Sustainable, safe and economically feasible energy concepts and technologies for European Inland Shipping

D5.10 Data collection and analysis of pilot case for on-board monitoring systems with after-treatment

Public report

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1 Introduction

This deliverable reports on the results of the on-board monitoring (OBM) mounted onto the Pilot vessel of SWP 5.3. In SWP 5.3 ‘Pilot standardized retrofit diesel after-treatment systems` an attempt on the standardisation of the emission after-treatment (EAT) system has been performed. The goal was to design two standardized systems. One of which the emissions have to be fully compliant with NRMM Stage V and one of which only the NOx emissions have to be below the required levels in NRMM Stage V. The resulting standard designs were installed on one pilot vessel. All public details of the installation and standardisation can be found in deliverable D5.9 ‘Data collection and analysis of pilot test case for standard after-treatment configurations’.

This deliverable reports the measurement results of the OBM system that was installed onto the vessel. This installation was the second part of task 5.3.1 ‘Installation of after-treatment system and on-board monitoring system on existing and new ships with after-treatment’, being the installation of an on-board monitoring system. The content of the task is identical to task 5.1.1 ‘On-board monitoring existing vessels’, but executed on the SWP 5.3 pilot vessel named Donau. The results provided in this document are presented in the same format as in the public deliverable D5.8 ‘Technical recommendations on options for specifications of monitoring equipment and database set-up’. It is recommended to read D5.8 as an introduction to this deliverable.

2 Description of measurement equipment

The installation of the on-board measuring system is identical to the Multronic installation carried out on the vessels participating in SWP 5.1. This setup and methodology has been discussed in detail in deliverable D5.1 'Completed On-Board Monitoring on existing innovative ships'. The key features are mentioned below.

A dedicated Multronic logger measures and logs all required inputs. The logger is connected to a number of analogue inputs, the vessel's CAN bus line and digital automotive sensors communicating over CAN bus. It measures/registers all required values and stores them internally. Simultaneously the values required for the OBM calculations are broadcasted to an Automatic vehicle location module. This module also hosts the GPS receiver and broadcasts position, vessel speed and emission parameters to a server. On the pilot vessel, there are 4 temperature sensors, two NOx sensors and one back pressure sensor connected to every Multronic logger. RPM, MAP and fuel consumption are broadcasted by the engine ECU. The data transmitted to the server has to be post processed in order to obtain the requested variables. Figure 1 illustrates the setup used by Multronic.

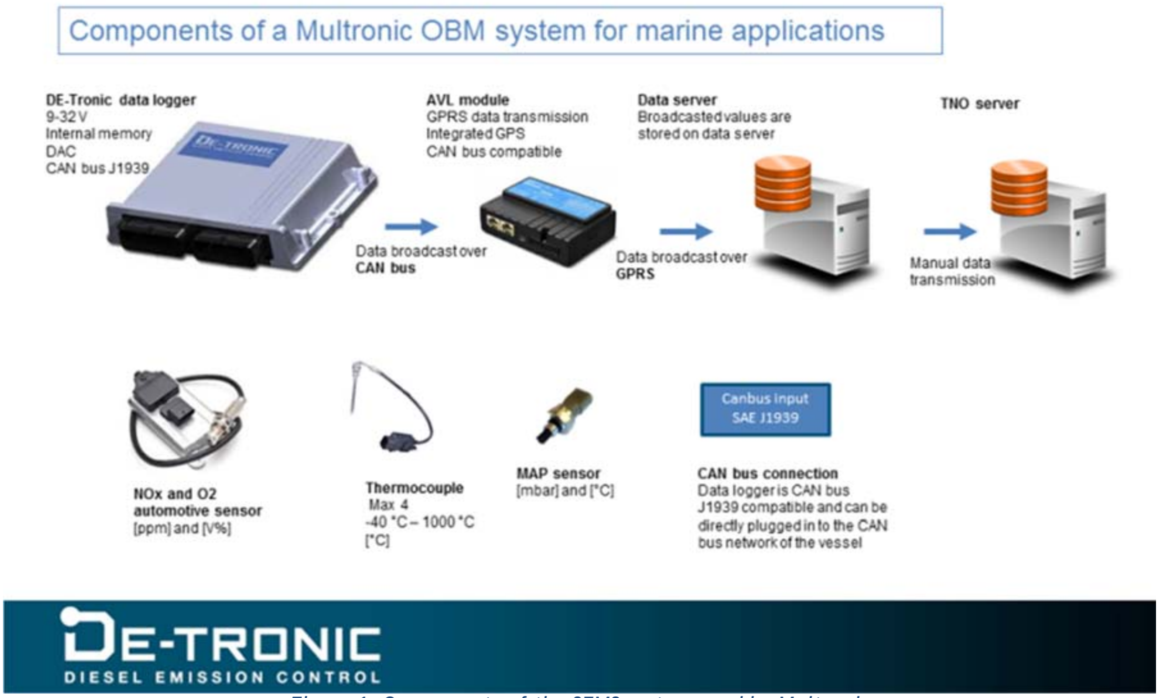


Figure 1: Components of the SEMS system used by Multronic

For every engine such a setup is required.

3 Telemetry development

During the execution of SWP 5.1 Multronic encountered a number of problems with the third-party server used by Multronic. Initially Multronic outsourced an automatic vehicle location (AVL) module. The product offered the possibly to transmit location, speed, RPM and 10 different CAN bus variables to the server of the subcontractor. During the course of the project the data stored on the server increased. The software to access the data on the server was not capable to download the larger data files, neither to access the data. (Figure 2 illustrates the software.) Despite a number of attempts, the partner company was not able to resolve these problems and Multronic was forced to develop an individual platform to perform OBM.

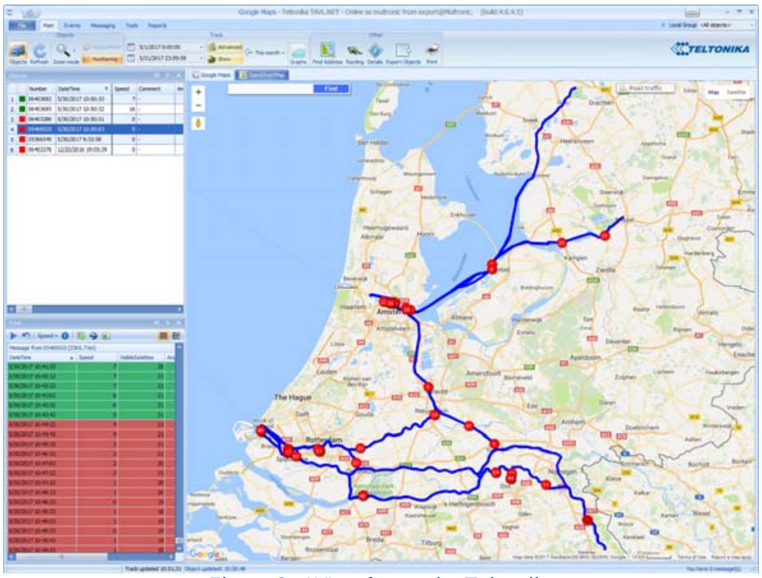


Figure 2: AVL software by Teltonika

With the platform developed by Multronic it is possible to forward a large range of CAN bus input to the server. A screenshot of the platform is given in Figure 3. This platform allows Multronic to transmit all variables available in the EAT system steering ECU. These are emission related parameters, but also all parameters related to the EAT system, such as AdBlue dosing rate, AdBlue level or diagnostic messages. Basic operations such as averages, minimum and maximum of the different parameters can be evaluated over different time periods. This allows the end-user to have a rapid judgement of the emissions and emission reductions.

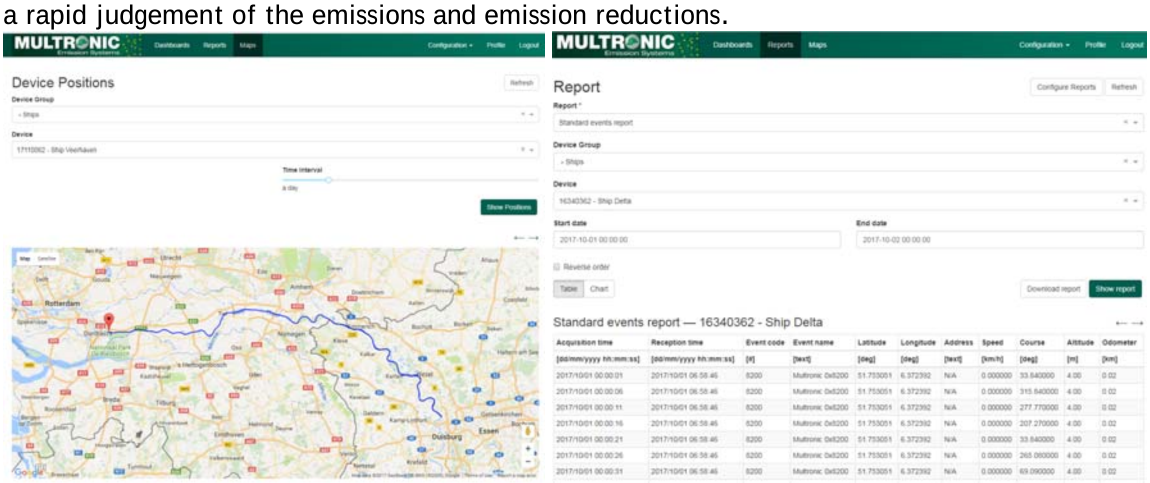
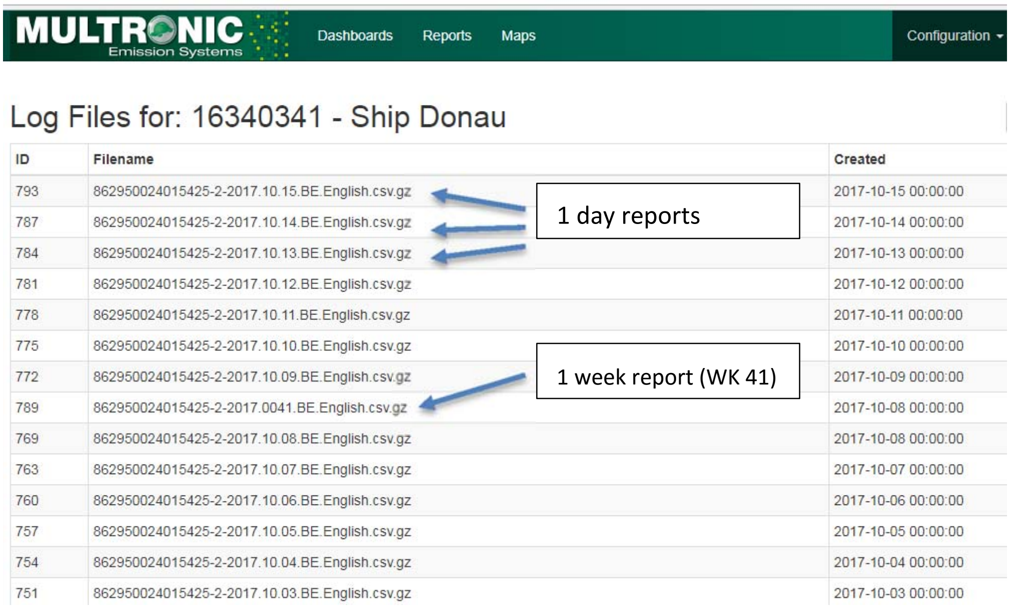


Figure 3: A look into the Multronic AVL environment

The data broadcasted to the server can be downloaded with a manual procedure or emailed to the end-user. These data reports are made on the server with fixed intervals: Daily, weekly and monthly. This resolves the issues that occur when larger reports are requested by the server on demand.



Log Files for: 16340341 - Ship Donau

ID	Filename	Created
793	862950024015425-2-2017.10.15.BE.English.csv.gz	2017-10-15 00:00:00
787	862950024015425-2-2017.10.14.BE.English.csv.gz	2017-10-14 00:00:00
784	862950024015425-2-2017.10.13.BE.English.csv.gz	2017-10-13 00:00:00
781	862950024015425-2-2017.10.12.BE.English.csv.gz	2017-10-12 00:00:00
778	862950024015425-2-2017.10.11.BE.English.csv.gz	2017-10-11 00:00:00
775	862950024015425-2-2017.10.10.BE.English.csv.gz	2017-10-10 00:00:00
772	862950024015425-2-2017.10.09.BE.English.csv.gz	2017-10-09 00:00:00
789	862950024015425-2-2017.0041.BE.English.csv.gz	2017-10-08 00:00:00
769	862950024015425-2-2017.10.08.BE.English.csv.gz	2017-10-08 00:00:00
763	862950024015425-2-2017.10.07.BE.English.csv.gz	2017-10-07 00:00:00
760	862950024015425-2-2017.10.06.BE.English.csv.gz	2017-10-06 00:00:00
757	862950024015425-2-2017.10.05.BE.English.csv.gz	2017-10-05 00:00:00
754	862950024015425-2-2017.10.04.BE.English.csv.gz	2017-10-04 00:00:00
751	862950024015425-2-2017.10.03.BE.English.csv.gz	2017-10-03 00:00:00

Figure 4: automatically generated daily, weekly and monthly reports

During the test phase both AVL devices were installed on the pilot vessel. After validation of the Multronic device, the device from the subcontractor was abandoned.
The data processing to obtain the figures according to the format described in Deliverable D5.8 has been done in MatLab. The development of automated broadcast to the TNO server was omitted. This development would have been too time-consuming and therefore considered beyond the scope of PROMINENT.

4 Vessel details

Ship	Donau
ENI	06105358
MMSI	205227090
Loa	22.54 m
B	10.04 m
T	2.35 m
Load capacity	74 ton
Build year hull	09/2012
Cargo type	Dry cargo / tanker barge push boat
Area of operations	FARAG / Rhein
Main engine	2x Caterpillar 3512
Build year main engine	2012 (CCR 2) Equipped with EAT system Starboard site: emissions are compliant with Stage V NRMM Port side: NOx emissions are compliant with Stage V NRMM
Max power main engine	746 kW @ 1600 rpm
Gear box	Masson 4400
Gear box ratio	5.077/1
Type of propeller	Combination propeller Caplan, ducted
Diameter of propeller	1700 mm
Number of blades	4
Generators	John Deere 4 cyl / 65 kVA Water cooled Hatz 4 cyl Silent pack 35 kVA Air cooled Axle generator on BB engine 65 kW
Build year generators	2012
Output generators	65 kW 35 kW
Bow thrusters	1x 1200 mm channel
Power bow thrusters	540 hp DAF
Unique features	CCNR2 Specially attention given to design of underwater hull Spoilers mounted behind propeller Giesen straalbuizen 1712 mm

	Engine heat recuperation for heating Heavy battery pack used overnight. 24h autonomy Only LED lightning Auxiliary deck equipment is driven hydraulically directly from the main engine
Measurements by	Multronic
OBM since	February 2017
URL	
Other features	

5 Factsheet per exhaust line

In this section the processed data recorded by the OBM system is given. Deliverable 5.7 reports in full extend on the specifications of the applied OBM technique. The figures and measurements described below are introduced and analysed in full extend in deliverable 5.7.
An introduction on the generated figures is given, followed by the results for the two EAT systems on the pilot vessel. A short conclusion of the measurements is presented.

5.1 Explanation of figures in factsheets

Vessel specifications

For each factsheet a table with the following specifications is given:

- **ID**: vessel ID and type of vessel;
- **Build year**: build year of the main engine(s);
- **Power**: brake power per main engine;
- **Num. engines**: number of main engines;
- **Brand and type**: brand and type of the main engine(s);
- **Features**: emission class of the main engine(s) and, if present, the after treatment system;
- **Area**: sailing area;
- **DWT**: maximum load capacity;
- **Modelled**: the parameters which were modelled instead of measured;
- **Hours**: monitored hours.

Exhaust temperature

The temperature is available differently for the different project partners. The fact sheet contains a histogram of the percentage of time that the exhaust temperature was in a range of 15 degrees width. Here we report the exhaust temperature (after the turbo), which is at disposal for a possible SCR installation. Often also the engine-out temperature is available, which is measured before the turbo. These temperatures differ significantly due to the pressure drop across the turbo.

Speed Over Ground (SOG) with NOx emissions in g/km

Vessel speed is reported relative to the land, in percentage of time. The bins have a width of 1 km/h. The average NOx in g/km is added for every speed. This calculation has been done for 'NOx engine-out' and for 'NOx EAT out'.
A second figure which gives the distribution of the effective NOx emissions over the different SOG bins, together with the NOx in g/km for every SOG. The left axis gives the emissions as a percentage of the total engine-out emissions. In blue the normalized distribution of the effective engine-out is given and in green the NOx emissions after the EAT system is given. This graph illustrate at which speeds the effective NOx emissions are produced and how far they are reduced by the EAT system.

Fuel consumption per hour

Fuel consumption per hour is obtained from the engine management. The figure is strongly related with the relative power distribution by the engine efficiency.

In the figure of the relative power distribution, the effective NOx in g/kWh is added. The results at high relative power do not correspond with the reality. They arise due to time lag and sparks in the exhaust system. The pilot vessel is not capable of running at full engine power, because the propellers have been under dimensioned. As a result a number of sparks in the power measurement give unrealistic values at loads where the data points are limited.

Specific NOx and relative power

NOx is measured on the vessels monitored by TNO and Multronic. The value of NOx represents the power bin averaged value. Values above 100% occur, note that these will likely 1-5% overshooting of the 100% limit.

Brake power is estimated from the fuel consumption. Relative power is plotted against the left axis. The NOx emissions measured by the NOx sensors are displayed by the blue curves: the solid curve gives the engine-out emissions and the dashed curve gives the EAT system out emissions. This figure helps to evaluate the real live effectiveness of the EAT system.

Again, a figure giving the distribution of the effective emissions is given. The percentage on the left axis, is the percentage of the emissions relative to the total engine-out emissions. Blue represents the relative emissions emitted by the engine at the specified engine power, where green gives the effectively emitted emissions by after the EAT system. This figure gives good insight in how NOx emissions are generated. It allows comparing the difference between the time distribution of the engine power and the emitted NOx distribution of the engine power.

Map

A map of the sailing track of the ship is included.

5.2 Pilot ship: SCR+DPF EAT system

ID	Donau - Push boat
Build year	09/2012
Power	746 kW @ 1600 rpm
Num. engines	2
Brand	Caterpillar
Type	3512
Features	SCR+DPF system: designed to comply with Stage V NRMM,
Area	FARAG / Rhein
DWT	-
Modelled	-
Hours	464
Note's	Monitoring period does not correspond with monitoring period of SCR-only system

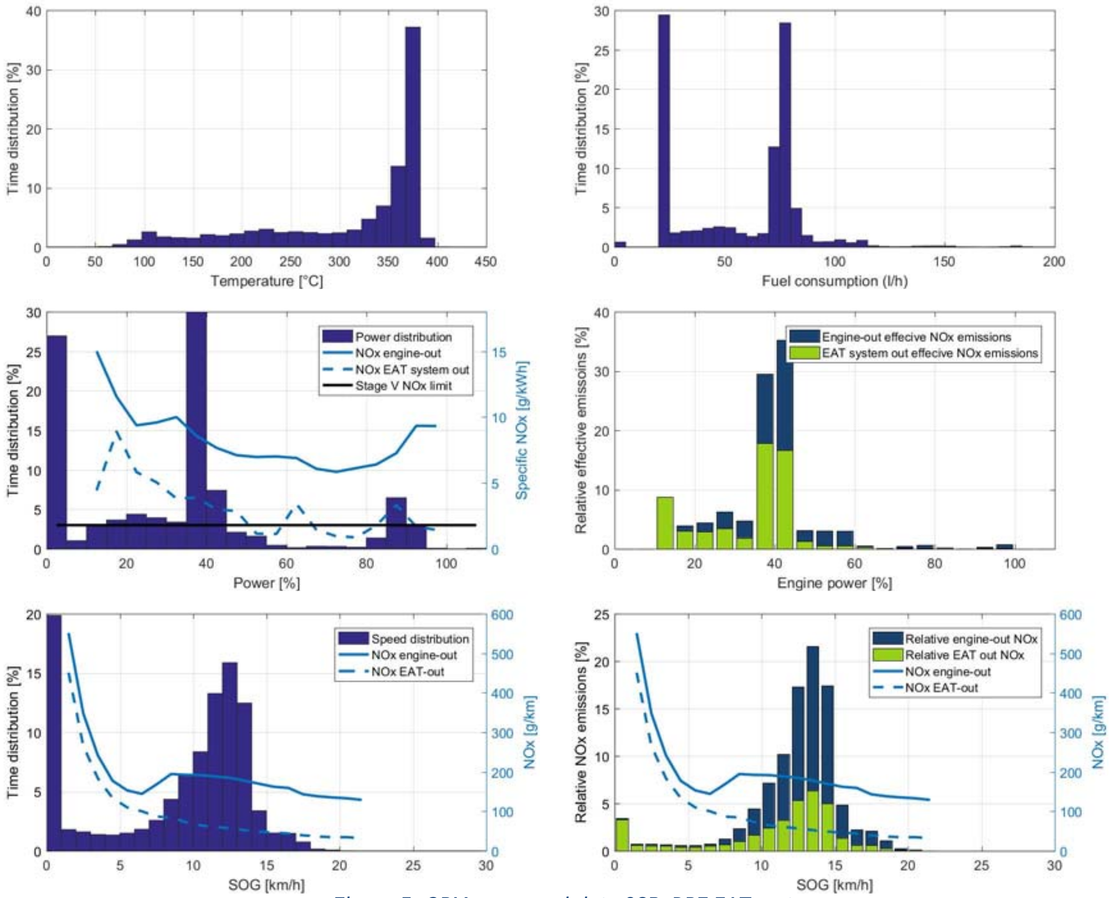


Figure 5: OBM processed data SCR+DPF EAT system

Figure 6: Operation area of the Donau

Comments:
The temperature profile shows that the operational temperature window of the engine is very narrow. The engine operates around 50% of the time in the 355 °C – 385 °C window. This window is optimal for NOx reduction. The lower temperatures are broadly scattered. These temperatures are recorded during idle and engine start-up and cool down. The time distribution of the fuel consumption and power are related by the propeller curve of the engine. It is logic that low power demand's (<25%), have high specific emissions [g/kWh].
When comparing the specific emissions to the effective emissions, it becomes clear that the emissions at these low power demands are significant contributors, but still about 6 to 7 times lower than the emissions produced in the sailing points of the load distribution. In this area effective NOx reduction are possible, as was illustrated in the E3 cycle.

The effective NOx emissions recorded by the OBM system are higher than the emission values measured in the ISO 8178 E3 cycle measurement. During the E3 cycle a score of 0.8 g/kWh was obtained for the SCR+DPF system. This is the result of a number of combined effects. The first one is the nature of the E3 cycle. In this cycle the engine is run for 10 minutes at a fixed load point and the last 3 minutes are used to calculate the average emissions. As a result, the temperature and NOx emissions are stable and high efficiency is obtained. In real life, the efficiency decreases because the exhaust has to warm up before the efficiency is optimal. Secondly, the NOx sensors are cross sensitive for NH3 and their reading is higher than the effective NOx emissions. The position of the NOx sensors and the mixing of the exhaust gasses are of critical importance in order to achieve high accuracy on readings of the NOx sensors. These effects are described in detail in deliverable 5.7. A difference of up to 20% between the OBM NOx sensors and the PEMS test equipment was recorded.

When comparing the time distribution of the SOG whit the effective NOx emitted at these speeds, similar conclusions can be drown. At higher speed most NOx is emitted by the engine and effective NOx reduction takes place. At lower speed, a lot of time is spent, but the effective emissions are a lot lower. NOx emission reduction at this mode is not possible.

5.3 Pilot ship: SCR-only system

ID	Donau - Push boat
Build year	09/2012
Power	746 kW @ 1600 rpm
Num. engines	2
Brand	Caterpillar
Type	3512
Features	SCR-Only system: NOx emissions are compliant with Stage V NRMM
Area	FARAG / Rhein
DWT	-
Modelled	-
Hours	762
Note's	GPS data is missing Monitoring period does not correspond with monitoring period of DPF+SCR system

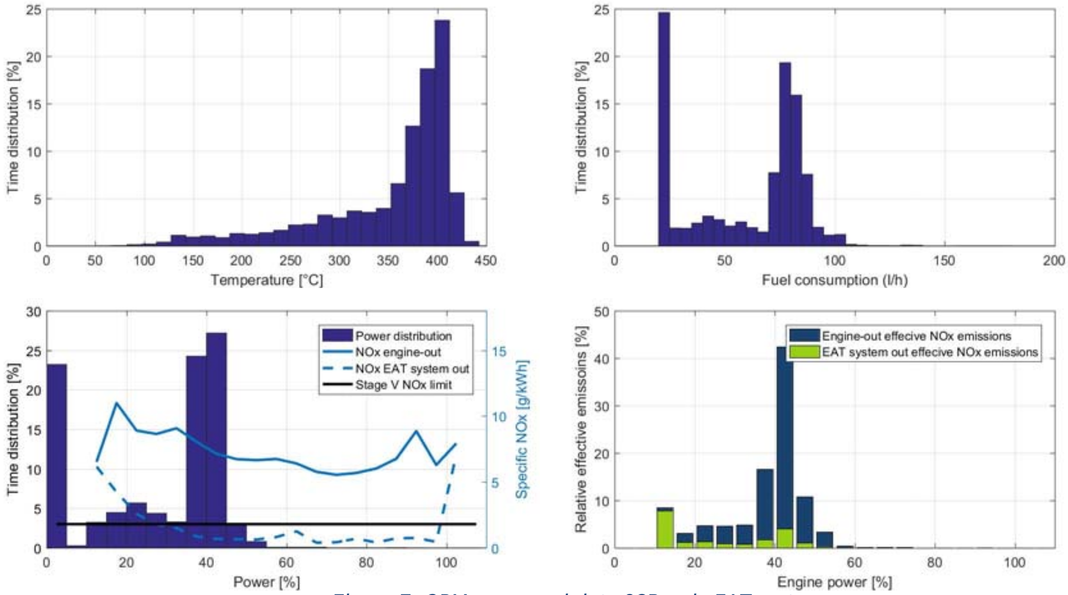


Figure 7: OBM processed data SCR-only EAT system

Comments:

The operational temperature profile and fuel consumption of this system are almost identical to that of the SCR+DPF system, as was expected.

NOx emissions are slightly higher than what would be expected from the results of the ISO 8178 E3 cycle measurement, where a score of 0.4 g/kWh was obtained. Compared to the SCR+DPF system the discrepancy with the E3 cycle is a lot smaller. This difference occurs because the NOx sensor is placed at a different location. When evaluating the effective emissions it becomes apparent within the sailing spectrum of the engine power, the emissions are reduced very effectively. The only emissions which remain are those emitted when the ship is not sailing, but in idle. These graphs give good insights in the potential for the reduction of NOx emissions and in the effective reductions.

6 Conclusions

Both engines of the pilot vessel have been equipped with OBM systems.

Due to a number of problems with the initial AVL device, Multronic was forced to develop a custom AVL application and corresponding hardware. Both developments have been executed successfully, allowing Multronic to finish the required monitoring period.

The recordings of the OBM were processed and published in section 0 of this report. The evaluation of the results was done in correspondence with the results published in deliverable 5.7, which reports on OBM on other pilot vessels within the PROMINENT project.

A number of additional figures were included, illustrating the difference between the time distribution of power demand and SOG and the effective emissions at these points. From the results in section 0 it can be concluded that the OBM monitoring is very effective in providing insights in the sailing emissions of a vessel. A comparison between the effective tailpipe emissions and the ISO 8178 E3-cycle was done to shortly indicate some of the root causes of the differences. The OBM can on one hand be used to check the real life performance of an EAT system. On the other hand, the data can be used to identify how emissions can further be improved.

Within this sub-workpackage, Multronic illustrated the feasibility of an on-board monitoring system and applied it on a pilot vessel which was equipped with a standardized emission after-treatment system developed within PROMINENT.