

DIESEL ENGINES WITH RESPECT TO EURO 6 AND BIN5/LEV II EMISSION LIMITS

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Abstract

The article presents future requirements concerning emission of toxic components of exhaust gases valid for Diesel engine passenger cars. Questions connected with fulfilment of these standards were discussed. Chosen structural solutions permitting fulfilment of future requirements concerning emission were presented. In Europe passenger cars equipped with Diesel engines which get the homologation certificate for the first time the emission limit determined by the standard Euro 6 will be binding from year 2014. The relation to the at present binding limit Euro 5 emission of nitric oxides, the sum of hydrocarbons and nitric oxides as well as emission of particulate matter must be reduced. On the European market use could be made of experience gained during exploitation heavy duty vehicles in which decrease in nitric oxides emission is achieved by means of selective catalytic reduction (SCR). A more complex system of emission appraisal is valid in USA and especially in the states where the so called Californian standards were adopted. On the example of Volkswagen 2.0 TDI engine it was shown that in modern constructions of combustion engines there is still a large developmental potential. In this case the development went in the direction of fulfilment of new very requiring standards of emission of toxic components of exhaust gases. Well known in Europe 2.0 TDI engine which in its new version fulfils the most strict emission standards BIN5/LEV II constitutes the structural basis of the drive unit designed for the American market. Under such conditions the firm Volkswagen belongs to the small number of cars producers who for a couple of year have offered with success, passenger cars equipped with Diesel engines.

Keywords: *combustion engines, emission of toxic components of exhaust gases*

1. Introduction

One of the effects of the world wide economical crisis was a considerable increase in engine fuel prices what in turn caused an essential change of preferences concerning the car market. This was especially noticeable on the American car market where vehicles of economical drive sources gained special interest.

Initially vehicles equipped with hybrid drive systems became more and more popular but soon it proved that the effect of fuel consumption decrease in these vehicles are felt only in intensive city traffic, whereas most of the vehicles are used by inhabitants of provinces where traffic conditions differ drastically. Out of these reasons the interest in diesel engine vehicles increased greatly on the American continent. It should be, however, mentioned that in USA retail prices of diesel oil do not differ greatly from those of gasoline. Hence the purchasers are motivated to buying vehicles equipped with Diesel engines only by their lower fuel consumption. Also in Europe this type of engines becomes more and more popular. At the beginning of the nineties of the XX century only every fifth car was fed with diesel oil, whereas, at present every second one.

This means that on the sale market during the last 20 years a 2.5 times increase in participation of new cars with Diesel engines was found. In countries such as France or Austria their participation in the sale market reaches even about 70%.

The basic condition of sale of this type of vehicles on the market is the guarantee of performances not worse than of vehicles with gasoline units and of fulfilment of regulations concerning emission of exhaust gases. These requirements are especially restrictive in these states of USA where Californian standards are valid. Special requirements concern there also functioning of the system of on board diagnostics OBD for which very low threshold values were established at which the engine changes to the state of failure work. A much differentiated diesel oil quality offered on the American continent is another serious problem. This concerns both fuel properties essential from the point of view of the combustion process occurring in the engine as well as chemical composition and especially sulphur content in the fuel. Out of this reason, on the American market only a few producers of passenger cars, among the ones, equip their cars with diesel engines. Volkswagen and Mercedes Benz belong to these producers. In the firm Volkswagen carrying on studies on engine 2.0 TDI CR with Common Rail drive system which fulfils requirements of the standard Euro 5 concerning emission, an engine version which satisfies the emission limits established for the future standard Euro6 was elaborated. This engine constituted also the structural basics for a drive unit designed for the American market; it had to fulfil the emission limits BIN5/LEV II regarded at present as the most rigorous ones in the world.

In Europe passenger cars equipped with Diesel engines which get the homologation certificate for the first time the emission limit determined by the standard Euro 6 will be binding from 1 September 2014 (Fig. 1). The relation to the at present binding limit Euro 5 emission of nitric oxides, the sum of hydrocarbons and nitric oxides as well as emission of particulate matter must be reduced.

	CO [g/km]	NOx [g/km]	HC+NOx [g/km]	PM [g/km]
EURO-5	0.5	0.18	0.23	0.005
EURO-6	0.5	0.08	0.17	0.005

Fig. 1. Euro 5 and Euro 6 emission limits for passenger cars equipped with diesel engines [3, 4]

A more complex system of emission appraisal is valid in USA and especially in the states where the so called Californian standards were adopted (Fig. 2). In this case in emission standards LEV II emission of toxic components of exhaust gases deriving from the fleet of vehicles fulfilling various categories of emission is subjected to assessment (Fig. 2).

	CO [g/mile]	NOx [g/mile]	NMOG [g/mile]	HCHO [g/mile]	PM [g/mile]
LEV	4.2	0.07	0.09	0.018	0.01
ULEV	2.1	0.07	0.055	0.011	0.01
SULEV	1.0	0.02	0.01	0.004	0.01
ZEV	0.0	0.0	0.0	0.0	0.0

Fig. 2. LEV II emission limits for passenger cars equipped with diesel engines [3, 4]

2. Structural properties of standard engine fulfilling the limits Euro5

In standard engine 2.0TDI of the firm Volkswagen which fulfils requirements of the standard Euro5 a Common Rail system and 8-holes piezoelectric injectors are applied. The injection process of a full dose divided into seven parts depending on the type of work mode may proceed in time of a 300° crankshaft rotation. Both the number of holes, fuel atomization degree, as well as range of the

jet was adjusted to the shape of the new combustion chamber. In place of the so far applied chamber of the type Omega a new chamber of bigger diameter and flat shape which protect against formation of areas of rich-mixture more liable to formation of particulate matter during combustion.

The new engine was also equipped with a so called low-temperature system of exhaust gases recirculation which causes a considerable decrease in emission of nitric oxides. For cooling of exhaust gases a cooler of the type fluid-exhaust gases of maximal power 8 kW was applied and this was achieved due to an additional electric pump of the cooling fluid causing its quicker flow through the cooler. The compression degree of the value 16.5 was applied, however it may cause problems with cold start of engine. With regard to this a starter of bigger power, which guarantees engine rotational speed of 450 rpm during start phase was applied. Moreover, glow plugs of a new type with a metal heating core were used. The exhaust gases cleaning system consists of oxidizing catalytic reactor and filter of particulate matter. These elements are placed together in one case at the outlet collector (Fig. 3). Metal cores instead of the commonly applied ceramic cores were used in order to get a faster warming up of the reactors active surfaces. The filter core got the so called zonal catalytic coating with a platinum and palladium alloy and due to it, is characterized by high durability and low thermal inertia. In consequence it may work properly in a short time after cold start of the engine. Regeneration of the filter is realized by itself by means of proper control of mixture composition in order to obtain a required temperature at which burn out of particles deposited on catalytic surfaces of the filter takes place.



Fig. 3. Standard exhaust gases cleaning module

3. Engine fulfilling the requirements of the standard Euro 6

Adapting the discussed engine to the requirements of the standard Euro 6 the basic task is to achieve a decrease in nitric oxides emission. On the European market use could be made of experience gained during exploitation heavy duty vehicles in which decrease in nitric oxides emission is achieved by means of selective catalytic reduction (SCR) (Fig. 4). For this purpose in Europe use is made of the commonly available aqueous solution of urea of the trade name AdBlue. This method, with necessary changes in the control system, was applied in engine 2.0 TDI which fulfils the requirements of the standards Euro 6 and under the trade name BlueTDI is already offered in chosen models designed for the European market. In the exhaust gases cleaning system a serial cleaning module was left; it is known from the engine basic version and composed of

a catalytic oxidizing reactor and filter of particulate matter. A catalytic reactor SCR and dosing valve of AdBlue was additionally introduced and a container of AdBlue of the volume 17 dm³ was installed in the luggage boot.



Fig. 4. Reactor SCR of 2.0 TDI engine

The applied, AdBlue reducing reagent is a not inflammable solution, undergoing a relatively quick decomposition in the environment, however, it comes into reaction with some structural materials which are in direct contact with the agent. Out of these reasons attention was drawn to choice of materials which are in contact with this agent applying elements made of polymers or some steel alloys avoiding structural steel or copper alloys. Another problem is insuring fluidity of the solution in low temperatures, since below temperature -11.5°C the inflammable crystallizes. With regard to this property a special heating system was foreseen. After each switch off of the engine the agent returns to the container leaving the supply conduits and the AdBlue injection valve void. There is another problem loss of AdBlue properties under the influence of temperatures higher than 40°C since then its slow decomposition into ammonia and carbon dioxide starts. Therefore the AdBlue container is thermally insulated and additionally equipped with a release valve, whereas, the control system controls all the time the temperature and pressure values in the container. The reducing agent AdBlue is supplied to the inlet system by an electronically controlled dosing valve at average dosing pressure equalling 5 bar (Fig. 5).

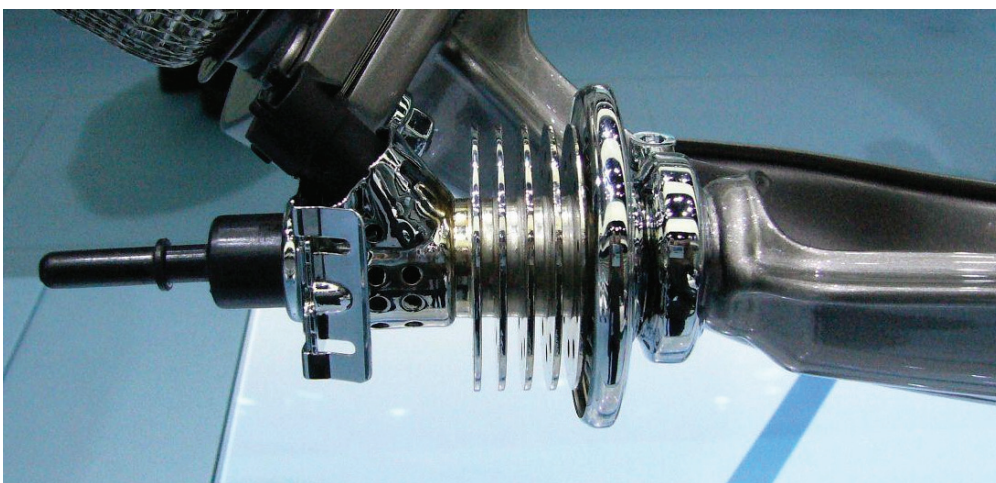


Fig. 5. AdBlue injection valve

Using the specially shaped fragment of the outlet pipe the agent may be injected into the middle of the stream of the flowing exhaust gases what prevents its deposition on the walls and

accelerates the mixing and evaporation process. Moreover, directly after the valve, in the so called zone of mixing an element causing whirl of the stream of exhaust gases accelerating mixing and evaporation of AdBlue before entering the reactor SCR is mounted (Fig. 6).

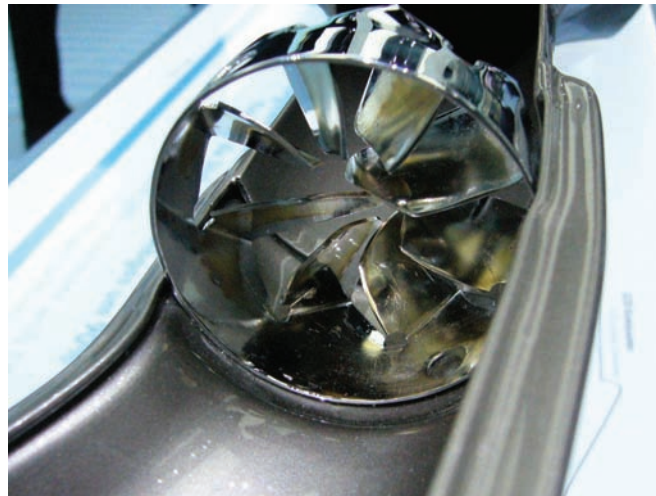


Fig. 6. AdBlue mixer in the outlet system of engine

A process of selective catalytic reduction occurs in metal-zeolite reactor SCR. With regard to the necessity of ensuring active operation of the reactor at temperature below 250°C, typical for vehicle exploitation in city traffic, a proper choice of the catalytic material of the reactor is essential. Because of it a catalytic coating CU-zeolite was chosen. This coating is characterized by high resistance to high temperature maintaining its characteristic at work in temperature up to 600 °C during vehicle mileage 160 tsd km.

4. Structural properties of engine fulfilling requirements of standards BIN 5/ LEV II

Elaborating an engine version designed for the American market other factors than those in case of engine designed for Europe should be considered. In the first case low quality of diesel oil, its sulphating as well as the state of technical infrastructure and purchasers' habits should be taken into regard. Taking into consideration the requirements of the American market, the special engine was elaborated, which does not need any additional attendance and is equipped with a system resistant to the effect of the generally used fuel of lower quality. Under such conditions the firm Volkswagen belongs to the small number of cars producers who for a couple of year have offered with success, passenger cars equipped with Diesel engines.

Well known in Europe 2.0 TDI engine which in its new version fulfils the most strict emission standards BIN5/LEV II constitutes the structural basis of the drive unit designed for the American market. In order to achieve the attempted effect and fulfilment of requirements concerning emission changes were introduced both in the combustion system and in the exhaust gases cleaning system. The combustion process was modified in the new engine version by introduction of another type of injectors, modification of the high pressure pump supplying the pressure rail, the course of fuel dozing was changed and a bi-cycle system of exhaust gases recirculation was introduced.

Modifications of piezoelectric injectors concerned decrease in the diameter of the holes and increase in pressure of fuel injection in the whole range of engine work. A better atomization of fuel was obtained, the range of the jet was enlarged and possibilities of fuel carbonization on the injector surface were reduced. Moreover, the jet of the injected fuel in form of a cone of the angle 162 ° was better fitted to the shape of the combustion chamber. This effect was obtained due to a new technology of injector production known as EDM (Electrical Discharge Machining) which permitted execution of the designed geometry of openings with adequate tolerance. The engine control system was adapted to the new strategy of fuel injection. Similarly as in the base engine

the fuel dose is injected in seven parts, whereas, in the new engine the quality of the first piloting dose and of the last one was diminished and accuracy of dosing in the range of low engine load was increased. The new injection strategy foresees a shorter time interval between the piloting dose and the next one and the two last small fuel doses follow one after the other in a short time interval. Such activity is conducive to flame development and to diminishing of soot and nitric oxides formation in the first phase of combustion, whereas, in the last phase of combustion it is favourable to soot oxidation. The gained effect is a 20% decrease in emission of particulate matter and decrease in concentration of hydrocarbons present in row exhaust gases.

In the engine 2.0 TDI which fulfils the emission standards BIN5/LEV II a system of individual control of combustion process dependent on the value of combustion pressure in particular cylinders was applied. Use was made here of modified glow plugs equipped with a so called movable heating core (Fig. 7). In dependence on the momentary pressure value in the cylinder the heating core of the plug moves and its motion is transferred into a membrane with tensometric sensors equipped with a thermal compensation system. This membrane is located in the upper part of the glow plug so it is not directly exposed to pressure and high temperature influence. The measurement is used for calculation of indicated pressure in every cycle on the basis of measured maximal pressure value and position with respect to the upper dead centre. This type of measurement and calculation is performed in real time in each cylinder.

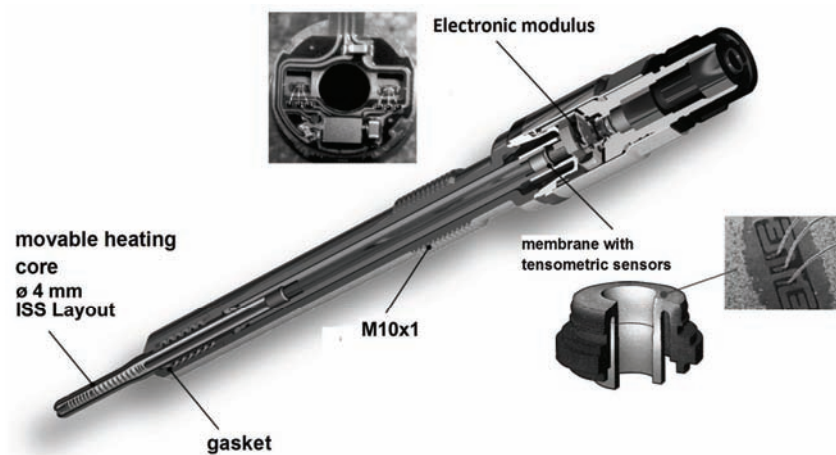


Fig. 7. Glow plug of 2.0 TDI engine fulfilling the emission standards BIN5/LEV II [1]

In dependence on the calculation results sequences of fuel dosing into the cylinder are chosen what makes control of combustion process possible.

Possibility of considerable decrease in emission of nitric oxides and particulate matter as well proper engine work on fuel of the lower cetane number is its measurable effect. There is also a possibility of application of other engine control in dependence on pressure values in particular work cycles. Use is made of this system for compensation of individual controlling signals in each of cylinders in dependence on inaccuracies of measurements of injected fuel doses, inaccuracies of the combustion system execution, fuel quality, and on variable factors influencing the indicated pressure value. Such mode of the combustion system control may constitute the basis for application of the method of homogeneous mixture combustion in determined cycles of engine work. For decrease of nitric oxides emission in row exhaust gases a new system of recirculation composed of a low- and high pressure recirculation was applied (Fig. 8). In the low pressure system exhaust gases are taken from the outlet system after the filter of particulate matter, then they are cleaned in a catalytic oxidizing reactor cooled in the cooler of power 8 kW and supplied to the zone of mixing with an air stream flowing into the turbocharger. In the case of a too low value of exhaust gases pressure in the outlet system its value is raised by means of a regulating throttle placed in the outlet system. In the range of higher loads the low pressure recirculation is complemented with high pressure

recirculation due to which it is possible to obtain a high degree of exhaust gases recirculation without losses during cylinder filling. The high pressure recirculation system is also used for thermal stabilization of the charge during engine work in extreme low temperature of the surrounding.

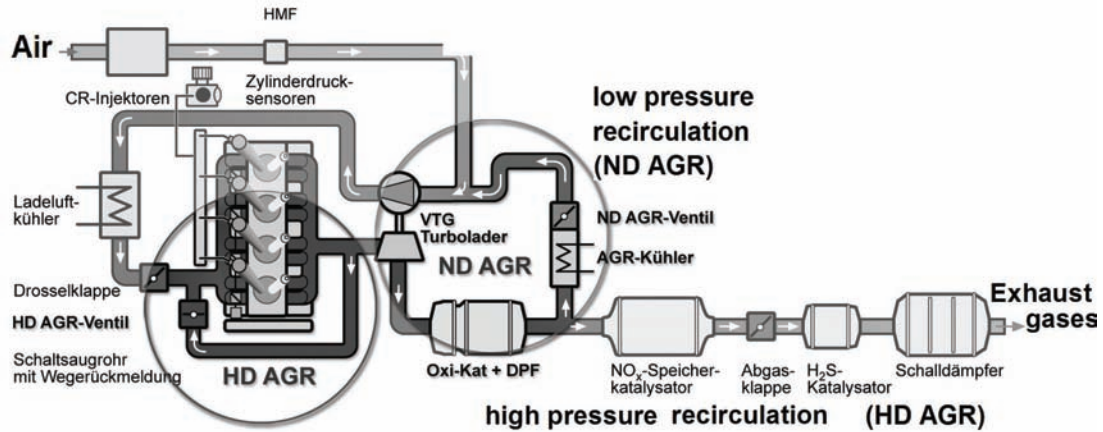


Fig. 8. Exhaust gases recirculation system, low pressure (ND AGR) and high pressure (HD AGR).[1]

The exhaust gases cleaning system contains a standard module consisting of a catalytic oxidizing reactor and a filter of particulate matter and additionally of a nitric oxides trap. The exhaust gases cleaning system specific for the American market, where the offered diesel oil often contains sulphur, is complemented with an additional catalytic reactor cleaning exhaust gases from hydrogen sulphide H₂S formed during desulphurization of reactor storing nitric oxides (Fig. 9). In the cleaning system two lambda sensors were installed; the first placed before the oxidizing reactor is responsible for a proper exhaust gases composition from the point of view of work of the catalytic storing reactor. It cooperates with the other lambda sensor placed after the storing reactor and it controls the process of the reactor regeneration. The cleaning system is complemented with three sensors of temperature giving signals to the on board diagnostic system (OBD) and regeneration system of the storing reactor.

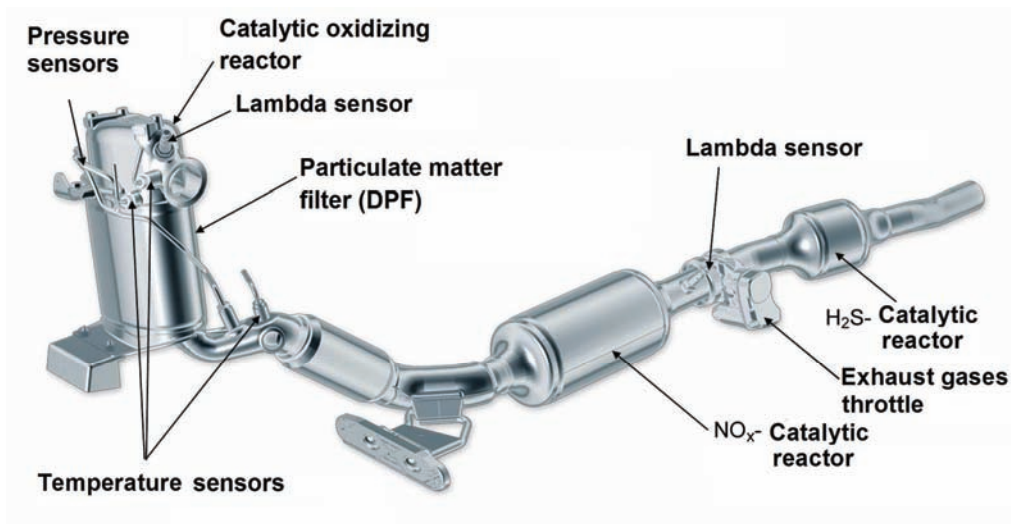


Fig. 9. Exhaust gases cleaning system of engine fulfilling the emission standards BIN5/LEV II [1]

The regeneration process of the particulate matter filter proceeds at engine feeding with a lean mixture at the temperature about 650°C. Exothermic reactions taking place in the oxidizing reactor are very helpful in achievement of required temperature of regeneration. Regeneration of the nitric oxides reactor proceeds during a momentary enrichment of the mixture in temperature of 250-450°C.

Hydrocarbons, carbon monoxide and free hydrogen are then the agents reducing nitric oxides. Necessity of periodical desulphurization of the nitric oxides reactor is a specific feature of the cleaning system of exhaust gases in the outlet system of engine designed for the American market.

The exhaust gas cleaning system is closely linked with the feeding system and the whole is constantly controlled by an engine control system. In agreement with the requirements of the American standards every stage of exhaust gases cleaning must be subjected to appraisal by on board diagnostics (OBD). Work of the oxidizing reactor is appraised by signals of temperature sensors received during exothermic reactions occurring during regeneration of particulate matter filter. Information on proper work of the nitric oxides reactor is obtained from analysis of the signals from both lambda sensors during the reactor regeneration.

5. Conclusions

Fulfilling of requirements of the American market as vehicles equipped with Diesel engines are concerned is not an easy task therefore the engine version 2.0 TDI adapted to the requirements of the standard BIN5/ LEV II built in the firm Volkswagen should be regarded as great success, taking into regard a low quality of diesel oil offered on this market. On the example of this engine it was shown that in modern constructions of combustion engines there is still a large developmental potential. In this case the development went in the direction of fulfilment of new very requiring standards of emission of toxic components of exhaust gases. It was proved that this developmental potential lies both in construction of the engine itself as well as methods of cleaning of exhaust gases beyond the engine. In the case of engine offered on the American market specific exploitation conditions as well as quality of the offered fuel was taken into consideration. Summing up it should be stated that all opinions indicating at the already achieved top of development of contemporary combustion engines do not find confirmation in practice.

References

- [1] Hadler, J., Rudolph, F., Dorenkamp, R., Stehr, H., Düsterdiek, T., Hilzendeger, J., Mannigel, D., Kranzusch, S., Veldten, B., Kösters, M., Specht, A., *Der neue 2.0l TDI- Motor von Volkswagen zur Erfüllung niedrigster Abgasgrenzwerte*, 29, Internationales Wiener Motorensymposium, 2008.
- [2] Dorenkamp, R., Hadler, J., Rudolph, F., Bühren, F., Düsterdiek, T., Gehrke, V., Kösters, M., Kuiken, S. R., Schütte, T., *Der neue 2,0l TDI-Motor von VOLKSWAGEN zur Erfüllung niedrigster Abgasgrenzwerte in Europa*, 17, Aachener Kolloquium Fahrzeug- und Motorentechnik, 2008.
- [3] *Worldwide Emission Standards and Related Regulations*, Continental Automotive GmbH, March 2010.
- [4] *Worldwide Emission Standards- Passenger Cars & Light Duty Vehicle*, Delphi 2010/2011.