

**ANNEX 2****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>75</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: _____			

1.15.1 Specific lubrication oil consumption	SLOC:	<u>N/A</u>	[g/kWh]
	Breaking-in period:	<input type="checkbox"/> finished <input type="checkbox"/> not finished <input type="checkbox"/> not applicable	
1.15.2 Cylinder liner lubrication	<input type="checkbox"/> none <input checked="" type="checkbox"/> yes, active at	<input checked="" type="checkbox"/> 100% <input checked="" type="checkbox"/> 75% <input checked="" type="checkbox"/> 50% <input checked="" type="checkbox"/> 25% <input checked="" type="checkbox"/> 10%	Feed rate: <u>18830</u> [g/h] Feed rate: <u>14405</u> [g/h] Feed rate: <u>9980</u> [g/h] Feed rate: <u>5733</u> [g/h] Feed rate: <u>2932</u> [g/h]

**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]

Breaking-in period:

☒ finished  
☐ not finished  
☐ not applicable

**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		
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: 0.26 [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	01/07/2016
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Measurement at mode points: 

100	100	75	50	25
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 [%]  
↓ ↓ ↓ ↓ ↓**6.1 Stabilized mode point**Actual Speed 

97.3	97.4	88.4	77.6	61.5
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 [rpm]Speed variation during measuring 

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

13500	13510	10160	6810	3415
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 [kW]Load variation during measuring 

N/A	N/A	N/A	N/A	N/A
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 +/- [%]6.2 Charge air temperature 

46	46	41	34.5	39
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 [°C]6.3 Charge air pressure 

3420	3430	2410	1500	520
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 [mbar]6.4 Exhaust gas temp. at engine outlet 

226	229	212	212	229
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 [°C]6.5 Exh. gas temp. at sampling point 

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 [°C]

(only if there is a significant difference to the exhaust gas temperature at the engine outlet)

6.6 Exhaust gas back pressure 

26	26	13	9	4
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 [mbar]6.7 Exhaust gas mass flow 

103901	104710	84242	62305	35639
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 [kg/h]**Ambient conditions**6.8 Ambient temp. at engine inlet 

29.2	29.3	28.5	28.4	29.4
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 [°C]6.9 Ambient pressure at engine inlet 

1008.6	1008.3	1008.9	1010.5	1011
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 [mbar]6.10 Absolute humidity of ambient air 

18.13	17.71	17.54	17.15	17.23
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 [g/kg]**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**

0.023	0.023	0.005	0.002	0.047
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Remark: DMX fuel ratio at 100% load : 6.5%, 15%