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Calculation Methods Impact on Real-Driving-Emissions Particulate Number Evaluation: Moving Averaging Window in China 6 vs. Raw Mileage Averaging in Euro 6d

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Abstract

RDE test has been introduced to the light-duty vehicle certification process in both China 6 and Euro 6d standards. The RDE test shall be performed on-road with PEMS, which is developed to complement the current laboratory certification of vehicles and ensure cars to deliver low emissions under more realistic on-road driving conditions. Particulate matter has been highly perceived as a significant contributor to human health risks and thus strictly regulated globally. For the RDE evaluation, the MAW method used by the China 6 standard is usually found less stringent than the RMA method used by the Euro 6d standard. In the present study, both of the MAW and RMA methods were applied to different driving cycles and operating conditions, which met the general RDE test requirements, yet resulted in different evaluated PN results. Special focus was directed towards the initial vehicle operations, for example, the vehicle lift-off time after engine ignition and driving dynamics before engine fully warmed up, in addition to the $\boldsymbol{CO_2}$ generation over the RDE cycle. The results showed that the calculation methods can greatly impact the RDE PN emission evaluation. Emphasis to details in the test procedures was recommended to appropriately protect the application and avoid underestimating the RDE emissions in case of realistic operating scenarios.

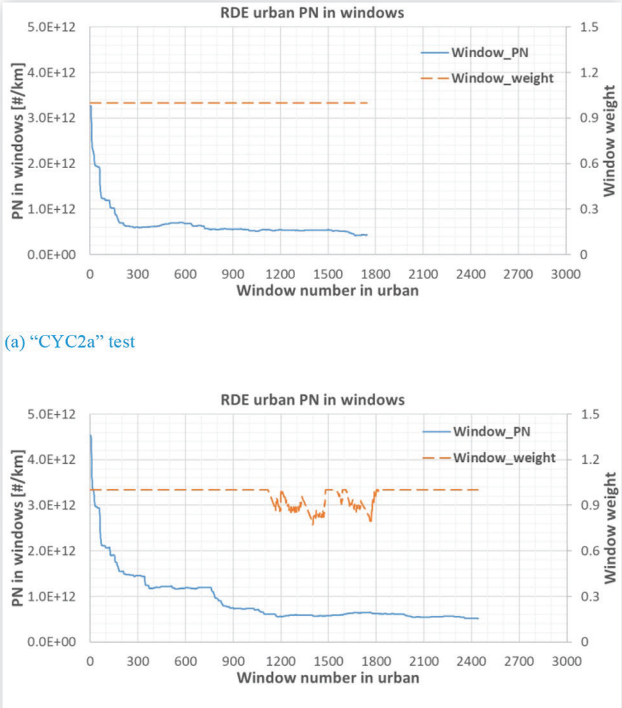
Introduction

The Real-Driving-Emissions (RDE) framework was triggered in the early 2010s under the supervision of the European Commission [1]. It aims to stipulate that the manufacturers shall enable the vehicles to comply with emissions standards in real-world use, covering a representative range of driving conditions [2-4]. The on-road test procedure is based on the application of Portable Emissions Measurement System (PEMS) since 2014 to determine heavy-duty vehicles' in-use compliance in Euro 6. The Not-To-Exceed (NTE) limit was allowed to include the PEMS uncertainties, with a so-called Conformity Factor (CF) for NOx and Particulate Number (PN) emissions. Since the RDE test becomes a type-approval certification in both Europe and China, it brings lots of challenges to control the particulate emissions under various on-road boundary conditions and thus leads to dedicated efforts by manufactures in developing PN control technologies [5-8].

In fact, the RDE legislation in Europe was introduced into the Euro 6 through 4 packages [9]. The 1st RDE package was voted in May 2015 and defined the RDE test procedures. The package 2 was voted in October 2015 and defined the NOx CF as well as the introduction dates. The RDE package 3 (voted in December 2016) added a PN CF and included the RDE cold-start emissions. The RDE package 4 was voted in May 2018 and dealt with In-Service Conformity (ISC) RDE testing and market surveillance. The manufacturers were allowed to meet the RDE requirements in two phases, i.e. transitional phase and compliant phase [10]. In the transitional phase, the 1^{st} package is only used to monitor and report the RDE emissions without the requirement of an NTE limit, which was applied to Euro 6c in April 2016. The compliant phase is in regard to the RDE package 2, 3, and 4. The RDE type approval test was mandatory in Euro 6d-TEMP from September 2017, with package 2 adopted against a temporary NOx CF of 2.1 and package 3 adopted against an additional temporary PN CF of 1.5. Euro 6d took effect in January 2020 with the final CF of NOx as 1.5 defined in package 2 and lowered to 1.43 in package 4, and the final PN CF as 1.5 defined in package 3.

The China 6 standard was released on December 23, 2016, and took effect on July 1, 2020 [11]. It takes the best practices from European regulation and introduces RDE requirements based on the RDE package 2 in Euro 6d, with modification addressing the unique driving conditions in China. Similarly, the China 6 RDE comes into forces with two subsequent stages. The transitional stage China 6a only requires monitor

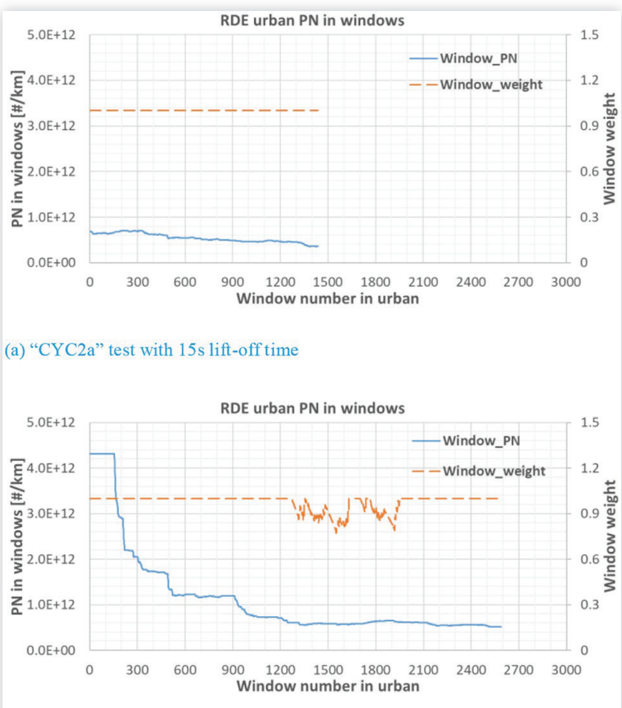
FIGURE 20 PN emissions in windows of RDE tests with 300s lift-off time.



(a) “CYC2a” test

(b) “CYC2b” test

FIGURE 21 PN emissions in windows of RDE tests with 15s and 450s lift-off time.



(a) “CYC2a” test with 15s lift-off time

(b) “CYC2b” test with 450s lift-off time

dynamics with a cold engine, and the fuel consumption or the CO_2 emission ratio between the RDE cycle and WLTC cycle after the engine warmed up. Therefore, besides the extreme or “worst-case” RDE test boundary conditions, the manufacturers should give emphasis to the RDE test procedures during their clean engine development to comply with the China 6 RDE standard.

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Definitions/Abbreviations

RDE - Real Driving Emissions

PEMS - Portable Emissions Measuring System

PN - Particulate Number

NTE - Not-To-Exceed

CF - Conformity Factor

ISC - In-Service Compliance

MAW - Moving Averaging Window

RMA - Raw Mileage Averaging

CVS - Constant volume sampler system

GPF - Gasoline Particular Filter

GDI - Gasoline Direct Injection

MPI - Multi-Port Injection

TC - Turbo Charged

NA - Natural Aspirated

PMP - Particle Measurement Programme

CPC - Condensation Particle Counters

PTT - Particle Transfer Tube

VPR - Volatile Particle Remover

WLTC - Worldwide harmonized Light vehicles Test Cycles

RTS95 - RTS is derived from standardized random test and 95 refers to aggressive driving style

$(v \cdot a_{pos})_{urban}[95]$ - 95th percentile of the product of vehicle speed per positive acceleration greater than 0.1 m/s^2 for urban trip [m^2/s^3 or W/kg]

RPA_{urban} - relative positive acceleration for urban trip [m/s^2 or kWs/(kg×km)]

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