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Development of road transport emission standards

Eszter Horvath[1], Adam Torok[2]

[1] PhD., KTI Institute for Transport Sciences Non Profit Ltd., Division for Transport Informatics, e-mail: horvath.eszter@kti.hu
[2] PhD., KTI Institute for Transport Sciences Non Profit Ltd., Division for Transport Economics, e-mail: torok.adam@kti.hu

Abstract. Emissions from road vehicles are playing an important role in air quality which has a significant impact on human health. Pollutant emissions have to be precisely determined to ensure that air quality plans are designed and realized properly. Vehicle emissions standards, and associated improvements in fuel quality, have been shown internationally to be the most cost-effective measures to reduce urban air pollution from the road transport sector. So far, nonvolatile particle mass (PM) has been used as a measure to measure and limit vehicle emission. Further significant reductions in emission limits couldn't be achieved, therefore new measurement methods had to be introduced. The European Commission introduced a limit for nonvolatile particle number (PN) emission. 23 nm for new light-duty (LD) vehicles in 2011 and similar legislation for new heavy-duty (HD) vehicles in 2012. Measuring particle number is not possible with the equipment used to measure particle mass, therefore new investments are needed for the EURO VI measurements. The authors of this article have analysed the development tendencies.

Key words – emissions limits, technical standards, test cycles

1. Introduction

Increasing transport activity is a basic human necessity and a key factor of economic growth which in turn, has a large effect on environmental pollution. From global energy use, the transport sector produces about a quarter of carbon dioxide (CO_2) emissions (RIBEIRO S. K., KOBAYASHI S., BEUTHE M., GASCA J., GREENE D., LEE D. S., MUROMACHI Y., NEWTON P. J., PLOTKIN S., SPERLING D. 2007). Road transport currently accounts for almost three-quarters of total transport CO_2 emissions. Therefore large reductions in harmful gas emissions, development of management and strategies are needed to prevent serious climate destabilization. The polluted air affects the health of people or animals and affects vegetation as well. There are various types of air pollutant and 90 % of all air pollution is as a result of the primary pollutants (LANDON M. 2006). These constituents are:

- particles,
- sulphur dioxide (SO_2),
- nitrogen oxides (NO_x),
- carbon monoxide (CO),
- hydrocarbons (HC) and photochemical oxidants.

These pollutants contribute to several health problems. Eye and nose irritation can be caused by particulates from exhaust fumes and can lead to serious respiratory problems such as asthma. One of the main reasons for the 'ground' ozone formation is NO_x which is the key component of the smog that overwhelms cities around the world. Ground level or so-called bad ozone is not emitted directly into the air, but is created by chemical reactions between NO_x and volatile organic compounds (VOC) in the presence of sunlight. Even relatively low levels of ozone can irritate the respiratory system, invoke coughing, choking, and reduced lung capacity. Children are most exposed to ground level ozone because they spend more time outside and their lungs are still developing (TABAKU A., BEJTJA G., BALA S., TOCI E., RESULI J. 2011).

Particulate Matter (PM)

Particle pollution also known as particulate matter (PM) consists of solid particles and liquid droplets suspended in the air. There are subtypes of atmospheric particle matter including suspended particulate matter (SPM), inhalable coarse particle also known as respirable suspended particle (RSP) with a diameter of 10 micrometers or less so-called PM_{10}, fine particles that are 2.5 micrometers and smaller ($PM_{2.5}$), and ultrafine particles, and soot. Particulates are the most dangerous form of air pollution because they can be breathed deeply into the lungs and absorbed into the blood stream unfiltered, resulting in lung inflammation (LI R., NING Z., MAJUMDAR R., CUI J., TAKABE W., JEN N., SIOUTAS C., HSIAI T. 2010), permanent DNA mutations (QUINN J. S. 2009), heart attacks and premature mortalit.

Oxides of Nitrogen (NOx)

NO_x is a general phrase for mono-nitrogen oxides NO and NO_2, a colorless and odorless gas produced from the reaction of nitrogen and oxygen gases when fuel is burned at high temperatures, as in a combustion of a mixture of air and fuel. A significant amount of nitrogen oxides can be formed polluting the atmosphere whenever combustion occurs in the presence of nitrogen. NO_x gases – as a precursor of ground level ozone – react to form photochemical smog through their reaction with hydrocarbons (LEE S. B. 2010). NO form nitric acid when dissolved in atmospheric moisture, forming a component of acid rain (FOWLER D., FLECHARD C., SKIBA U., COYLE M., CAPE J. 1998). Due to a higher intensity of sunshine, the effects of ground level ozone are typical during the warmer summer months (BRIMBLECOMBE P. 2012).

Sulfur Dioxide (SO_2)

SO_2 is a toxic gas with a pungent, irritating and rotten smell and comes from the family of sulfur oxide gases (SO_x). Fuel containing sulfur, such as coal and oil when burned can lead to the production of SO_x gases. Most sulfur dioxide is produced by the combustion of elemental sulfur. Sulfur dioxide also negatively reduces visibility. SO_2 was also present in motor vehicle emissions, as a result of fuel combustion. Recently, motor vehicle exhausts have not been an important source of sulfur dioxide in air due to stricter fuel quality regulations.

Carbon Monoxide (CO)

CO is a colorless and odorless gas, slightly less dense than air, poorly soluble in water. CO is formed when carbon in fuel is not burned completely. It is a common component of diesel exhaust. The total yearly CO emissions into the atmosphere has been estimated to be approximately 15 % from human activities (ANGELBRATT J., MELLQVIST J., SIMPSON D., JONSON J. E., BLUMENSTOCK T., BORSDORFF T., DUCHATELET P., FORSTER F., HASE F., MAHIEU E., DE MAZIÈRE M., NOTHOLT J., PETERSEN A.K., RAFFALSKI U., SERVAIS C., SUSSMANN R., WARNEKE T., VIGOUROUX C. 2011) Anthropogenic emissions of carbon monoxide originates mainly from incomplete combustion of carbonaceous materials. The largest proportion of these emissions is produced as exhausts of internal combustion engines, especially by motor vehicles with petrol engines. The highest levels of CO occur during the colder months of the year when inversion weather conditions are more frequent and air pollutants become trapped near the ground beneath a layer of warm air.

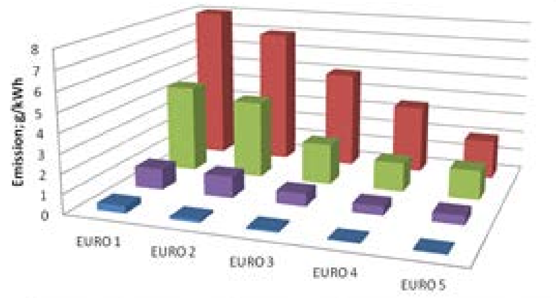
2. Methodology

Studies found direct linkages to health problems from exposure to vehicle exhausts. The extremity of the impacts on human health from emissions could not be ignored. Therefore it is important to keep a balance between the growth in goods movement and the environment. Emission norms are prescribed CO, HC and NO_x levels set by the government which a vehicle would emit when running on roads. Governments have taken steps to manage and reduce the amount of sulfur dioxide produced by implementing national fuel quality standards. Sulfur levels have been declining in the European Union (EU) since at least 1980. In 2001, the European Commission also proposed a directive calling for the phase-in of "zero sulfur" fuels, which were defined as 10 ppm maximum. The final directive required these near-zero sulfur fuels to be introduced in 2005 and for 10 ppm to be the maximum allowable sulfur level in all transportation fuels by 2009. As of 2006, almost all of the petroleum-based diesel fuel available in UK, Europe and North America is of an Ultra-low-sulfur diesel (ULSD) type.

All the manufacturers need to implement the same for vehicles being manufactured from the date of implementation. In 1988, Europe first introduced heavy-duty (HD) vehicle emission standards. The name "Euro" and standard was introduced in 1992 with increasingly stringent requirements implemented every few years. Roman numerals are used to number the heavy-duty Euro standards, whereas Arabic numbers for light-duty standards. Heavy-duty vehicle testing is performed on engines alone instead of complete vehicles. The standard limits are expressed in terms of g/kWh in case of duty heavy-vehicles and in case of light-duty vehicles and passenger cars limits are expressed in g/km.

Many countries have followed the European standards and their regulations were aligned in large part with it. The United States and Japan have also implemented stricter emission standards related to new heavy-duty engines used in heavy trucks and buses. Outside of Europe most of the countries follow the European model for engine emission certification, including China, Russia, India, Thailand, South Korea and Brazil. Some countries, such as Mexico, allow either U.S. or European-certified engines. The directives of less-developed countries aim to fulfill the Euro IV and Euro V standards. The most important intervening steps in the heavy-duty engine regulation (RHYS-TYLER G.A., LEGASSICK W., BELL M.C. 2011).

A summary of EURO regulation development can be seen in Fig. 1.



	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5
PM	0,36	0,15	0,1	0,02	0,02
HC	1,1	1,1	0,66	0,46	0,46
CO	4,5	4	2,1	1,5	1,5
NOx	8	7	5	3,5	2

Fig. 1. Overview of emission standards.

When Euro IV and Euro V standards were adopted, regulators expected the stringent PM emission standards to require the use of DPFs (Diesel Particulate Filters) in commercial heavy-duty vehicles. However, manufacturers are unable to comply with the Euro IV and V emission standards without the use of DPFs. These manufacturers use selective catalytic reduction to lower tailpipe NO_x emissions to meet Euro IV and Euro V standards. However, this compliance strategy does not reduce emissions of the smallest and most hazardous particles to the same degree as DPFs.

3. Results

Emissions from petrol cars of each pollutant were all observed to display a statistically significant reduction with the introduction of each successive Euro emissions standard from Euro 1 onwards. Generally, the change from Euro 3 to Euro 4 resulted in a smaller reduction in petrol car emissions than earlier changes in Euro standards (for example, from Euro 2 to Euro 3), but the reduction was still measured to be statistically significant. The effect of emission limits of newer Euro standards on air quality is not sustainable, because the tendency of reduction starts to reach its limit. The implementation dates of standards and the change were visualized in logarithm scale in order to better understand the magnitude of improvement (Fig. 2).

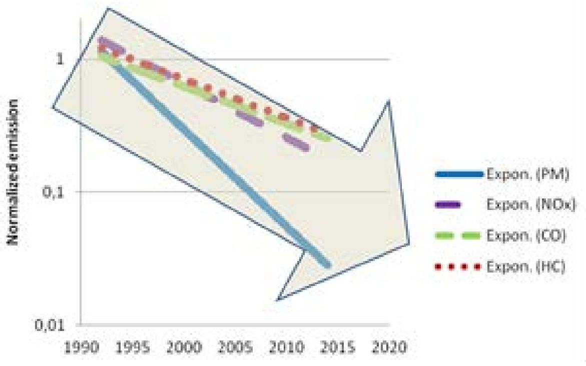


Fig. 2. Improvement of emission standards and their implementation dates, [%].

This trend is particularly prominent in the case of particle mass emission.

4. Discussion

So far nonvolatile particle mass (PM) was used as a measure to measure and limit vehicle emission. Further significant reductions in emission limits couldn't be achieved, therefore new measurement methods had to be introduced. The European Commission introduced a limit for nonvolatile particle number (PN) emissions higher than 23 nm from light-duty (LD) vehicles in 2011, and similar legislation for heavy-duty (HD) vehicles in 2012. Measuring particle number is not possible with the equipment used to measure particle mass, therefore new investments are needed for the EURO VI measurements.

Euro VI emission standards were introduced by Regulation No 595/2009, which was published in 2009. The technical details were specified in the 'comitology' Regulation 582/2011. The new emission limits, comparable in stringency to the US 2010 standards, became effective in 2013 for new type approvals and for all registrations in 2014. Diesel engines have to be tested over the World Harmonized Stationary Cycle (WHSC) and World Harmonized Transient Cycle (WHTC) tests, while positive ignition engines are tested over the WHTC only. EURO VI also describes the ammonia (NH_3) concentration limit of 10 ppm applied to diesel (WHSC and WHTC) and gas (WHTC) engines. The WHTC test is defined by the global technical regulation (GTR) No. 4 developed by the UN ECE GRPE group. The regulation is based on the world-wide pattern of real heavy commercial vehicle use. The two representative test cycles, a transient test cycle (WHTC) with both cold and hot start requirements and a hot start steady-state test cycle (WHSC), cover typical driving conditions in the EU, USA, Japan and Australia. The WHTC is a transient test of 1800 s duration, with several motoring segments. Normalized engine speed and torque values over the WHTC cycle are schematically shown below.

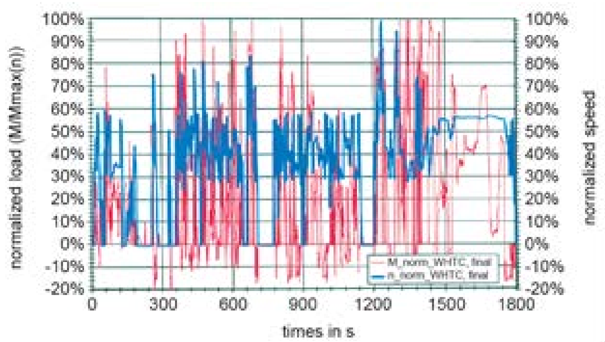


Fig. 3. World Harmonized Transient Cycle (WHTC).

A maximum limit for the NO_2 component of NO_x emissions will be defined in the implementing regulation. Euro VI regulation introduced a new off-cycle emissions (OCE) testing and In-Service Conformity Testing (in-use testing). EU Member States are allowed to use tax incentives in order to stimulate marketing and sales of vehicles meeting new standards ahead of the regulatory deadlines. However, the use of incentives is contingent upon the following:

- They apply to all new vehicles offered for sale on the market of EU Member States that comply in advance with the mandatory limit values set out by the directive.
- They terminate when the new limit values come into effect.
- They must not exceed the additional cost of the technical solutions introduced for each type of vehicle. This is to ensure compliance with the limit values.

5. Conclusion

Vehicle manufacturers have utilized a range of exhaust treatment technologies to achieve compliance with the increasingly stringent type approval limits.

However, laboratories also have to adapt to these new conditions.

Emission	Euro 1 1992	Euro 2 1996	Euro 3 2000	Euro 4 2005	Euro 5 2009	Euro 5+ 2011	Euro 6 2014
CO, THC, NOx, CO2	✓						
Diluted Hot THC – CI only („Diesel")	✓						
Particulate Mass – CI only („Diesel")	✓						
NMHC					✓		
Particulate Mass – PI-GDI only					✓		
Particle Number – CI only („Diesel")						✓	
CO2 Limit						✓	
Particle Number – all PI („Gasoline")							(✓)

Fig. 4. Overview of measurement technology.

The new method in measurement requires investment. **Furthermore, not only the dynamometer and a NO_X analyser need to be implemented for high capital costs but measurement techniques to measure particulate number as well**. In the European particle number measurement, only solid particles are measured and nucleation is prevented by adequate pretreatment.

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