Marine Advanced Retrofit System

Deliverable 3 - Baseline Raw Emissions on test bed and comparison of Measurements on the Vessel

for:

New Technology Research and Development Program

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Submitted by:

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Table of Abbreviations

DOC – Diesel oxidation catalyst
DPF – Diesel particulate filter
SCR – Selective catalytic reduction
NH_3 – Ammonia
PM – Particulate matter
NMHC - non-methane hydrocarbon
HC – Hydrocarbon
CO – Carbon monoxide
NO_x – Nitrogen oxides
DCU – Dosing control unit
DEF – Diesel exhaust fluid

Greek Letters

γ -- Flow uniformity index

Abstract / Executive Summary

This report describes the third deliverable of the Marine Advanced Retrofit System (MARS) project funded by the TCEQ. According to the initial project plan, in the first task of the second phase of this development a marine aftertreatment system has been built and the test engine has been installed on the test bench.

The main focus in this report is baseline testing of the procured marine diesel engine (Cummins KTA19-M3) which is the same engine as in the selected vessel in Port of Houston. This task describes the engine sensors, boundary conditions, and the raw emissions of this engine. Furthermore, a comparison of the measured data on the vessel with the portable emission measurement devices will be evaluated.

Introduction/Background

The goal of this project is to develop a diesel emission reduction aftertreatment retrofit system that includes both a selective catalytic reduction (SCR) and a diesel particulate filter (DPF) for diesel-powered harbor crafts. This SCR-DPF aftertreatment retrofit system is particularly important for vessels operating within the United States Environmental Protection Agency's (US-EPA) National Ambient Air Quality Standards non-attainment areas such as those within the state of Texas, including the Port of Houston. The proposed retrofit system has the potential to reduce nitrogen oxides (NO_x) and particulate matter (PM) by 75% and 90%, respectively; i.e. it would reduce the emissions on US-EPA Tier 0 and 2 (current regulation) engines down to Tier 2 and Tier 4 engine levels, respectively.

This stand-alone retrofit system will be not only applicable to newer, electronically controlled engines, but also to older, mechanically governed ones (i.e. Tier 1 and earlier). This is significant since these older and higher emitting engines may still have considerable remaining useful lifetime and their replacement is neither desirable nor cost-effective. This retrofit system would provide a cost-effective solution at around $25,000 installed cost for engines up to 500 kilowatts (680 horsepower) which is significantly lower than current retrofit and repower options. It is planned to verify this aftertreatment technology before the start of its production and distribution, anticipated to take place in 2012.

Project Objectives/Technical Approach

Phase 1 includes identifying a harbor vessel for which the SCR-DPF system is to be designed, followed by measuring its engine baseline emissions. These measurements are needed for the proper design of the aftertreatment system, selection of the catalysts, computational fluid dynamics (CFD) analysis of the component and system performance, and for selecting an engine for dynamometer testing in later phases, amongst others. Also, in Phase 1 advanced engineering models and simulation tools such as CFD and one dimensional models are used to achieve appropriate system design.

Phase 2 will include developmental testing and analysis performed in an engine dynamometer lab where the following regulated emissions will be measured: NO_x, PM, total hydrocarbons (THC), non-methane hydrocarbon (NMHC), carbon monoxide (CO), and carbon dioxide (CO_2). The exhaust gas temperature will be measured before the particulate filter to ensure a proper passive regeneration temperature profile, maintaining with this the proper operation of the diesel soot filter.

In Phase 3, a prototype SCR-DPF aftertreatment system will be installed on the vessel and in-situ measurement of the conversion efficiency will be made. Testing will be completed according to the acceptable industry standards.

Tasks

Phase 2: Task 1 - System Installation and Baseline Measurements

From the Grant Activities (Scope of Work):

> *Task 3: Build System and Laboratory Baseline Emissions Measurements*
>
> *2.3. Task Statement: The PERFORMING PARTY will procure and build the retrofit aftertreatment system, procure and install a comparable marine engine for laboratory testing, and complete baseline emissions testing on the laboratory test engine.*
>
> *2.3.1. The PERFORMING PARTY will procure all components of the aftertreatment retrofit system including the DPF, DOC, SCR catalyst, SCR supply module, SCR dosing module, SCR control unit, sensors, and exhaust pipes. The PERFORMING PARTY will assemble these components into a complete retrofit device.*
>
> *2.3.2. The PERFORMING PARTY will select and purchase a marine engine with an identical marine emissions rating, a similar displacement, and a similar exhaust flow rate to the test engine in the field marine vessel. The PERFORMING PARTY will install the laboratory test engine on the engine test bed.*
>
> *2.3.3. The PERFORMING PARTY will instrument the laboratory test bed engine for test bed measurements and emissions measurement, including PM, NOx, CO, and HC measurements. The PERFORMING PARTY will collect baseline raw emissions measurements from the laboratory test bed engine and compare these baseline test results with the baseline marine vessel data.*
>
> *2.3.4. Schedule: The PERFORMING PARTY shall complete this task within 7 months of the signed Notice to Proceed Date as issued by TCEQ.*
>
> *2.3.5. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to evidence, including pictures, of the constructed aftertreatment retrofit, installation of laboratory test engine, laboratory test bed baseline raw emissions data, and comparison of raw baseline emissions between the test bed engine and the actual marine vessel engine.*

Based on Task 3 of the contract Scope of Work the following basic subtasks were required to be completed:

1.1 Procurement of aftertreatment components

1.2 Engine selection

1.3 Installation of test engine without aftertreatment system

1.4 Baseline raw emissions without aftertreatment system

Phase 2: Task 1.1 – Procurement of aftertreatment components

The after treatment system consist of many parts as described in the deliverable report for Task 2. Most of these parts are procured from several suppliers, for instance the catalyst or particulate filter.

Phase 2: Task 1.2 – Engine selection

Based on the engine of the selected test vessel in Houston, we used a Cummins KTA19-M3 diesel engine for emission and calibration work on the test bench. This engine is a mechanically governed one with 600 horsepower and was rebuilt in 2006 (Figure 1).

Figure 1. Test engine on the sellers test bed

Before the engine was purchased from the engine seller, internal testing was conducted to compare the torque and power curve to the Cummins' specification. In Figure 2 the comparison of three different measurements and one advertised power curve from Cummins (red) are shown. The first (black) and second (green) curve illustrate a wrong fuel pump calibration, which was finally recalibrated by a Cummins technician (blue curve).

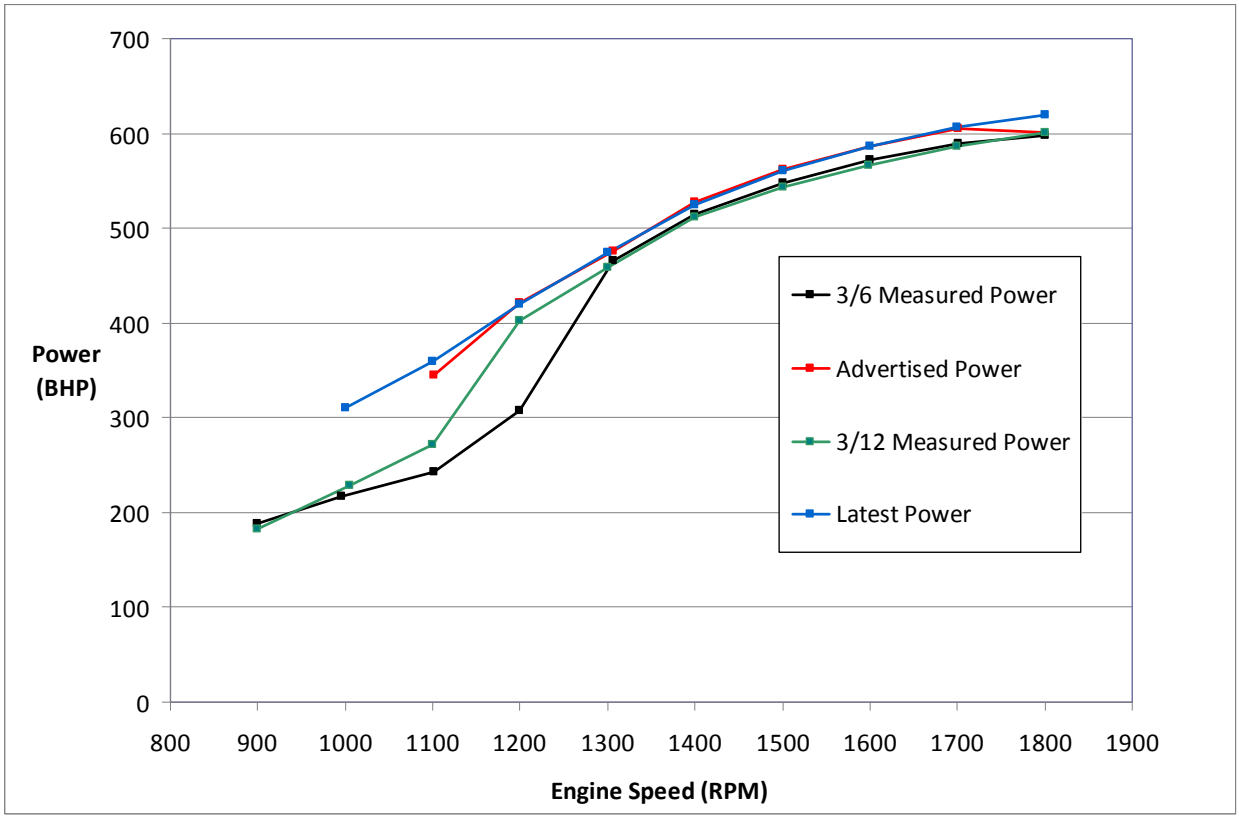

Figure 2. Comparison of power curve measured at engine dealer facilities

Phase 2: Task 1.3 – Installation of test engine without aftertreatment system

The engine was shipped from the seller facilities to the test bench where the complete aftertreatment calibration will be conducted.

Figures 3 and 4 illustrate the installed sensors to monitor the engine status during the testing with and without the aftertreatment system.

No	Type	Description
1	T, P	Compressor Inlet
2	T, P	Intake manifold
3	T, P	Engine coolant out
4	T, P	Engine coolant in
5	T, P	Turbo Out
6	T, P	Exhaust Manifold
7	T, P	Fuel return
8	P	Fuel rail pressure
9	T, P	Oil Gallery
10	T	Oil Sump
11	T, P	Boost Temp and Press Sensor
12	T	Coolant Tempertaure Sensor

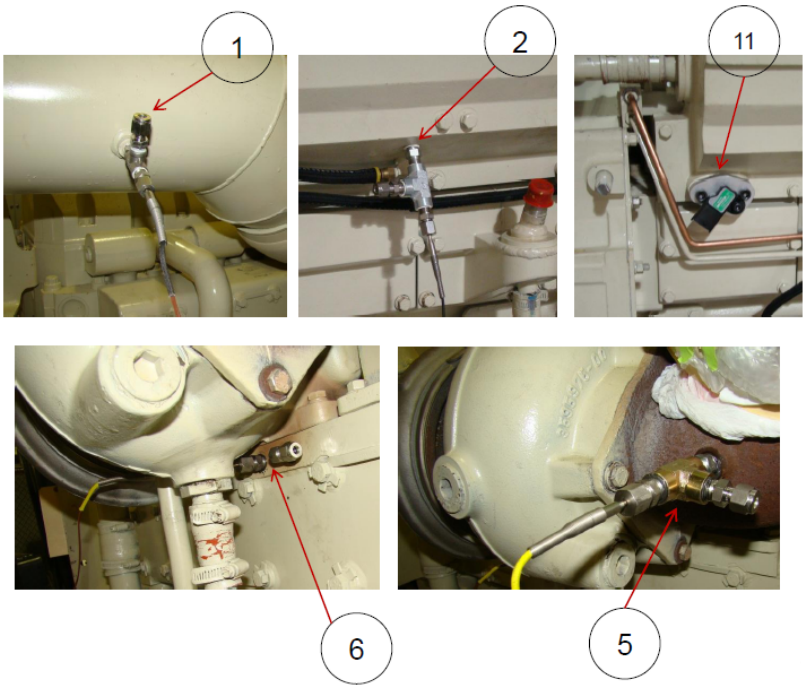

Figure 3. Engine sensors installation on test bench: Part 1

No	Type	Description
1	T, P	Compressor Inlet
2	T, P	Intake manifold
3	T, P	Engine coolant out
4	T, P	Engine coolant in
5	T, P	Turbo Out
6	T, P	Exhaust Manifold
7	T, P	Fuel return
8	P	Fuel rail pressure
9	T, P	Oil Gallery
10	T	Oil Sump
11	T, P	Boost Temp and Press Sensor
12	T	Coolant Tempertaure Sensor

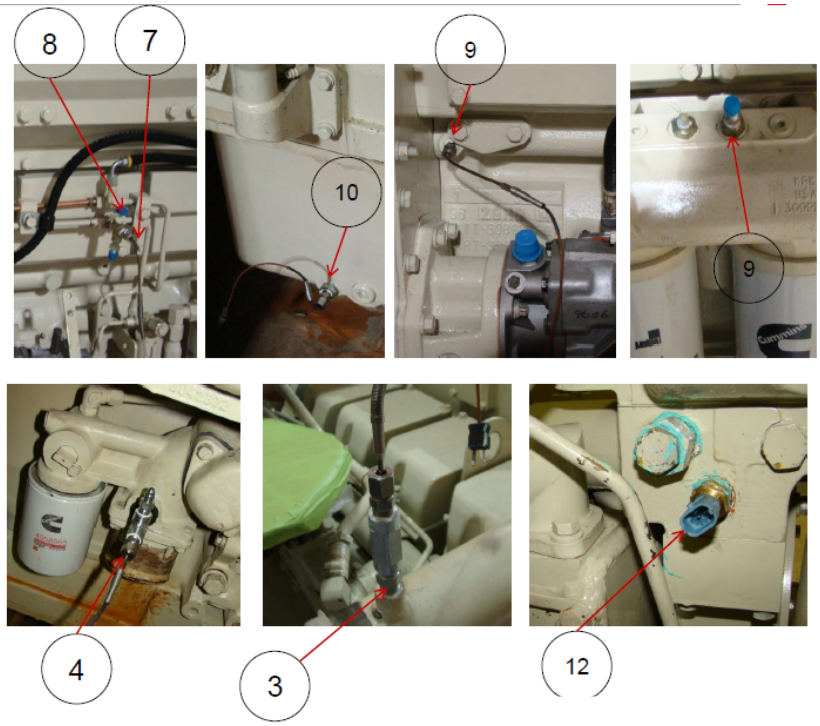

Figure 4. Engine sensors installation on test bench: Part 2

Phase 2: Task 1.4 – Baseline raw emissions without aftertreatment system

As a first step, we verified power, torque, and fuel curve at full throttle and propeller law conditions to ensure the correct settings for the engine will be used. These parameters are compared with the Cummins declared data, as shown in Figure 5. Excepting the fuel flow rate at full load operation, both curves correlate very well with the data given from Cummins' specification. The fuel offset is about 4%, however it does not affect the full load curve.

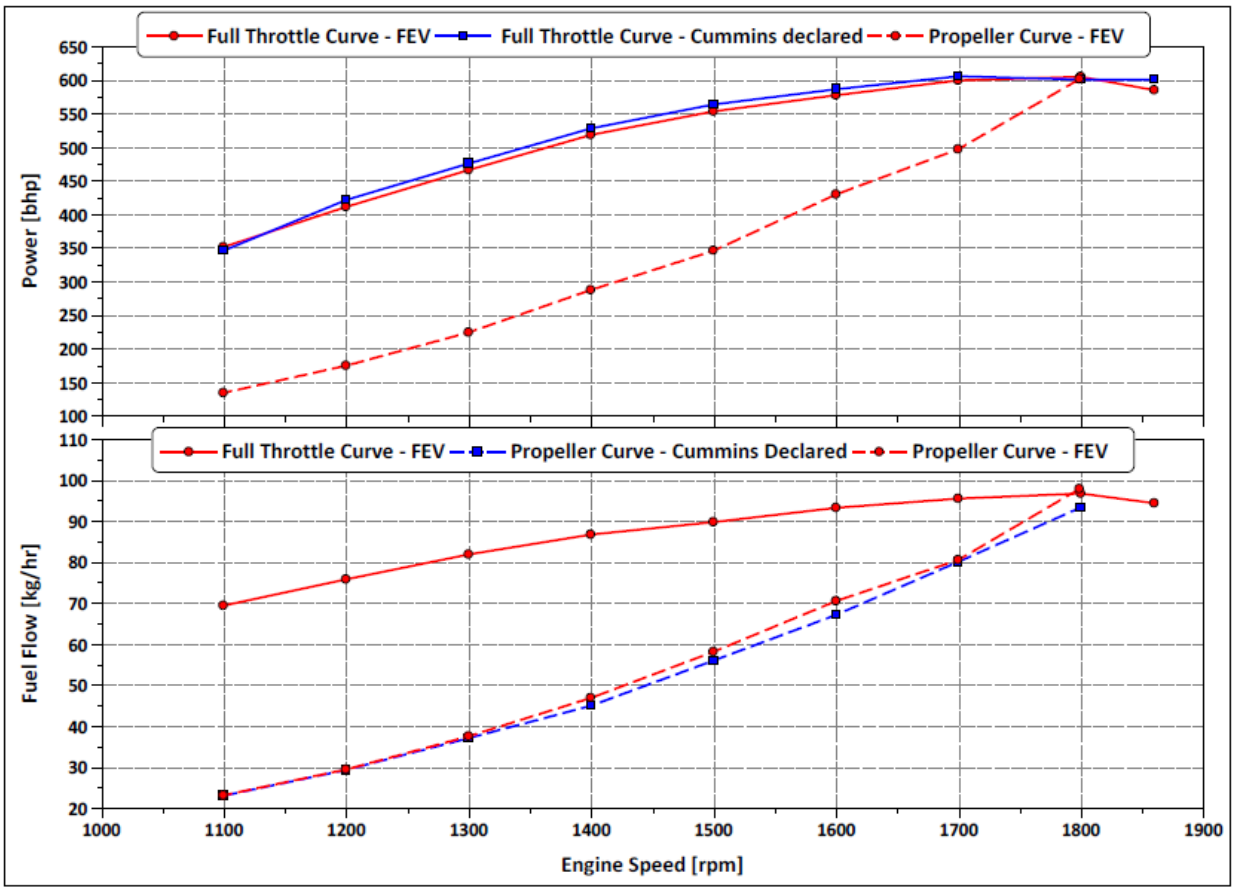

Figure 5. Power and fuel curve comparison

Figure 6 shows the E3 cycle according to ISO 8178-4 for determining the emission for marine applications. It consists of four modes and needs to be preconditioned at rated point as per specification ISO 8178-1.

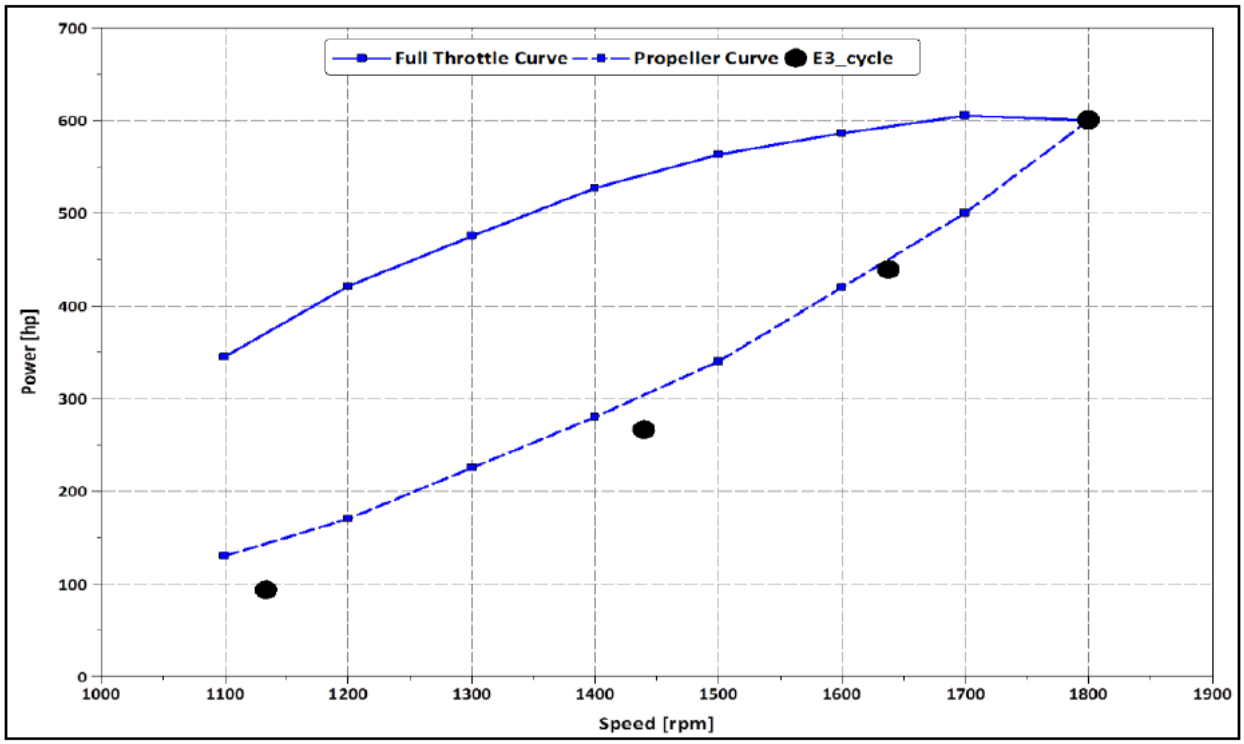

Figure 6. E-3 Cycle according ISO 8178

The following table compares engine out emissions data from the procured KTA19-M3 engine to the Cummins emission data for E3 cycle based on the marine performance curves from Cummins. Compared to the specifications, NO_x values are higher while CO and HC emissions are lower.

Table 1. Tested engine out emissions versus manufacturer specifications

Emissions (grams/kilowatt-hour)	Cummins Declared	FEV Measured
NO_x	9.08	11.45
HC	0.74	0.40
CO	2.74	1.56

Comparison of baseline testing on the test bench and baseline testing on the vessel

Since it was not possible to adjust the correct operating points according to the E3 test cycle on the vessel (see deliverable report for Task 1: Baseline testing on the vessel), the E3 test cycle could not be performed. However, the typical driving cycle was measured and is compared in Figure 7. NO_x emissions are different especially for the load point. The offset is a result from using mobile measurement equipment (black) compared with test bench equipment (red and blue).

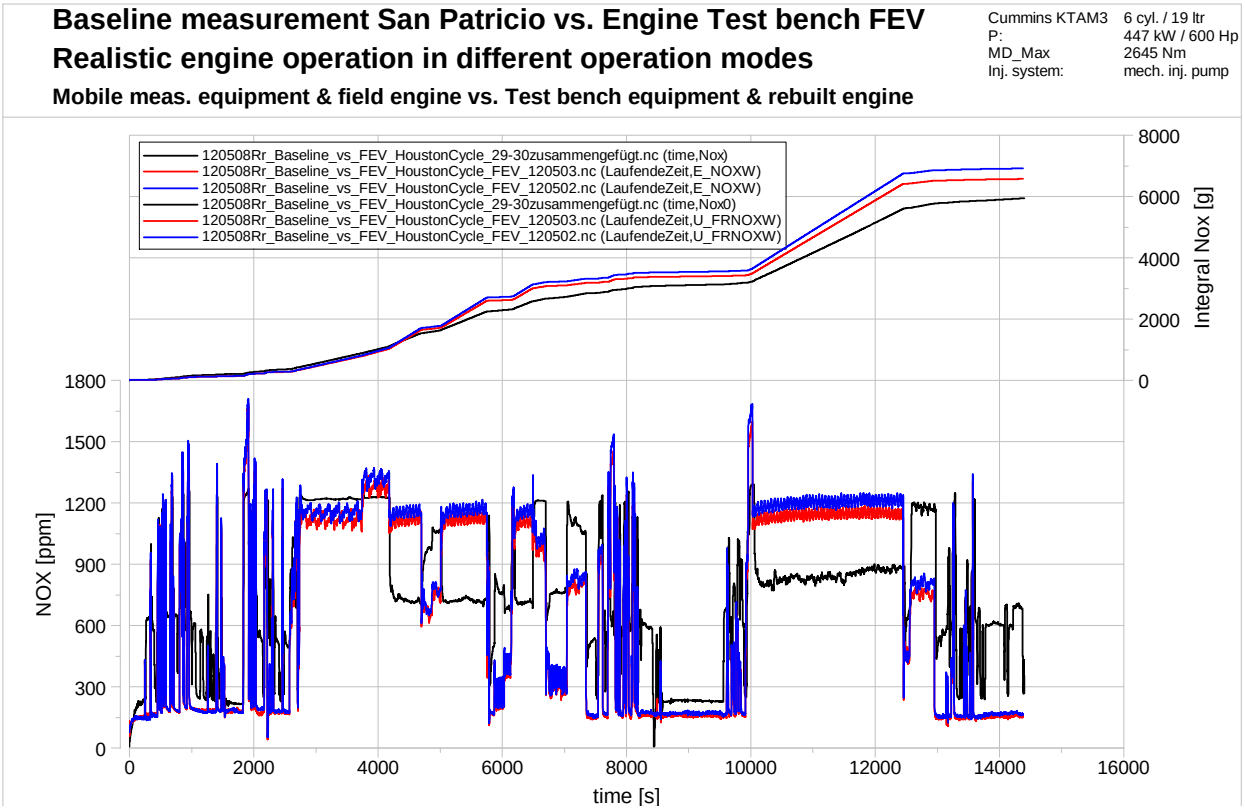

Figure 7 Comparison of baseline testing from vessel and test bench

Discussion/Observations

Objectives vs. Results

The measured emission values from the test bench show a significant offset compared to the values from the baseline testing on the vessel. The different measurement equipment can be a reason.

Based on the PM and NO_x measurements over the entire driving cycle it can be assumed that the passive filter regeneration is working properly in the relevant load points (full load and half load point). Further testing and investigation will be demonstrated in the next test phase with the aftertreatment system

Critical issues

None.

Technical and commercial viability of the proposed approach

To date, no risks in achieving in the initially-proposed commercial objectives of this development are seen. Technical barriers have not been identified so far.

Scope for future work

The following table is a summary of the remaining tasks and phases to be pursued and reported in the upcoming steps:

PHASE/TASK	DESCRIPTION	WEEKS
PHASE II	Dynamometer Testing	6-28
Task 2	Final Design Changes, Measurement of Emissions Reduction	16-28
2.1	Install aftertreatment system.	16-18
2.2	Final design changes to system and emissions measurement with aftertreatment. Several iterations of the design are anticipated to determine final mixer location and design, mixer location, dosing location and orientation. Durability study to determine deposits. Catalyst characterization and calibration of software. Determine proper NO/NO2 ratio. Change out catalyst design to optimize emissions reduction. Measurement and optimize for minimum ammonia slip.	18-28
Deliverable 2	Final system design for marine vessel. Measurement of emissions reduction.	28
MILESTONE II	End of PHASE II: Report and Review of Deliverables 1, 2	28
PHASE III	Emissions Reduction on Marine Vessel	28-36
Task 1	Measurement of Actual Emissions Reduction on Marine Vessel	28-36
1.1	Ship and install system on marine vessel.	28-31
1.2	Install PEMS equipment for emissions measurement. Minimum of two days testing with emissions during normal operation including raw and engine out emissions. Final calibration changes to the software.	31-33
1.3	Final analysis of data and report writing	33-36
Deliverable 1	Verification of emissions reduction on vessel including a comparison of simultaneous raw and engine out emissions.	36
MILESTONE III	End of PHASE III: Report and Review of Deliverables 1	36

Intellectual Properties/Publications/Presentations

None to this point.

Summary/Conclusions

The test engine was procured and shipped to the test facilities. Baseline testing was conducted with a complete engine map, marine cycle and a typical tug boat driving cycle. The test engine shows higher NO_x values compared with the Cummins specification, which is not critical for the emission reduction.