VEHICLES AND EXHAUST EMISSION: A REVIEW OF THE TECHNOLOGICAL IMPROVEMENTS

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Abstract: *Vehicles growth has continuous negative influence on air pollution problem especially in urban areas. Exhaust emissions from vehicles contribute for a significant amount of toxic air polluters, harmful both for the environment and health. This underlines the need for development and implementation of technological measures aimed towards emission control and reduction. Technological measures are under continuous research and innovative development, and as a result vehicles have the opportunity to be equipped with different solutions for emission control. Used technological measures at the moment, as well as the next generation measures are all included in the categorized review presented is this paper. Also, a suitable kind of technological measures for countries like Macedonia without industry for car production and with older vehicle fleet are presented.*
***KEYWORDS**: TECHNOLOGICAL MEASURES, EXHAUST EMISSIONS*

1. Introduction

Constantly increasing number of vehicles continues to increase air pollution problems especially in urban areas [1]. With the increase of the number of vehicles, it becomes very important for pollutant emissions to be kept at the acceptable levels.

Concerns for the exhaust emission impact on the environment and health have stimulated the development of the technological measures for air pollution reduction. The aim of technological measures built in the vehicles is to achieve required performances of the system for fuel management and system for control and reduction of exhaust emissions. For example, control of the preparation of the fuel-air mixture and control of the burning process, post-treatment of the exhaust emissions, usage of the computerized devices for the control of the catalysts are just a part from all the available and effective technological measures that have a potential to reduce exhaust emissions.

Today's modern vehicle is a result of several technological improvements, which will continue further with a purpose to satisfy the requirements for better performances referring exhaust emission and fuel consumption. Also, at the same time, they should provide effective power transmission, increased comfort and safety of the vehicle. The main focus of technological development for exhaust emission control is reduction of hydrocarbons, particles and nitrogen oxides, as the most harmful polluters from exhaust emissions.

The aim of this analysis is to present a categorized review of technological measures that have potential to contribute for emission control. At the same time, measures suitable for developing countries, like Macedonia, without car industry and older national vehicle fleet are recommended.

2. Systematic approach in the definition of the technological measures

There are several directions for the development of the technology available for car manufacturers, in order a lower emission levels to be achieved. For this, a systematic approach comprising the following activities should be used (Fig. 1):

- improvement of the engine technology and improvement of the burning process
- development of the devices for emission control (catalysts)
- development of sensors for control of the catalysts
- increase of the fuel quality through modification of its chemical content.

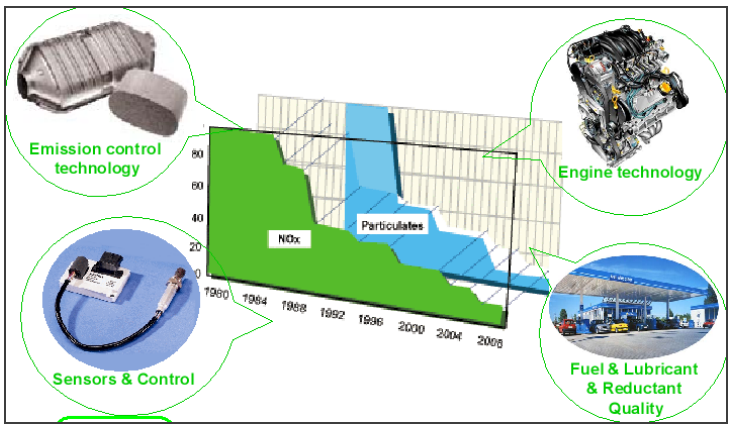

***Fig. 1:** A systematic approach of the technologies for exhaust emission control*

Source: [2]

The main aspects in achieving decreased emissions using different technological measures are [3]:

- preservation of the close relation between vehicle's technologies and fuel quality (needed for accomplishing real improvements in the fuel quality)
- application of advanced technology at several systems in the vehicle (ignition system, fuel system, exhaust emission system etc.)
- improvement of the technological measures for control of the process for exhaust emission reduction and the condition of the catalysts.

Today, development of the vehicle's engine is directed to the decrease of the toxic exhaust emission at the needed level and decrease of the fuel consumption, keeping its good performances at the same time.

3. Categorization of the technological measures

Introduction of the Euro standards for exhaust emissions and their constant aggravation have contributed for the improvement of the technological measures for vehicles, for example, better engine design and fuel efficiency. Hence, emissions per vehicle are decreased as a result of advanced engine design and introduction of computerized controlled technologies for reduction of fuel consumption and control of exhaust emission [2].

Categorization of technological measures for the control of the vehicle's toxic emissions is presented at the fig. 2.

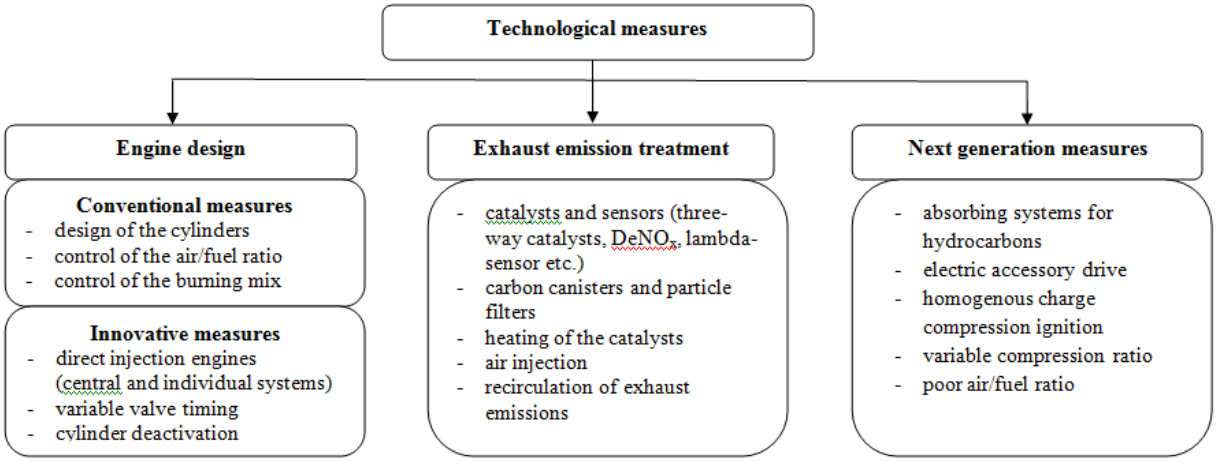

Fig. 2: *Categorization of technological measures at vehicles*

Source: Made by the authors

New engine characteristics for emission reduction, although contribute for its higher complexity, include direct injection system, as well as the systems for emission control with electronic surveillance and adjustment of the engine under different operational conditions [3]. Additional devices are added to the engine for dealing with the air and fuel intake and exhaust emission release, as well as for computerized surveillance and control of its performances.

At the same time with the development of the technological measures for exhaust emission reduction, an improvement of fuel quality is taking place. Reformulated fuels have modified chemical structure designed to improve exhaust emissions. For example, at the gasoline, lead is removed and sulfur level is reduced, which improved the efficacy of the three-way catalyst. Additional improvements in the gasoline include reduction of the evaporation (especially of hydrocarbons) and wide spread use of special additives [3].

For identification of high polluting vehicles, good support provide OBD systems (On-Board Diagnostic Systems). These are systems for diagnostics built in the vehicles and sensitive to the performances of the system for exhaust emission control. OBD identifies malfunctions of particular components and informs the driver through the display at the instrumental board. These capabilities of OBD had stimulated big car manufacturers to start with their massive application in the vehicles. In Europe, since 2000, every new vehicle is equipped with OBD [4]. Today, OBD systems have durability of 16000 km with minimal maintenance [3].

The challenge for environmental protection from exhaust emission is serious. For this, numerous additional technological systems for emission control will be used in the future, from which a higher durability and resistance during the life time of the vehicles will be required [3]. These solutions will comprise modern engine technologies and equipment for post-treatment of exhaust emissions, and for their optimality in the usage, a high quality fuels should be introduced. Measures for exhaust emission reduction during the cold starts should be especially aggravated, as well as the measures for reduction of fuel evaporation [3].

However, the changes in the engine design will reduce some of the components in the exhaust emissions, but will contribute for increase of the other [3]. This, from the other side, makes it more difficult to precisely predict the harmful environmental effects. All designed measures cannot be accepted as rational and justified from an engineering point of view, especially if low fuel consumption is expected.

4. National vehicle fleet in Macedonia

4.1. Characteristics of the trend of passenger vehicles

The trend of the passenger vehicles depends of the national economical and political circumstances under which transport sector works. The number of passenger vehicles in Macedonia in the last decade continuously is changing with an increasing trend. For example, the number of registered passenger vehicles in 2013, compared with 2012, has increased for 12,9% [5]. The increasing trend of the number of passenger vehicles is a good indicator for the extent of air pollution problem in urban areas.

Table 1: *Registered road transport vehicles*

	2009	2010	2011	2012	2013
Total	332365	360789	364019	350762	411637
Motorcycles	9 097	7 761	8 373	8 473	8 093
Passenger cars	282196	310231	313 080	301761	346798
Buses	2 454	2 695	2 636	2 719	3 022
Goods vehicles	27 771	28 795	27 917	26 542	30 167
Road tractors	4 263	4 505	4 636	4 219	4 934
Tractors	645	567	1 109	1 059	9 740
Work vehicles	551	577	585	547	585
Trailers	5 388	5 658	5 683	5 442	8 298

Source: [5]

Table 2: *Road vehicles per fuel type (data for 2013)*

	Total	Motorcycles	Passenger cars	Buses	Goods vehicles	Work vehicles	Road tractors	Tractors
Total	403 339	8 093	346 798	3 022	30 167	585	4 934	9 740
Gasoline	230 283	7 681	213 808	287	7 661	88	498	260
Diesel	161 143	249	122 443	2 671	21 818	482	4 274	9 206
Mix	521	150	272	7	81	1	3	7
Gasoline-gas	11 341	10	10 241	54	597	14	185	367
Electric energy	51	3	34	3	10	-	1	-

Source: [5]

Table 3: Average age of the passenger vehicles

	Unit of measu-ement	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total	/000	300	310	308	300	249	253	242	249	263	282	310	313	302	347
<=2 years	%	6.3	4.2	2.6	2.3	4.6	5.4	6.9	8.3	9.4	7.8	4.3	3.3	2.3	1.7
<=5 years	%	9.3	8.4	9.4	8.3	7.3	5.1	7.0	8.0	9.8	11.0	12.2	11.2	9.3	5.8
<=10 years	%	15.0	14.8	20.8	21.7	23.1	21.8	18.4	16.7	13.6	13.0	11.9	13.4	15.2	17.3
>10 years	%	69.4	72.6	67.2	67.7	65.0	67.7	67.7	67.0	67.2	68.2	71.6	72.1	73.2	75.2

Source: [5]

There aren't available data for the participation of passenger vehicles without catalysts or with improper catalysts function, although assumptions could be maid according to the categories of vehicle age (table 3). Newer passenger vehicles are much cleaner and have lower emissions, but older and most polluting vehicles (Euro 1 vehicles, especially passenger gasoline vehicles without three-way catalyst), are still in a significant number on the roads in Macedonia [1].

4.2. Changes in vehicle fleet: import of used vehicles

The stagnation in the supply with new vehicles and the import of old vehicles contributed for the ageing of the national fleet of passenger vehicles. From the environmental point of view, this is highly unfavorable, because old vehicles that prevail on the roads, as well as the bad maintenance of the vehicles, contribute for multiple higher exhaust emissions compared with new vehicles.

In the period between 2010-2014 when a privileged import was allowed a total of 158.512 used vehicles were imported in Macedonia. The biggest import happened in 2010, when 51.399 old vehicles were imported. Every next year, an import of old vehicles is decreasing (table 4).

Table 4: *Imported old vehicles per year*

year	number of vehicles
2010	51.399
2011	34.326
2012	28.546
2013	29.560

The import of the Euro 1 and Euro 2 vehicles had contributed for the social issues to be accomplished (every family to afford a car), but from the other side, those vehicles are the highest air polluters.

At the same time when this kind of import of old vehicles was allowed, a sale of new vehicles decreased. In the period from March 2010 (when privileged import was allowed), until July 2014, a total of 20.784 new vehicles were imported. Before, the yearly sale of new vehicles was three times bigger than the current one.

Table 5: *Imported new vehicles per year*

year	number of vehicles
2009	10.574
2010	7.183
2011	5.795
2012	4.021
2013	3.288

However, according to the legislation changes, Euro 3 vehicles were imported until 30 June 2014. Since 1 July 2014, the vehicles import is possible only if the vehicle belongs at least to Euro 4. The purpose of this is to renew the national vehicle fleet.

These terms for import of passenger vehicles are more acceptable than the previous ones. Hence, it is expected that will have:

- positive effect for the improvement of age structure of the vehicle fleet
- direct contribution for air pollution reduction.

5. Recommendations for Macedonia

Having in mind that Macedonia doesn't have automobile industry, technological measures that can be recommended for our fleet can be grouped in two groups: programs for technical inspection and maintenance and limitations in the national legislation.

5.1. Regular programs for technical inspection and maintenance

Effective programs for regular technical inspection and maintenance could identify the problems and provide their timely repair. Providing a good preventive maintenance practice, these programs remain as the best proved way for protection of the investments in the technology for emission control.

Regular servicing of the vehicles is needed in order to keep the efficiency during the exhaust emission reduction. Hence the contribution of this program for better air quality. Not sufficiently maintained vehicles spend more fuel and emit higher levels of particles, hydrocarbons and nitrogen oxides compared with those vehicles with a regular maintenance. The real experiences shows that high-quality programs for regular technical inspection and maintenance could reduce exhaust emission of hydrocarbons and carbon monoxide approximately for 20-30%. These programs have need of minimal investments [6].

For the countries with insufficient emission control or without any control, the simple programs for regular technical inspection and maintenance could be a good starting point for the emission control, during which even a vehicles without built-in system for emission control could profit.

5.2. Limitations in national legislation

This kind of measure isn't strictly in the group of technological measures, but has indirect connection with it through the definition of laws based of the technological condition of the vehicle.

Macedonia doesn't have an industry for car production, meaning that technological measures cannot be directly implemented at the vehicles. But, indirectly, the technological characteristics of the national vehicle fleet could be maintained and controlled by introduction and aggravation of national laws. For example, the process of renewing the national fleet has began with limitation of the maximal age of vehicle (Euro 4), allowed to be imported. Additionally, for supporting the import of new vehicles, lower import and customs taxes should be introduced, joined with national subsidies. Also, higher registration taxes could be introduced for older vehicles, or taxes for using these vehicles in the urban traffic.

In parallel, the legislation should support the use of high quality fuel through strictly defined chemical content. This could help vehicles to maintain the built technological measures for emission control at a good level.

6. Summing the effects of the technological measures for exhaust emission reduction

Decrease of the exhaust emissions is a result of the improved vehicle performances, i.e., implementation of new technologies and improvement of the fuel quality. Application of catalysts and other technological measures at the gasoline and diesel vehicles has significantly reduced pollutant emissions. For example, the decrease of the emissions was around 24-35% in the period between 1990-2001, mostly as a result of the technological development and introduction of cleaner fuels as a response to the European emission legislation [7].

The continuous development and implementation of the technological measures for emission control will result with additional air quality improvement [1]. Still, in large part of Europe, the current European standards for air quality are exceeded [8]. Although the emissions per vehicle will further decrease as a result of the improved technology and severe emission standards, the traffic growth, increase of the number of diesel vehicles, high number of short urban journeys and frequent traffic jams could reduce the benefits from the technological improvements [1].

Wide usage of previously categorized technological measures and equipment may provide a cleaner air in the next 10-15 years, although doesn't represent long-term solution for air pollution problem in urban areas [3]. Some of the measures have success – for example, introduction of catalysts brought significant improvements of air quality in the last 20 years [3]. However, it should be considered that equipping the vehicles with these measures will newer produce a completely not-polluting vehicle. It's necessary that these technological measures are combined with the schemes for traffic management and control in urban areas, as well as with the efforts for stimulating the drivers to use their vehicles less than usual [1].

The future programs for emission control from the vehicles will be directed to the reduction of hydrocarbons, nitrogen oxides and particles. Hence, an indirect reduction in the ozone will be achieved [3]. Apart of this, considering the impact that carbon dioxide has on global warming, significant importance will be dedicated to the technological solutions for emission control that would effectively decrease the greenhouse gasses, without increasing the problems in urban air pollution [9].

7. Conclusion

Vehicles are significant source for urban air pollution, and as such would probably remain in the next decades [3]. Maintenance of the needed air quality imposes the implementation of technological innovation, directed to the achievement of adequate performances of the vehicle's engine and devices for exhaust emission reduction and control during the vehicle life time period.

Technological development has high influence on the current state of the vehicle's engine and systems for control of exhaust emission, contributing for their continuous evolution into the new and more advanced design. Therefore, the future progress would be directed to the continuation of the exhaust emission reduction and fuel consumption, at the same time improving the engine power and efficacy [3].

Use of the technological measures for emission control, especially different kinds of catalysts and sensors, as well as the use of high quality fuels, has resulted with significant decrease of vehicle exhaust emission [3]. However, despite the achieved fall in the levels of vehicles exhaust emission, the quality of urban air didn't significantly improve, mostly because of the vehicle's increasing trend [1]. Therefore, the intention of development and effective implementation of technological measures for reduction of toxic exhaust emission continues.

Technological measures implemented in vehicles at the moment, as well as the next generation measures, are systematically categorized in this paper. A bigger durability and resistance during the vehicle life time period from all of them would be expected. Measures comprise modern engine technologies and post-treatment equipment for exhaust emissions, and for their optimality, fuel quality should be improved. Especially would be necessary to aggravate the measures for exhaust emission reduction during the cold starts and measures for reduction of fuel evaporation. Additionally, measures like programs for regular maintenance and legislative changes are proposed for countries without car industry and with old vehicle fleet, like Macedonia.

Today, emissions per vehicle are decreased as a result of the advanced development in the engine design and introduction of computerized technologies for reduction of fuel consumption and exhaust emission control [3]. But, benefits made per vehicle are overshadowed by the increased number of the vehicles. Improved performances of advanced technology for emission control currently are insufficient for dealing with the growth of transport systems. Improvements in air quality and emission reduction are lower than expected - the vehicles will remain a dominant source of

air pollution. Therefore, it becomes clear that there isn't a smallest chance for reaching the levels of pollution before several decades ago [3]. Hence, a success will be even the minimal decrease of the damage and deceleration of the pollution process.

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