

**ANNEX 3****IMO measurement protocol for Black Carbon determination****1. Engine design parameters (to be completed before measurement)**

<b>1.1 Engine</b>	Production year: <u>2016</u>
	Location: <input checked="" type="checkbox"/> Testbed <input type="checkbox"/> Ship
<b>1.2 Engine freshly manufactured</b>	<input checked="" type="checkbox"/> yes <input type="checkbox"/> no If no: Documentation of relevant maintenance provided <input type="checkbox"/> yes
<b>1.3 Engine total running hours</b>	<u>75</u> [h]
<b>1.4 Regular maintenance interval</b>	<u>-</u> [h]
<b>1.5 Hours since last regular maintenance</b>	<u>-</u> [h]
<b>1.6 Engine category</b>	<input type="checkbox"/> 4-stroke <input checked="" type="checkbox"/> 2-stroke
<b>1.7 Engine fuel type</b>	<input type="checkbox"/> Diesel <input type="checkbox"/> Gas <input checked="" type="checkbox"/> Dual fuel
<b>1.8 Engine max. rated power</b>	<u>13450</u> [kW]
<b>1.9 Mean effective pressure at rated power</b>	<u>17.3</u> [bar]
<b>1.10 Engine speed</b>	<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
<b>1.11 Method of air aspiration</b>	<input type="checkbox"/> Naturally aspirated <input checked="" type="checkbox"/> Pressure-charged single stage <input type="checkbox"/> Pressure-charged multi stage
<b>1.12 Injection system</b>	<input type="checkbox"/> Conventional <input checked="" type="checkbox"/> Common rail
<b>1.13 Applicable emission limit</b>	<input type="checkbox"/> IMO Tier I <input checked="" type="checkbox"/> IMO Tier II <input type="checkbox"/> IMO Tier III <input type="checkbox"/> Others: _____
<b>1.14 Applicable test cycle</b>	<input type="checkbox"/> C1 <input type="checkbox"/> D2 <input type="checkbox"/> E2 <input checked="" type="checkbox"/> E3 <input type="checkbox"/> Others: _____

### 1.15.1 Specific lubrication oil consumption

SLOC: N/A [g/kWh]

Breaking-in period:

- ☐ finished
- ☐ not finished
- ☐ not applicable

### 1.15.2 Cylinder liner lubrication

☐ none

☒ yes, active at

■ 100%	Feed rate:	<u>18830</u> [g/h]
■ 75%	Feed rate:	<u>14405</u> [g/h]
■ 50%	Feed rate:	<u>9980</u> [g/h]
■ 25%	Feed rate:	<u>5733</u> [g/h]
■ 10%	Feed rate:	<u>2932</u> [g/h]

Breaking-in period: ☒ finished  
☐ not finished  
☐ not applicable

### 1.15.3 Inlet valve seat lubrication

☒ none

☐ yes, active at

☐ 100%      Feed rate: \_\_\_\_\_ [g/h]  
☐ 75%        Feed rate: \_\_\_\_\_ [g/h]  
☐ 50%        Feed rate: \_\_\_\_\_ [g/h]  
☐ 25%        Feed rate: \_\_\_\_\_ [g/h]  
☐ 10%        Feed rate: \_\_\_\_\_ [g/h]

### 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    ☐ RMK

☐ 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	Remark
Methane number*)	[-] / DIN EN 16726	77	
Lower calorific value*)	[MJ/kg] / ISO 6976	49.3	
Higher calorific value	[MJ/kg] / ISO 6976	54.7	
Wobbe Indices Ws / Wi	[MJ/m <sup>3</sup> ] / ISO 6976	55.1622	
Density*)	[kg/m <sup>3</sup> ] / ISO 6976	0.78168	
Methane*)	wt.-% [kg/kg] / ISO 6974 or DIN 51894	85.26	
Ethane*)	wt.-% [kg/kg] / ISO 6974 or DIN 51894	8.05	
Propane*)	wt.-% [kg/kg] / DIN 51894	3.77	
Isobutane*)	wt.-% [kg/kg] / DIN 51894	1.28	
N-Butane*)	wt.-% [kg/kg] / DIN 51894	1.31	
Pentane	wt.-% [kg/kg] / DIN 51894	0.08/-	i-C5H12/n-C5H12
Hexane	wt.-% [kg/kg] / DIN 51894		
Heptane	wt.-% [kg/kg] / DIN 51894		
Nitrogen	wt.-% [kg/kg] / ISO 6974	0.24	
Sulfur*)	wt.-% [kg/kg] / ISO 6326-5		
Hydrogen sulfide	wt.-% [kg/kg] / ISO 8819		
Carbon dioxide	wt.-% [kg/kg] / ISO 6974		
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	Remark
Kind of fuel	Grade / ISO 8217	DMX	
Flash point*)	[°C] / ISO 2719		
Viscosity @ 40/50°C **)	[mm <sup>2</sup> /s] / ISO 3104	7.742	ASTM D445
Density @ 15°C *)	[kg/m <sup>3</sup> ] / ISO 3675 or 12185	900.9	ASTM D4052
Net calorific value (Hu) *)	[J/g] / DIN 51900	42056	ASTM D4868
Sulfur content*)	ppm [mg/kg] / ISO 8754 or 14596	2.4	ASTM D4294
Ash content*)	ppm [mg/kg] / ISO 6245	-	
Water content*)	ppm [mg/kg] / ISO 3733	190	ASTM D6304
Carbon content*)	wt.-% [kg/kg] / ASTM D5291	87.31	ASTM D5291
Hydrogen content*)	wt.-% [kg/kg] / ASTM D5291	11.83	ASTM D5291
Nitrogen content*)	wt.-% [kg/kg] / DIN 51444	0.06	ASTM D5762
Oxygen content*)	wt.-% [kg/kg] / DIN 51732	0.57	Calc.
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	1.55	ASTM D4530
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	Remark
Lube oil	Brand / Type	SK Supermar AS	
Grade	multi / mono		
BN	mg KOH/g / ISO 3771	7.48	
Ash content	wt.-% [kg/kg] / ISO 6245		
Viscosity	[mm <sup>2</sup> /s] / ASTM D7042	12.04	@100°C
Sulfur content	wt.-% [kg/kg] / ISO 20884		

#### 3.2 Cylinder oil Please fill in as far as possible Please fill in if applicable

Property	Unit / Standard	Actual value	Remark
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 <sup>2</sup> /s] / ASTM D7042	20.2	@100°C
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	Remark
Lube oil	Brand / Type		
Grade	multi / mono		
BN	mg KOH/g / ISO 3771		
Ash content	wt.-% [kg/kg] / ISO 6245		
Viscosity	[mm <sup>2</sup> /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: 415SE

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 ☐  $\text{mg}/\text{m}_n^3$  (wet basis; act.  $\text{O}_2$ -concentration)  $\text{H}_2\text{O}$ -conc.: \_\_\_\_\_ [Vol.-%] (wet)  
☐  $\text{mg}/\text{m}_n^3$  (dry basis; act.  $\text{O}_2$ -concentration)  
☐  $\text{mg}/\text{m}_n^3$  (dry basis; Ref.  $\text{O}_2$ -concentration)  $\text{O}_2$ -conc.: \_\_\_\_\_ [Vol.-%] (dry)  
☐  $\text{mg}/\text{kWh}$  refer to 5.  
☒ FSN  
☐  $\text{mg}/\text{kg}$  fuel refer to 5.  
☐ Others: \_\_\_\_\_

4.5 Reference conditions Norm temperature: \_\_\_\_\_ [°C]  
(only if 4.4 is referred to Norm-cubic meters [ $\text{m}_n^3$ ]) 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 [°C]  
Pressure inside measuring cell: ambient [mbar]  
Wavelength(s) used: 550 [nm]  
Mass absorption cross section(s) used: 2 [ $\text{m}^2/\text{g}$ ]  
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 ☐ no

Temperature of the dilution medium: \_\_\_\_\_ [°C]

Temperature of the diluted exhaust gas: \_\_\_\_\_ [°C]

Evaporation tube ☐ yes ☒ no  
Temperature \_\_\_\_\_ [°C] acc. manufacturer spec. ☐ yes ☐ no

Catalytic stripper ☐ yes ☒ no  
Temperature \_\_\_\_\_ [°C] acc. manufacturer spec. ☐ yes ☐ no

Thermo-denuder ☐ yes ☒ no  
Temperature \_\_\_\_\_ [°C] acc. manufacturer spec. ☐ yes ☐ no

Others: \_\_\_\_\_

#### 4.10 Sample flow rate/volume

Acc. manufacturer specification: ☒ yes ☐ no

Sample flow rate of the raw exhaust gas: \_\_\_\_\_ 10 [l/min]

Sample flow rate of the diluted exhaust gas: \_\_\_\_\_ [l/min]

Sample volume of the raw exhaust gas: \_\_\_\_\_ [l]

Sample volume of the diluted exhaust gas: \_\_\_\_\_ [l]

☐ 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: 70 [°C]

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 ☐ no

### 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 [mm<sup>2</sup>]

Backflushing sample probe between measurements: ☒ yes ☐ no

## 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 ☐ no

☐ Others: \_\_\_\_\_

Distance between engine outlet and sampling point: approx. 8.5 [m]

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. 0.2 [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. 2 [m]

downstream sample probe: approx. 2.5 [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, O<sub>2</sub> and CO<sub>2</sub> (if applicable)

5.1 Determination of values, instrument performance and calibration shall be in accordance with the requirements of

**NO<sub>x</sub> 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 O<sub>2</sub> and CO<sub>2</sub> determination**

Horiba PG 250/350

**5.6.2 Estimated accuracy of O<sub>2</sub> and CO<sub>2</sub> determination**

+/- <2 [%] of reading

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

Date of measurement (dd.mm.yyyy) 

01/07/2016	01/07/2016	01/07/2016	01/07/2016	
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Measurement at mode points: 

100	75	50	25	
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 [%]

↓ ↓ ↓ ↓

**6.1 Stabilized mode point**

Actual Speed 

97.4	88.5	77.5	61.5	
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 [rpm]

Speed variation during measuring 

N/A	N/A	N/A	N/A	
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 +/- [%]

Actual Load	13510	10200	6810	3415		[kW]
Load variation during measuring	N/A	N/A	N/A	N/A		+/- [%]

6.2 Charge air temperature	48	42	37	40		[°C]
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6.3 Charge air pressure	3840	2960	1850	770		[mbar]
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6.4 Exhaust gas temp. at engine outlet	252	215	209	204		[°C]
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6.5 Exh. gas temp. at sampling point						[°C]
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(only if there is a significant difference to the exhaust gas temperature at the engine outlet)

6.6 Exhaust gas back pressure	30	17	10	4.00		[mbar]
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6.7 Exhaust gas mass flow	113243	96894	72129	44307		[kg/h]
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### Ambient conditions

6.8 Ambient temp. at engine inlet	29.7	28.3	28.1	28.4		[°C]
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6.9 Ambient pressure at engine inlet	1008.3	1009.5	1010.2	1011.3		[mbar]
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6.10 Absolute humidity of ambient air	18.6	17.22	17.17	16.91		[g/kg]
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**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	0.016	0.02	0.016	0.024		
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Remark: \_\_\_\_\_