An Enhanced Method of Evaluation of Harmful Emissions from Gasoline Engines During Operation

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**Abstract.** It is obvious that a vehicle's operating modes significantly impact the composition and amount of engine exhaust gases. Various limitations have been adopted in the standard methods for determining the amount of exhaust gases under different operating conditions. The standard method determines the composition of gases at low (usually idling) and high angular speeds while the car is in its normal operating mode and stationary. However, this method is insufficient for determining the amount of exhaust gases in operation. This is especially true for modern electronically controlled engines equipped with a three-component catalyst in the exhaust gas path. Methods for determining exhaust gases in automobile production have improved over the last 60 years. These methods include dynamometric bench testing (UNECE No. 49), creating a standard driving cycle, testing in a bench driving cycle (UNECE No. 83), designing the engine supply system with increasing exhaust gas requirements, improving electronic control, and testing on the road using a standardized driving cycle (PEMS). While these methods evaluate the environmental friendliness of designs, they do not accurately represent performance under various operating conditions. Developing new methods to determine automobile exhaust gas emissions under operating conditions is an important task. This article proposes a method to determine CO₂ emissions per unit of travel distance at various constant speeds and loads, considering the operating characteristics of a stationary gas analyzer.

**Keywords:** Gasoline engine, OBD-II, electronic control unit measurements, CO₂ exhaust gas, exhaust gas measurement, on-board diagnostics, calculation model, transport emissions, gas analyzer, engine parameters

# INTRODUCTION

The methods used to test and calculate the identification of harmful gases released by motor vehicles are diverse, and these methods are based on a number of approaches. Engine dynamic testing is often used for detailed experimental analyses of automotive engines and for specifying and tuning their parameters [9, 11, 16]. Chassis dynamometer tests are among the most significant laboratory devices for examining vehicle emissions. During these tests, the entire vehicle drivetrain is examined, and various loads and driving conditions can be applied. However, this practice cannot fully recreate operating conditions [1, 7, 8]. Since 2011, a method of exhaust gas measurement using a PEMS (portable emission measurement system) gas analyzer has been developed for vehicles that meet Euro 5 standards under real conditions. The PEMS gas analyzer can measure the exhaust gases of HC, NO, CO, CO₂, and PM [10, 15]. Other studies have demonstrated that, under identical test conditions and test objects, PEMS is more efficient than dynamometer measurements [2, 5, 17]. In addition to the benefits of state-of-the-art PEMS equipment and test procedures, using modern equipment has some drawbacks. For example, the equipment weighs approximately 170 kg and consists of analyzers, a battery, a generator, and an additional operator besides the driver is needed to run it. Resistance to gas movement and back pressure are generated by the installation of the equipment tube in the exhaust gas system. This affects the vehicles' fuel consumption and exhaust gas emissions. Additionally, environmental testing of vehicles on the road is slow and costly. The aforementioned final testing methods are employed in the final stages of the vehicle manufacturing process to adjust ECU parameters and estimate design progress.

In most developed states, the emissions of exhaust gases in the running of vehicles are calculated in real time and when in motion with the aid of remote sensing technology [4]. The approach has been implemented in many countries including the USA, Great Britain, Germany, Netherlands, Sweden, China and South Korea considering as a good instrument in monitoring the environment and in establishing the environmental status of road vehicles. The primary benefit of the approach is that it can allow measuring a substantial number of vehicles within a relatively short period, remotely. It is possible to adopt social and environmentally significant solutions quite quickly and correctly (such solutions can be, for example, the introduction of environmental zones, the identification of highly contaminating automobile parks).

In recent years, the United Nations Economic Commission for Europe has tightened EURO environmental requirements for vehicle exhaust gases [13]. Requirements related to controlling and limiting CO₂ emissions into the atmosphere have been reflected in various international and national legal and regulatory documents. Notable examples include the Paris Climate Agreement (2015) [14] and UNECE Regulation No. 101 [12], which strictly establishes CO₂ emission standards under EU regulations (EU) 2019/631 and (EU) 2023/851 [6]. The main reason for this trend is that CO₂ is the primary greenhouse gas causing climate change. It should be noted that the concentration of CO₂ in the atmosphere increases when internal combustion engine vehicles are operated [3]. This accelerates the process of global climate change. Therefore, it is essential to improve the methodology for determining the amount of CO₂ emitted by vehicles and to introduce numerical mathematical models for assessing it in real operating conditions. These approaches are cost-effective and practical in determining exhaust gases because they take into account the vehicle's real-time operation.

Current methods and standards for determining exhaust gases from vehicles in operation do not sufficiently cover the capabilities of the improved design of modern vehicles. According to the test methods, the composition of exhaust gases is measured in stationary mode, at a certain engine speed and without load. This does not allow for an accurate assessment of the amount of harmful gases produced in real operating conditions (city traffic jams, mountainous or uneven roads, frequent changes in speed). In addition, there are no requirements for the measurement of amount of CO₂, methods for determining its amount per unit of travel. This does not provide a sufficient assessment of the environmental characteristics of a vehicle in terms of exhaust gases.

# RESEARCH OBJECTIVE

The aim of this study is to develop a method for measuring the CO2 concentration in exhaust gases of gasoline-powered vehicles taking into account the technical characteristics and scope of application of existing testing equipment, and to create a mathematical model that allows calculating the amount of CO2 in exhaust gases based on vehicle ECU data.

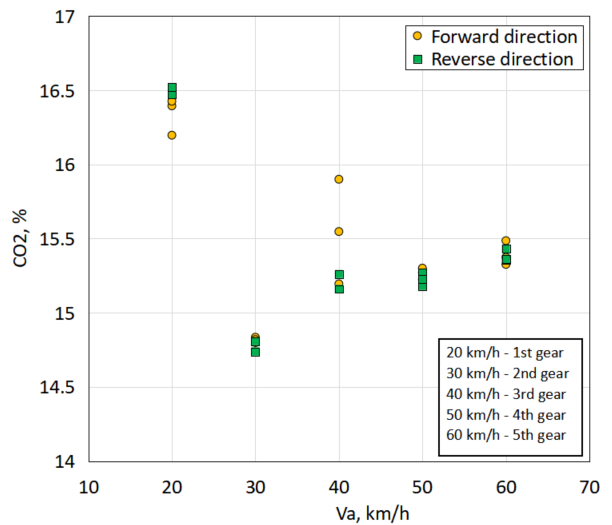
# METHODOLOGY

Determining the composition of exhaust gases from in-service vehicles is one of the most important environmental issues. Therefore, a methodology has been developed to determine the amount of exhaust gases from in-service gasoline-powered vehicles, based on the technical characteristics of the existing technology, the level of sensitivity, and the scope of application.

Based on the operating conditions of the gas analyzers used in stationary mode during the test, the vehicle's conditions at various constant speeds were considered when organizing the test. The tests were carried out at constant speeds of 20, 30, 40, 50, and 60 km/h (Figure 1). Using the constand gear of the gearbox during the test ensures stable vehicle operation at the specified speeds and constant engine speed at different loads. This ensures that the gas analyzer passes an accurate and stable amount of exhaust gases and records its indicators. At the Pskent testing ground (Figure 1), testing was conducted on a road that allowed the vehicle to travel at each constant speed for at least two minutes. The main components of the exhaust gases — CO, CO2, NOx, and HC — were recorded using a gas analyzer (Figure 2). Figure 3 shows the CO2 emission results measured by a gas analyzer while the car was moving at various constant speeds.

As shown in Figure 3, the test results indicate that there is no significant change in the proportion of CO2 emissions entering the atmosphere as vehicle speed increases.

|  |  |
| --- | --- |
|  |  |
| **FIGURE 1.** General view of the test ground site in  Pskent and the distance traveled at constant speed | **FIGURE 2.** Synchronous recording of test results |



**FIGURE 3.** The proportion of CO2 in the composition of gases obtained from a gas analyzer at various constant speeds

**TABLE 1.** Measurement equipment

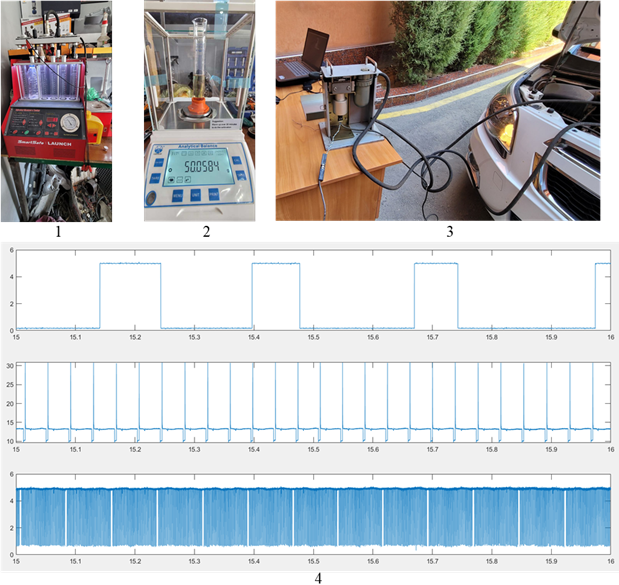
|  |  |  |
| --- | --- | --- |
| **No.** | **Instruments** | **Quantity** |
|  | Gas Analyzer Infrakar | 1 |
|  | Flowmeter Ono sokki | 1 |
|  | OBD-II, SCANMATIC | 1 |
|  | Digital Thermo-Hygrometer | 1 |
|  | Stopwatch | 1 |
|  | Measuring Tape | 1 |
|  | Anemometer | 1 |
|  | Road Cones | 6 |
|  | Manometer | 1 |
|  | Depth Gauge | 1 |
|  | Speed, acceleration, and distance measuring device ISD-3.1 | 1 |
|  | Ballast | 200 kg |
|  | GPS | 1 |

This experimental method provided repeatable and statistically reliable test results. It was possible to determine reliable results within the range of sensitivity of the gas analyzer and to identify changes in emission parameters at different speeds. Furthermore, during the test, not only were the levels of exhaust gas measured, but the vehicle's ECU parameters were also measured simultaneously in real time using the Scanmatik scanning device through the OBD-II connector (Figure 2). Table 1 shows the equipment used to conduct the tests, and Table 2 shows the recorded ECU data.

**TABLE 2.** Parameters received from the Electronic Control Unit

|  |  |  |
| --- | --- | --- |
| **No.** | **Parameter Name** | **Unit** |
|  | n – Engine crankshaft speed | rpm |
|  | Δti – Injector pulse width | ms |
|  | Intake manifold absolute pressure | kPa |
|  | Intake air temperature | °C |
|  | Air mass flow | g/s |
|  | Oxygen sensor 1 voltage | V |
|  | Absolute air pressure | kPa |
|  | Throttle position | % |
|  | Coolant temperature | °C |
|  | Va – Vehicle speed | km/h |
|  | Engine torque | Nm |

Fuel consumption is one of the most important indicators when assessing the efficiency of internal combustion engines. In modern cars, the ECU controls the amount of fuel injected into the cylinders using injectors. Therefore, this study conducted practical experiments based on several test methods to evaluate the reliability of using ECU data to directly determine fuel consumption. The test equipment is shown in Figure 4: 1) determining the dependence of fuel consumption on the duration of the injector valves opening (injector pulse width); 2) determining the fuel consumption injected by one injector for 30 seconds using high-precision electronic scales; and 3) measuring the fuel consumption using fuel flow meter.



**FIGURE 4.** Equipment used in tests: *1 - LAUNCH injector tester, 2 - electronic scale, 3 - ONO SOKKI fuel flow meter*



**FIGURE 5.** Oscilloscope measurements from fuel flow meter (1st and 2nd rows), injector valve opening (3rd row), and engine speed (4th row) from ECU

Figure 5 shows the waveforms of the fuel flow meter pulse and the injector pulse, as well as the variation in crankshaft rotation speed over time. An empirical equation for calculating total fuel consumption using ECU signals was established based on the analysis of the test results.

(1)

where: *Qt* - fuel consumption per unit of time, [g/sec]; a=0,00368 – the proportionality coefficient of fuel consumption by [g/ms]; – number of fuel injections per second in the operating mode of the internal combustion engine; – open duration of the injector valve, [ms]; – number of engine crankshaft revolutions, [rpm]; 4 – number of cylinders.

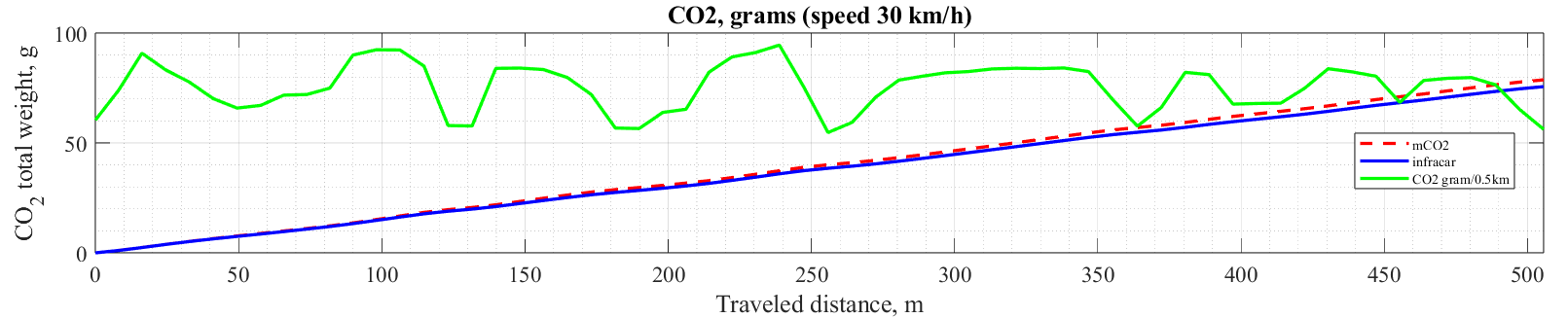
|  |  |
| --- | --- |
|  |  |
| **FIGURE 6:** Comparison of test and calculation results for amount of fuel consumed | **FIGURE 7:** Fuel consumption per kilometer traveled by a vehicle at a constant speed |

The error between the calculated results and the experimental measurements was no greater than 5% (Figure 6). This proves that this approach to calculating fuel consumption using ECU data is reliable. The consumed fuel per one kilometer of travel is shown in Figure 7.

The following equation (2) was derived to determine the amount of CO2 emitted during a vehicle's travel. A mathematical model was also developed that corresponds to the amount of CO2 emitted per unit distance traveled at a constant speed (Figure 8).

(2)

where: – total fuel consumption, [g/s]; 3.08 – coefficient, the mass of CO₂ emitted from the combustion of one gram of gasoline; constant driving speed of the vehicle, [m/s]; distance traveled by the vehicle in one second, [km]; - travel time equal to one second, [s]; – angular velocity of the engine crankshaft, [rad/s]; – transmission ratio of final gear; – transmission ratio gearbox at corresponding engaged gear; rk – wheel rolling radius, [m].



**FIGURE 8.** Comparative graph of CO₂ emissions per unit of travel determined by test results and mathematical calculation method

The CO₂ emission results calculated by the algorithm were compared with the values recorded by a gas analyzer during practical tests. The results of this comparison showed (Figure 8) that the difference between the CO₂ emission values calculated using the mathematical model and the CO₂ amounts measured based on the tests was in the range of ±5%. This difference is due to the sensitivity limit of the available sensors and environmental conditions. However, since the error level falls within acceptable limits, the model can be used as a reliable tool for assessing CO₂ emissions from operating vehicles.

# CONCLUSION

The current research proposes an estimation method for the CO₂ concentration in the exhaust gases of gasoline-powered vehicles under actual working conditions without the use of a gas analyzer. To prove the suggested approach, experiments were conducted at fixed velocities ranging from 20 to 60 km/h.

During these tests the concentrations of the CO₂ measured using a gas analyzer and the operating parameters of the engine were continuously monitored through an ECU. The CO₂ values in direct gas analysis and the values that were determined using ECU data were compared. As an outcome of this study, a mathematical model was developed to estimate the amount of CO₂ emissions. The output generated by the numerical model was compared with actual measurements, It was observed that the average relative error is within ±4...5% range. This relative error confirms that the model is useable in the real world to estimate emissions.

The results of the study show that for gasoline vehicles equipped with three-component catalysts, the determination of CO₂ emissions based on numerical model with data obtained through the ECU is highly effective. This approach is not only economically and technically feasible, but can also be used in a variety of real operating conditions.

The proposed method allows for the development of real-time environmental monitoring systems, assessment of the environmental condition of vehicles, as well as rapid and reliable detection of harmful substances in exhaust gases.

Future studies are being conducted to apply it to dynamic vehicle driving modes. This approach is of great practical importance in monitoring the compliance of the operating vehicle fleet with environmental standards.

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