

# EUROPEAN REGULATION ON VEHICLE REAL DRIVING EMISSIONS CONTROL

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**UDC: 629.341;629.3.078**

*DOI: 10.24874/mvm.2017.43.02.04*

**ABSTRACT:** The paper discusses the actual problem of NO<sub>x</sub> emission in real driving conditions. In the first part of the paper the existing situation in regard to the NO<sub>x</sub> emission of light vehicles in real use is presented using the tests performed all around Europe. Since the obtained emission is several times higher than existing limits according to EU standards, the main causes for such differences have been analysed. Special attention is paid to the use of defeat devices applied by many car manufacturers using certain emission control strategies at approval tests to obtain low emissions and another control strategy in real driving to obtain good fuel economy. To prevent excessive emission in real use, the EU Commission has undertaken regulatory measures to accept new regulations which define new limits for NO<sub>x</sub> emission in real use as well as control testing of light vehicles in real driving conditions.

**KEY WORDS:** passenger cars, exhaust emissions, regulation, real driving, NO<sub>x</sub>

## EVROPSKI PROPISI O KONTROLI EMISIJE VOZILA U STVARNOJ VOŽNJI

**REZIME:** U radu se razmatra aktuelni problem emisije NO<sub>x</sub> u stvarnim uslovima vožnje. U prvom delu se prikazuje postojeća situacija u pogledu emisije NO<sub>x</sub> lakih vozila u stvarnoj eksploataciji koristeći rezultate ispitivanja obavljenih širom Evrope. Pošto je izmerena emisija nekoliko puta veća od granica propisanih standardom, analiziraju se glavni uzroci tih razlika. Posebna pažnja se poklanja primeni uređaja za promenu kontrolne strategije kod mnogih proizvođača vozila kada se koristi jedna strategija za kontrolu emisije pri homologacionom ispitivanju u cilju dobijanja niske emisije, a druga kontrolna strategija u stvarnoj eksploataciji u cilju postizanja povoljne ekonomičnosti goriva. Kako bi se sprečila preterana emisija u stvarnoj eksploataciji, Evropska Komisija je preduzela korake ka stvaranju propisa koji bi definisali nove granice dozvoljene emisije NO<sub>x</sub> u stvarnoj eksploataciji kao i kontrolno ispitivanje lakih vozila u stvarnim uslovima vožnje.

**KLJUČNE REČI:** putnička vozila, izduvna emisija, propisi, stvarna vožnja, NO<sub>x</sub>

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<sup>1</sup> *Received February 2017, Accepted March 2017, Published On Line June 2017*

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## 1. INTRODUCTION

Euro 6 standards entered into force at the end of 2014. The main novelty in them in relation to the Euro 5 was significant reduction of NO<sub>x</sub> emission limits for light vehicles (passenger cars – PC and light duty vehicles – LDV) with diesel engines: from 180 mg/km to 80 mg/km. This reduction is practically equalized nitric oxides (NO<sub>x</sub>) emissions of light vehicles with gasoline and diesel engines (Figure 1) [1].

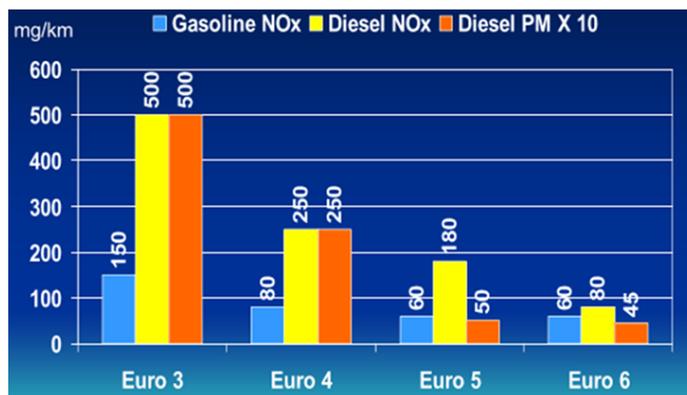


Figure 1 EU standards on NO<sub>x</sub> and Particulate Matters (PM) for light vehicles

Gasoline NO<sub>x</sub> limits were significantly lower than diesel NO<sub>x</sub> limits until Euro 6 standard [2]. Actually, to reach NO<sub>x</sub> limits it was much easier to gasoline engines than to diesel engines. Application of three way catalyst (TWC) technology for gasoline engines successfully solves the problem of NO<sub>x</sub> emission, as well as CO and HC emissions, allowing very small limits. However, it is very difficult for diesel engine to find a solution that successfully reduces at the same time particulate matters PM and NO<sub>x</sub>.

Euro 5 standard [2] was generally requested drastically reduction of diesel engine particles emission and therefore introduced almost mandatory application of diesel particulate filter (DPF). The NO<sub>x</sub> emission was only slightly reduced by this standard, but to achieve the required limits it was necessary further diesel engine improvement and the application of additional solutions, primarily exhaust gas recirculation (EGR) and eventually lean NO<sub>x</sub> trap (LNT).

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Euro 6 standard has significantly reduced  $\text{NO}_x$  emissions of diesel engines by about 60%. New limits for  $\text{NO}_x$  required more sophisticated solutions such as electronically regulated cool exhaust gas recirculation (EGR), lean  $\text{NO}_x$  trap (LNT) or selective catalytic reactor (SCR). Although SCR is the most efficient technology for reduction of  $\text{NO}_x$  emissions, this solution have not found wide application in passenger vehicles because of its complexity and higher costs. Therefore, in the domain of passenger vehicles mainly dominates the application of EGR with a possible addition of LNT. However, the efficiency of the EGR system is not too big and a higher decrease of  $\text{NO}_x$  reduction can jeopardize the economy of the engine.

## 2. REAL DRIVING EMISSIONS OF PASSENGER CARS

Unfortunately it turned out that the exhaust emissions of vehicles in real driving conditions can be significantly higher than the limits defined by standards. Figure 2 shows mean  $\text{NO}_x$  emission factors (values in  $\text{g}/\text{km}$  converted in  $\text{g}/\text{kg}$  fuel using measured fuel consumption rates) of gasoline (left) and diesel (right) passenger cars (PC) and light commercial vehicles (LCV) as a function of model year [3].  $\text{NO}_x$  emission is measured in test cycle that represents real driving conditions. Obtained mean values during the test of different model year vehicles are presented with 95% confidence interval over the mean.

Actually it was concluded that passenger vehicles with gasoline engines do not have a lot of problems with exhaust emission in real use since TWC technology is very effective, especially with normally warmed engine. Therefore, the emissions in normal driving conditions correspond very well to the emissions obtained during approval test.

In the case of passenger cars with diesel engine a situation is much worse. Though the  $\text{NO}_x$  emission limits were constantly diminished, the emission in real driving conditions stayed almost the same. Therefore the gap between test and real driving results for diesel engines was very big. Figure 3 schematically illustrates the comparison between approval limits and real driving  $\text{NO}_x$  emissions for different classes of vehicles. Actually diesel engines  $\text{NO}_x$  emission in real driving conditions can be higher than limits by a factor of 2 for Euro 3 cars, more than 3 times for Euro 4, and more than 4 times for Euro 5 [4]. It was believed that the main reasons for the observed gap were different test and real conditions.

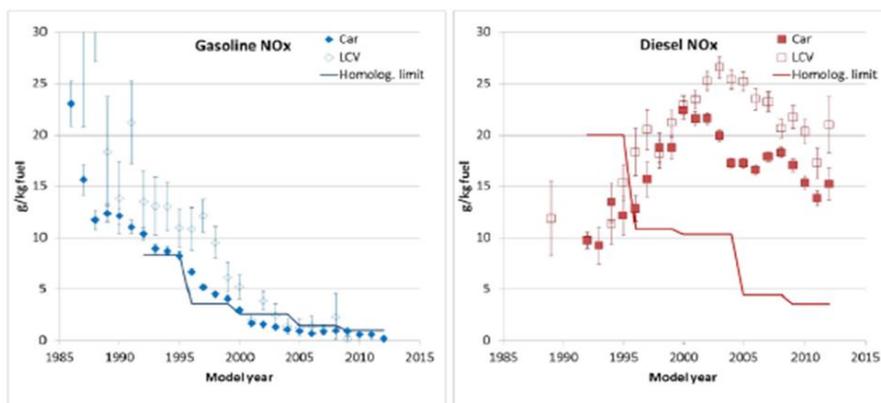


Figure 2 Mean hot  $\text{NO}_x$  emission of gasoline (left) and diesel (right) passenger cars and light commercial vehicles (LCV) as a function of model year [3]

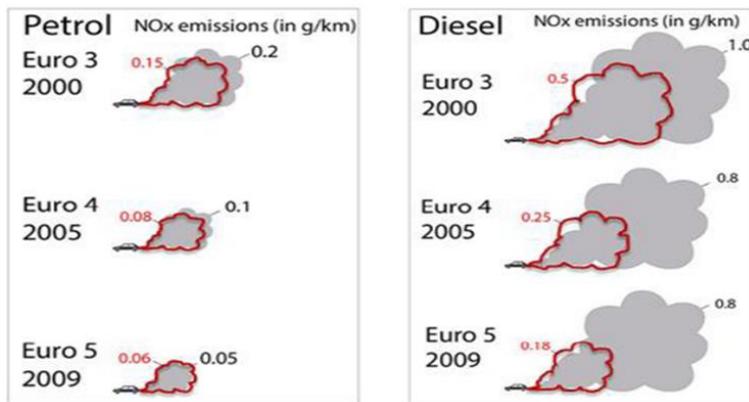


Figure 3 Test and real driving results (red – approval limits, black – real drive) [4]

However, the situation became more serious when in September 2015 the U.S. EPA and the California Air Resources Board announced that a number of VW 2.0L diesel vehicle models sold in the U.S. during model years 2009 to 2015 was equipped with illegal defeat devices. The EPA issued a second notice of violation in November 2015 for VW model year 2009–2016 vehicles equipped with 3.0L diesel engines stating that “VW manufactured and installed software in the electronic control module (ECM) of each vehicle that causes the vehicle to perform differently when the vehicle is being tested for compliance with EPA emission standards than in normal operation and use.” While the description of the defeat device was more detailed than in the September notice of violation, in both cases the vehicles were operating under two emissions control regimes: one during emissions testing, and one at other times. The EPA described the defeat device used in the 3.0L vehicles as software that determines when the vehicle has begun the FTP 75 certification test and then employs a low-NO<sub>x</sub> temperature conditioning mode, varying a number of engine parameters to yield lower engine-out [5].

Having in mind critical situation and knowing that also a lot of other European vehicles have high emissions in real driving conditions, from the beginning of 2015 started in Europe intensive testing of real driving exhaust emissions of passenger cars (PC) and light commercial vehicles (LCV). Tests have been performed in laboratories simulating real driving conditions, as well as on roads in real traffic.

It was found [6] that over four in five cars that meet the Euro 5 standard for NO<sub>x</sub> in the laboratory (180g/1000km), and were sold between 2010-2014, years, actually produce more than three times this level when driven on the road. Also two-thirds of Euro 6 cars (most on sale since 2015) still produce more than three times the 80g/1000km limit when driven on the road.

When Euro 6 vehicles first entered the market in 2014 they typically produced in real use around 600mg/km of NO<sub>x</sub> or 7.5 times the 80mg/km limit. More recent models are better, typically 5.5 times the limit (440mg/km). However, some models' exceedances are over 10 times. It is estimated that about 80% of total registered Euro 5 vehicles and about 64% of Euro 6 diesel cars exceed existing NO<sub>x</sub> limits [6].

According to the performed tests in last year and recently published results on NO<sub>x</sub> exhaust emission in real driving conditions there are a lot of cars manufacturers which sold cars with higher emissions than declared level at approval test. For Euro 5 cars, the five

worst performing companies were (in order of the highest emissions): Renault (including Dacia), Land Rover, Hyundai, Opel/Vauxhall (including Chevrolet) and Nissan. The best performing Euro 5 cars were made by (in order of lowest emissions): Seat, Honda, BMW (including Mini), Ford and Peugeot. For current Euro 6 cars a different pattern emerges. The worst performers are: Fiat (including Alfa Romeo + Suzuki to whom Fiat supply engines); Renault (including Nissan, Dacia and Infiniti); Opel/Vauxhall; Hyundai; and Mercedes. The cleanest Euro 6 car is VW Group with VW cars, followed by Seat, Skoda and Audi; BMW (including Mini) and Mazda [6]. Fig. 4 illustrates this situation using the EQUA Air Quality Index results on real-world emissions data.

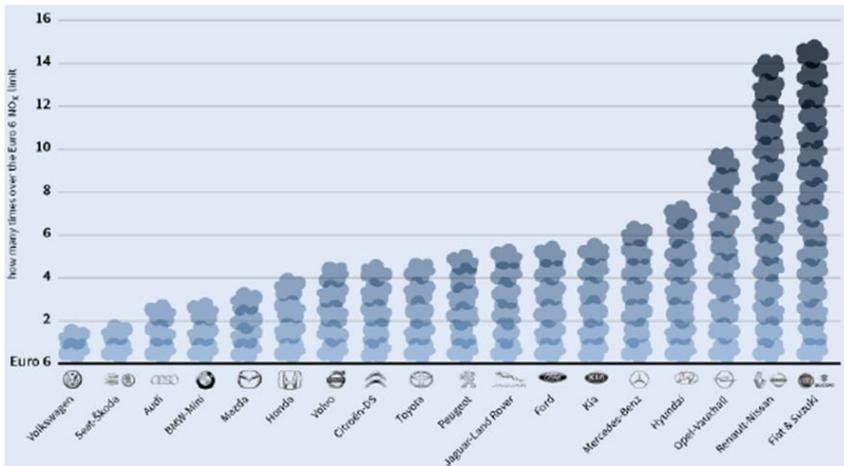


Figure 4 Euro 6 manufacturers (selling cars in Europe) over approval limits rated according to their average real driving emissions index [6]

Similar situation is also in United Kingdom. Fig. 5 shows the results of tested used cars taken from rent companies in England. Euro 5 cars have six times greater emission than limits and Euro 6 cars seven times exceedance.

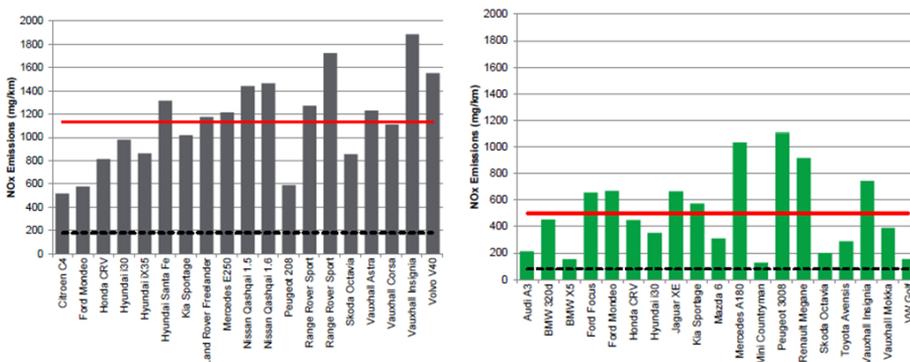


Figure 5 Real driving emissions (RDE) of certain Euro 5 (left) and Euro 6 (right) cars (red line – mean RDE, black dotted line – limits) [7]

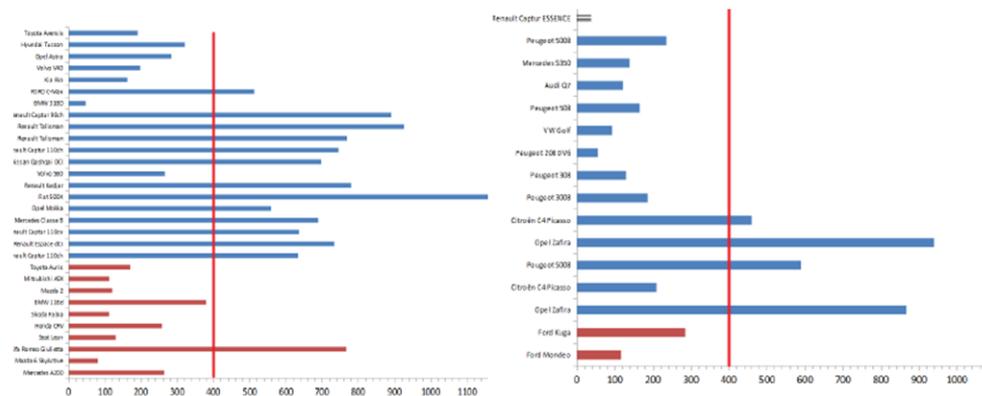


Figure 6 NO<sub>x</sub> emissions measured on track of vehicles without SCR (left – red are with EGR only and blue are with EGR + LNT) and with SCR (right – red are with SCR+EGR+LNT and blue with SCR+EGR) [8]

The results of Euro 6 vehicles tested in France are shown in Fig. 6 [8]. The aim of tests was to find the vehicles with NO<sub>x</sub> emission five times the limit. The vehicles were driven at open track (not in laboratory) using approval cycle NEDC (New European Driving Cycle) but in real driving conditions. The emissions values were measured using PEMS (Portable Emissions Measurement System) equipment. The worst results in RDE conditions have Euro 6 passenger cars with EGR + NO<sub>x</sub> trap (LNT): some of them five up to 15 times over the limits. The better results have Euro 6 passenger cars with SCR, but again some of them are ten times over the limits.

### 3. THE REASONS FOR HIGHER EMISSIONS IN REAL DRIVING CONDITIONS

There are two principal causes for the failure to meet limits on the road.

First, the laboratory test procedure used to measure the pollutant and CO<sub>2</sub> emissions in Europe in the past is unrealistic and does not represent real-world driving conditions. The actual NEDC driving schedule practically has not transient regimes and high loads, testing conditions are almost ideal and the test is performed with specially prepared vehicle for approval. Also, there are too many flexibilities and loopholes in the testing protocols that allow carmakers to game the system.

It is allowed to carmakers to “shop around” for the best offer from the regulators that compete among themselves for type approving business. Some, for example, approval authorities KBA in Germany, CNRV in France and MIT in Italy, protect their national carmakers. Others, like the VCA in the UK, RDW in the Netherlands or SNCH in Luxembourg see type approval as a lucrative business [6].

This feeble system of approvals is exacerbated by technical services that are supposed to undertake tests but routinely only witness these in carmakers’ own labs and are paid for their assistance. Sometimes the testing and approval organizations are even the same. Once the vehicle has been approved there are virtually no independent on-road checks to verify its performance in use due to a lack of will or resources. Figure 7 illustrates where are performed approval tests for first fifty cars with the high emissions in real driving



It has been identified that a lot of PC and LDV models show the presence of a “thermal window” defeat devices. These devices switch off or lower the effectiveness of the exhaust treatment systems at temperatures below those typically used during laboratory tests (23 - 29°C). Tests conducted in late autumn, winter and early spring on track or road produced high emissions highlighting that the cars were turning down or switching off the emission control systems during these tests. Manufacturers claim such behaviour is needed to protect the engine and therefore switch off their pollution control systems bellow certain temperature (some models of Opel and Vauxhall bellow 17oC, Renault and Nissan also bellow 17oC, Daimler bellow 10oC, Peugeot bellow 5oC, etc. [6]).

The second type of defeat device relates to “hot restarts”. Again a high number of the models on the road show much higher emissions after a hot engine restart than when the engine is cold. Manufacturers’ explanation is that high emissions are generated by hotter engine temperatures experienced at warm restarts. However the effectiveness of the after-treatment should be much better when hot conditions. High warm start emissions are highly suspicious and suggest that during the EU test cold start a different and more effective engine and exhaust calibration is being used.

The third defeat device relates to “test recognition” strategy. Such defeat device was described as a “switch” that “senses whether the vehicle is being tested or not based on various inputs including the position of the steering wheel, engine compartment cover, vehicle speed and load, the duration of the engine’s operation, etc. It was reported that several tests by the German type approval authority (KBA) have found evidence that the exhaust treatment system in some Fiat models would switch itself off after 22 minutes (test duration is 20 minutes). Also some of Ford and Fiat models switch off their pollution control systems at high vehicle speeds and when a car is full with passengers [6]).

However, it is proved that only Volkswagen Group used the defeat device recognizing control test and switching software for emission control [10]. Fig. 8 show the results of NO<sub>x</sub> emissions during unrecognized and recognized test of Škoda passenger car. The recognition was done according to the shape of the first part of driving cycle. At normal start of standard cycle (laboratory NDEC) the engine used base emission control software enabling low emission of NO<sub>x</sub>. If reverse cycle was used (first extra urban cycle and then urban cycle) the driving cycle was not recognized and the engine used auxiliary emission control software giving high NO<sub>x</sub> emissions.

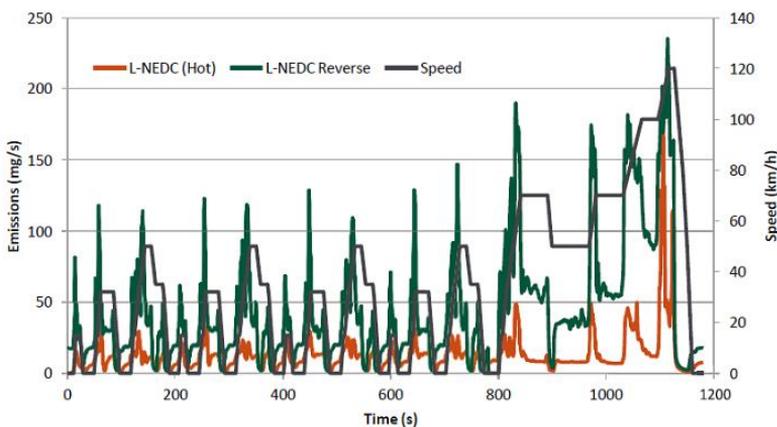


Figure 8 Test recognized (red) and unrecognized (green) NO<sub>x</sub> emission [10]

#### 4. MEASURES FOR THE IMPROVEMENT OF REAL DRIVING EMISIONS

Keeping in mind current situation, the European Commission, in cooperation with research institutions, not governmental associations and vehicle manufacturers, has undertaken regulatory measures to reduce emissions in real driving conditions. These measures have included the monitoring of current situation, the determination of possible emissions deviations in real exploitation, the improvement in the existing regulations regarding the performance of approval tests conformity checks in exploitation, the definition of emission limits in real driving conditions and the proposal of RDE control test. It is envisaged that the entire process of creating additional regulations to control emissions in real use is carried out in several steps.

The first step was already implemented in 2015 using EU research institutions in order to check the possible variations of approved  $\text{NO}_x$  emission values of new vehicles comparing them with the measurements in realistic conditions. Actually it was immediately concluded that there is a high probability that the emission during real operation is greater than the value from homologation. The first reason is that during the approval the vehicle is running from cold conditions in contrary to the hot engine of vehicle used in real driving conditions. Second reason is that the environmental conditions (pressure and temperature) differ from standard conditions prescribed for the control in laboratory. Third reason is the use of different emissions control software in laboratory and in real driving. This is illustrated in Figure 9 for the same new car tested in and out the laboratory [10]. If the standard driving control cycle (NDEC) is performed with a hot engine, laboratory  $\text{NO}_x$  emission already exceeds the limits by more than 50% (left side - red of figure 9). However if the test is performed outside the laboratory in real environmental conditions differences are much greater (right side – green).

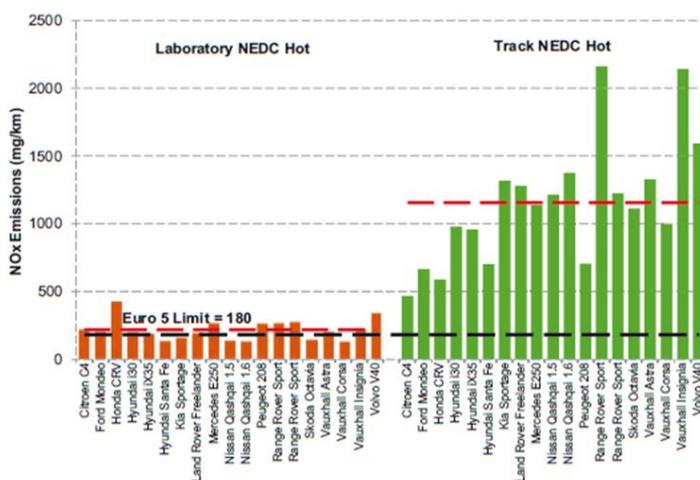


Figure 9 Laboratory versus track  $\text{NO}_x$  emission of new Euro 5 vehicles [10]

Based on these measurements, so-called Conformity Factor, defined as the ratio between real  $\text{NO}_x$  emission and standard limit, should be establish. The Conformity Factor will be then used to define the maximum allowed  $\text{NO}_x$  emission in real driving conditions, so called Not To Exceed (NTE) limit, according to the expression

$$\text{NTE limit} = \text{Conformity factor} \times \text{Euro 6 limit}$$

On the October 2nd 2015 European Commission sent the proposal [11] on so called First RDE package to the EU Council and on 10 November 2015, the Council gave its green light to the adoption of the first package of rules on real driving emission (RDE) tests to measure pollutants emissions of light vehicles. This first package introduces the concept of RDE procedures with a portable emissions measurement system. It will apply from 1 January 2016. At this initial stage the system will be used only for monitoring purposes. It will therefore not yet have any implications on the approval of new models.

During the discussion about future conformity factors, the European Commission had proposed significantly more stringent limits applying conformity factors of 1.6 in the short term and 1.2 in the longer term, but a lot of Member states suggest much higher values [12]. On the 28 October 2015, the European Commission and Member states reached an agreement on the Second RDE package establishing implementation dates and conformity factors on NO<sub>x</sub> RDE. On 12 February 2016, the Council gave its green light to the adoption of the second package of rules with real driving emission (RDE) limits. According to this package 2.1 short term and 1.5 long term conformity factors are adopted. This second conformity factor will be annually reviewed to take into consideration technical improvements to the test equipment during RDE control test definition. The implementation dates of RDE limits for new model type approvals and for all new vehicles are shown in Figure 10 [12].

	New Type Approvals	All vehicles
1.1.2016		Testing commences
1.9.17	Not to exceed limit 168mg/km	
1.9.19		Not to exceed limit 168mg/km
1.9.20	Not to exceed limit 120mg/km	
1.9.21		Not to exceed limit 120mg/km

Figure 10 RDE limits and implementation dates [12]

Meanwhile the discussion on RDE control test continued. Proposal of Third RDE package includes three important items [13]:

- a) Particle number (PN) PEMS RDE testing. PN PEMS testing seems to be possible, albeit with somewhat higher uncertainties than the NO<sub>x</sub> PEMS testing. The results of the testing at the JRC as well as of the interlaboratory exercise were presented at the RDE-LDV meeting of 20th April 2016. [14, 15].
- b) Coverage of the vehicle cold start. There are two possibilities: to include the cold start data in the normal RDE data evaluation and to calculate separately the contribution of the cold start and weighing it in the RDE data evaluation [16].
- c) Special RDE testing conditions for hybrids. All hybrids should be certifiable with the RDE procedure and appropriate evaluation methods need to be developed [17].

In September 2016 also started consideration of Fourth RDE package which should cover the definition of in-use-conformity RDE testing including the concepts developed by the “RDE surveillance task force” [13].

All agreed items are included in EU Commission Regulation 2016/646 from April 20, 2016 [18]. This Regulation defines two emissions strategies: ‘base emission strategy’ that is active throughout the speed and load operating range of the vehicle, and ‘auxiliary emission strategy’ that becomes active and replaces or modifies a BES for a specific purpose and in response to a specific set of ambient or operating conditions and only remains operational as long as those conditions exist. Appendix 6 to Annex I of this Regulation introduces Euro 6c and 6d standards for different classes of vehicles supplied by gasoline, diesel, E10 and B7 fuels. The implementation dates are defined according to norm levels and vehicle classes with the application from 1.9.2017 to 1.1.2022. RDE testing is also included with NTE limits. Annex II of this regulation defines final and temporary NTE limits as well as proposal of procedure of RDE control test with the verification and calculation of testing results.

New requirements for low real driving emissions need the application of new more expensive technologies. It is concluded that Euro 6 light vehicles with real-world compliance are technically feasible, even with stringent RDE requirements. Therefore, EGR system, frequently used in light vehicles, will be probably change to SCR system which gives smaller deviations in real use. The additional production costs of vehicle equipped with SCR can be up to €500.

Taking in account all undertaken measures it is expecting that in 2021 approval and in use emissions data will be closer. The forecast is shown in Figure 10.

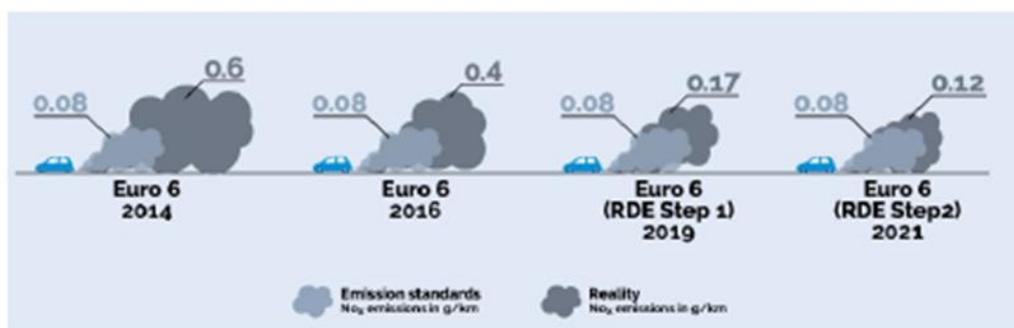


Figure 10 The forecast of future NO<sub>x</sub> emission according to EU standards and in real driving conditions [6]

## 5. CONCLUSIONS

NO<sub>x</sub> emissions of light vehicles is several times higher in real driving conditions than in laboratory during approval test. It is higher by a factor of 2 for Euro 3 vehicles, more than three times for Euro 4, four times for Euro 5 and seven times for Euro 6 vehicles.

The main reasons for higher NO<sub>x</sub> emissions in real driving conditions are:

1. The standard test procedure used to measure the pollutant in laboratory is unrealistic and does not represent real-world driving conditions.

2. The manufacturers of diesel cars are failing to operate their exhaust after-treatment systems for most of the time the car is driven with the aim to improve fuel economy as well as to keep the durability of the emissions treatment systems they have chosen to use.

EU Commission has undertaken certain regulatory measures to improve the level of NO<sub>x</sub> emissions in real driving conditions. These measures involve the adoption of so-called „RDE Packages“. The proposals of First and Second RDE packages are already accepted and Third and Fourth are under consideration. Their conclusions will be included in EU Regulation 2016/646 with adopted conformity factors (defining permitted deviation between standard limits and real driving data), temporary and final NTE (Not To Exceed) limits with the implementation dates, real driving emissions (RDE) test procedure, and validation and calculation of test data.

## ACKNOWLEDGEMENT

The authors with to thanks TEHNOLAB, Centre for Motore Vehicle, Belgrade for financial and official support in the collection of literature and data on the problem of real driving emissions and in the participation of real driving emissions programm.

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