Computer modelling of automobile engine performance as the source of implications for automobile technology management

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Abstract. The need for finding the replacement for fossil fuels causes several technical and technological problems in the engine construction as well as the fuel production and its standardisation. This particularly concerns biofuels. The variety of biological resources and possible conversion routes leads to the multiplication of fuel properties. The regional dependence of biomass resources might cause interregional incompatibility of fuels, which should be avoided. Our previous studies have shown that computer modelling is capable of providing information on the dependence of engine performance upon the type of the fuel used, also under conditions of simulation of road tests. Based on computer simulations of the given engine cycle, the impact of the use of biofuels on carbon dioxide emissions from a diesel and gasoline engine was analysed. The tested fuels were: gasoline 95, diesel, ethanol, DME dimethyl ether, and FAME fatty acid methyl esters. The differences in CO₂ emissions of the tested fuels were large (up to 17%), but none of the analysed fuels exceeded the maximum emission limits allowed by legal regulations. The results of such simulations might be used for planning the development of various types of engines - possibly adjustable to fuels of various origin, as well as for planning the fuel composition assuring the best performance in a wide spectrum of engine constructions.

1. Introduction

Nowadays increasing attention is paid to the problems of environmental protection [1, 2]. The preservation of clean air is essential for the comfort of human life and health [3, 4]. The economic development, including transportation, forces the increase in energy consumption [5]. The side effect of burning fuel necessary for motor vehicle movement is the emission of pollutants, in particular CO₂ [6]. A huge and increasing number of passenger cars and the wide use of lorries and other means of transport causes that the attempts to mitigate air pollution become an enormous challenge [7, 8]. It should be emphasised that the environmental challenges are not only connected with the technological development but also with the very complex ways of technology management. Road transport, which is one of the key sectors of the European economy, has been considered for many years to be one of the major emitters of substances that impair the quality of atmospheric air [9, 10]. About 30% of total CO₂ emissions in the EU come from the transport sector, 72% of which – from road transport. There are two ways to reduce CO₂ emissions from cars: increasing vehicle efficiency or changing the fuel. Most of the energy used in transport comes from conventional fuels, but refineries are and will be forced through legal regulations to produce more and more environmentally friendly fuels [11]. The binding European
directives oblige member states to implement biofuels and bio-components on the fuel market. In the directive’s sense, alternative fuels are fuels or energy sources that serve, at least in part, as a substitute for petroleum-based energy sources in transport and which can potentially help to reduce the dependence of EU Member States on oil imports and support the decarbonisation of transport, consequently improving the environmental performance of this sector [12]. The fuels, alternative to diesel oil and gasoline have already been used on a large scale. Derivatives of plant materials such as vegetable oils or their esters are used for diesel engines while ethanol – as a replacement of petrol or its additive for spark ignition engines [13]. Alternative fuels and also electro-mobility are promoted and introduced to the market [14, 15]. Increasingly restrictive driving tests are being introduced, intensifying the race towards reduction of pollutant emissions [16, 17]. The designing and use of computer simulation programmes and models leading to determination and comparison the parameters of engine performance become significant tools in research and development works in automobile testing and evaluation [18, 19].

2. Materials and methods

The aim of this work was to determine the impact of biofuels on the emission of carbon dioxide from an internal combustion engine. For this purpose, computer simulations were used to model the given engine work cycle.

The actual technical specifications of the Fiat Panda 1.3 MultiJet passenger car, equipped with a diesel engine, and Fiat Seicento 1.1 with a gasoline engine [20, 21] were implemented in the simulation. The choice of the vehicles was dictated by their typically urban character (small displacement of the engine, small dimensions) and various fuels that they can be supplied with. The basic technical data for the 1.1 Fire and 1.3 MultiJet II engines are listed below in Table 1.

| Parameter                        | Units | 1.1 Fire | MultiJet II |
|----------------------------------|-------|----------|-------------|
| The number of cylinders          |       | 4        | 4           |
| Cylinder layout                  |       | In-line  | In-line     |
| Injection type                   |       | Direct, multipoint | Direct, multistage |
| Compression ratio                |       | 9.6: 1   | 16.8: 1     |
| The diameter of the cylinder     | mm    | 70       | 69.6        |
| Piston stroke                    | mm    | 72       | 82          |
| Displacement                     | cm³   | 1108     | 1251        |
| Maximum power                    | kW    | 40       | 55          |
| Maximum torque                   | N·m   | 88       | 190         |
| Rotational velocity at maximum power | rpm | 5000     | 4000        |
| Rotational velocity at maximum torque | rpm | 2750     | 1500        |
| Idle speed                       | rpm   | 850±50   | 850±20      |

The computer program enabled simulations for fuels with different properties and compositions: gasoline 95, diesel fuel; and for alternative fuels (100% content): ethanol, dimethyl ether DME, fatty acid methyl esters FAME. The basic properties of the fuels are listed in Table 2.

| Parameter                        | Gasoline 95 | Ethanol | DME | Diesel oil | FAME |
|----------------------------------|-------------|---------|-----|------------|------|
| Carbon content [%]               | 86.4        | 52.1    | 52.1| 86.5       | 78.0 |
| Hydrogen content [%]             | 13.6        | 13.1    | 13.1| 13.4       | 12.0 |
| Oxygen content [%]               | 0           | 34.7    | 34.7| 0          | 10.0 |
| Heating Value [MJ/kg]            | 45          | 30.4    | 28.8| 44.0       | 37.0 |
| Air to fuel ratio [gair/gfuel]    | 14.7        | 9.06    | 9.06| 14.5       | 12.5 |
Scilab software [22] was used to build simulation models. It is an open source package for scientific applications offering advanced calculation functions. The software allows creating dynamic models based on complicated mathematical calculations and algorithms. Its scope of use includes design, simulation, recording and compilation of developed solutions. In addition to choosing the suitable software, it was also important to choose the right work cycle for each vehicle for a reliable verification of the obtained results. Each newly manufactured vehicle, before it is allowed to be used on the road, must undergo the vehicle approval procedure to determine the values of various parameters (including exhaust emissions) and compare them with the applicable standards. The NEDC homologation test (New European Driving Cycle) has been in force since 1990 and it has been the basis for the decision approving new cars for road use. A new test procedure has been in force since September 2017, however, it applies to new cars only [23, 24, 25, 26]. For those, there are completely different emission limits for both carbon dioxide and other exhaust components. Both Fiat Seicento and Fiat Panda were examined based on the former NEDC procedure and, therefore, this one was chosen for simulation in the present study.

The scheme of the simulation model developed as part of the conducted tests is shown in figure 1.

![Diagram of the simulation model for calculation of the mass exhaust values.](image_url)
3. Results

As mentioned, the simulation model was used to analyse the operation of two different engine types fed with different types of fuels according to the NEDC test procedure. Figure 2 shows the results generated by the "NEDC generator" block, showing the following waveforms: vehicle speed, the force acting on the wheels and the gear number in the gearbox.

![Figure 2](image)

**Figure 2.** Signals generated by the "NEDC generator" module during the simulation (A – Fiat Seicento, B – Fiat Panda). v – vehicle speed, d – distance travelled by the vehicle during the test, F – force exerted on the wheels and p – gear number in the gearbox.

The above signals indicate the correctness of the entire model. It was found that the courses are consistent with the literature data, and that at this stage no deviations occur that would depend on the simulated engine type.

The results generated by the "Calculation emission from fuels" module, which determined the emission values of carbon dioxide and water vapour, are presented in figure 3.

![Figure 3](image)

**Figure 3.** Signals generated by the "Calculation emission from fuels" module during the simulation (A – Fiat Seicento, B – Fiat Panda).
The graphs show time dependencies of: the mass flux of carbon dioxide emission during the test, mass flux of water vapour emission, total carbon dioxide emission and total water vapour emission from 95 gasoline and diesel oil.

On the basis of the above graphs, slight differences in the mass emission of carbon dioxide and water vapour for the considered fuels can be observed. However, the "total carbon dioxide emission," chart indicates higher emission from gasoline engine than from diesel.

The detailed results are presented in Table 3. The table gives the list of total carbon dioxide and water vapour emissions for individual fuels.

**Table 3. Results of total carbon dioxide and water vapour emissions for the used fuels.**

| Emitted substance | Gasoline 95 | Ethanol | DME | Diesel oil | FAME |
|-------------------|-------------|---------|-----|------------|------|
| CO$_2$ [kg]       | 1.51        | 1.41    | 1.54| 1.29       | 1.38 |
| H$_2$O [kg]       | 0.750       | 0.898   | 0.948| 0.488      | 0.517|

The differences in the emissions of the indicated fuels are in favour of diesel and its alternatives. During the test, the diesel engine emitted more than 17% less carbon dioxide than the gasoline engine. However, FAME fuel turned out to be more emissive in relation to conventional fuel in terms of both carbon dioxide and water vapour. The difference amounts to approx. 7% CO$_2$ and 6% H$_2$O respectively. In the case of gasoline and its substitutes, conventional fuel has shown carbon dioxide emissions in the middle between its own alternative fuels. Ethanol showed lower emissivity (more than 7% less CO$_2$ in the test), while dimethyl ether DME about 2% more. In the case of water vapour, the emission value compared to conventional gasoline was higher by about 20% for ethanol and 26% for DME, respectively.

The total carbon dioxide and water vapour emissions that discharged during the NEDC test by the tested engines are presented in Table 4. The results obtained are given in g/km, and compared with the permissible levels set out in relevant standards. On this basis, it was estimated whether a given propulsion unit could be allowed to operate on the basis of this very criterion.

**Table 4. List of CO$_2$ emission results for individual fuels with values from regulations.**

| Emitted substance | Gasoline 95 | Ethanol | DME | Diesel oil | FAME |
|-------------------|-------------|---------|-----|------------|------|
| CO$_2$ [kg]       | 1.51        | 1.41    | 1.54| 1.29       | 1.38 |
| CO$_2$ [g/km]     | 137.27      | 128.18  | 140.00| 117.27     | 125.45|
| CO$_2$ [g/km] limit from the regulation | 170          | 170     | 170 | 130        | 130 |

The limiting values were accepted accordingly to production year of the given automobile, i.e. 170 g/km for FIAT Seicento manufactured in 2010 and 130 g/km for FIAT Panda with diesel engine, produced in 2015. Despite the differences in carbon dioxide emissions from individual fuels, each of them is within the permissible range.

The car equipped with a diesel engine has shown lower CO$_2$ emission than the car fuelled with gasoline. Such a result can be attributed to the better fuel economy of the car with diesel engine in road conditions corresponding to the NEDC tests. It needs to be noted that the simulation programme does account for the formation of substances (environmentally rather harmful, e.g. tars) other than CO$_2$ and water vapour. Consequently, conclusions concerning the ecological impact of the cars under analysis cannot be considered as complete.

4. Conclusions

Based on the conducted simulations, the following conclusions can be made:

- In the conditions of NEDC tests and the use of dedicated fuels, the car equipped with a diesel engine has shown smaller CO$_2$ emission than the car with spark-ignition engine. This difference seems to be attributable to differences in the behaviour of cars as whole units;
The comparison of diesel fuel with its alternative FAME fuel, showed a higher emission of carbon dioxide by about 7% when the FAME was used. This corresponds to a higher content of carbon in the chemical composition of FAME. It has to be recognised, however, that in the case of diesel fuel the emitted carbon is derived from fossils and, therefore, introduces additional carbon to the atmosphere, while the biofuel contains the carbon that was already in the atmospheric carbon cycle. Consequently, the use of biofuel has a positive ecological impact, despite higher emission of CO$_2$.

With respect to gasoline and its substitutes, the lowest value of emitted carbon dioxide was obtained for ethanol, while the dimethyl ether, DME, emitted more CO$_2$ than conventional gasoline 95. While the first observation could be associated with smaller carbon content in ethanol than in other fuels, the result observed for DME appears to be in contrast with the chemical composition, and probably indicate some problems with the combustion of this fuel in the conditions required by the test. The problem requires further studies for deeper understanding.

Despite observed differences in emissivity, in the case of both cars, each fuel analysed in the test procedure gave the result within the CO$_2$ emission limits allowed by the regulations.

The developed simulation programme reflects the work cycle of real engines powered by different fuels and can be a helpful tool in the process of planning experiments or a valuable source of data for further consideration. The actual state of the programme is dedicated only to the determination of the main components of exhaust gases. In spite of the compliance with NEDC tests, it cannot serve as a tool for deeper ecological assessment of the car’s performance.

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