SADRŽAJ – CONTENS

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APPLICATION OF MODERN SYSTEMS FOR AFTER TREATMENT OF EXHAUST GAS OF AGRICURTULAR ENGINES

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ABSTRACT

In the paperwork had been observed nessesery steps in the introduction of diesel engines final production application in the last ten to twenty years, it can be clearly concluded that their development is significantly dictated by the legal regulations on permitted exhaust emissions. In order to meet these regulations, successively with the introduction of increasingly stringent requirements, improvements were made to the engine and its systems in order to reduce the emission of toxic components below the prescribed limits, ie to meet them. The biggest problem was achieving the required emission levels of PM particles and nitrogen oxides NOx. This is all the more so because the requirements for reducing these components were very often contradictory, ie solutions that reduced particulate emissions most often increased the emission of nitrogen oxides.

Key words: diesel engine, exhaust emission, application of afthertreatment methodology

INTRODUCTION

During the 90s of the last century, another step was done on improving the combustion process and the formation of the mixture from the aspect of the desired improvement of energy thermodynamic efficiency of the engine and thus achieving optimal regulation of combustion rules. Therefore, the introduction of advanced technologies, additional systems and devices on the engine had to be approached in order to reduce the emission of nitrogen oxides and particulate matter.

Such supplementary systems prevented the formation of toxic components during the process in the operating (combustion chamber), and significantly reduced their concentration after leaving the engine exhaust system. The first group includes exhaust gas recirculation (EGR) systems, while the second group includes subsequent exhaust gas treatment systems such as oxidation catalysts and diesel particulate traps, such as the DPF-diesel particulate filter. Unfortunately, it was shown very early on that only the improvement of the combustion process and the formation of the mixture, preferably in order to improve the thermodynamic energy efficiency of the engine, was not enough. Therefore, it was necessary to introduce

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additional systems and devices on the diesel engine in order to reduce the emission of nitrogen oxides and/or particles. These supplementary systems either most commonly prevented the formation of toxic constituents during the process in the engine workspace or eliminated or reduced their concentration after their expulsion from the engine.

USA 2010, US HDTC, ESC
Tier 4, NRTC
Europe 2013, ESC, ETC, proposal for EU 6

Component	Emission limit [g/kWh]	Efficiency of aftertreatment system [%]	Engine-out devel. target [g/kWh]
PM USA	0.013	90	0.1
PM Japan *	0.01	90	~0.08
PM Europe *	0.01	90	0.08
NOx USA	0.27	80 - 85	1.0 - 1.4
NOx Japan *	0.70	65 - 70	~1.5
NOx Europe *	0.3 - 0.4	85 - 90	1.6-2.4 (for 0.3 limit)

* not yet fixed

Fig. 1. Limits of road and non-road engines and required emission at the exit of the engine without further treatment[2]

Figure 2 shows the influence of the EGR system on the NOx and PM concentration in the engine cylinder. Namely, in order to achieve extremely strict requirements after 2013, regardless of all the very subtle and expensive improvements of diesel engines, the subsequent treatment had to eliminate about 90% of particles and about 80% of nitrogen oxides.

EXHAUST GAS RECIRCULATION

One of the very effective solutions for reducing the emission of nitrogen oxides NOx is the use of exhaust gas recirculation (EGR). By diluting the fresh charge with residual inert gases, it reduces the maximum temperature of the combustion products, which slows down the formation of NOx. At the same time, even a small amount of inert recirculated gases significantly reduces NOx emissions. Since the dilution of fresh charge in principle reduces engine power and increases smoke emissions, recirculation is not switched on at full load, ie then EGR = 0%. There is no damping at partial diesel engine loads, so a small amount of fuel is injected into a larger amount of air, which means that a significant amount of exhaust gas can be introduced, so that at low diesel engine loads, the recirculation percentage goes up to EGR = 50% [2].

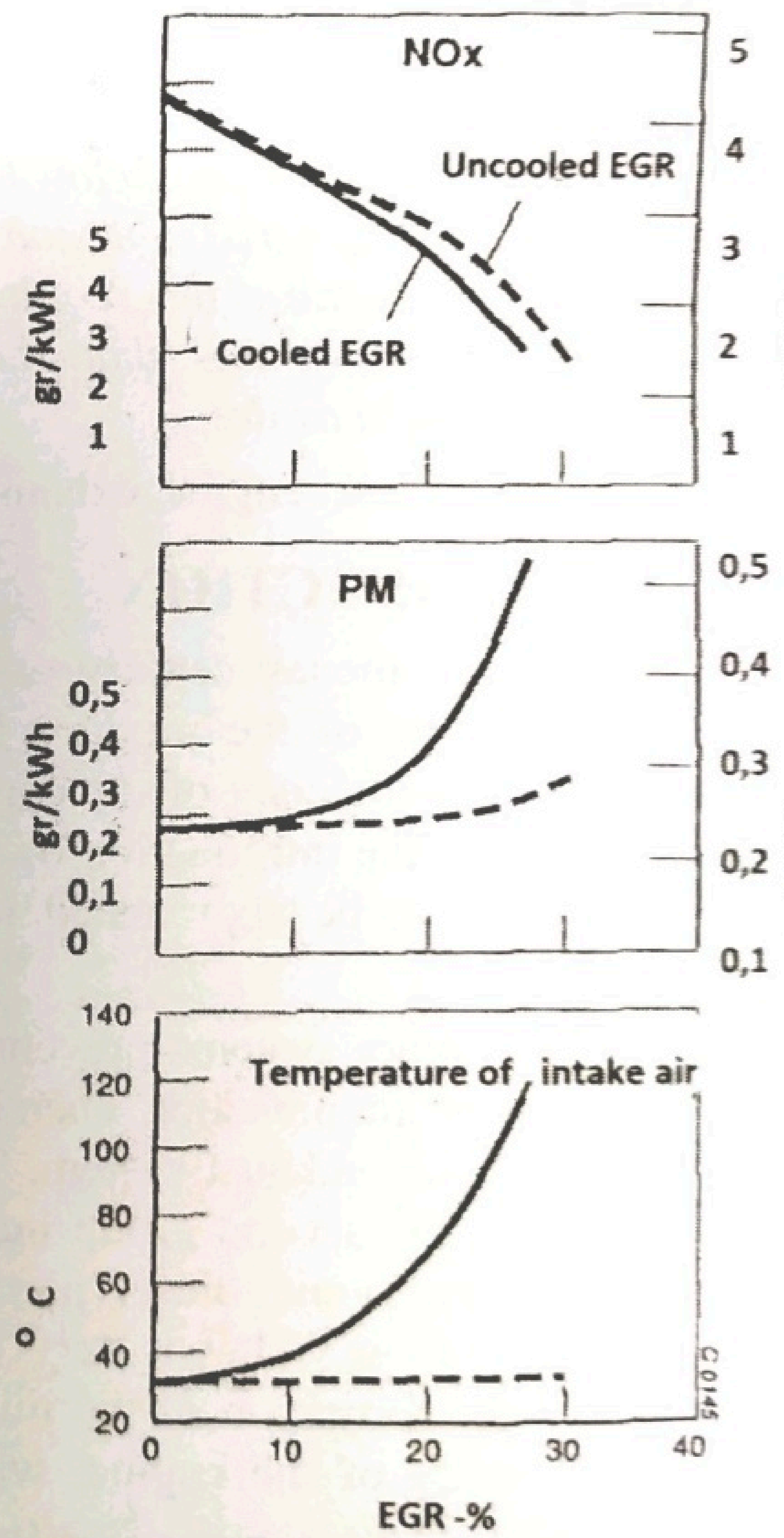

Fig. 2. Effect of refrigerated and uncooled EGR exhaust gas recirculation to reduce NOx[2]

Since the addition of hot exhaust gases accelerates the formation of soot, if uncooled recirculation is used, the emission of particles increases. Therefore, with diesel engines, the use of cooled recirculation is a much more favorable solution, ie before the introduction of recirculated exhaust gas into the intake pipe, it should first be cooled (usually with engine coolant, but it is also possible with ambient air). Figure 2 shows the effect of uncooled recirculation. A distinct effect of recirculation on NOx emissions can be seen: at 20% recirculation, the NOx reduction is about 50%. At higher percentages of recirculation, however, there can be a significant increase in particulate emissions. But cooling the recirculated gas can significantly mitigate this negative effect, although then there may be a slight deterioration in NOx emissions due to lower temperatures during the ignition delay, which increases its length, increases the amount of fuel injected during the first phase of latent combustion and more rapid combustion in the second phase, (rapid combustion) which leads to a slight increase in maximum temperature. Nevertheless, intercooling of the recirculated gas is very important to prevent an increase in particulate emissions while significantly reducing NOx emissions. At the same time, as it was said, it is important to achieve (by electronic) control the amount of recirculation from zero at full load to full at low loads.

Subsequent exhaust gas afther treatment

However, legislation after 2015 is difficult to achieve (without loss of power) without subsequent exhaust gas treatment. Reduction of emissions of gaseous pollutants CO, HC and NOx) can be achieved by the use of catalysts, while the emission of particles can only be effectively reduced by a filter (particle trap).

The oxidation catalyst can be very efficient in diesel engines because it works with a lean mixture so there is always enough air for subsequent oxidation. The problem is that it also needs a temperature of over 300 °C, so its efficiency in terms of CO and HC conversion is relatively good and is about 60 to 80%, while the efficiency of reducing particulate emissions is only 20%. Therefore, this catalyst is mostly used as a supplement to other solutions. The construction of the catalyst is similar to that of gasoline engines: a ceramic monolith in the form of tubes with a base of AL_2O_3 on which a micron layer of precious metal (Pt, Rh, etc.) is applied. Diesel engines for forklifts also use a catalytic converter with ceramic balls coated with a carrier and catalytic layer.

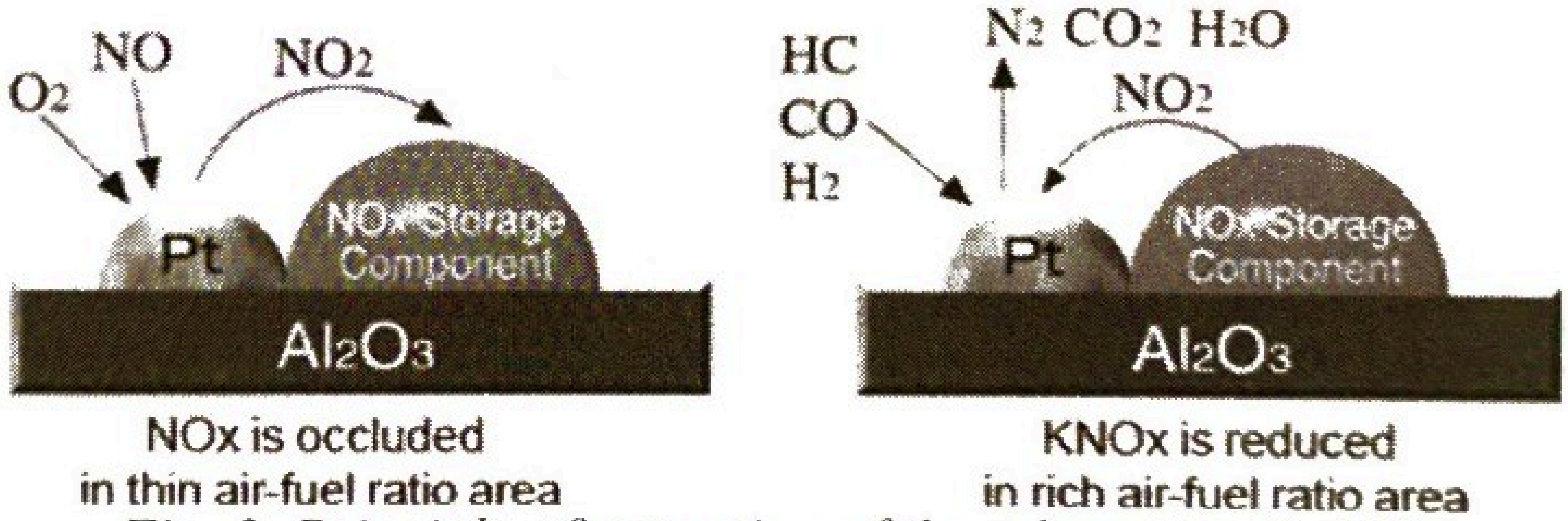

Fig. 3. Principle of operation of the adsorption DeNOx catalyst[2]

Since the problem with diesel engines is NOx emissions, and the diesel engine runs on a lean mixture so that there is no reducing medium necessary to eliminate NOx, it would be useful to use a catalyst that can reduce NOx emissions in the lean mixture. This role can be performed by the previously mentioned absorption catalyst, ie the so-called DeNOx Catalyst. In this catalyst there is another coating based on barium salts that absorb nitrogen oxides NOx. After saturation of the catalyst, short-term fuel injection is performed (subsequent injection into either the exhaust system, or, in modern engines, into the cylinder at the end of expansion to create a reduction medium suitable for NOx elimination. Although the exhaust gas temperature corresponds to DeNOx catalyst (range 300 up to 500 °C), its efficiency is relatively low (maximum up to about 60%), and sulfur from diesel fuel especially reduces its efficiency, which is why its application on diesel engines is still quite rare.

The so-called diesel engine is especially interesting. "SCR catalyst", ie a catalyst that selectively reduces components from the exhaust gas by eliminating only NOx. Its chemical principle of operation is shown in Figure 4. Namely, NOx reduction is performed using ammonia NH_3, which is introduced into the catalyst by injecting a certain amount of urea (NH2) 2CO into the exhaust system in the form of an aqueous solution (commercial designation in Germany). "Ad Blue") from a special tank on the vehicle. Urea decomposes in the hydrocatalyst and releases ammonia NH_3 with the help of exhaust gas steam. The operating temperature range of SCR catalysts is from 200 to 550 °C, and the conversion efficiency is up to 70%. One of the problems of using urea as a reducer is the necessary elimination of excess NH_3 from the exhaust gas and the provision of a urea dosing system to the exhaust gas.

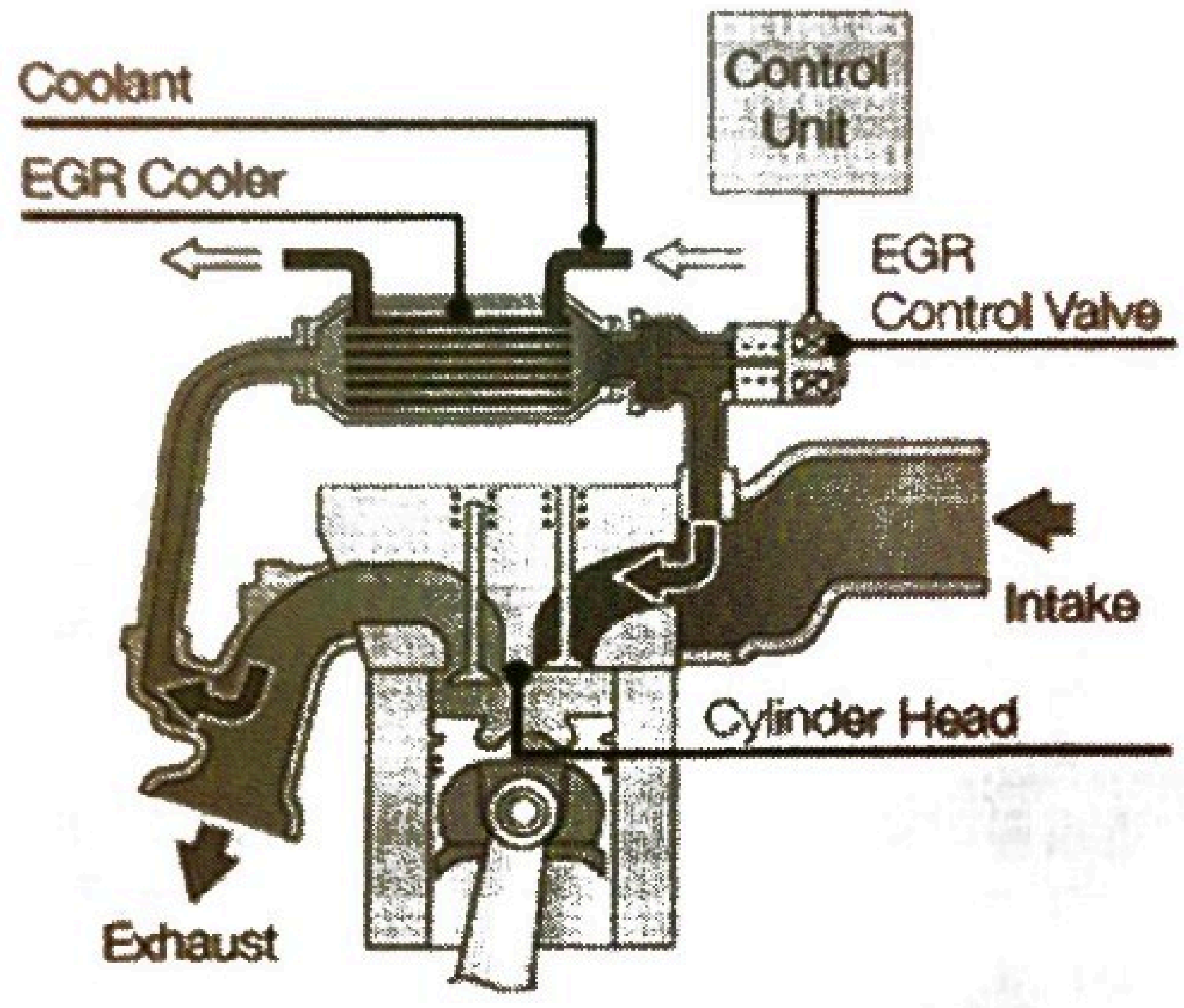

Fig. 4. Shematic of ehxaust gas afther treatment [5]

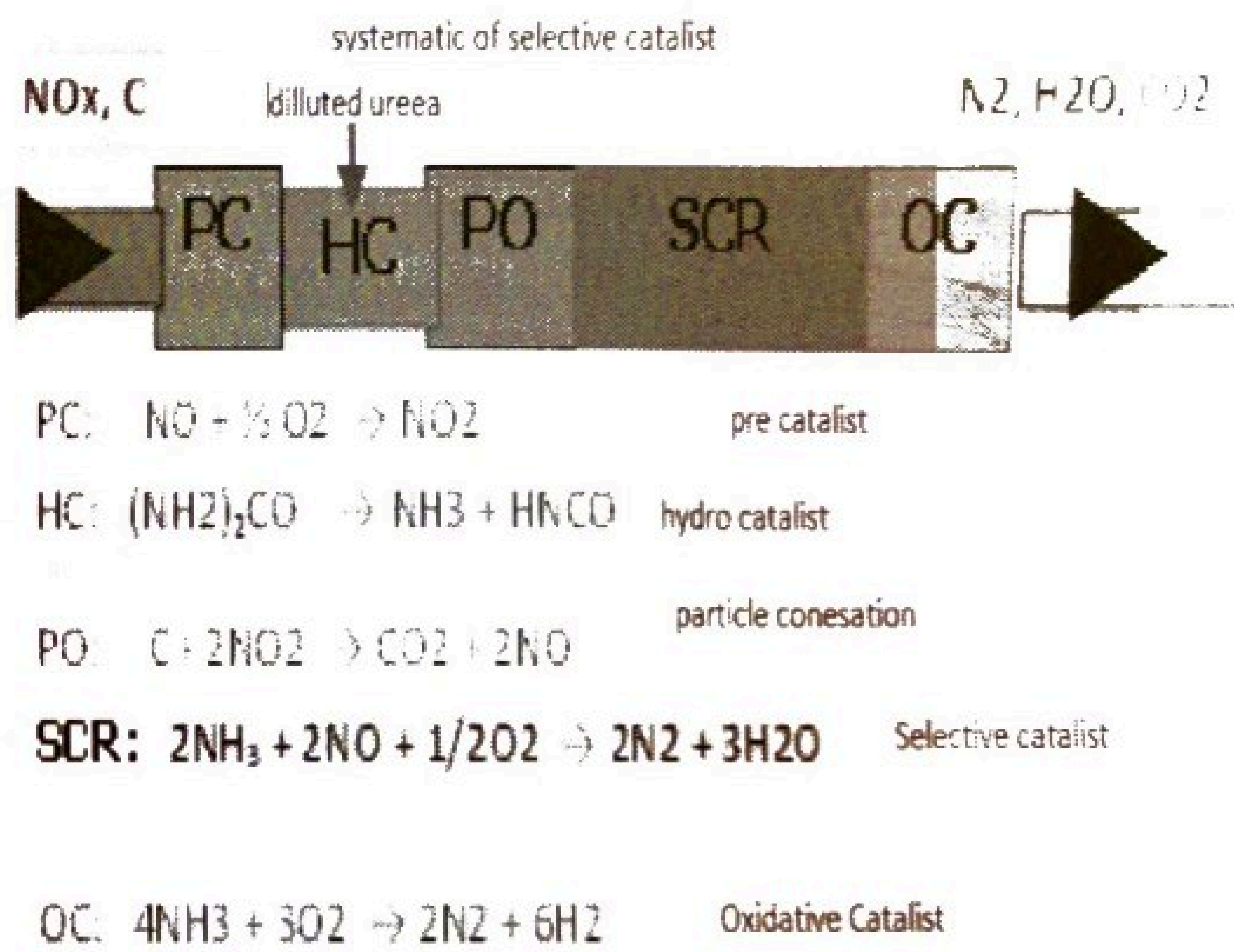

Fig. 5. Working principle of SCR catalyst [5]

Subsequent treatment of particulate emissions is much more complex and by far the best results are given by "particulate filters" in the engine exhaust system. Of course, it is desirable that the engine emits as few particles as possible, primarily the size of 100nm to 50μm, and that the filter has the ability to regenerate so that after a certain deposition of particles, or after increasing the blow resistance to a certain extent, the combustion of the deposited soot. The particle filter is made in the form of ceramic monoliths similar to the catalyst but with a larger diameter of the tube openings – app.2-3 mm - which are alternately blocked so that the exhaust gas must pass through a porous wall that retains particles larger than 500 nm (Fig. 6). Unfortunately, there remains the problem of emitting

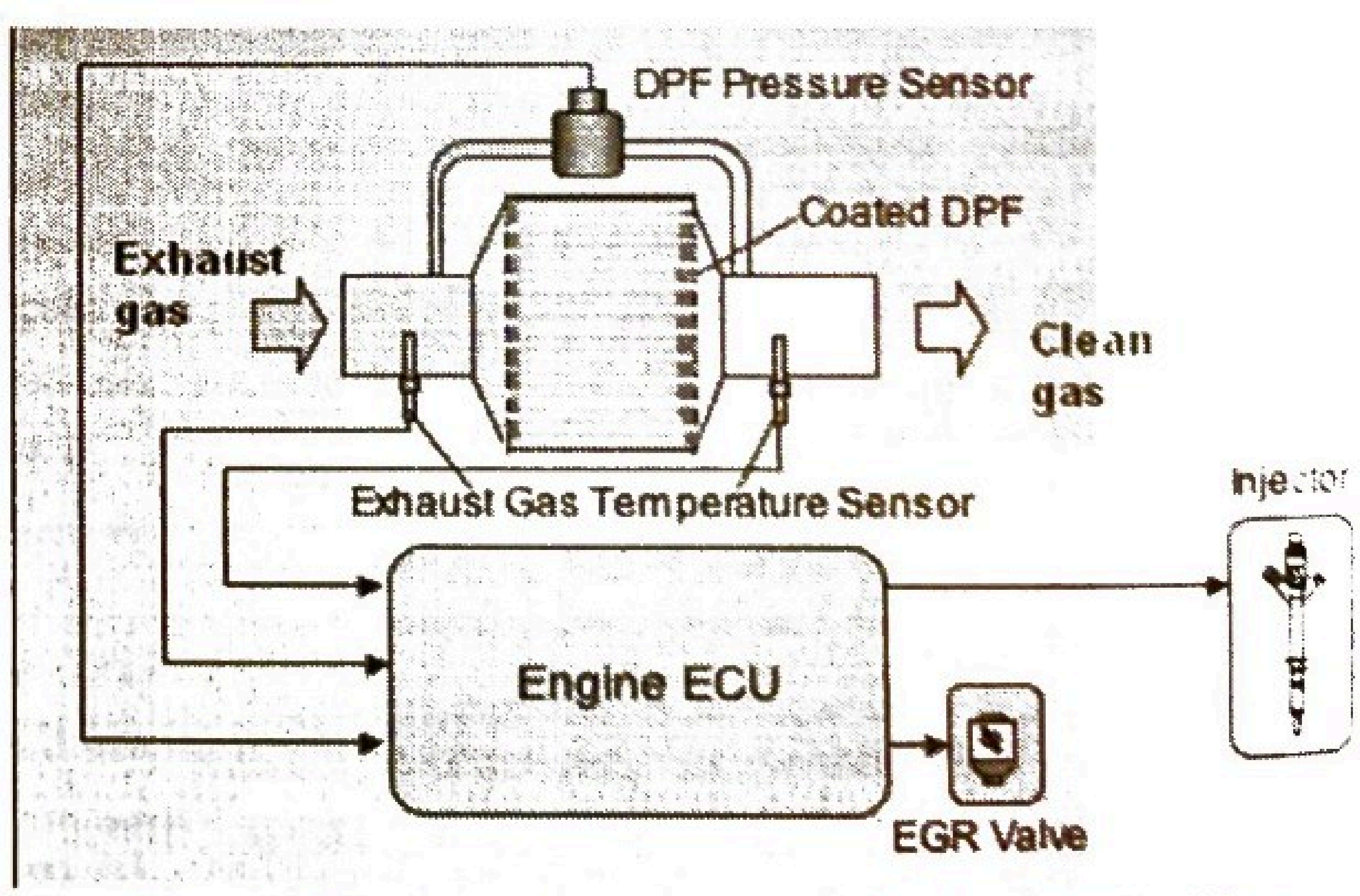

Fig. 6. Electronic unit controlled particle filter scheme[6]

ultra fine (nano) particles, which are extremely small in mass but relatively large in number.

Special problem is the rapid increase in blow resistance for sure, which is why the filter must be regenerated. In principle, there are particle filters of non-regenerative and regenerative type. Particle filters of non-regenerative type are used mainly in diesel engines of stationary and less mobile machines (such as forklifts, special vehicles, etc.) and after a certain increase in resistance, ie the period of operation of the engine with the filter, the filter is removed from the engine and its regeneration in a special device where soot is burned with hot gases with a temperature over 700°C. Particle filters of the regenerative type are very often applied today on motor vehicles, where regeneration is performed on the engine during operation, either by means of a special burner (which is less frequent) or subsequent injection into the cylinder at the end of expansion, which is switched on. work. For this purpose, a special contribution is provided by the common rail injection system, which has the ability to carry out subsequent injection at the end of the injection stroke, under the action of a signal from the control unit. In order to achieve extremely strict future requirements, all the above-mentioned systems of additional exhaust gas treatment will have to be combined, as shown in Fig. 8. This includes cooled exhaust gas recirculation (cooled EGR), and all post-treatment systems to eliminate particulate matter and NOx. The electronic control unit will have to monitor and control through functions, such as NOx concentration at the inlet and outlet of the system, possibly the oxygen sensor, resistance (pressure drop) in the particle filter, temperatures in front of all devices, etc. Subsequent fuel injection, primarily externally for the more active function of the oxidation catalyst and particulate filter, will have to be switched on by the electric control unit depending on the resistance in the exhaust system and the operating mode. At the beginning of the exhaust system should be an oxidation catalyst (DOC - diesel oxidation catalyst), in order to improve the low temperature characteristics of the particulate filter and selective catalyst. The diesel particulate filter (DPF), with a precious metal catalytic coating, is of the regenerative type. A urea tank (UREA) is included in the system, which is injected into the exhaust system behind the particle filter in the form of an aqueous solution (UREA solution). After injection, the aqueous urea solution goes to a mixer which acts as a hydro catalyst to produce NH_3 ammonia. Ammonia then goes to the Selective Catalytic Reactor (SCR) where nitrogen oxides are reduced. At the end of the chain, there is another oxidation catalyst (NH_3 Cat) which has the task of eliminating the free ammonia left after the reaction in the selective catalyst, because future regulations also define the maximum emission of free ammonia.

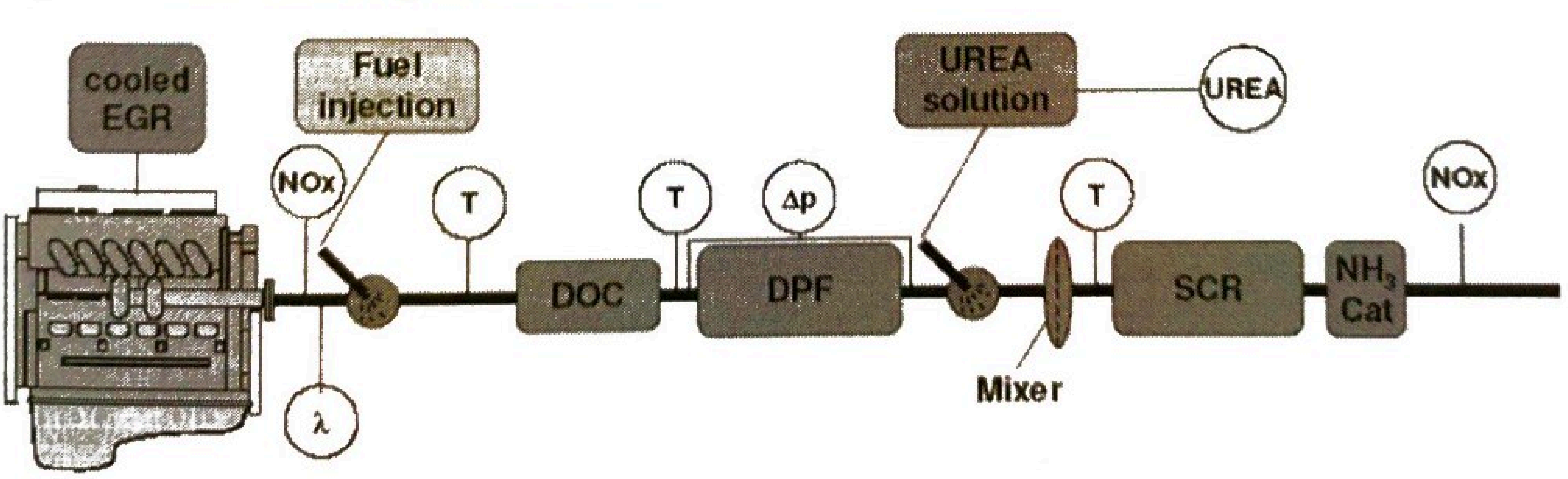

Fig. 7. Shows Specification of neseserry aftertreatment elements for raw ehxaust gas[6]

Given the announced trend of tightening requirements for gas and particulate emissions since 2014 (blue), it can be concluded in principle that very subtle and expensive improvements of individual engine systems are expected with the development and technology by which exhaust gases are subsequently treated in a very effective way. The application of these solutions, such as systems for additional treatment of diesel engine exhaust gases, is expected to reduce emissions of particulate matter by 90% and nitrogen oxides by 80%.

Starting from the previous one, fig. 8 shows the possibilities of reducing NOx and particulate emissions by applying certain technologies, starting from the level of one average uncontrolled level to the extremely strict requirements of EURO 6 and Stage IV norms. The first step of perfecting the engine (2) (chambers, vortices, injection, etc.) led to a reduction in particulate emissions and, to a lesser extent, NOx emissions. The second step of refinement is usually followed by the application of turbocharging (3) which gives an even more significant reduction of particles with a slight reduction of NOx emissions, which can be further reduced by additional intercooling of the intake air (4).

Analysis of the entire system for controlling emissions and fuel consumption

Increasingly stringent regulations required the gradual introduction of the individual systems described above. As it was said, these systems were first introduced in road vehicles, mainly on passenger vehicles and then on Increasingly stringent regulations required the gradual introduction of the individual systems described above. As it was said, these systems were first introduced in road vehicles, mainly on passenger vehicles and then on commercial vehicles.

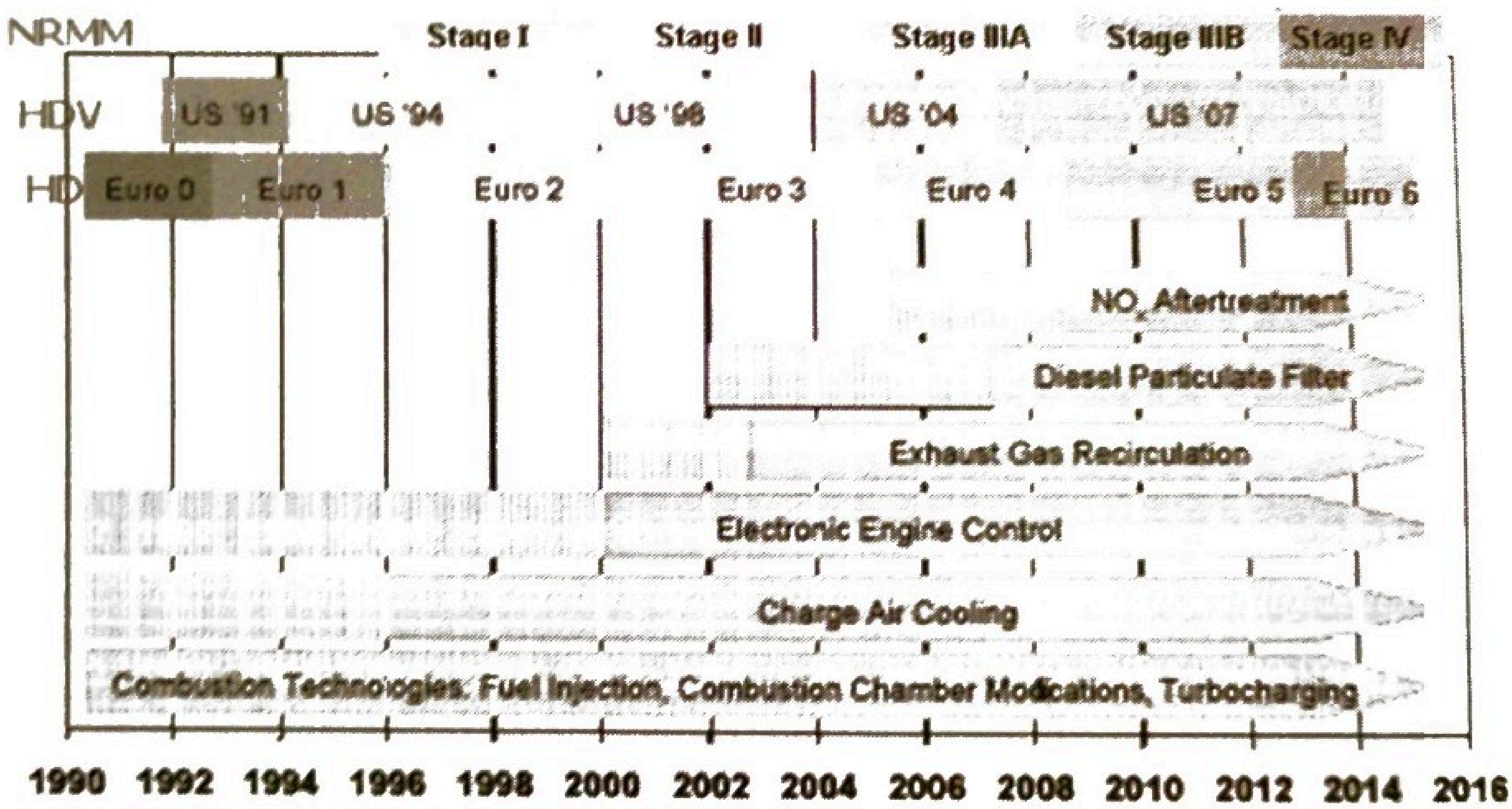

Fig. 8. The order of introduction of certain motor technologies[8]

Application on agricultural tractors was usually delayed by one to three years (just as the regulations for them were delayed). However, the requirements for road and non-road vehicles are practically equal today.

Figure. 9 shows the time of introduction of certain technologies in terms of achieving the requirements in terms of emissions of non-road vehicles (NRMM - Non Road Mobile Machinery) according to European regulations (Stage I-IV), as well as in terms of emissions of heavy vehicles (HDV - Heavy Duty Vehicles) according to American (US '91 -'07) and European (Euro 0 - 6) regulations. Based on the previous analysis, fig. 8 shows the possibilities of reducing NOx and particulate emissions by applying certain technologies, starting from the level of one average uncontrolled level to the extremely strict requirements of Euro 6 standards. The first intervention was usually the improvement of the engine (2) (chambers, vortices, injections, etc.) which mainly led to a reduction in particulate emissions and, to a lesser extent, NOx emissions.

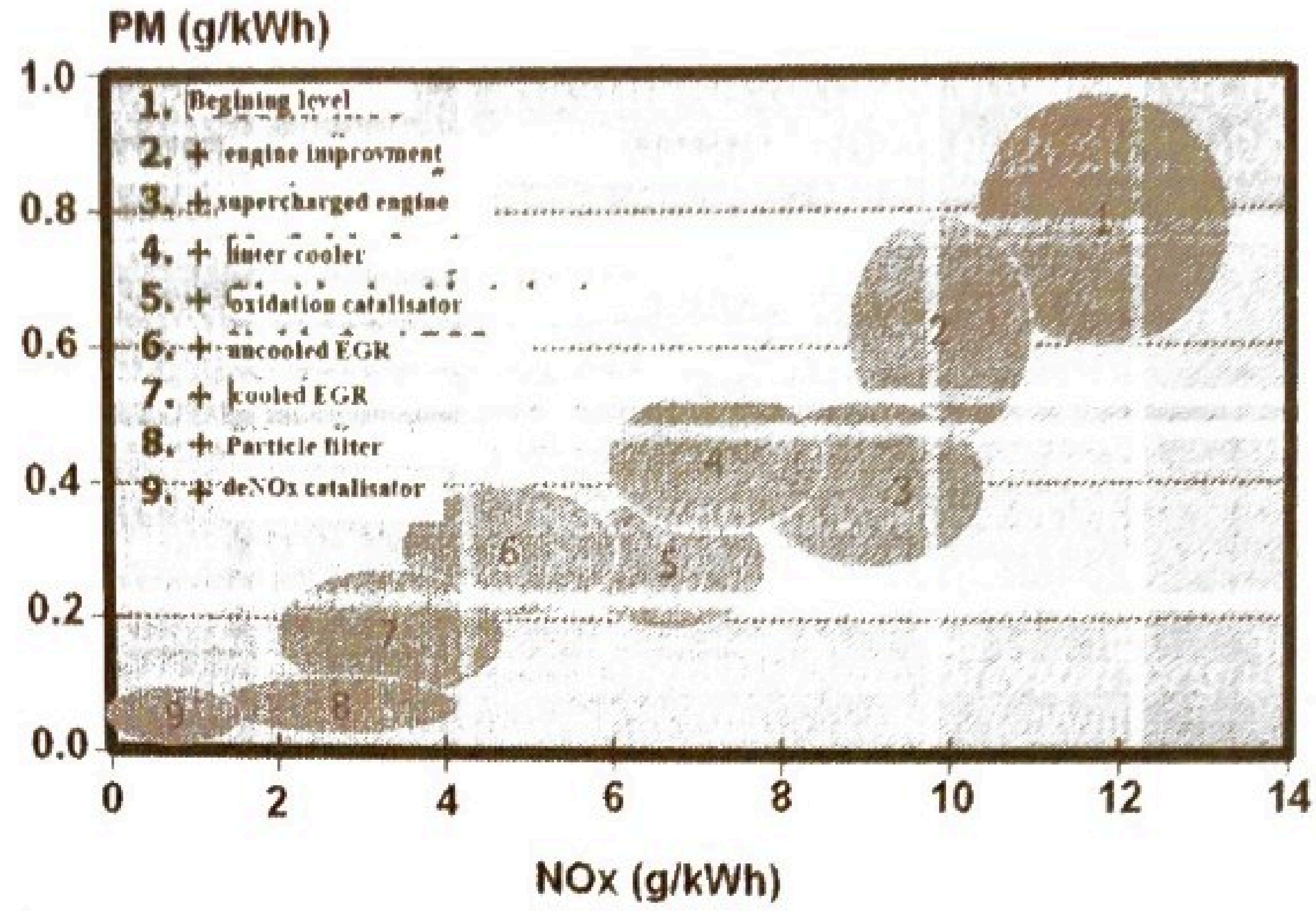

Fig. 9.Genesis of application of certain solutions in order to satisfy legal regulations

This is usually followed by the application of turbocharging (3) which gives an even more significant reduction of particles with a slight reduction in NOx emissions, which can be further reduced by additional intercooling (4). Further reduction (but not large) of particulate emissions can be provided by the use of an oxidation catalyst (5). The application of uncooled EGR recirculation (6) significantly reduces NOx emissions, but can increase particulate emissions. Therefore, cooled EGR recirculation (7) reduces particulate emissions, with an additional smaller reduction in NOx. Finally comes the application of a particle filter (8) which practically eliminates the emission of particles. The use of SCR or DeNOx catalysts (9) further reduces NOx emissions so that the diesel engine exhaust remains as clean as ambient air.

Today, tractor engine manufacturers never make their products only for their own needs and the needs of their market, but for several tractor manufacturers outside their home country and for different markets. Given that different levels of emission requirements (from Stage II to Stage IIIB) apply to the world market in different regions of the world today (and in some countries without special requirements regarding emission levels of agricultural tractors), tractor engine manufacturers usually offer their products in a range of applied technological solutions according to individual requirements. Derivation from previously said by an approximate overview of the applied technologies used to achieve certain required emission levels in different markets of the world.

Unfortunately, the introduction of these new technologies is neither so simple nor cheap. The right column of Table 1 shows the approximate increase in the price of the base engine when applying new technologies to achieve new requirements.

Of course, these values are only approximate, because this increase depends on a number of factors: engine size, production series, type of accessories, equipment quality, etc. In any case, this accessory significantly affects the price of the engine. In the period ahead, modern diesel engines are assumed to have a competitive price of starting fuel (available to the consumer), and the unit to have nominal performance that meets the operating requirements in accordance with the weight of the tractor and most importantly by meeting regulations regarding exhaust emissions.

CONCLUSION

Regarding the engines of agricultural tractors, it is estimated that the characteristics of torque, consumption, emissions, noise, compactness, and the ability to drive attachments are extremely important. Of moderate importance are specific strength, life-to-load ratio, reliability, maintenance intervals, and easy maintenance. Of less importance is the weight of the engine. Fuel consumption is mainly important for vehicle and mobile machinery while the show is important for all applications, especially for road and non-road vehicle applications. Noise is important for almost all applications, and weight only for vehicle applications. However, it can be said that the introduction of increasingly strict legal regulations on permitted emissions dictated the application of certain improvements and technological solutions.

Tab. 1. Approximate increase in the price of the base agicultural engine when applying new technologies to achieve new requirements [8]

Level	Application of needed technology	Price increase
Stage I	Improvment of fuel injection, emgine electronic control and ECU	100 Eur
Stage II	Further improvment in fuel injection control, swirl cember	400 Eur
Stage IIIA	+ intercooler, further improvment of combustion camber 4.valave introducing, common rail with ECU, and EGR	800 Eur
Stage IIIB	+ cooled recircuelation (cooled EGR), afther treatmant of exhaust gas DeNOx absorption or selective catalisator катализатор (SCR), and reduction of PM (DOC – diesel oxidation catalyst) and (DPF – diesel particulate filter)).	1500 Eur
Stage IV	+ Supercharging application on adaptable combustion chamber and pilot and main injection, Electronicaly regulated superharged electronicaly regulated cooled reciculation of raw exhaust gasesu EGR, oxidation catalisator pasive and active paticle filter, selective catalisator with zeolite, thus comlite electronical regulation regulated and controlled with on bord diagnostics	2200 Eur

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