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DETERMINING THE AIR-FUEL RATIO (AFR) FOR GASOLINE AND GASOLINE-ETHANOL BLENDS (E5 AND E10): DIFFERENCES IN CALCULATION METHODS AND TECHNICAL AND COMMERCIAL SIMPLIFICATIONS

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Abstract. In basic thermodynamic calculations, gasoline is commonly approximated as octane (C_8H_{18}), for which the stoichiometric air-fuel ratio (AFR) is 15.1. However, in automotive applications involving the control of spark-ignition engines, the AFR for gasoline is typically assumed to be 14.7. This value reflects the average hydrocarbon composition of commercial gasoline, which is a complex mixture of various hydrocarbons including alkanes, cycloalkanes, and aromatics. The averaged elemental composition of gasoline is often expressed as $C_1H_{1.95}$, which does not correspond to a specific molecule but adequately describes the bulk properties of the fuel. A similar issue arises when determining the AFR for commercially available fuels, such as E5 and E10, which are mixtures of gasoline and ethanol with 5 % and 10 % ethanol content by volume, respectively. Using a simplified volumetric approach, the AFR for E5 is approximately 14.4 and for E10 about 14.1. However, because ethanol is denser than gasoline, volume-based calculations do not accurately reflect the true stoichiometry. In mass terms, the ethanol content increases by approximately 6.5 % for E5 and 13 % for E10. Taking into account the averaged hydrocarbon composition of gasoline and the mass-based ethanol content, the AFR values can be adjusted to 14.33 for E5 and 13.95 for E10. The aim of this article is to determine correction coefficients for exhaust gas analysers or fuel-air mixture control systems in vehicles. The study compares two methods for evaluating the AFR: one based on the oxygen content in exhaust gases using a wideband exhaust oxygen sensor, and the other based on the concentrations of exhaust gas components using a simplified Brettschneider equation. The latter method analyses oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) in the exhaust gases. It was demonstrated that the difference in results between the two applied methods does not exceed 2.3 %, and that including the correction factors for E10 fuel decreases the lambda coefficient by 4.5 % to 5.7 %.

MSC 2010: *80A25, 65C20, 74F10*
Keywords: *lambda coefficient correction calculation, spark-ignition combustion engine control, determining the Air-Fuel Ratio (*AFR*) value, biofuel additives, ethanol*

1. Introduction

Increasing awareness of the harmful effects of internal combustion engine emissions [1] has driven advances in exhaust after-treatment systems [2], engine efficiency technologies [3, 4], and the adoption of cleaner or more sustainable fuels [5, 6]. One of the key challenges in modern engine engineering is integrating precise control systems with environmentally friendly fuels.

Maintaining the correct lambda (λ) coefficient is essential for achieving optimal performance, fuel efficiency, and low emissions in spark-ignition engines. Lambda represents the ratio of the actual air-fuel mixture to the stoichiometric mixture, with $\lambda = 1$ being ideal for complete combustion in gasoline engines. Deviations from this value caused by sensor aging [7], fuel quality fluctuations [8] or control system faults [9, 10] can lead to incomplete combustion, increased emissions and reduced engine performance. Rich mixtures ($\lambda < 1$) may enhance cooling and power under certain conditions but significantly increase fuel consumption and pollutant levels [11]. On the other hand, lean mixtures ($\lambda > 1$) can improve fuel economy but raise the risk of engine knock and higher nitrogen oxide (NO_x) emissions.

Different fuels require specific air-fuel ratios (AFR) to ensure complete and efficient combustion. AFR, defined as the mass ratio of air to fuel, depends on the fuel's chemical composition. The stoichiometric AFR is approximately 14.7:1 for gasoline (E0), 15.5:1 for liquefied petroleum gas (LPG), and 17.2:1 for compressed natural gas (CNG). The λ coefficient represents the ratio of the actual AFR to the stoichiometric AFR for a given fuel.

This relationship allows the combustion process to be assessed and controlled consistently across various fuel types. Maintaining a λ value close to 1 ensures optimal combustion efficiency and compatibility with emission control systems, regardless of the fuel used.

Under the revised Renewable Energy Directive (RED II), EU member states have increased the use of ethanol in gasoline, leading to the widespread adoption of E5 and E10 blends containing 5 % and 10 % ethanol, respectively. These fuels support efforts to cut greenhouse gas emissions and reduce fossil fuel dependence [11].

The use of ethanol-gasoline blends challenges engine control, as their stoichiometric air-fuel ratio differs from that of pure gasoline. Without proper calibration, engines may run at incorrect lambda values, causing inefficient combustion, higher emissions, or reduced performance [10, 11].

This issue is especially relevant in diagnostic stations, carburetted equipment, and older vehicles produced before the fuel transition, which often lack ethanol detection systems. Without knowing the ethanol content, fuelling adjustments and lambda interpretation may be inaccurate, making emissions testing and engine control unreliable.

This article aims to determine AFR values for gasoline-ethanol blends and compare lambda measurements from an engine-integrated sensor and an exhaust gas analyser used in inspection stations. It also evaluates how ignoring ethanol-related correction factors affects the accuracy of λ readings.

2. Methods for calculating the AFR coefficient with consideration of the impact of technical and commercial simplifications in the automotive sector

2.1. Method for calculating the amount of air required for complete fuel combustion used in thermodynamics (assuming C_8H_{18} as the main component of gasoline) – mass-based calculation method

In thermodynamic calculations, gasoline is commonly approximated as octane (C_8H_{18}), based on the assumption that C_8H_{18} is the main component of gasoline. The complete combustion process of such a fuel follows equation (1). Equation (1) represents the stoichiometric complete combustion of C_8H_{18}. One mole of octane requires 12.5 moles of O_2. Since atmospheric air contains approximately 21 % oxygen by volume, this corresponds to about 4.76 moles of air per mole of O_2 (equation (2)). Therefore, complete combustion requires 12.5 · 4.76 = 59.5 moles of air per mole of octane.

$$\mathrm{C_8H_{18}} + \frac{25}{2}\mathrm{O_2} \rightarrow 8\mathrm{CO_3} + 9\mathrm{H_2O} \tag{1}$$

$$1\ \mathrm{mol\ O_2} \rightarrow \frac{100}{21} \approx 4.76\ \mathrm{mol\ air} \tag{2}$$

The mass of 1 mole of octane (C_8H_{18}) is 0.11423 kg, as shown in equation (3).

$$M(\mathrm{C_8H_{18}}) = 8 \cdot 12.1\ \mathrm{g/mol} + 18 \cdot 1.008\ \mathrm{g/mol} = 114.23\ \mathrm{g/mol} = 0.11423\ \mathrm{kg} \tag{3}$$

The average molar mass of air is 28.96 g/mol, or 0.02896 kg/mol. Therefore, if the complete combustion of one mole of octane (C_8H_{18}) requires 59.5 moles of air, the stoichiometric (AFR) for this fuel can be calculated as 15.09 kg of air per 1 kg of gasoline (C_8H_{18}), as shown in equation (4).

$$\mathrm{AFR}_{\mathrm{C_8H_{18}}} = \frac{\mathrm{m_{air}}}{\mathrm{m_{C_8H_{18}}}} = \frac{1.724\ \mathrm{kg}}{0.11423\ \mathrm{kg}} \approx 15.09 \tag{4}$$

2.2. Method for calculating the amount of air required for complete fuel combustion used in the automotive industry, based on the average hydrocarbon composition of gasoline (commercial gasoline approximated as $C_1H_{1.95}$)

Gasoline is a mixture of hydrocarbons and therefore does not have a single, precise chemical formula. The model described earlier represents gasoline as C_8H_{18}. However, in the automotive industry, particularly in engine control processes, a standardized average composition is used, approximating gasoline as $CH_{1.95}$. This formula represents an unstable hydrocarbon with a variable composition and does not correspond to a specific chemical compound. Combustion of such a fuel can be described using a simplified equation (equation (5)), in which the coefficients a, b, and c are determined stoichiometric ally. In practice, it is accepted that the stoichiometric air-fuel ratio for $CH_{1.95}$ is 14.7, meaning that 14.7 kilograms of air is required to completely combust 1 kilogram of gasoline ($CH_{1.95}$).

$$\mathrm{CH_{1.95} + aO_2 \rightarrow bCO_3 + cH_2O} \tag{5}$$

2.3. Method for calculating the amount of air required for complete combustion of ethanol (C_2H_5OH) – mass-based calculation method

The complete combustion of ethanol (C_2H_5OH) requires 14.28 moles of air, as shown in equation (6). The lower air requirement is due to the presence of oxygen within the fuel molecule itself. One mole of ethanol requires 3 moles of O_2. Equation (6) represents the complete combustion reaction of ethanol (ethyl alcohol).

$$\mathrm{C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O} \tag{6}$$

The mass of 1 mole of ethanol (C_2H_5OH) is 0.04607 kg, as shown in equation (7).

$$\begin{aligned}\mathrm{M(C_2H_5OH)} &= 2 \cdot 12.1\,\mathrm{g/mol} + 6 \cdot 1.008\,\mathrm{g/mol} + 16 = 46.07\,\mathrm{g/mol} = \\ &= 0.04607\ \mathrm{kg}\end{aligned} \tag{7}$$

Assuming, as before, that the average molar mass of air is 0.02896 kg/mol, and given that the complete combustion of ethanol (C_2H_5OH) requires 14.28 moles of air, the stoichiometric air-fuel ratio for this fuel is calculated to be 8.95 kg of air per 1 kg of ethanol (C_2H_5OH), as shown in equation (8).

$$\mathrm{AFR_{C_2H_5OH}} = \frac{\mathrm{m_{air}}}{\mathrm{m_{C_2H_5OH}}} = \frac{0.4122\ \mathrm{kg}}{0.04607\ \mathrm{kg}} \approx 8.95 \tag{8}$$

2.4. Determination of the AFR value for E5 and E10 fuel mixtures using a method that accounts for the volumetric share of the fuel

Assuming the volumetric share, the content of gasoline and ethanol in E5 fuel is 95 % gasoline and 5 % ethanol, and in E10 fuel it is 90 % gasoline and 10 % ethanol, respectively. The analysis presented in the previous sections showed that the AFR value for fuel can vary (e.g., $\mathrm{AFR_{C_8H_{18}}} \approx 15.09$, $\mathrm{AFR_{C_1H_{1.95}}} \approx 14.7$, $\mathrm{AFR_{C_2H_5OH}} \approx$ ≈ 8.95). In the further analysis, all of these variants will be considered.

The determination of the AFR value for the E5 fuel mixture using the bypass method is presented for $\mathrm{AFR_{C_8H_{18}}}$ in equation (9) and for $\mathrm{AFR_{C_1H_{1.95}}}$ in equation (10). For E10 fuel, the values are presented for $\mathrm{AFR_{C_8H_{18}}}$ in equation (11) and for $\mathrm{AFR_{C_1H_{1.95}}}$ in equation (12).

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E5}} &= 0.95 \cdot \mathrm{AFR}_{\mathrm{C_8H_{18}}} + 0.05 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = 0.95 \cdot 15.09 + 0.05 \cdot 8.95 = \\ &= 14.78\end{aligned} \tag{9}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E5}} &= 0.95 \cdot \mathrm{AFR}_{\mathrm{C_1H_{1.95}}} + 0.05 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = 0.95 \cdot 14.7 + 0.05 \cdot 8.95 = \\ &= 14.41\end{aligned} \tag{10}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E10}} &= 0.90 \cdot \mathrm{AFR}_{\mathrm{C_8H_{18}}} + 0.1 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = 0.90 \cdot 15.09 + 0.1 \cdot 8.95 = \\ &= 14.48\end{aligned} \tag{11}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E10}} &= 0.90 \cdot \mathrm{AFR}_{\mathrm{C_1H_{1.95}}} + 0.1 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = 0.90 \cdot 14.7 + 0.1 \cdot 8.95 = \\ &= 14.13\end{aligned} \tag{12}$$

Although commercial fuels are sold as volumetric mixtures, for combustion processes the mass fraction in E5 and E10 fuel mixtures is more relevant. To select the AFR more precisely, the AFR must be determined based on the mass share of the components in the mixture.

2.5. Determination of the AFR value for E5 and E10 fuel mixtures using a method that accounts for the mass share of the fuel

When considering the mass fraction in E5 and E10 fuel mixtures, it should be noted that ethanol (approximately 0.789 kg/L) is denser than gasoline (approximately 0.74 kg/L). Therefore, a volumetric share of 10 % ethanol in the mixture corresponds to approximately 13 % by mass for E10 fuel and about 6.5 % by mass for E5 fuel.

The determination of the AFR value for the E5 fuel mixture using the mass-based method is presented for $\mathrm{AFR}_{\mathrm{C_8H_{18}}}$ in equation (13) and for $\mathrm{AFR}_{\mathrm{C_1H_{1.95}}}$ in equation (14). For E10 fuel, the corresponding values are given for $\mathrm{AFR}_{\mathrm{C_8H_{18}}}$ in equation (15) and for $\mathrm{AFR}_{\mathrm{C_1H_{1.95}}}$ in equation (16).

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E5}} &= 0.935 \cdot \mathrm{AFR}_{\mathrm{C_8H_{18}}} + 0.065 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = \\ &= 0.935 \cdot 15.09 + 0.065 \cdot 8.95 = 14.69\end{aligned} \tag{13}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E5}} &= 0.935 \cdot \mathrm{AFR}_{\mathrm{C_1H_{1.95}}} + 0.065 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = \\ &= 0.935 \cdot 14.7 + 0.065 \cdot 8.95 = 14.33\end{aligned} \tag{14}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E10}} &= 0.87 \cdot \mathrm{AFR}_{\mathrm{C_8H_{18}}} + 0.13 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = \\ &= 0.87 \cdot 15.09 + 0.13 \cdot 8.95 = 14.29\end{aligned} \tag{15}$$

$$\begin{aligned}\mathrm{AFR}_{\mathrm{E10}} &= 0.87 \cdot \mathrm{AFR}_{\mathrm{C_1H_{1.95}}} + 0.13 \cdot \mathrm{AFR}_{\mathrm{C_2H_5OH}} = \\ &= 0.87 \cdot 14.7 + 0.13 \cdot 8.95 = 13.95\end{aligned} \tag{16}$$

2.6. Assessment of AFR calculation methods

In automotive applications, specifically for powering internal combustion engines, it is most practical to adopt an AFR value of 14.7 for gasoline, which corresponds to the fuel commonly available at fuel stations. In January 2024, Poland replaced E5 gasoline (95 octane) with E10 gasoline, which contains up to 10 % bioethanol derived from second-generation sources such as agricultural residues.

For this reason, it is necessary to account for the AFR value corresponding to the actual fuel in engine control processes. For E5 fuel, the most accurate AFR value is 14.33, while for E10 fuel it is 13.95.

3. Materials and methods

The lambda sensor distinguishes between rich and stoichiometric mixtures not only based on the oxygen content itself, but also by detecting changes in the chemical characteristics of the exhaust gases, which influence the electrochemical voltage. In lean mixtures, the oxygen content is elevated. In contrast, stoichiometric and rich mixtures are characterized by zero residual oxygen in the exhaust, although they differ in the chemical balance of the exhaust composition. During stoichiometric combustion, the available oxygen is sufficient to fully oxidize the fuel. There is no free oxygen, but also no unburned hydrocarbons or carbon monoxide. The main combustion products are CO_2 and H_2O. During rich combustion, oxygen is insufficient, resulting in the formation of carbon monoxide (CO), hydrocarbons (HC), hydrogen (H_2), and sometimes soot. While the oxygen content may also approach zero, the chemical equilibrium of the exhaust differs significantly. The gas becomes reducing rather than neutral, which affects the voltage signals of the lambda sensor.

In the experimental setup, a STAG AFR system equipped with a Bosch LSU 4.2 lambda sensor from Robert Bosch GmbH (Bamberg, Germany) was used. This constitutes the first method, designated as M1. The Bosch LSU 4.2 is a wideband lambda sensor designed for precise AFR measurements. It operates effectively within an AFR range of approximately 5:1 to 20:1 for gasoline applications, corresponding to a lambda range of about 0.65 to 2.0. The sensor requires a warm-up time of around 20 to 30 seconds before reaching its optimal performance. During operation, it maintains a temperature between 650 °C and 800 °C. The sensor provides a controlled output voltage ranging from 0 V to 5 V, managed via an external sensor controller. Its measurement accuracy is high, with an AFR precision of ±0.1 when the lambda value is near 1.

Parallel research was conducted using a second measurement system for lambda values, employing the Capelec CAP3201 exhaust gas analyzer (Montpellier, France). The analyzer measures CO, CO_2, and HC using the NDIR (Non-Dispersive Infrared) method. In this method, each infrared light emission at a specific wavelength is attenuated by a particular gas. The drop in signal corresponds to the concentration of that gas in the exhaust.

O_2 is measured using an active electrochemical sensor based on the principle of electrolysis. When oxygen is present, an ionic current flows through the sensor, altering the voltage at the electrodes.

After measuring the concentrations of CO, CO_2, HC, and O_2, the CAP3201 calculates the λ value using a simplified Brettschneider equation (equation (17)). This constitutes the second measurement method, designated as M2.

$$\lambda = \frac{21 - O_2}{21} \cdot \frac{CO_2}{CO_2 + CO} \tag{17}$$

where:

λ – excess air ratio,

O_2 – percentage volume of oxygen in the exhaust gas [%],

CO_2 – percentage volume of carbon dioxide in the exhaust gas [%],

CO – percentage volume of carbon monoxide in the exhaust gas [%],

21 – percentage volume of oxygen in atmospheric air.

The formula assumes that the main components of the exhaust gases are CO_2, CO, and O_2, while other constituents (such as NO_x or hydrocarbons) are considered negligible. The factor $\frac{21-O_2}{21}$ expresses how much oxygen has been consumed relative to the oxygen content in atmospheric air (21 %). The factor $\frac{CO_2}{CO_2+CO}$ represents the degree of carbon oxidation. The higher the proportion of CO_2 relative to CO, the more complete the combustion. This equation is a simplified version of the Brettschneider approach but still provides an accurate estimation of the actual lambda value, especially for spark-ignition (gasoline) engines.

However, it performs less reliably in the presence of oxygenated fuel components such as ethanol in E5 and E10 fuels. In such cases, the full Brettschneider equation (equation (18)) should be used.

$$\lambda = \frac{(O_2 + CO_2)}{(CO + HC)} \cdot \frac{a + \frac{b}{4} - \frac{c}{2}}{a + \frac{b}{4}} \tag{18}$$

where:

O_2 – oxygen content in the exhaust gas,

CO_2 – carbon dioxide content,

CO – carbon monoxide content,

HC – hydrocarbon content.

Stoichiometric coefficients of the fuel with the general formula $C_aH_bO_c$:

a – number of carbon atoms,

b – number of hydrogen atoms,

c – number of oxygen atoms.

The factor $\frac{(O_2+CO_2)}{(CO+HC)}$ represents the ratio of oxidized to unoxidized combustion products. The factor $\frac{a+\frac{b}{4}-\frac{c}{2}}{a+\frac{b}{4}}$ accounts for the fact that oxygen may already be present in the fuel molecule (for example, in ethanol), which reduces the amount of oxygen required from the air. For instance, in the case of ethanol (C_2H_5OH), where $a = 2$, $b = 6$, and $c = 1$, this factor, according to equation (19), lowers the calculated lambda value compared to a purely hydrocarbon-based fuel, since part of the required oxygen comes from the ethanol molecule itself.

$$\lambda' = \frac{a+\frac{b}{4}-\frac{c}{2}}{a+\frac{b}{4}} = \frac{2+\frac{6}{4}-\frac{1}{2}}{2+\frac{6}{4}} = \frac{2+1.5-0.5}{2+1.5} = \frac{3.0}{3.5} = 0.857 \tag{19}$$

where λ' is the component of the full Brettschneider equation that accounts for the presence of oxygen in the fuel molecule.

In exhaust gas analyzers such as the Capelec CAP3201, this formula (or its simplified version) is implemented in the device's software, so the user does not need to calculate it manually.

For gasoline-type fuels (C_8H_{18}), the formula simplifies because $c = 0$ and the values are $a = 8$, $b = 18$.

Regardless of the chosen method for calculating lambda, analyzers typically assume that the AFR reference value corresponds to pure gasoline without ethanol additives, meaning that an AFR of 14.7 is used as the base value for converting lambda. However, if the tested fuel and its AFR at $\lambda = 1$ are known, correction factors can be applied. For example, for E5 fuel, the correct AFR is 14.33 at lambda 1, and for E10 fuel, it is 13.95 at lambda 1.

The correction equations for E5 (equation (20)) and E10 (equation (21)) are as follows:

$$\lambda_{rzE5} = \frac{\lambda_{E0}\cdot AFR_{E5\ at\ \lambda=1}}{AFR_{E0\ at\ \lambda=1}}\cdot\lambda_1 = \frac{1\cdot 14.33}{14.7}\cdot\lambda_1 \approx 0.97\cdot\lambda_1 \tag{20}$$

$$\lambda_{rzE10} = \frac{\lambda_{E0}\cdot AFR_{E10\ at\ \lambda=1}}{AFR_{E0\ at\ \lambda=1}}\cdot\lambda_1 = \frac{1\cdot 13.95}{14.7}\cdot\lambda_1 \approx 0.95\cdot\lambda_1 \tag{21}$$

where:

$AFR_{E0\ at\ \lambda=1}$ – value determined for stoichiometric combustion at lambda equal to 1, assumed for E0 fuel (pure gasoline) with AFR of 14.7,

$AFR_{E5\ at\ \lambda=1}$ – value determined for stoichiometric combustion at lambda equal to 1, assumed for E5 fuel with AFR of 14.33,

$AFR_{E10\ at\ \lambda=1}$ – value determined for stoichiometric combustion at lambda equal to 1, assumed for E10 fuel with AFR of 13.95 λ_{E0} – value equal to 1 for AFR 14.7, in an analyser configured for standard gasoline (E0 – without ethanol),

λ_1 – value read from the exhaust gas analyser configured to measure gasoline (E0), using the default AFR value of 14.7.

This method is more accurate than using a lambda sensor, as the NDIR technique provides precise measurements of exhaust gas components. The active O_2 sensor determines the amount of free oxygen. The lambda value is calculated based on the overall proportions between all measured gases, which is more reliable than relying solely on the O_2 measurement. As a result, the CAP3201 delivers accurate AFR and lambda values, ensuring compliance with standards (ISO 3930, OIML R99) and enabling precise engine diagnostics.

The exhaust gas analyser is capable of measuring the following components: CO in the range of 0 % - 15 % with a resolution of 0.001 %, CO_2 from 0 % to 20 % with a resolution of 0.1 %, HC up to 20,000 ppm with a resolution of 1 ppm, and O_2 in the range of 0 % - 21.7 %, with a resolution of 0.01 % for concentrations below 4 % and 0.1 % for concentrations above 4 %. It also measures NO_x in the range of 0 ppm - 5,000 ppm with a 1 ppm resolution. Additionally, the analyser determines the λ coefficient within the range of 0.8 to 1.2, with a resolution of 0.001.

Modern internal combustion engines, under steady-state operating conditions, are regulated to maintain a lambda value of 1, which makes it difficult to observe other measurements. In contrast, small non-road engines in the European Union fall under a separate set of regulations. Their fuel supply systems are still commonly based on carburetted fuel-air delivery mechanisms. As a result, their regulation behaviour is more interesting from the perspective of analysing the lambda signal response.

For this study, two rescue ventilation units used by fire services for building smoke extraction were tested. The tested units were new, and thus were not affected by wear or damage. The tested fans, designated as F1 and F2, featured different configurations and manufacturers. Fan F1 was the FOGO MW 22 model produced by FOGO Sp. z o.o. in Wilkowice, Poland, while fan F2 was the GF210-20” model manufactured by Taizhou Lion King Signal Co., Ltd. in Taizhou, China. F1 had 8 rotor blades and no flow straightener on the impeller, whereas F2 had 9 rotor blades and was equipped with a flow straightener. The fans were powered by different combustion engines: F1 used a 750 series 163 cm^3 engine from Briggs & Stratton Corporation (Milwaukee, WI, USA) with a power output of 4.4 kW, while F2 was driven by a GX270 engine from Honda Motor Co., Ltd., Kumamoto Factory (Kumamoto, Japan) with a displacement of 196 cm^3 and a power output of 5.1 kW.

The study was conducted on two positive pressure ventilation (PPV) fans (F1 and F2) under two operating conditions: idle operation at low engine speed (1200 rpm) (W1) and full-power operation under load at high engine speed of approximately 3600 rpm (W2).

The lambda coefficient in the exhaust was measured simultaneously using a lambda sensor and an exhaust gas analyser. Results were corrected using a fuel-specific factor (Fig. 1). Tests were conducted with E10 fuel, which contains up to 10 % ethanol and has a Motor Octane Number (MON) of 85 and Research Octane Number (RON) of 95. Its density ranges from 750 kg/m^3 to 765 kg/m^3, with a calorific value of about 42.0 MJ/kg and a boiling range of 25 °C to 225 °C.

To assess measurement uncertainty, the arithmetic mean was adopted as an estimator of the target value, and the confidence interval was determined at a significance level of $p = 0.05$. The statistical evaluation followed methods suitable for datasets exhibiting normal distribution characteristics.

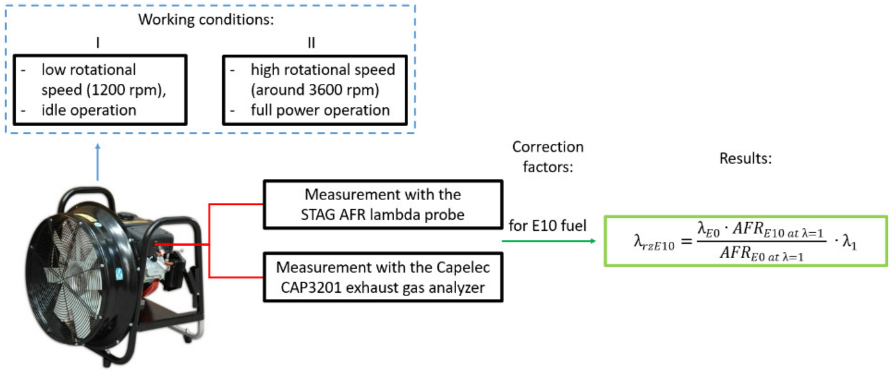

Fig. 1. Measurement procedure including the correction factor

4. Results and discussion

An example fragment of the λ coefficient results obtained during real-world tests of fans F1 and F2 under different operating conditions (W1 and W2), using two measurement methods (M1 and M2), is presented in Figure 2. The main objective of the study is to demonstrate the differences between the tested methods, which are summarized in Table 1 based on a comparison of arithmetic means. It can be observed that for low rotational speed conditions, the measurements are consistent between the methods, with a difference not exceeding 1.1 %. In contrast, higher rotational speed and operation at increased power are associated with a greater discrepancy between the results of the tested methods, reaching 2.4 %.

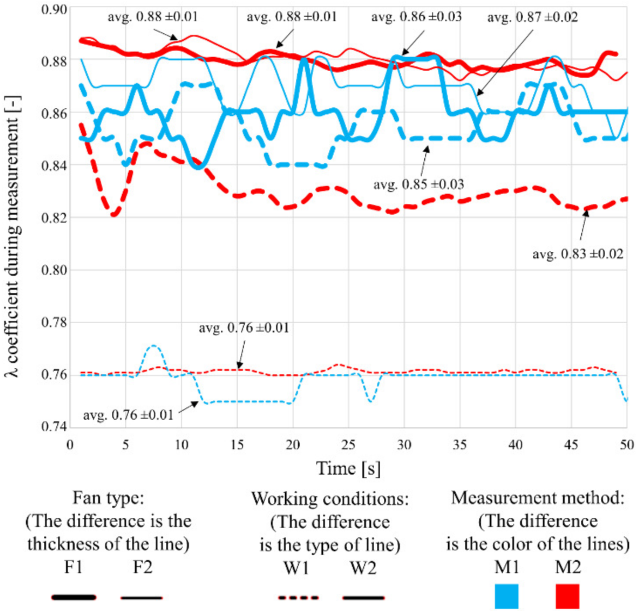

Fig. 2. λ coefficient during measurement

Table 1. Difference in the λ coefficient result depending on the adopted testing method

Fan type	F1		F2	
Operating conditions	W1	W2	W1	W2
Difference based on the arithmetic mean results: $\Delta_{\frac{M1}{M2}}=\frac{\lambda_{avgM1}-\lambda_{avgM2}}{\lambda_{avgM2}}\cdot 100\ \%$	2.3 %	1.1 %	2.4 %	0 %

The analysis of lambda coefficient values in the context of air-fuel mixture control requires the use of a correction factor λ_{rzE10}. The results of the arithmetic mean values, after applying the correction factor related to the tested fuel (E10), are presented in Table 2. It can be observed that failing to apply the correction factor may lead to an interpretation error ranging from 4.5 % to 5.7 %. Moreover, after accounting for the correction factors, thus obtaining more probable results, the tested engines are characterized by richer air-fuel mixtures.

Table 2. Difference in results depending on the inclusion of the correction factor

Fan type	F1				F2			
Operating conditions	W1		W2		W1		W2	
Measurement method	M1	M2	M1	M2	M1	M2	M1	M2
Lambda coefficient results from measurement reading (λ_1)	0.85	0.83	0.86	0.88	0.76	0.76	0.87	0.88
Lambda coefficient result (λ_{rzE10}) after applying correction factors	0.81	0.79	0.82	0.84	0.72	0.72	0.82	0.84
Difference in results depending on the application of the correction factor $\Delta_{\frac{\lambda_1}{\lambda_{rzE10}}}=\frac{\lambda_{rzE10}-\lambda_1}{\lambda_{rzE10}}\cdot 100\%$	4.7 %	4.8 %	4.7 %	4.5 %	5.3 %	5.3 %	5.7 %	4.5 %

In carburetted engines, λ values vary with operating conditions and design. At idle, values between 0.72 and 0.79 align with literature data [12, 13]. The richer mixture results from the carburettor's mechanical design, which lacks electronic control or feedback. Idle circuits are set to provide excess fuel to ensure stable operation, often at the cost of efficiency and emissions. Compared to fuel injection, carburettors are less precise, especially at low airflow, where fuel delivery relies on pressure differences rather than exact metering.

λ values between 0.82 and 0.84 under high speed and load are consistent with literature data [14, 15]. In carburetted engines, the mixture is intentionally enriched at full power to reduce combustion temperatures, prevent knock, and protect the engine. Since these systems lack electronic control, enrichment is mechanically triggered at high airflow through larger main jets, ensuring sufficient fuel delivery for safe and effective operation.

5. Conclusions

This study compared methods for determining AFR and the λ coefficient in spark-ignition engines running on gasoline-ethanol blends (E5 and E10), focusing on the effects of common technical and commercial simplifications. Two methods were evaluated: a wideband lambda sensor (M1) and an exhaust gas analyser using a simplified Brettschneider equation (M2). Both yielded similar λ values at idle, with differences under 1.1 %, but discrepancies grew to 2.4 % at full load. Applying ethanol correction factors in E10 fuel lowered λ values by 4.5 % to 5.7 %, showing that omitting these corrections can lead to significant errors. The results also confirm that carburetted engines tend to run richer mixtures at both idle and full load. The key contribution of this work lies in highlighting how simplified assumptions in AFR calculations can distort lambda readings, particularly in older or non-electronically controlled engines, and in proposing practical correction coefficients to improve diagnostic and regulatory accuracy.

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