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THE DEVELOPMENT OF REGULATIONS ON APPROVED HARMFUL SUBSTANCES EMISSIONS FROM IC ENGINES

Abstract

The paper describes the development of regulations on approved harmful substances emissions from internal combustion engines in Europe from the year 1970 till today, and it also emphasizes their development in the future. Apart from legally restricted use of harmful substances emissions, it also discusses the requirements for fuels which need to be met according to Euro 5 and 6, as well as the CO_2 emission, which is not restricted by the law but it is the greenhouse gas covered by the Kyoto Protocol.

A considerable progress has been made in reducing the harmful substances emissions by the constant improvement of cleaning techniques of gas emissions and by the use of more quality fuels. Here we need to emphasize that the quality of fuels required by the Worldwide Fuel Charter – WWFC, which represents the wishes of engine manufacturers, differs from the quality of fuels required by the EU regulations. The development of the future regulations on the emissions and the requirements on the quality of fuels combines the desires and possibilities of engine and vehicle manufacturers, fuel manufacturers, politics, legislation and the pressure of the green activists. The fact that the EU depends on the fuel import and stands out as the leader in the field of alternative fuel use and bringing new, more stringent regulations on harmful substances emissions has a great impact on the body behind the new regulations in the EU.

Introduction

Fuel combustion in the engines of road vehicles produces the exhaust gases containing more than a hundred different compounds which are harmful for the environment and human health. Homologational regulations (in Europe ECE – regulations[1] and EEC - directives[2]) determined the approved limits of harmful

[1] *Economic Commission for Europe (UN)*
[2] *European Economic Community*

substances emissions and prescribed test method for the following harmful components: carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxides (NO_X). With compression ignition engines (diesel engines) there is an additional limit for the quantity of PM (Particulate Matter; most of which is soot), opacity of exhaust gases and non-methane hydrocarbons (NMHC). With vehicles to run on compressed natural gas, there is also a methane (CH_4) limit in the exhaust gases. The quantity of volatiles that are exhausted in the environment from the container and the fuel system has also been limited. Generally, the reduction of harmful substances emissions is conducted by the constant improvements of the combustion process in an engine cylinder, the treatment of exhaust gases after they come out of the engine, improving the fuel quality (primarily by sulphur content reduction), reducing driving resistance and optimizing engine and vehicle management.

Approved emissions of harmful substances

At first only the emission of CO from the exhaust gas systems was limited in Europe and from 1970 the HC emission is also limited. From 1977 the NO_X emission is limited (at first just for the external combustion engines-Otto engines), and from 1988 the quantity of particulate matter (PM) with diesel engines is limited. From 1992 certain levels of approved emissions for harmful substances are called Euro.

Table 1: Maximum approved quantities (g/km) of certain harmful substances in the exhaust system of engines from M1 vehicle category [1]

	Entry into force	CO	HC	HC+NO_X	NO_X	PM
Diesel			(g/km)			
Euro 1	1992/07	3,16	-	1,13	-	0,18
Euro 2, IDI	1996/01	1,00	-	0,70	-	0,08
Euro 2, DI	1996/01	1,00	-	0,90	-	0,10
Euro 3	2000/01	0,64	-	0,56	0,50	0,05
Euro 4	2005/01	0,50	-	0,30	0,25	0,025
Euro 5	2009/09	0,50	-	0,23	0,18	0,005
Euro 6	2014/09	0,50		0,17	0,08	0,005
Otto			(g/km)			
Euro 1	1992/07	3,16	-	1,13	-	-
Euro 2	1996/01	2,20	-	0,50	-	-
Euro 3	2000/01	2,30	0,20	-	0,15	-
Euro 4	2005/01	1,00	0,10	-	0,08	-
Euro 5	2009/09	1,00	0,10	-	0,06	0,005
Euro 6	2014/09	1,00	0,10	-	0,06	0,005

The Table 1 shows that Euro 5 and 6 requirements, which are still to enter into force, aim to achieve additional emission reduction of NO_X and particulate quantity of both Otto and diesel engines. It needs to be emphasized that the reduction is more intensive with diesel engines.

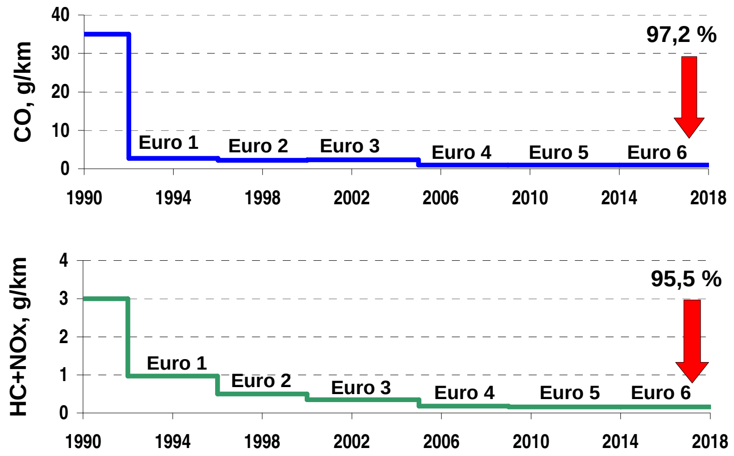

Figure 1: Emission reduction of Otto engines from M1 vehicle category

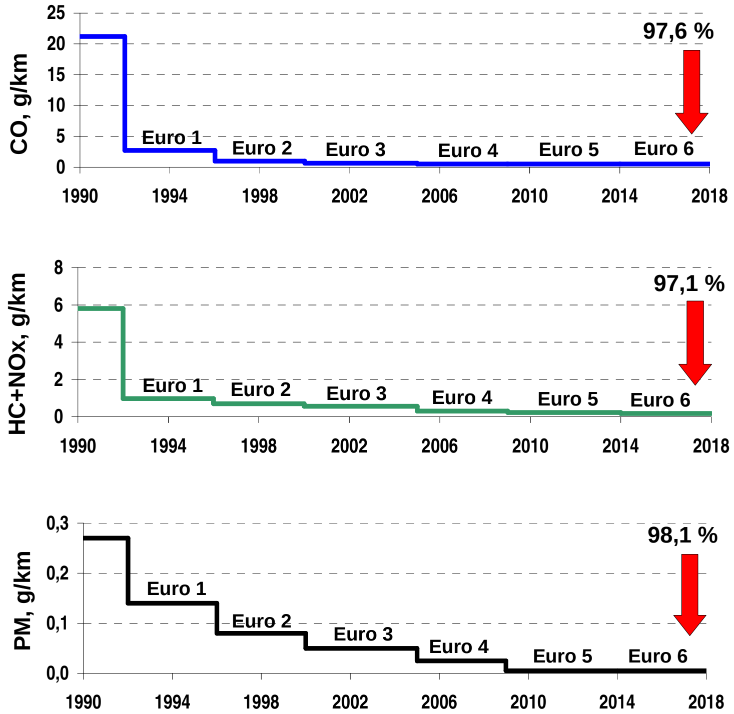

Figure 2. Emission reduction of diesel engines from M1 vehicle category

Figures 1 and 2 show reduction of harmful substances emission for M1 vehicle category. Euro 1 entered into force in 1992, and in the literature Euro 0 usually marks the maximum approved quantity of harmful substances before that period. The Euro 0 levels in diagrams are gained by the supplemental tests conducted on these vehicles and recalculated into current standards. Similar scales of reduction of approved emissions such are these in the Picture 2 are also achieved in other vehicle categories.

CO_2 emission reduction

Carbon dioxide (CO_2) is not poisonous and thus its emission is not legally limited, but as the greenhouse gas it effects the global warming. By accepting the UN agreement on the climate change from Kyoto (1997), the preconditions for the reduction of greenhouse gases emission were made. According to the European Environment Agency (EEA) in 15 EU countries 19 % of total greenhouse gases emission originated from the traffic in 2005. In order to reduce that, the EU prescribed by the Directive 2003/30 that 5,75 % of fossil fuels in the traffic should be substituted with fuels from renewable sources by the year 2010, and ACEA[3] set a goal to achieve CO_2 emission of 140 g/km for that year, and in 2012 it should be 120 g/km. This emission is expressed for the whole fleet of manufactured automobiles of a certain manufacturer in the current year. The Japanese and Korean manufacturers JAMA[4] i KAMA[5] will achieve 140 g/km in 2009.

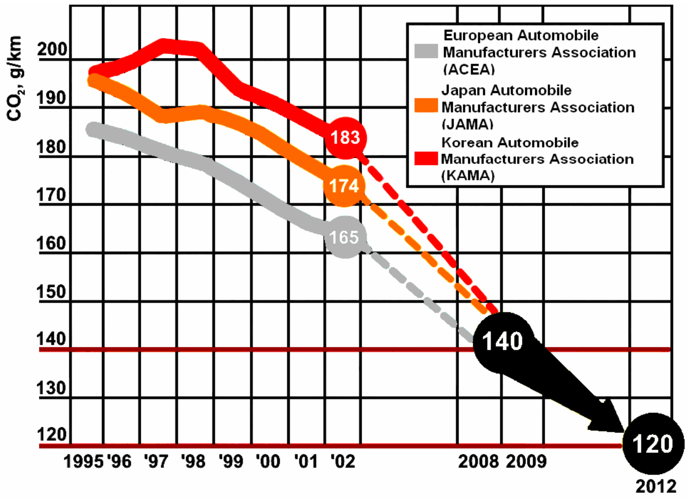

Figure 3: Goals of automobile industry in CO_2 emission reduction [2]

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[3] ACEA - *Association des Constructeurs Européens d´Automobiles*
[4] JAMA - *Japan Automobile Manufacturers Association*
[5] KAMA - *Korean Automobile Manufacturers Association*

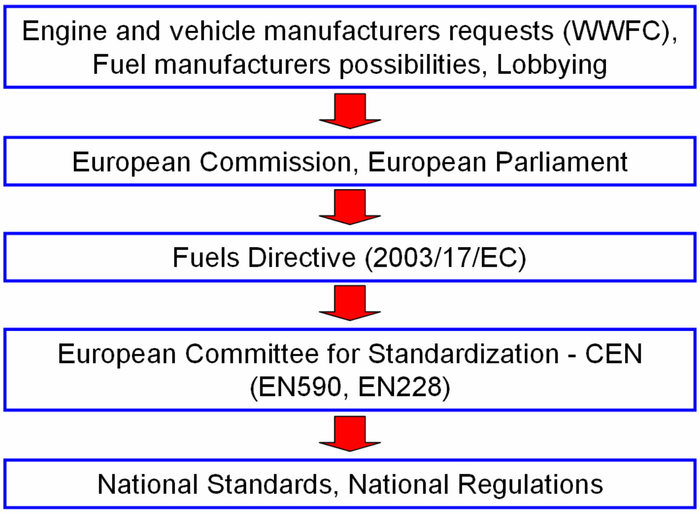

Figure 4: Establishing regulations on the fuel quality

Fuel

Any fuel which is placed on the EU market needs to comply with the regulations prescribed by the EU legislative bodies as a result of the agreement between engine and vehicle manufacturers and fuel manufacturers.

Requirements of automobile manufactures

Emissions of harmful substances from the exhaust gas systems of motor vehicles depend on the vehicle technological level and the fuel quality. Each fuel of any quality (Euro 1, 2, 3, …) needs to comply with the legislative requirements. The Worldwide Fuel Charter (WWFC) sums up the requirements of engine and vehicle manufacturers concerning fuel properties. The WWFC suggests four categories of petrol and diesel fuel, separately, with properties complying with technological levels of engines and vehicles within different legislative requirements for harmful substances emission all around the world. The WWFC is based on comprehensive negotiations among its members (associations of automobile manufacturers from all around the world). Among all the properties defining the fuel quality, the sulphur content is most emphasized. Problems caused by sulphur have first been noticed with diesel engines since it leads to increased soot concentration which results in black smoke coming out of engine exhaust pipe under high load. The debates on sulphur in the petrol started at the beginning of 1990's and in 1992 the EU proposed the sulphur content limit in future petrol, and these limits were introduced only in 1996. The properties of Euro 5 and Euro 6 comply with the requirements of the 4th category according to the WWFC (Table 2). The Tables 3 and 4 show the properties of petrol and diesel fuels arranged in four categories.

Table 2: Fuel distribution in four categories and sulphur content as proposed by Worldwide Fuel Charter 4th Edition, 2006

		Category 1	Category 2	Category 3	Category 4
Emission requirements level →		None or first degree, Tier 0, Euro 1	Tier 1, Euro 2 ili 3	US/Cal LEV or ULEV, Euro 3 JP 2005	Tier 2, Cal LEV II, Euro 4, HD (US 2007/10, non-road Tier 4, Euro 5)
EU → (petrol)	(1000)[6]	Euro 2 (1996.) 500	Euro 3 (2000.) 150	Euro 4 (2005.) 50	(Euro 5; 2009.[7]) (10)
S (mg/kg) BENZIN		1000	150	30	10
S (mg/kg) DIESEL		3000	300	50	10
EU → (diesel)	EU 1993 2000 EU 1987: 3000	Euro 2 (1996.) 500	Euro 3 (2000.) 350	Euro 4 (2005.) 50	(Euro 5; 2009.) (10)
Use →		Market without or with the first level of harmful emission regulation, primarily based only on basic emission regulation systems.	Market with mild regulations connected with harmful emission regulation or other market requirements.	Markets with advanced requirements connected with harmful emission regulation or other market requirements.	Markets with future advanced requirements connected with harmful emissions, providing the use of advanced technology for exhaust gases treatment (emission reduction of NO_X and particulates) (including engines with direct injection with lean mixture).

[6] Sulphur content in Germany by the mid-1970's.

[7] The directive 2003/17/EC prescribes the sulphur content of 10 mg/kg in petrol and diesel fuel by 1 January 2009.

Table 3: The 4th category petrol properties [3]

PROPERTIES	UNIT	LIMIT	
		Min	Max
91 RON – research octane number	-	91	
– engine octane number		82.5	
95 RON – research octane number	-	95	
– engine octane number		85	
98 RON – research octane number	-	98	
– engine octane number		88	
Oxidation stability	min	480	
Sulphur content	mg/kg (ppm)		10
Metal content (Fe, Mn, Pb, other)	mg/l	not measurable by test method	
Phosphorus content	mg/l	not measurable by test method	
Silicium content	mg/kg	not measurable by test method	
Oxide content	%		2.7[8]
Olefine content	%		10
Aromate content	%		35
Benzene content	%		1
Sludge	mg/l		1
Density	kg/m^3	715	770
Injector cleanness, Method 1	% flow loss		5
Injector cleanness, Method 2	% flow loss		10
Air throttle cleanness 2			
Method 1 (CEC F-05-A-93) or	approximately mg/vent		30
Method 2 (ASTM D 5500) or	approximately mg/vent		50
Method 3 (ASTM D 6201)	approximately mg/vent		50
Deposits in combustion chamber			
Method 1 (ASTM D 6201) or	% basic fuel		140
Method 2 (CEC-F-20-A-98) or	mg/engine		2500
Method 3 (TGA FLTM BZ154-01)	% of weight at 450°C		20

EU regulations on fuel quality

Basic petrol and diesel properties in the EU are regulated by the Directive 2003/17/EZ. Fuels on the European market have to comply with EN228 and EN590 requirements prescribed by the CEN (European Committee for Standardization), which are coordinated with the Directive 2003/17/EZ.

Device for exhaust gas treatment

The Euro 5 requirement implementation becomes obligatory in 2009. When compared with Euro 4, Otto engines in M1 vehicle category have reduced approved

[8] Methanol is not allowed, maximum alcohol content is 0.1%. Eters are prefered..

limit emission of NO_X and for the first time the quantity of particulates in the exhaust gases are limited, and with diesel engines the approved quantity of particulates and NOx emission is reduced. The Euro 6 requirements will enter into force in 2014 and only with diesel engines they additionally reduce the approved emission of NO_X (Table 1). From the perspective of current technology, the additional exhaust gas treatment system needs to be built in.

Table 4: The 4th category Diesel fuel properties [3]

PROPERTIES	UNIT	LIMIT	
		min	Max
Cetane number		55	
Cetane index		55 (52)	
Density na 15°C	kg/m³	820	840
Viscosity na 40°C	mm²/s	2	4
Sulphur content	mg/kg		10
Metal content (Zn, Cu, Mn, Ca, Na...)	g/l	not measurable by test method	
Total contents of aromates	%		15
Content of PAH (di+, tri+)[9]	%		2
T90[10]	°C		320
T95[11]	°C		340
Final boiling point	°C		350
Ignition point	°C	55	
Carbon residue	%		0.2
CFPP[12]	°C	Maximum has to be equal or lower than the surrounding temperature	
Water content	mg/kg		200
Oxidation stability	g/m³		25
Foam volume	ml		100
Foam disappearing time	s		15
Fatty ethyl esters content	%	not measurable by test method	
Methanol/ethanol content	%	not measurable by test method	
Iron corrosion			Weak rusting
Ash content	%		0.001
Particle content in fuel	mg/kg		10
Fuel injectors cleanness	% air flow loss		85
Lubrication	micron		400

[9] Polyaromatic hydrocarbons
[10] Temperature in 90 % destilation
[11] Temperature in 95 % destilation
[12] The lowest temperature allowing fuel through the filter

Table 5: Petrol properties requirements according to EN228 [4]

PROPERTIES	UNIT	LIMIT min	LIMIT Max
91 RON – research octane number – engine octane number	-	91 82.5	
95 RON – research octane number – engine octane number	-	95 85	
98 RON – research octane number – engine octane number	-	98 88	
Oxidation stability	min	360	
Sulphur content	mg/kg (ppm)		150
Metal content (Fe, Mn, Pb,…)	mg/l	not measurable by the test method	
Phosporus content	mg/l	not measurable by the test method	
Silicium content	mg/kg	not measurable by the test method	
Oxide content	%		2.7
Olefine content	%		18
Aromate content	%		42
Benzene content	%		1
Deposit	mg/l		5
Density	kg/m³	715	720-755

Table 6: Requirements for diesel fuel properties according to EN590 [5]

PROPERTIES	UNIT	LIMIT min	LIMIT max
Cetane number		51	
Cetane index		46	
Density at 15°C	kg/m³	820	840
Viscosity at 40°C	mm²/s	2	4,5
Sulphur content	mg/kg		50
PAH content (di+, tri+)	%		11
T95	°C		360
Final boiling point	°C		350
Ignition point	°C	55	
Carbon residue	%		0.3
Water content	mg/kg		200
Oxidation stability	g/m³		25
Foam volume	Ml		100
Foam disappearing time	S		15
Fatty ethyl esters content	%	5	
Ash content	%		0.01
Particle content in the fuel	mg/kg		24
Lubrication	Micron		460

Elements for exhaust gas treatment of Otto engines

Otto engines with utterly stehiometric mixture ($\lambda = 1$) use three-way catalyst which reduce CO, HC and NO_X, while those with lean mixture ($\lambda_{max} \approx 3$) also use adsorber catalyst. Today these devices are highly developed, and they tend to extend their durability and to reduce production costs.

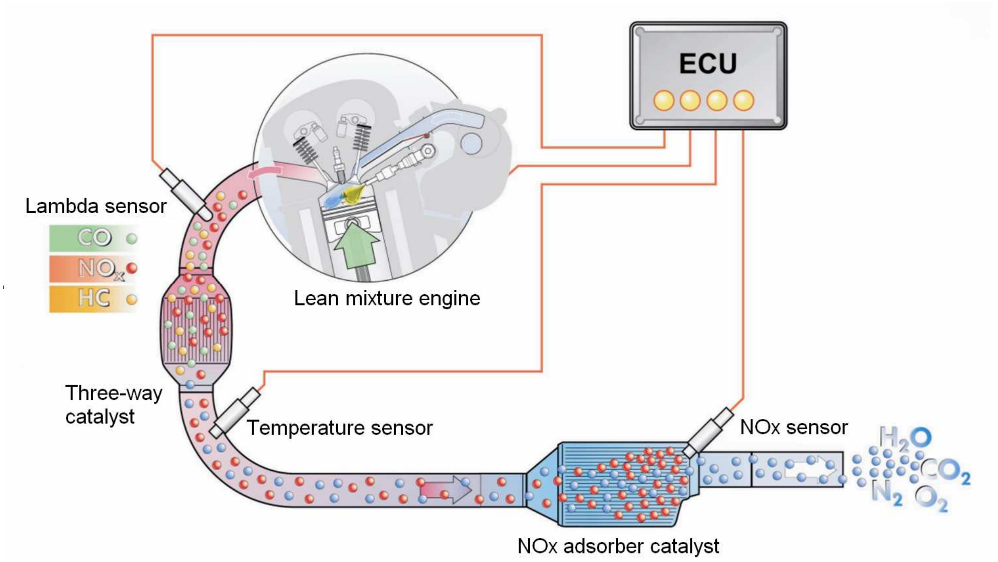

Figure 5: Scheme of exhaust gas treatment system of Otto engine Euro 5 (Euro 6) with two catalysts: three-way catalyst (for CO, HC, NOx) and adsorber catalyst (for NOx) [2]

Elements for exhaust gas treatment of diesel engines

Since diesel engines operate with lean mixtures ($\lambda > 1$), the combustion is almost complete, so the emissions of CO and HC are very low. The main problem are solid particulates (soot) and nitrogen oxides (NO_X).

The Picture 6 shows the construction of the exhaust gas system of diesel engines complying with the Euro 5 requirements. Diesel oxidation catalyst (DOC) is used for the reduction of NOx in the exhaust gas systems of diesel engines. Since these engines work with great air glut, the three-way catalyst which is used with Otto engines meet requirements for the reduction of NO_X. Diesel particulate filter (DPF) is used for the reduction of particulate quantity, and a device for exhaust gas recirculation (EGR) or significantly more efficient device for selective catalytic reduction (SCR) is used for the reduction of NOx content.

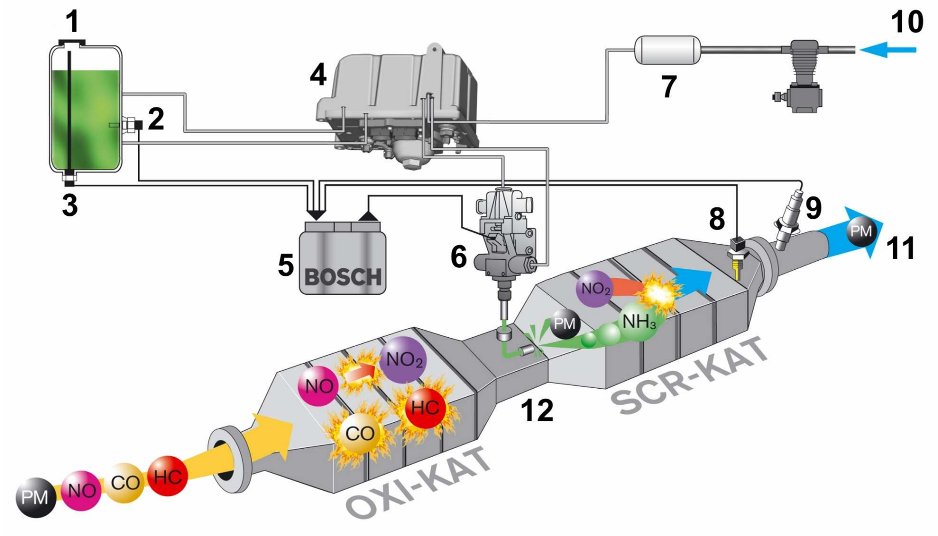

Figure 6: Scheme of exhaust gas treatment system of diesel engines Euro 5

Labels: 1-urea solution container (AdBlue), 2-temperature sensor, 3-full container detector, 4-supply module, 5-steering device, 6-dosing module, 7-air container, 8-temperature sensor, 9-exhaust gas sensor, 10-air intake, 11-treated exhaust gases, 12-diffuser pipe.

The Figure 7 shows the scheme of the exhaust gas treatment system of diesel engine which will have to comply with Euro 6 requirements for harmful substances emission. Oxidation catalyst (DOC) serves to reduce the quantity of NO_X in the exhaust system, soot particle filter (DPF) serves to store particles and subsequently to burn them, SCR+ASC catalyst (Selective Catalytic Reduction + Ammonia Slip Catalyst) serves to reduce NOx.

The European commission estimates that the vehicle price increase due to transfer from Euro 4 to Euro 5 is 377 € for a vehicle with diesel engine, and 51 € for a vehicle with Otto engine [6.]

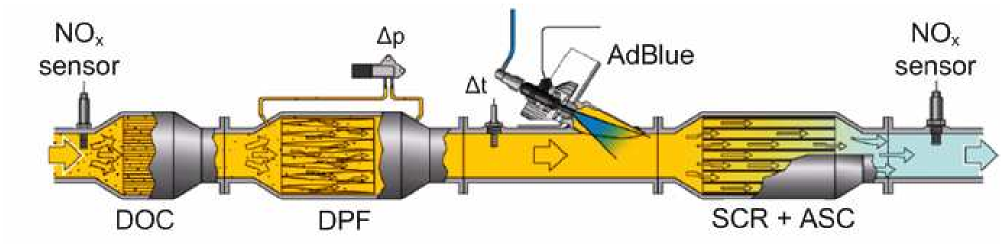

Figure 7: Scheme of Euro 6 exhaust gas system of diesel engine Euro 6

Regulated minimum durability of a device for exhaust gas treatment is from 100000 km or 5 years for vehicles of M1 categories complying with Euro 5 regulation, and after Euro 6 regulation entering into force in 2014 these limits will be increased to 160000 km or 5 years.

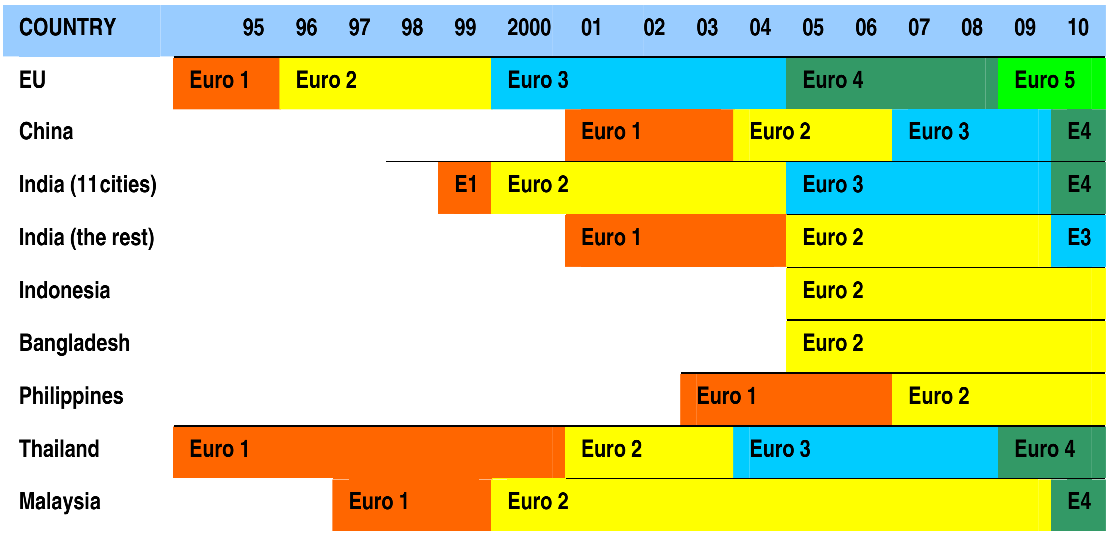

Figure 8: Asian countries follow the EU by making regulations which are equivalent to the European ones [7]

EU – leader in regulations

The EU is one of the leaders in the field of environmental protection and it has the most stringent regulations relating harmful substances emission from internal combustion engines. The EU standards connected with harmful substances emission IC engines are followed by all the Asian countries (except Japan, South Korea and Taiwan), with the 5-8 year implementation postponement.

The lawmakers have to deal with the fact that there are three billion people living in these Asian countries, which is six times more when compared with 500 million people living in 27 EU member states. The European manufacturers are in great advantage when setting new standards, the new technologies are first used in the domestic EU market, and when a certain technology is fully developed and when the manufacture costs are reduced, it becomes an excellent export product for this huge market making almost a half of the world population.

EU and the need for energy independence

The biggest portion of the fossil fuels in the EU market is imported, and it is expect that this dependence will grow. Greater energy independence of the EU is a very important long-term goal of all member states because of the high price of crude oil and unstable political situation in the world, which can always result in reduced energy supply.

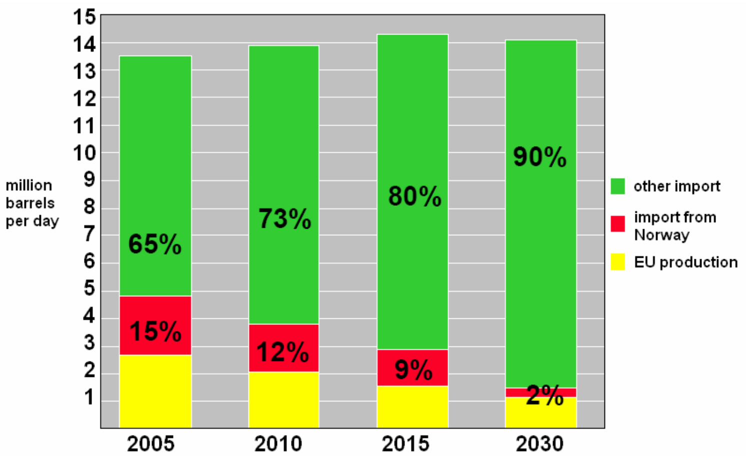

Figure 9: Current and estimated dependence of the EU on oil import [8]

Fuels from renewable sources are expected to reduce this dependence on the import, at certain extent. Increasing the portion of renewable fuels is also a necessary contribution in the combat with global climate changes since these renewable energy sources have a very important role in the reduction of carbon dioxide emission.

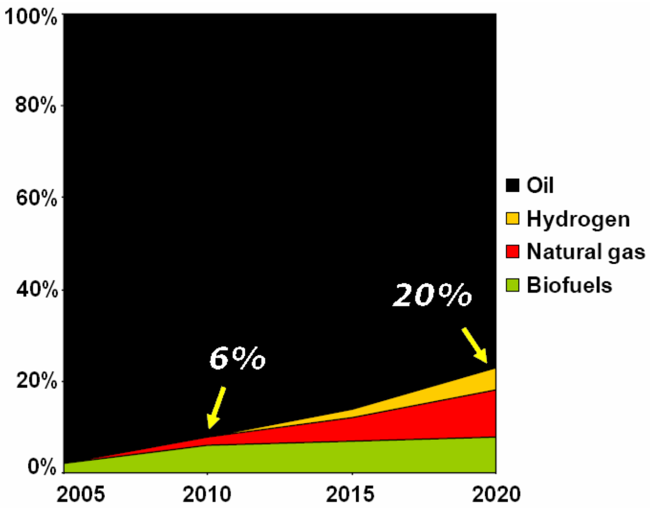

Figure 10: Predictions of portion percentage of alternative fuels in the EU transport

Although, the fossil fuels will still be dominant fuels for motor vehicles in the next twenty years, the EU member states set an ambitious goal to increase portion of fuels from renewable sources, and therefore the portion of biofuels in the traffic should reach 5,75 % by 2010, and even 10 % by 2020.

Conclusion

The necessary preservation of the environment and human health leads to increasingly stringent requirement considering approved limits of harmful substances emissions from the engine. With the constant improvement of combustion process in the engine cylinder, the improvement of the existing or development of new exhaust gas treatment systems and optimizing engine and vehicle management, the fuel quality has lately become one of the important factors needed to comply with these stringent requirements. Therefore, the fuel has become an important parameter in the engine construction, and especially in the exhaust gas treatment system.

The development of the future regulations on value limits of harmful substances emission is under pressure of politics and green activists trying to lower these limits on one hand, and engine and vehicle manufacturers and fuel manufacturers trying to resist it on the other hand. Furthermore, engine and vehicle manufacturers and fuel manufacturers have different views on the fuel quality which is needed for complying with the emission requirements, both aiming to reduce production costs..

Literature

1. European emission standards - cars and light trucks, www.dieselnet.com
2. Mahalec I., Lulić Z., Šagi G., Štetne emisije motora s unutarnjim izgaranjem i pročišćavanje ispušnih plinova, interna skripta, FSB, Zagreb, 2007
3. Worldwide Fuel Charter, 4th edition, 2006, http://www.acea.be/images/uploads/pub/Final%20WWFC%204%20Sep%202006.pdf
4. EN 228, europska norma o kvaliteti benzina, 2004
5. EN 590, europska norma o kvaliteti dizelskog goriva, 2004
6. European Federation for Transport and Environment, Euro 5 and 6 emissions standards for cars and vams, 2006, www.transportenvironment.eu
7. Worldwide Emissions Standards, Passenger Cars & Light Duty Trucks, Delphi, 2008, www.delphi.com
8. Beate R., European production and security of supply, Fossil Fuels Forum, Berlin, 2007

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