3):

FSN

Unit (see 4.4): FSN

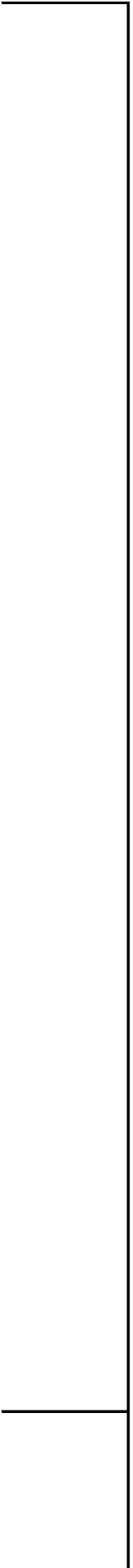
Estimated accuracy of BC-measurement

-	-	-	-	-
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Black Carbon Emission

0.003	0	0.002	0.002	0.002
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Remark: _____



[g/h]
[g/h]
[g/h]
[g/h]
[g/h]

[g/h]
[g/h]
[g/h]
[g/h]
[g/h]

☐ RMK

Remark
ISO 6976
-

ISO 6974
ISO 6974
ISO 6974
ISO 6974
ISO 6974
i-C5H12/n-C5H12
ISO 6974
ISO 6974
ISO 6974

Remark
ASTM D445
ASTM D4052
ASTM D4868
ASTM D4294
ASTM D6304
ASTM D5291
ASTM D5291
ASTM D5762
Calc.
ASTM D4530

l)

Remark
@100°C

Remark

@100°C
Remark

--

[Vol.-%] (wet)

[Vol.-%] (dry)

le

le

cable

[%]

☐ no

☐ no

☐ no

☐ no

[l/min]
[l/min]
[l]
[l]

[°C]

☒ no

☐ no

[mm^2]

☐ no

☐ no

[m]

$I \text{ CO}_2$

f

ps)

[%]

[rpm]
+/- [%]

[kW]
+/- [%]

[°C]

[mbar]

[°C]

[°C]

[mbar]

[kg/h]

[°C]

[mbar]

[g/kg]

+/- [%]

