Real-world NOx emissions of Stage V NRMM

Robin Vermeulen, Pierre Passchinger, TNO Joachim Demuynck, Dirk Bosteels, AECC

25th International Transport and Air Pollution Conference • Gothenburg • 25 September 2023



Focus on real-world emissions for on-road HDVs

Introduction of on-road testing in Euro VI significantly reduced the air quality impact
Implementation of advanced emission control systems in a compact design
Actual emissions reduction in the fleet confirmed by remote sensing data



Source: DAF

Source: Average NOx emissions of heavy-duty trucks by European emission standards for Flanders remote sensing campaign, <u>ICCT, 2022</u>

Introduction of Real-Driving Emissions procedure expected in Euro 7



NRMM legislation usually follows on-road trend

O But NRMM Stage V only requires In-Service monitoring with PEMS

♦ Specified in Delegated Regulation (EU) 2017/655 for NRE-v-5 and NRE-v-6 between 56 and 560 kW

Extended to all sub-groups in Delegated Regulation (EU) 2022/2387, published 8 December 2022

Currently no discussions on Stage VI in EU, in contrast to Tier 5 in US

NRMM has a significant impact on air quality

- Example of total NOx emissions in the Netherlands
- Mobile machinery similar to inland shipping and ~45% of total road contribution



NRMM: Non-Road Mobile Machinery PEMS: Portable Emissions Measurement Systems



Scope and objective of this NRMM study

- Investigate NOx emissions of NRMM during operation in the field
- Database of 13 Stage IV and V machines
 - Available data from projects of the Dutch Ministry of Infrastructure and Water Management
 - SEMS measurements done by TNO during daily operation in the Netherlands
 - Range of categories including excavator, wheel loader, tractor, transporter and pile driver
 - AECC asked TNO to apply new analysis on entire database





SEMS: Smart Emissions Measurement Systems



A large variation is observed in real-world NOx emissions

- Main category NRE-v-5 and NRE-v-6
 - 4 machines with average NOx emissions below or around the limit set for the engine cycle
 - 4 machines with significantly higher average NOx emissions
- NOx emissions are around the higher engine cycle limit for the lower power categories
- The example of the high-power category (pile driving rig) shows high NOx emissions





Investigation of distribution of emissions

- Application of Moving Average Window (MAW) post-processing methodology
- According to In-Service Monitoring procedures
 - Invalid data
 - Non-working events
 - For example, for < 10% power, cold-start, < -7 °C, ...
 - Merging of short working events
 - Take off after long non-working event
 - Invalid MAW if average power < 20%
 - Valid data
 - Remaining valid windows
 - Should be > 50% of MAWs



Moving Average



Investigation of distribution of emissions

Excluded data can be significant for some applications investigated





A large variation is observed in real-world NOx emissions

♦ 3 examples from the database to illustrate

ASSOCIATION FOR EMISSIONS CONTROL BY CATALYS

- Majority of valid MAWs is below 1 g/kWh
- Distribution can have a tail of emissions between 2 to 10 g/kWh
- Nearly all data from the transporter is not considered by the monitoring provisions



Potential root causes for higher NOx emissions

- Some applications with higher emission limits are not equipped with SCR
- Significant amount of low engine power operation
 - € 68% of data < 20% of rated power</p>

● 37% of data < 200 °C exhaust gas temperature (no or limited urea dosing)





Potential root causes for higher NOx emissions

> High percentage of total NOx emissions are during idle operation

● Impact of automatic engine-off after certain time investigated

● 3 to 44% of total NOx emissions can be saved by switching off the engine after 5 minutes



Direct engine off After 1 min After 2 min After 3 min After 5 min After 30 min



Summary and outlook

- NRMM contributes significantly to the total NOx and PM emissions in NL
- There are many NRMM types and their use pattern varies significantly
- A large variation is observed in real-world NOx emissions
 - Average emissions can be below the limit but were significantly above in several examples
 - Distribution of emissions shows significant amount of high emission events
- NRMM regulation does not consider a substantial share of the real working conditions
- Technical solutions include
 - NOx abatement with improved performance at low load operation
 - ♦ Introduction of DPF for low and high-powered diesel engines
 - ♦ Automatic engine shut off
- It is expected that a new Stage VI regulation better covers real-world emissions



On-road example of emissions reduction at low load

- HD diesel demonstrator vehicle
- Euro VI-C certified base engine
 - € 12.8 litres, 6 cylinder in-line
 - ♦ High Pressure EGR + DOC + DPF + SCR
- AECC emissions control system
 - Phase 1: ccDOC, ccSCR/ASC+ ufDOC+cDPF+ SCR/ASC, twin AdBlue dosing and HC doser
 - ♦ Phase 2: additional EHC as part of the ccDOC
 - Components are hydrothermally aged targeting 500k km





P. Mendoza Villafuerte, et al.; "Demonstration of Extremely Low NOx Emissions with Partly Close-Coupled Emission Control on a Heavy-duty Truck Application", 42nd Vienna Motor Symposium 2021 P. Mendoza Villafuerte, et al.; "Future-proof heavy-duty truck achieving ultra-low pollutant emissions", Transportation Engineering, Volume 9, September 2022, 100125, 2022



THANK YOU



AECC (Association for Emissions Control by Catalyst)

AECC eu

