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Parameters Characterizing the Performance of Automotive Electronic Control Systems on Petrol Engine Emissions †

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Abstract

It is evident that a novel engineering solution is required in order to elevate a greater number of polluting cars into a higher category. There appears to be a paucity of direct interest in upgrading Euro 1, 2, 3, 4, and 5 vehicles to the highest possible level, primarily through software modifications of the parameters determining the performance of the internal combustion engine (ICE). The potential for advancement in this area is evidenced by the presence of systems that enhance environmental efficiency, even in Euro 2 vehicles. These include exhaust gas recirculation, catalytic converter, lambda sensor, electronic control fuel injection, and ignition timing. It is precisely these vehicles that are subject to optimization, a process which would allow the maximum service life of otherwise more reliable but older vehicles to be exploited.

Keywords: improve emission standard; optimize engine control parameters; internal combustion engine

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1. Introduction

Pollutants emitted by the transport sector of the economy contribute to air pollution and put significant pressure on the environment and human health in Europe. In recent decades, there has been a tremendous effort by the international policy community to reduce transport-related air pollution from its various modes (road, rail, aviation, marine time). Thanks to these policies, progress has been made in reducing emissions of many pollutants from the transport sector. Between 1990 and 2022, emissions of nitrogen oxides (NO_x) from transport in the EU-27 have decreased by 51%, sulfur oxides (expressed as SO_2) by 82%, carbon monoxide (CO) by 90%, methane (CH_4) and non-methane volatile organic compounds (NMVOC) by 76% and 91%, respectively. Over the same period, transport emissions of particulate matter (including non-exhaust emissions) with a particle diameter of 10 µm/2.5 µm or less ($PM_{10}/_{2.5}$) decreased by 46%/58%, respectively. The pandemic of COVID-19, which led to a significant reduction in transport volumes in 2020, has also had a minor impact. However, many pollutant levels have recovered to their pre-pandemic values [1]. There has been a long evolution of environmental standards (from Euro 1 to Euro 6d for cars and from Euro I to Euro VI-E for heavy goods vehicles) since they were first introduced in the early 1990s. Summarizing the specialized and reliable sources, during these years, the NO_x emission limits have been significantly reduced for both passenger cars and HGVs, from 0.97 gNO_x + THC/km to 0.08–0.06 gNO_x/km and from 8 gNO_x/kWh

to 0.46 gNO_x/kWh, respectively. This trend is not unprecedented and is also observed for other pollutant emissions subject to regulation [2]. Vehicles equipped with a spontaneous combustion engine have been able to meet the first set of requirements (Euro I to Euro IV) through engine calibration and the use of techniques such as EGR. Due to the more demanding requirements of the latest regulations, vehicle manufacturers have equipped their light- and heavy-duty diesel vehicles, with advanced inline systems, which in the latest models always include SCR $deNO_x$ systems. On the other hand, the use of these systems has given rise to growing concern about the emission of non-essential pollutants such as N_2O and NH_3, two compounds that were previously unregulated for passenger cars, while NH_3 was regulated only for heavy-duty vehicles [3].

A number of scientific studies have demonstrated a strong correlation between NH_3 emissions and CO emissions during the operation of an internal combustion engine (ICE) utilizing an enriched fuel mixture [4–8]. Spark ignition (SI) engines have been observed to emit elevated levels of carbon monoxide (CO) during operation in the aforementioned condition until the optimal operating temperature is attained, at which point the fuel is in excess relative to air. It is evident that these conditions are conducive to the process of hydrogen formation by hydrocarbon reforming subsequent to the cessation of catalyst activity. The presence of H_2 and NO results in the formation of NH_3. It can be concluded from the evidence presented that the operation of the internal combustion engine (ICE) with a rich fuel mixture leads to both the evolution of carbon monoxide (CO) and the conditions for ammonia (NH_3) formation and evolution. Consequently, these emissions materialize concurrently during the operation of the vehicle, as illustrated in Figure 1 [9].

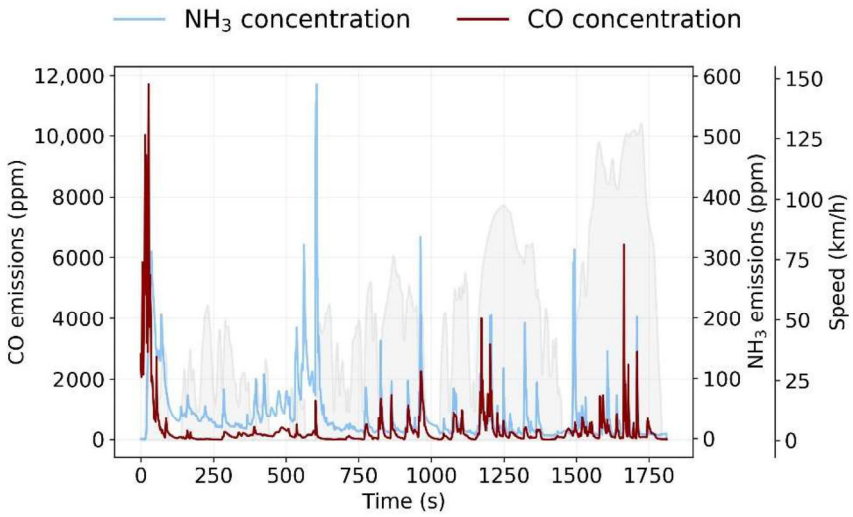


Figure 1. NH_3–CO concentrations [9].

Emissions measurements have also been collated in studies to test whether detonation combustion affects vehicle emissions and as an additional tool to understand the impact of lower octane fuels on vehicle performance. Emission measurements are made during the NEDC (hot start) cycle as well as during full load accelerations. Although these tests are not directly comparable to the regulated NEDC cold start test, they provide insight into how vehicle performance changes as the octane rating of the fuel changes. Averaging the values, HC and NO_x emissions are generally within the regulatory limits, while CO emissions are higher [10,11].

Places where the main source of air pollution is car exhausts are dangerous for the health of the population, and such places are areas with concentrations of car traffic, traffic jams and intersections, especially in developed and large cities [12]. The steadily increasing volume of car traffic worsens the cumulative environmental performance of cars, as well

as their impact on the environment, traffic safety and quality of life in urban areas with heavy traffic. In high-traffic areas where vehicles have to start and stop frequently, the proportion of pollutants emitted into the environment increases. Studies have shown that air pollution causes many illnesses, leading to a poor quality of life for people and visitors in developed megacities, which also translates into increased health-related costs and reduced productivity [13,14].

2. Materials and Methods

The important task for the engineers of that time is to optimize not only the performance indicators of the engine, but also the ecological ones too. Since then, many constructors experiment with many theories in order to achieve the power for which each driver dreams, complying with increasingly strict standards for pollution emissions in exhaust gases. The main advance in this ongoing race is the accomplishment of a fully complete combustion of the fuel entered in the combustion chamber. In addition to helping the engine operate in established modes without constant changes in throttle valve opening angle, the economy mode of operation aids combustion, which is less prone to detonation combustion, and reduces heat loss as it reduces the average combustion chamber temperature. Furthermore, it can reduce fuel consumption [15] and emissions of pollutants such as carbon monoxide (CO) and nitrogen oxides (NO_x). Since the emissions of internal combustion engines are particularly sensitive to the air–fuel ratio, this engineering solution proved to be a successful one as illustrated in Figure 2. However, at present, mixture enhancement using conventional ignition systems is very limited, as the combustion process instability appears particularly high, reaching unacceptable levels due to cylinder temperature reduction and more frequent unrealized ignitions [16]. A number of experimental studies have been carried out, the subject of which being the simultaneous use of EGR and spark timing variation to control the load of an SI engine methanol engine under full load and stoichiometric mixture operation. The methanol engine is modified from a diesel engine, with a compression ratio of 18.0/1 and methanol injectors located in the charge line. The results show that at a speed of 1400 rpm and full load, the methanol engine can operate stably without detonation combustion, with ignition times ranging from 18 to 12 °CA BTDC. Adjusting the ignition timing aims to achieve better engine performance under frequent load changes. High load operation requires little exhaust gas re-entering the combustion chamber, and ignition timing must be retarded to avoid detonation combustion. Completely mirroring the lower load operation, the fresh air to exhaust ratio should be increased by opening the EGR. In this case, the ignition advance angle should be increased to maintain good combustion quality. These adjustment steps are conducive to optimum engine fuel economy in low load modes. Compared to the traditional throttle valve load control mode, the method of controlling the fresh air to exhaust gas ratio and ignition timing at higher load achieves better performance and lower emissions; while, at lower load, the specific fuel consumption and HC and CO emissions are degraded [17,18]. Otherwise, most scientific research and experiments lean in the direction of replacing unleaded petrol as a main source of power in SI engines. One of the most popular alternatives is Liquid Petrolium Gas (LPG) or Compressed Natural Gas (CNG) [19]. Investigating the effects of varying the volumetric efficiency on the emission characteristics of an engine with different levels of LPG use (25%, 50%, 75% and 100%) in an engine operating with a new generation closed loop, multipoint and sequential gas injection system, the following was found: when using 50%, 75%, and 100% LPG, the volumetric efficiency decreases as the amount of LPG used increases. The fuel–air ratio decreases with increasing LPG use. It has been found that the minimum value of the air–fuel ratio is obtained when LPG is fully used. In the case where a mixture of 1/4 or 25% LPG is used, the specific fuel

and energy consumption during braking decreases while the thermal efficiency during braking is maintained. Regardless of the level of LPG used, it always has a beneficial effect on exhaust emissions. The best results are achieved when 100% LPG is used in terms of exhaust emissions [20].

In order to meet the increasingly stringent restrictions on the quantity and content of emissions produced by the operation of ICE, it is important to reduce the factors leading to their production as a consequence of the combustion process. This necessitates the implementation of exhaust after-treatment systems to minimize exhaust emissions released into the environment. The undisputed efficiency of catalytic converters has led to their widespread application in the automotive industry, mainly in the reduction in harmful emissions generated by internal combustion engines. The expected introduction of future emission regulations, which will include limits on CO_2, will promote HCCI and the operation of the engine with poor fuel mixtures (supersaturated with oxygen). These developments result in the need for an appropriate exhaust after-treatment system to reduce HC, CO, and NO_x emissions to the maximum allowed. However, exhaust gas converters containing the well-known three-way catalyst (TWC) are not very effective at neutralizing NOx (as well as some hydrocarbons). Under engine operating conditions, fuel–air ratios are above stoichiometric and HCCI when the exhaust temperature is low [21–23]. The relationship between fuel inlet components and hydrocarbons in engine exhaust has been the subject of a number of studies. It has been reported that 65–75% of the HC in the exhaust are components that are also present in the raw fuel [24–26].

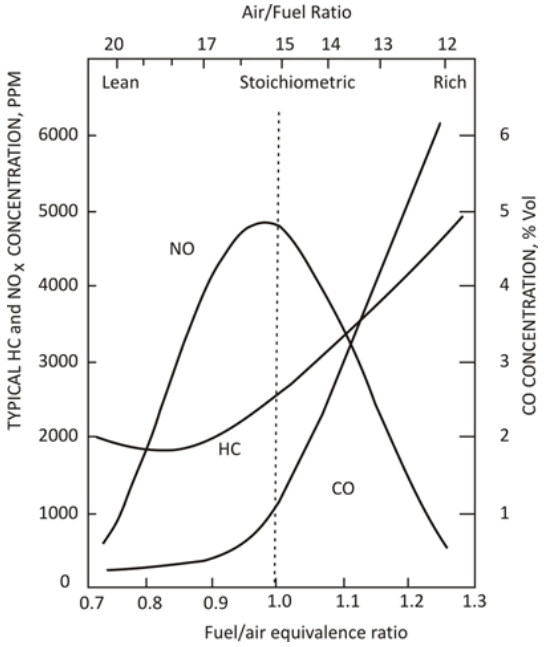


Figure 2. Variation in CO, HC, and NOx emissions for a SI engine [27].

An effective way to reduce emissions from a spark ignition internal combustion engine is to use a three-way catalytic converter and a suitable control system [28]. The basic type of ICE control imposed due to the characteristic of the three-way catalytic converter (TWC) is closed-loop control (3 varies between 1 ± 1% [29]). This type could not lead to a particularly reduction in fuel consumption. To improve the economy and reduce the emissions, the dynamic characteristic of the converter to store and release oxygen in the ceramic pit plays a major role. CeO_2-type catalysts have been the subject of repeated studies. Considering their dynamic characteristic and the emission variation at the inlet and outlet of the catalytic converter, Descorme [30] developed a method to determine

the oxygen storage capacity of the catalytic converter in the transient state. Harmsen et al. [31–33] constructed the kinetic model of the catalytic converter under initial start-up conditions before reaching operating temperature and calculated the concentrations on the surface of Pt, CeO_2, Û-Al_2O_3. James [34] proposed to combine the oxygen storage model with statistical data to diagnose whether the catalytic converter is malfunctioning. Using the oxygen storage capacity of the converter, Wang et al. [35] developed a new on-board diagnosis (OBD) algorithm.

3. Conclusions

Taking into account the scientific research conducted to date, it can be concluded that only a very small proportion of today's engineers are engaged in establishing and integrating modern methods and means of upgrading the engines of aging cars to a higher environmental category. Currently, scientific research is focused on replacing the main fuels (gasoline and diesel) with alternatives, adapting the relevant engine and its control systems for this type of conversion. The aim of future developments is to reduce exhaust emissions and bring vehicles into a higher environmental category. This includes qualitative and quantitative studies of key environmental indicators of vehicles in service. Such improvements should be achieved by optimizing the parameters characterizing the operation of automotive electronic systems, without the need for investment in mechanical modifications to the vehicles.

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