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Theoretical determination of air-fuel ratio for two-stroke engines fueled with gasoline, ethanol, and two-stroke mixing oils

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ABSTRACT

The study aimed to determine the theoretical air-fuel ratio (AFR) for ternary fuel mixtures composed of gasoline, ethanol (E5 and E10), and lubricating oils (mineral, semi-synthetic, and synthetic) used in two-stroke spark-ignition engines. The background of this work arises from the widespread introduction of ethanol-containing fuels in the European Union and the necessity to calibrate two-stroke engines operating on mixtures of gasoline and oil. The research was conducted using stoichiometric combustion equations for each component, considering their molecular formulas, molar masses, and densities. Volumetric fuel-to-oil ratios of 1:25, 1:50, and 1:100 were converted into mass proportions to determine the composite AFR for each blend. The obtained stoichiometric AFR values were: for E5 fuels – 14.42 (mineral, 1:25), 14.41 (mineral, 1:50), 14.40 (mineral, 1:100), 14.40 (semi-synthetic, 1:25–1:100), and 14.36–14.38 (synthetic, 1:25–1:100); and for E10 fuels – 14.13–14.10 (mineral), 14.11–14.10 (semi-synthetic), and 14.07–14.08 (synthetic). The influence of oil type and fuel-to-oil ratio was negligible, with AFR variations not exceeding 0.06 and 0.03, respectively. In contrast, increasing ethanol content from E5 to E10 decreased AFR by approximately 0.30. Corresponding correction coefficients for analyzers calibrated to pure gasoline (AFR = 14.7) were 0.98 for E5 and 0.96 for E10. The results provide a quantitative reference for accurate AFR calibration, carburetor adjustment, and lambda correction in two-stroke engines, supporting the adaptation of diagnostic systems to modern ethanol-blended fuels.

Keywords: petrol chainsaws, spark-ignition internal combustion engine, fuel mixtures, stoichiometric lambda coefficient, exhaust gas testing.

INTRODUCTION

The air-fuel ratio (AFR) is a key parameter governing combustion efficiency and stability in internal combustion engines (1). It defines the mass proportion of air to fuel supplied to the cylinder and directly affects exhaust emissions (2), fuel consumption (3), and engine performance (4). A mixture with the stoichiometric AFR provides the optimal amount of oxygen required for complete fuel oxidation, resulting in minimal emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) (5, 6). When the mixture is richer (lower AFR), excess fuel leads to incomplete combustion, higher HC and CO emissions (7), and increased fuel consumption (8). Conversely, a lean mixture (higher AFR) contains excess air, improving fuel economy but potentially increasing nitrogen oxide (NO_x) emissions (9) and causing unstable combustion (10).

The AFR depends on the type of fuel used, as each chemical compound requires a different amount of oxygen for complete oxidation. Stoichiometric AFR values are well established and commonly used in thermodynamic analyses and in the calibration of internal combustion engine control systems. For gasoline, an AFR of 14.7 (11) is typically adopted in automotive applications, while a value of 15.1 is often used in theoretical and thermodynamic calculations (12). In the case of LPG (liquefied petroleum gas – a propane-butane mixture), the stoichiometric AFR is approximately 15.5 (13), whereas for CNG (compressed natural gas – primarily methane) it is about 17.2 (14). These differences arise from variations in the hydrogen content of the respective fuels, which directly affect the amount of oxygen required for complete combustion, and consequently the mass of air needed to achieve a stoichiometric mixture.

Changes in European Union regulations have introduced mandatory bio-components in motor fuels. As a result, E5 and E10 gasolines containing up to 5% and 10% ethanol by volume have become widely available (15, 16). Consequently, conventional gasoline without ethanol additives is no longer commonly available at fuel stations (17). However, determining the theoretical AFR for such blends is not straightforward, since the E5 and E10 designations refer to volumetric ethanol content, whereas AFR is defined as the ratio of air mass to fuel mass. The difference in density between ethanol (0.79 g/cm³) (18) and gasoline (approximately 0.74 g/cm³) (19) means that volumetric and mass proportions are not equivalent, affecting the calculated stoichiometric ratio.

Two-stroke engines are still available on the market (20), although in automotive applications they have been almost completely replaced by four-stroke units (21, 22). Due to their simple design, low weight, and the absence of a separate lubrication system (23), two-stroke engines continue to be widely used in portable equipment such as chainsaws (24, 25), brush cutters (26), sprayers, generators (27), and personal watercraft (28). In such devices, frequent changes in orientation and operating position, as well as rapid accelerations and tilts, make it difficult to maintain effective lubrication in conventional four-stroke systems (29). For this reason, two-stroke engines remain the preferred solution in many portable and mobile applications, despite their disadvantages in terms of exhaust emissions.

In two-stroke engine fuel mixtures, a dedicated lubricating oil is added to ensure proper lubrication of moving components (30). This oil is delivered together with the fuel into the combustion chamber, where it forms a thin lubricating film on the surfaces of cooperating parts such as the piston, cylinder, and crankshaft bearings (31, 32). Depending on the base oil type and production technology, three main categories of lubricants are distinguished: mineral oils, semi-synthetic oils, synthetic oils (30, 33). Each of these categories exhibits different physicochemical properties, including viscosity, density, oxidation stability, and cleanliness of combustion. The selection of an appropriate oil type directly affects engine durability (34, 35), exhaust smoke levels (29, 34, 35), and the formation of combustion deposits (36, 37).

The proportion of lubricating oil additives in fuel mixtures varies depending on the engine design, type of oil used, and operating conditions (38). Manufacturers of two-stroke engines specify recommended fuel-to-oil ratios, typically ranging from 1:25 (for older designs and mineral oils) to 1:50 or even 1:100 (for modern engines and high-quality synthetic oils) (34, 39). An insufficient oil content may result in inadequate lubrication and accelerated wear of engine components, whereas excessive oil content can lead to excessive exhaust smoke, carbon deposit formation, and contamination of the exhaust system.

The composition of gasoline available at fuel stations has changed due to the mandatory addition of ethanol in the form of E5 and E10 blends. In two-stroke engines, such as chainsaws, gasoline is additionally mixed with lubricating oil to ensure proper lubrication. Consequently, it is necessary to determine the theoretical AFR for a three-component fuel mixture composed of gasoline, ethanol, and lubricating oil.

Each of these components possesses a distinct chemical composition and density, which define the specific amount of oxygen necessary for complete combustion. Therefore, an accurate estimation of the AFR for such ternary mixtures requires the conversion of volumetric proportions into mass proportions and the inclusion of the stoichiometric combustion equations corresponding to each individual component.

Knowledge of the correct AFR is particularly important during carburetor adjustment procedures, especially after replacement, cleaning, or periodic maintenance. Proper AFR calibration ensures optimal combustion conditions, resulting in stable engine operation (40), easy starting (41), reduced fuel consumption, and lower exhaust emissions.

The aim of this article is to determine the theoretical AFR for fuel mixtures used in two-stroke engines, taking into account the presence of ethanol additives and various types of lubricating oils.

MATERIALS AND METHODS

Theoretical calculations were performed to determine the stoichiometric air-fuel ratio for fuels and fuel mixtures used in two-stroke engines. The procedure was divided into three stages: (1) determination of AFR values for primary (non-blended) fuels, (2) evaluation of AFR for lubricating oil additives of different origins, and (3) calculation of AFR for ternary fuel mixtures composed of gasoline, ethanol, and oil additives at selected blending ratios. The base AFR values were derived for gasoline and ethanol using standard stoichiometric combustion equations and molar mass relations. Gasoline was modeled both as n-octane (C_8H_{18}), representative of hydrocarbon fuels, and as a generalized empirical formula $CH_{1.95}$ used in automotive calibration. For ethanol (C_2H_5OH), the reduced AFR value was attributed to the oxygen atom already present in the molecule. Theoretical calculations were based on the assumption that the average molar mass of air equals 28.96 g/mol, and the oxygen fraction in atmospheric air is 21% by volume. Three representative types of oils were analyzed: mineral, synthetic, and semi-synthetic. The stoichiometric AFR for each was calculated based on their approximate molecular composition, molar mass, and the corresponding stoichiometric combustion equations. For E5 (95% gasoline and 5% ethanol by volume) and E10 (90% gasoline and 10% ethanol by volume), volumetric shares were converted into mass fractions using typical densities of 0.74 kg/L for gasoline and 0.789 kg/L for ethanol. In practical preparation of two-stroke engine mixtures, volumetric fuel-to-oil ratios of 1:25, 1:50, and 1:100 are most commonly used. For the purpose of AFR determination, these ratios were converted into mass-based proportions, accounting for the densities of the individual components: gasoline (0.74 kg/L), ethanol (0.789 kg/L), and oils – mineral (0.89 kg/L), semi-synthetic (0.87 kg/L), and synthetic (0.84 kg/L). The overall air–fuel ratio of each mixture was calculated using the mass-weighted average of the component AFRs according to Equation (1):

$$AFR_{mix} = \sum_i \omega_i \cdot AFR_i \tag{1}$$

where: $\omega_i \geq 0$ denotes the mass fraction of component i, for $i = 1, \ldots, n$, $n = 18$ enote the number of possible combinations [the AFR is anlysed for two types of fuel (E5, E10), three types of lubricating oils (mineral, semi-synthetic, synthetic) and possible mixture ratios (1:25, 1:50, 1:100)] and $\sum_{i=1}^{n} \omega_i = 1$.

PRIMARY FUEL CALCULATIONS

Gasoline fuel

In thermodynamic analyses, gasoline is typically modeled as n-octane (C_8H_{18}), since this compound is regarded as a representative constituent of conventional gasoline. The idealized stoichiometric combustion of n-octane is expressed in Equation 2. This reaction illustrates the complete oxidation of C_8H_{18}, in which one mole of fuel requires 12.5 moles of O_2. Considering that atmospheric air contains approximately 21% oxygen by volume, this translates to roughly 4.76 moles of air per mole of O_2, as shown in Equation 3. Consequently, the full combustion of one mole of octane demands about 12.5 × 4.76 = 59.5 moles of air. The molar mass of octane (C_8H_{18}) is 0.11423 kg, as indicated in Equation 4, while the mean molar mass of air equals 28.96 g/mol (0.02896 kg/mol). Therefore, for the complete combustion of one mole of octane, the stoichiometric AFR can be determined as approximately 15.09 kg of air per kilogram of fuel (Equation 5).

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

$$1\, mol\ O_2 \rightarrow \frac{100}{21} \approx 4.76\, mol\ air \tag{3}$$

$$m(C_8H_{18}) = 8 \cdot 12.1 + 18 \cdot 1.008 = 114.23 = 0.11423\ [\frac{kg}{mol}] \tag{4}$$

$$AFR_{C_8H_{18}} = \frac{m_{air}}{m_{C_8H_{18}}} = \frac{1.724}{0.11423} \approx 15.09 \tag{5}$$

Gasoline consists of a complex blend of hydrocarbons and therefore cannot be represented by a single definitive chemical formula. In simplified theoretical modeling it is often expressed as C_8H_{18}.

However, in the automotive industry, particularly within engine calibration and control systems, a generalized empirical composition is commonly applied, approximating gasoline as $CH_{1.95}$. This empirical formula describes a hypothetical hydrocarbon of variable composition rather than a specific chemical compound. The combustion of such a representative fuel can be described by a simplified stoichiometric equation (Equation 6), where the coefficients *a*, *b*, and *c* are determined according to stoichiometric balance. In practical applications, the stoichiometric AFR for $CH_{1.95}$ is assumed to be 14.7, which means that approximately 14.7 kilograms of air are required for the complete combustion of one kilogram of gasoline modeled by this formula.

$$\mathrm{CH_{1.95}} + a\mathrm{O_2} \rightarrow b\mathrm{CO_3} + c\mathrm{H_2O} \tag{6}$$

Ethanol (E100)

The stoichiometric combustion of ethanol (C_2H_5OH) requires approximately 14.28 moles of air, as illustrated in Equation 7. The reduced air demand compared with hydrocarbon fuels results from the oxygen atom already present in the ethanol molecule. For complete oxidation, one mole of ethanol reacts with three moles of O_2, which is reflected in the balanced chemical equation shown in Equation 7. The molar mass of ethanol (C_2H_5OH) equals 0.04607 kg, as indicated in Equation 8. Considering that the mean molar mass of air is 0.02896 kg/mol, and that full combustion of one mole of ethanol consumes 14.28 moles of air, the corresponding stoichiometric AFR is determined to be 8.95 kg of air per kilogram of ethanol, as presented in Equation 9.

$$\mathrm{C_2H_5OH} + 3\mathrm{O_2} \rightarrow 2\mathrm{CO_2} + 3\mathrm{H_2O} \tag{7}$$

$$m(C_2H_5OH) = 2 \cdot 12.1 + 6 \cdot 1.008 + 16 = 46.07 = 0.04607\ [\frac{kg}{mol}] \tag{8}$$

$$AFR_{C_2H_5OH} = \frac{m_{air}}{m_{C_2H_5OH}} = \frac{0.4122}{0.04607} \approx 8.95 \tag{9}$$

LUBRICATING FUEL CALCULATIONS

Mineral oil

Mineral oil is a mixture of hydrocarbons, primarily paraffinic (up to approximately 74% (42)), but it also contains naphthenic (7.9–38% (43)) and aromatic hydrocarbons (up to 10% (42)). It is obtained through the refining process of crude oil. Its chemical composition consists mainly of chemically inert compounds, which are modified by the addition of various substances such as antioxidants and corrosion inhibitors to adapt the oil to specific applications. The total content of such additives generally does not exceed 1%. Since paraffinic hydrocarbons are the dominant component of mineral oil, its simplified chemical formula can be approximated as $C_{16}H_{34}$. For the simplified composition of mineral oil assumed as hexadecane ($C_{16}H_{34}$), the stoichiometric combustion Equation 10 can be written as follows:

$$\mathrm{C_{16}H_{34}} + a\mathrm{O_2} \rightarrow 16\mathrm{CO_2} + 17\mathrm{H_2O} \tag{10}$$

The oxygen balance on the right-hand side of the equation includes 16 molecules of carbon dioxide containing (16 × 2 = 32) oxygen atoms and 17 molecules of water containing (17 × 1 = 17) oxygen atoms. In total, this gives (32 + 17 = 49) oxygen atoms, corresponding to (49 / 2 = 24.5) moles of oxygen molecules (O_2). Thus, the stoichiometric coefficient *a* is equal 11 to:

$$a = 24.5 \left[\frac{\mathrm{mol\ O_2}}{\mathrm{mol\ fuel}}\right] \tag{11}$$

Since the volumetric fraction of oxygen in air is approximately 21%, the number of moles of air required to burn one mole of fuel is (Equation 12):

$$n_{air} = \frac{24.5}{0.21} = 116.67 \left[\frac{\mathrm{mol\ air}}{\mathrm{mol\ fuel}}\right] \tag{12}$$

To determine the stoichiometric mass air–fuel ratio (kg of air per kg of fuel), the molar masses of the components must be considered. For the fuel molecule $C_{16}H_{34}$, the molar mass is (Equation 13):

$$m(C_{16}H_{34}) = 16 \cdot 12.01 + 34 \cdot 1.008 = 226.46 = 0.22645\ [\frac{kg}{mol}] \quad (13)$$

The average molar mass of air is 28.96 g/mol. Therefore, the mass of air required to burn one mole of fuel is (Equation 14):

$$m_{air} = n_{air} \cdot 29.96 = 3.3798\ [\frac{kg}{mol}] \quad (14)$$

Hence, the mass $\text{AFR}_{C_{16}H_{34}}$ can be expressed as (Equation 15):

$$\text{AFR}_{C_{16}H_{34}} = \frac{m_{air}}{m_{C_{16}H_{34}}} = \frac{3.3798}{0.22645} \approx 14.92 \quad (15)$$

Synthetic oil

A synthetic oil consists of artificially produced base oils such as polyalphaolefins, esters, or polyglycols, which are obtained through chemical synthesis or deep refining of mineral oils. This base is enriched with a range of additives that enhance lubricating properties, including detergents, dispersants, and corrosion inhibitors. A simplified representation of synthetic oil can be approximated by the chemical formula $C_{33}H_{66}O_2$, which corresponds to a typical molecule of a synthetic ester used as a base component in modern lubricants. The combustion equation (complete oxidation reaction) of $C_{33}H_{66}O_2$ is expressed by Equation (16):

$$\text{C}_{33}\text{H}_{66}\text{O}_2 + a\text{O}_2 \rightarrow 33\text{CO}_2 + 33\text{H}_2\text{O} \quad (16)$$

In the synthetic oil molecule with the empirical formula $C_{33}H_{66}O_2$, there are two oxygen atoms originating from ester groups. During complete combustion, each carbon atom in the molecule reacts with oxygen to form a molecule of CO_2, while each hydrogen atom forms half a molecule of H_2O. For a compound containing 33 carbon atoms and 66 hydrogen atoms, complete oxidation of all components requires a total of 99 oxygen atoms (66 to form CO_2 and 33 to form H_2O).

Since the fuel molecule itself contributes two oxygen atoms, the remaining 97 oxygen atoms must come from atmospheric oxygen. This corresponds to a = 48.5 moles of O_2 molecules required for the complete combustion of one molecule of $C_{33}H_{66}O_2$. Because atmospheric oxygen constitutes approximately 21% of the volume of air, a much larger amount of air is needed to supply this oxygen. It is commonly assumed that one mole of oxygen corresponds to approximately 4.76 moles of air.

Therefore, to provide the required oxygen for the complete combustion of $C_{33}H_{66}O_2$, approximately 230.9 moles of air are necessary. This value forms the basis for further calculation of the theoretical AFR, expressed as the ratio of the mass of air to the mass of fuel. The calculation of the molar mass of the fuel (Equation 17), the molar mass of air (Equation 18), and the determination of the AFR (Equation 19) follow from this relationship.

$$m(C_{33}H_{66}O_2) = 33 \cdot 12.01 + 66 \cdot 1.008 + 2 \cdot 15.9 = 494 = 0.4949\ [\frac{kg}{mol}] \quad (17)$$

$$m_{air} = 48.5 \cdot 4.76 \cdot 0.02896 = 6.69\ [\frac{kg}{mol}] \quad (18)$$

$$\text{AFR}_{C_{33}H_{66}O_2} = \frac{m_{air}}{m_{C_{33}H_{66}O_2}} = \frac{6.69}{0.4949} \approx 13.52 \quad (19)$$

Semi-synthetic oil

Semi-synthetic oils, also referred to as partially synthetic or synthetic blend oils, are formulated by mixing mineral oil with synthetic oil. The exact percentage composition of these oils may vary depending on the manufacturer and the specific application requirements. Semi-synthetic oils typically consist of a combination of mineral and synthetic base stocks. The synthetic component may include various types of synthetic base oils such as polyalphaolefins (PAO) and synthetic esters (44,45). According to Sulek and Ogorzałek (2013), the synthetic component in semi-synthetic oils can range from 10% to 40%, with the remainder being mineral oil (46). In subsequent calculations, the semi-synthetic oil is assumed to consist of 70% mineral oil and 30% synthetic oil by volume. This proportion is the most common among semi-synthetic oils designed for two-stroke engine fuel mixtures.

The adopted volumetric ratio of the semi-synthetic mixture, consisting of 70% mineral oil and 30% synthetic oil, must be converted into a mass ratio, as the two components differ in density. Considering typical density values (0.89 kg/L for mineral oil and 0.84 kg/L for synthetic oil), the actual mass ratio is 71.2% mineral oil and 28.8% synthetic oil. The calculation of the AFR for the semi-synthetic oil is shown in Equation 20:

$$\mathrm{AFR}_{0.712\cdot C_{16}H_{34}+0.288\cdot C_{33}H_{66}O_2} = \left(0.712\cdot AFR_{\cdot C_{16}H_{34}}\right) + \left(0.288\cdot AFR_{C_{33}H_{66}O_2}\right) = (0.712\cdot 14.92) + (0.288\cdot 13.52) \approx 14.51 \quad (20)$$

GASOLINE-ETHANOL BLENDS CALCULATIONS

Gasoline–ethanol blends (E5)

E5 fuel is a volumetric mixture consisting of 95% gasoline and 5% ethanol. Since the AFR is defined as the mass ratio of air to fuel, the volumetric composition must be converted into mass fractions. Ethanol has a higher density (approximately 0.789 kg/L) than gasoline (approximately 0.74 kg/L), resulting in a slightly higher mass fraction of ethanol in the mixture compared with its volumetric share. After conversion using typical density values, the actual mass ratio of the E5 fuel mixture is approximately 93.5% gasoline and 6.5% ethanol**.** This difference is important when determining the theoretical AFR value, as it affects the total amount of oxygen required for complete combustion of the mixture. The calculation of the AFR for the E5 is shown in Equation 21.

$$\mathrm{AFR}_{E5} = \left(0.935\cdot AFR_{(gasolne\ AFR=14.7)}\right) + \left(0.065\cdot AFR_{ethanol}\right) = (0.935\cdot 14.7) + (0.065\cdot 8.95) \approx 14.33 \quad (21)$$

Gasoline–ethanol blends (E10)

For E10 fuel, which is a volumetric mixture of 90% gasoline and 10% ethanol, the actual mass fraction of ethanol is higher due to its greater density compared with gasoline. After converting the volumetric ratios to mass fractions, the mixture consists of approximately 87% gasoline and 13% ethanol. These values should be considered when determining the theoretical AFR for E10 fuel, is shown Equation 22.

$$\mathrm{AFR}_{E5} = \left(0.870\cdot AFR_{(gasolne\ AFR=14.7)}\right) + \left(0.130\cdot AFR_{ethanol}\right) = (0.870\cdot 14.7) + (0.130\cdot 8.95) \approx 13.95 \quad (22)$$

Determination of the mass fraction of fuel mixtures

When calculating the air–fuel ratio (AFR), the percentage mass fraction of each component must be considered, while in practical preparation of fuel and oil mixtures, volumetric proportions are typically applied, most often 1:25, 1:50, and in some cases 1:100. Taking into account the differences in the densities of the individual components, namely gasoline (0.74 kg/L), ethanol (0.789 kg/L), and oils with densities of 0.89 kg/L for mineral oil, 0.84 kg/L for synthetic oil, and 0.87 kg/L for semi-synthetic oil consisting of 71.2% mineral and 28.8% synthetic oil, it is possible to determine the actual mass fractions in the three-component fuel mixture. Table 1 presents the calculated percentage mass fractions of gasoline, ethanol, and mineral, synthetic, or semi-synthetic oil for the respective mixture variants.

Table 1. Mass fractions of fuel–oil mixture components

Fuel	Type of oil	Ratio (fuel:oil)*	Gasoline [%]	Ethanol [%]	Oil [%]
E5	Mineral	1:25	90.35	5.07	4.58
E5	Mineral	1:50	92.47	5.19	2.34
E5	Mineral	1:100	93.56	5.25	1.18
E5	Semi-synthetic	1:25	90.45	5.08	4.48
E5	Semi-synthetic	1:50	92.52	5.19	2.29
E5	Semi-synthetic	1:100	93.59	5.25	1.16
E5	Synthetic	1:25	90.59	5.08	4.33
E5	Synthetic	1:50	92.59	5.20	2.21
E5	Synthetic	1:100	93.63	5.25	1.12
E10	Mineral	1:25	85.33	10.11	4.56
E10	Mineral	1:50	87.32	10.34	2.33
E10	Mineral	1:100	88.35	10.47	1.18
E10	Semi-synthetic	1:25	85.42	10.12	4.46
E10	Semi-synthetic	1:50	87.37	10.35	2.28
E10	Semi-synthetic	1:100	88.38	10.47	1.15
E10	Synthetic	1:25	85.55	10.13	4.32
E10	Synthetic	1:50	87.44	10.36	2.21
E10	Synthetic	1:100	88.41	10.47	1.12

Note: * One part of oil per 25 (or 50, 100) parts of fuel.

As the ratio value increases, for example from 1:25 to 1:100, the oil content in the mixture decreases almost linearly. The influence of the oil type (mineral, synthetic, or semi-synthetic) on the mass fraction is minimal, with differences not exceeding 0.2%. In E10 mixtures, the ethanol content in the total mass is nearly twice as high as in E5 (approximately 10% compared to 5%), which is significant when calculating the air–fuel ratio (AFR). For the 1:50 ratio, which is typical for recreational two-stroke engines, the oil content in the mixture ranges from 2.2% to 2.3% by mass, regardless of the type of oil used.

Additive of fuel (E5) to mineral oil

The theoretical AFR for the E5 fuel mixture with the addition of mineral oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 23 presents the calculation procedure, where the resulting value of approximately 14.42 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (90.35%), ethanol (5.07%), and mineral oil (4.58%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 24 and 25, respectively.

$$\begin{aligned}\mathrm{AFR}_{E5\ +Mineral\ oil\ (1:25)} &= \left(0.9035 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + (0.0507 \cdot AFR_{Ethanol}) \\ &+ \left(0.0458 \cdot AFR_{(Mineral\ oil\ (1:25))}\right) \\ &= (0.9035 \cdot 14.7) + (0.0507 \cdot 8.95) + (0.0458 \cdot 14.92\ ) \approx 14.42\end{aligned} \tag{23}$$

$$\begin{aligned}\mathrm{AFR}_{E5\ +Mineral\ oil\ (1:50)} &= \left(0.9247 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + (0.0519 \cdot AFR_{Ethanol}) \\ &+ \left(0.0234 \cdot AFR_{(Mineral\ oil\ (1:50))}\right) \\ &= (0.9247 \cdot 14.7) + (0.0519 \cdot 8.95) + (0.0234 \cdot 14.92\ ) \approx 14.41\end{aligned} \tag{24}$$

$$\begin{aligned}\mathrm{AFR}_{E5\ +Mineral\ oil\ (1:100)} &= \left(0.9356 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0525 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0118 \cdot AFR_{(Mineral\ oil\ (1:100))}\right) \\ &= (0.9356 \cdot 14.7) + (0.0525 \cdot 8.95) + (0.0118 \cdot 14.92\,) \approx 14.40\end{aligned} \tag{25}$$

Additive of fuel (E10) to mineral oil

The theoretical AFR for the E10 fuel mixture with the addition of mineral oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 26 presents the calculation procedure, where the resulting value of approximately 14.13 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (85.33%), ethanol (10.11%), and mineral oil (4.56%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 27 and 28, respectively.

$$\begin{aligned}\mathrm{AFR}_{E10\ +Mineral\ oil\ (1:25)} &= \left(0.8533 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1011 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0456 \cdot AFR_{(Mineral\ oil\ (1:25))}\right) \\ &= (0.8533 \cdot 14.7) + (0.1011 \cdot 8.95) + (0.0456 \cdot 14.92\,) \approx 14.13\end{aligned} \tag{26}$$

$$\begin{aligned}\mathrm{AFR}_{E10\ +Mineral\ oil\ (1:50)} &= \left(0.8732 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1011 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0233 \cdot AFR_{(Mineral\ oil\ (1:50))}\right) \\ &= (0.8732 \cdot 14.7) + (0.1011 \cdot 8.95) + (0.0233 \cdot 14.92\,) \approx 14.11\end{aligned} \tag{27}$$

$$\begin{aligned}\mathrm{AFR}_{E10\ +Mineral\ oil\ (1:100)} &= \left(0.8835 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1047 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0118 \cdot AFR_{(Mineral\ oil\ (1:100))}\right) \\ &= (0.8835 \cdot 14.7) + (0.1047 \cdot 8.95) + (0.0118 \cdot 14.92\,) \approx 14.10\end{aligned} \tag{28}$$

Additive of fuel (E5) to semi-synthetic oil

The theoretical AFR for the E5 fuel mixture with the addition of semi-synthetic oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 29 presents the calculation procedure, where the resulting value of approximately 14.40 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (90.45%), ethanol (5.08%), and mineral oil (4.48%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 30 and 31, respectively.

$$\begin{aligned}\mathrm{AFR}_{E5\ +Semi-Synthetic\ oil\ (1:25)} &= \left(0.9045 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0508 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0448 \cdot AFR_{(Semi-Synthetic\ oil\ (1:25))}\right) \\ &= (0.9045 \cdot 14.7) + (0.0508 \cdot 8.95) + (0.0448 \cdot 14.51\,) \approx 14.40\end{aligned} \tag{29}$$

$$\begin{aligned}\mathrm{AFR}_{E5\ +Semi-Synthetic\ oil\ (1:50)} &= \left(0.9252 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0519 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0229 \cdot AFR_{(Semi-Synthetic\ oil\ (1:50))}\right) \\ &= (0.9252 \cdot 14.7) + (0.0519 \cdot 8.95) + (0.0229 \cdot 14.51\,) \approx 14.40\end{aligned} \tag{30}$$

$$\mathrm{AFR}_{E5\ +Semi-Synthetic\ oil\ (1:100)} = \left(0.9359 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0525 \cdot AFR_{Ethanol}\right) + \left(0.0116 \cdot AFR_{(Semi-Synthetic\ oil\ (1:100))}\right) = (0.9359 \cdot 14.7) + (0.0525 \cdot 8.95) + (0.0116 \cdot 14.51) \approx 14.40 \tag{31}$$

Additive of fuel (E10) to semi-synthetic oil

The theoretical AFR for the E10 fuel mixture with the addition of semi-synthetic oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 32 presents the calculation procedure, where the resulting value of approximately 14.11 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (85.45%), ethanol (10.12%), and mineral oil (4.46%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 33 and 34, respectively.

$$\mathrm{AFR}_{E10\ +Semi-Synthetic\ oil\ (1:25)} = \left(0.8542 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1012 \cdot AFR_{Ethanol}\right) + \left(0.0446 \cdot AFR_{(Semi-Synthetic\ oil\ (1:25))}\right) = (0.8542 \cdot 14.7) + (0.1012 \cdot 8.95) + (0.0446 \cdot 14.51) \approx 14.11 \tag{32}$$

$$\mathrm{AFR}_{E10\ +Semi-Synthetic\ oil\ (1:50)} = \left(0.8737 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1035 \cdot AFR_{Ethanol}\right) + \left(0.0228 \cdot AFR_{(Semi-Synthetic\ oil\ (1:50))}\right) = (0.8737 \cdot 14.7) + (0.1035 \cdot 8.95) + (0.0228 \cdot 14.51) \approx 14.10 \tag{33}$$

$$\mathrm{AFR}_{E5\ +Semi-Synthetic\ oil\ (1:100)} = \left(0.8838 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1047 \cdot AFR_{Ethanol}\right) + \left(0.0115 \cdot AFR_{(Semi-Synthetic\ oil\ (1:100))}\right) = (0.8838 \cdot 14.7) + (0.1047 \cdot 8.95) + (0.0115 \cdot 14.51) \approx 14.10 \tag{34}$$

Additive of fuel (E5) to synthetic oil

The theoretical AFR for the E5 fuel mixture with the addition of synthetic oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 35 presents the calculation procedure, where the resulting value of approximately 14.36 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (90.59%), ethanol (5.08%), and mineral oil (4.33%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 36 and 37, respectively.

$$\mathrm{AFR}_{E5\ +Synthetic\ oil\ (1:25)} = \left(0.9059 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0508 \cdot AFR_{Ethanol}\right) + \left(0.0433 \cdot AFR_{(Synthetic\ oil\ (1:25))}\right) = (0.9059 \cdot 14.7) + (0.0508 \cdot 8.95) + (0.0433 \cdot 14.52) \approx 14.36 \tag{35}$$

$$\mathrm{AFR}_{E5\ +Synthetic\ oil\ (1:50)} = \left(0.9259 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0520 \cdot AFR_{Ethanol}\right) + \left(0.0221 \cdot AFR_{(Synthetic\ oil\ (1:50))}\right) = (0.9259 \cdot 14.7) + (0.0520 \cdot 8.95) + (0.0221 \cdot 14.52) \approx 14.37 \tag{36}$$

$$\begin{aligned}\mathrm{AFR}_{E5\ +Synthetic\ oil\ (1:100)} &= \left(0.9363 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.0525 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0112 \cdot AFR_{(Synthetic\ oil\ (1:100))}\right) \\ &= (0.9363 \cdot 14.7) + (0.0525 \cdot 8.95) + (0.0112 \cdot 14.52\ ) \approx 14.38\end{aligned} \tag{37}$$

Additive of fuel (E10) to synthetic oil

The theoretical AFR for the E10 fuel mixture with the addition of synthetic oil in a volumetric ratio of 1:25 was determined by taking into account the mass fractions of gasoline, ethanol, and oil in the mixture. The overall AFR was calculated as the weighted average of the individual AFR values for each component, using their respective mass shares as weighting factors. Equation 38 presents the calculation procedure, where the resulting value of approximately 14.36 represents the stoichiometric AFR for the three-component mixture consisting of gasoline (85.55%), ethanol (10.13%), and mineral oil (4.32%). The corresponding AFR values for the same fuel mixture with oil proportions of 1:50 and 1:100 are shown in Equations 39 and 40, respectively.

$$\begin{aligned}\mathrm{AFR}_{E10\ +Synthetic\ oil\ (1:25)} &= \left(0.8555 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1013 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0432 \cdot AFR_{(Synthetic\ oil\ (1:25))}\right) \\ &= (0.8555 \cdot 14.7) + (0.1013 \cdot 8.95) + (0.0432 \cdot 14.52\ ) \approx 14.07\end{aligned} \tag{38}$$

$$\begin{aligned}\mathrm{AFR}_{E10\ +Synthetic\ oil\ (1:50)} &= \left(0.8744 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1036 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0221 \cdot AFR_{(Synthetic\ oil\ (1:50))}\right) \\ &= (0.8744 \cdot 14.7) + (0.1036 \cdot 8.95) + (0.0221 \cdot 14.52\ ) \approx 14.08\end{aligned} \tag{39}$$

$$\begin{aligned}\mathrm{AFR}_{E10\ +Synthetic\ oil\ (1:100)} &= \left(0.8841 \cdot AFR_{(Gasolne\ AFR=14.7)}\right) + \left(0.1013 \cdot AFR_{Ethanol}\right) \\ &+ \left(0.0432 \cdot AFR_{(Synthetic\ oil\ (1:100))}\right) \\ &= (0.8841 \cdot 14.7) + (0.1013 \cdot 8.95) + (0.0432 \cdot 14.52\ ) \approx 14.08\end{aligned} \tag{40}$$

APPLICABILITY OF RESULTS

Determining the theoretical AFR for mixtures containing gasoline, ethanol, and lubricating oil has direct practical relevance for the calibration and operation of two-stroke engines. It enables optimization of the mixture composition in terms of combustion stability, engine start-up, performance, and emissions, while also allowing for accurate conversion of volumetric proportions into mass fractions, which is particularly important for E5 and E10 fuels and for various oil types.

The main practical applications include the adjustment of carburetors after maintenance, replacement, or cleaning, which involves the selection of jets, needles, and mixture screws, as well as the optimization of the fuel to oil ratio under various operating conditions to ensure adequate lubrication while avoiding excessive smoke or deposit formation.

Measurement systems for AFR or lambda in exhaust gas analyzers often rely on analytical reference values defined for conventional fuels (47) such as gasoline (AFR = 14.7) (48), LPG (AFR = 15.5) (49), or CNG (AFR = 17.2) (48) (Fig. 1). However, the limited availability of traditional ethanol-free fuels in the European Union and the use of lubricating oil additives in two-stroke fuel mixtures introduce deviations that affect the accuracy of lambda and AFR readings. Consequently, correction factors must be applied to improve measurement reliability in widely used diagnostic systems such as the Capelec CAP3201 exhaust gas analyzer (Montpellier, France) or the STAG AFR system equipped with a Bosch LSU 4.2 wideband lambda sensor (Robert Bosch GmbH, Bamberg, Germany).

In the analysis of combustion processes, two closely related parameters are of fundamental importance: the stoichiometric AFR and the

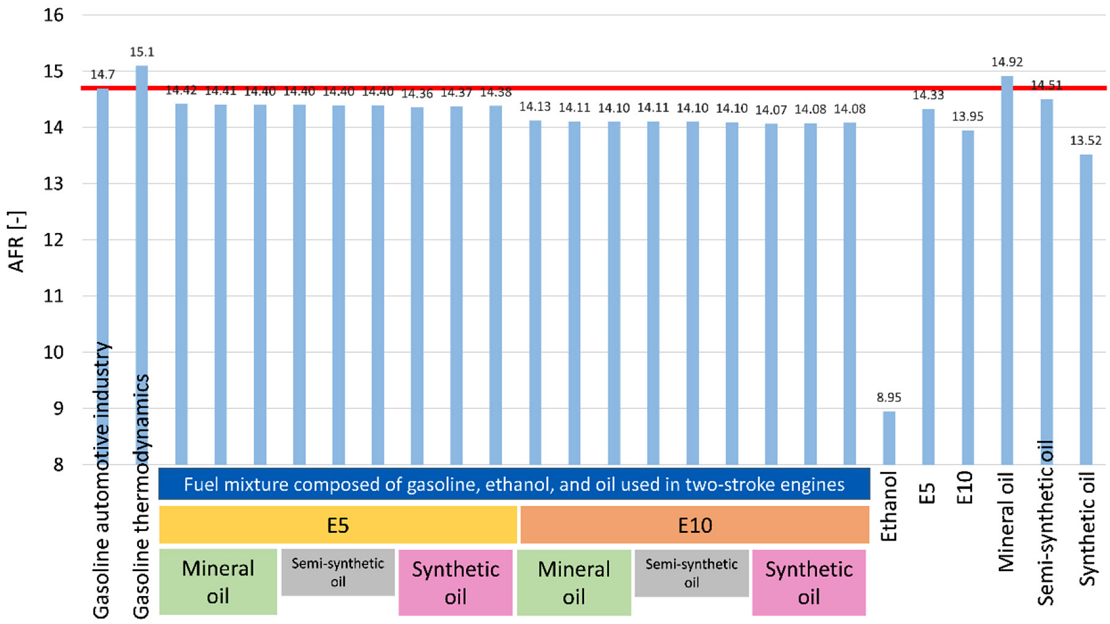

Figure 1. AFR values for base gasoline (red line, AFR = 14.7) and gasoline with fuel additives and other fuels.

excess air coefficient lambda (λ). Both describe the quantitative relationship between air and fuel in a mixture, but they represent it differently:

- AFR defines the actual mass ratio of air to fuel in the mixture.
- λ expresses the deviation from the stoichiometric condition, defined as the ratio of the actual AFR to the theoretical (stoichiometric) AFR for a given fuel.

The relationship between these two quantities is direct and allows for mutual conversion (Equations 41):

$$\lambda = \frac{AFR_{actual}}{AFR_{stechiometric}} \tag{41}$$

AFR CORRECTION FACTORS

Regardless of the method used to calculate λ, exhaust gas analyzers generally assume that the reference AFR corresponds to pure gasoline without ethanol additives, using 14.7 as the base value for λ conversion. However, when the actual fuel composition and its stoichiometric AFR at $\lambda = 1$ are known, correction factors can be introduced. For instance, the correct AFR value for E5 fuel is 14.33 at $\lambda = 1$, while for E10 fuel it is 13.95 at $\lambda = 1$. The correction equations for E5 (Equation 42) and E10 (Equation 43) are presented below:

$$\lambda_{rzE5} = \frac{\lambda_{E0} \cdot AFR_{E5\ at\ \lambda=1}}{AFR_{E0\ at\ \lambda=1}} \cdot \lambda_1 = \frac{1 \cdot 14.33}{14.7} \cdot \lambda_1 \approx 0.97 \cdot \lambda_1 \tag{42}$$

$$\lambda_{rzE10} = \frac{\lambda_{E0} \cdot AFR_{E10\ at\ \lambda=1}}{AFR_{E0\ at\ \lambda=1}} \cdot \lambda_1 = \frac{1 \cdot 13.95}{14.7} \cdot \lambda_1 \approx 0.95 \cdot \lambda_1 \tag{43}$$

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.

In a similar manner, correction coefficients were calculated for fuels containing ethanol and lubricating oils intended for two-stroke engines.

Table 2. Correction coefficient for fuels containing oil and ethanol additives, used during measurements with AFR or λ analyzers calibrated for pure, additive-free fuels

Fuel	Type of oil	Ratio (fuel:oil)*	AFR at λ = 1	Correction factor for multiplying
E5	Mineral	1:25	14.42	0.98
E5	Mineral	1:50	14.41	0.98
E5	Mineral	1:100	14.40	0.98
E5	Semi-synthetic	1:25	14.40	0.98
E5	Semi-synthetic	1:50	14.40	0.98
E5	Semi-synthetic	1:100	14.40	0.98
E5	Synthetic	1:25	14.36	0.98
E5	Synthetic	1:50	14.37	0.98
E5	Synthetic	1:100	14.38	0.98
E10	Mineral	1:25	14.13	0.96
E10	Mineral	1:50	14.11	0.96
E10	Mineral	1:100	14.10	0.96
E10	Semi-synthetic	1:25	14.11	0.96
E10	Semi-synthetic	1:50	14.10	0.96
E10	Semi-synthetic	1:100	14.10	0.96
E10	Synthetic	1:25	14.07	0.96
E10	Synthetic	1:50	14.08	0.96
E10	Synthetic	1:100	14.08	0.96

Note: * One part of oil per 25 (or 50, 100) parts of fuel.

The results are presented in Table 2. An example of the correction coefficient calculation for E5 gasoline with the addition of mineral oil at a 1:25 ratio is shown in Equation 44.

$$\lambda_{rzE5\ +Mineral\ oil\ (1:25)} =$$

$$= \frac{\lambda_{E0}\ \cdot\ AFR_{E5\ +Mineral\ oil\ (1:25)\ at\ \lambda=1}}{AFR_{E0\ at\ \lambda=1}} \cdot \lambda_1$$

$$= \frac{1 \cdot 14.42}{14.7} \cdot \lambda_1 \approx 0.98 \cdot \lambda_1 \quad (44)$$

where: $AFR_{E5+\text{Mineral oil (1:25)}}$ – value determined for stoichiometric combustion at λ equal to 1, assumed for E5 fuel with the addition of mineral oil in a ratio of 1:25 with AFR 14.42.

DISCUSSION

Scientific research is being conducted on the influence of the AFR on the performance of internal combustion engines. The stoichiometric AFR, which represents the ideal proportion for complete combustion, is frequently referenced and typically equals about 14.7:1 for gasoline engines (50–53). Different AFR values are applied depending on the intended performance characteristics. For example, AFRs of 10:1, 12:1, and 14:1 were tested with E50 fuel (a blend of 50% gasoline and 50% hydrated bioethanol) in a single-cylinder engine, and the stoichiometric AFR for E50 was found to be approximately 14:1, similar to that of pure gasoline (54). Panjaitan et al. (2020) investigated leaner AFR values of 17.6 and 20.54 to reduce fuel consumption in a small spark-ignition engine, achieving reductions of 5.5% and 9.4%, respectively (55). Goswami et al. (2015) conducted experimental studies on the determination of AFR for ethanol–gasoline blends (E0, E10, E20, E25, E50, E75, E100), showing that higher ethanol content generally requires AFR correction to optimize combustion and reduce emissions (56). Recent advancements in two-stroke engine oils have focused on improving low-temperature pumpability, compatibility with renewable fuels, and overall cost efficiency (33).

Although the stoichiometric AFR values presented in this study are derived from theoretical combustion modeling, it should be noted that real-world engine operation may deviate from these ideal conditions. In practical applications, the effective AFR can be influenced by factors such as fuel vaporization behavior, intake air and fuel temperature, transient engine operation, and incomplete mixing of the air–fuel–oil mixture, particularly in small two-stroke engines. Additional deviations may arise from oil film formation on intake and cylinder surfaces, variations in fuel composition, and non-uniform scavenging processes. Therefore, while the calculated AFR values provide a necessary and consistent reference for engine calibration and diagnostic correction, actual operating AFR values should be interpreted with consideration of these practical limitations.

The correction factors derived in this study can be directly integrated into commonly used diagnostic and measurement tools employed for small spark-ignition engines. Exhaust gas analyzers and AFR or λ measurement systems are typically calibrated for conventional gasoline (AFR = 14.7) and do not account for deviations caused by ethanol content or lubricating oil additives. By incorporating the proposed correction coefficients into analyzer software, post-processing algorithms, or manual adjustment procedures, more accurate interpretation of measured AFR and λ values can be achieved when E5 or E10 fuels and oil-containing mixtures are used. This is particularly relevant for service diagnostics, carburetor tuning, and comparative emission assessments, where uncorrected readings may lead to improper engine adjustment. The presented correction factors therefore offer a practical pathway for adapting existing diagnostic infrastructure to modern fuel compositions without the need for hardware modifications.

The calculations are based on representative densities and simplified surrogate chemical formulas for gasoline and oils. Although real fuels may vary slightly in density and composition, the sensitivity of the final AFR values to such deviations is low. Density changes affect only the mass fractions used in weighted averaging, and the oil share in the mixture remains small (1–5%), which limits its influence on the overall AFR. As demonstrated by the narrow AFR ranges obtained, ethanol content is the dominant factor, while reasonable variability in density or surrogate composition would alter AFR only by a few hundredths. Therefore, the adopted assumptions are sufficiently accurate for engineering calibration and diagnostic correction purposes.

Future research should extend the present theoretical analysis to experimental investigations conducted on real two-stroke engine facilities. The stoichiometric AFR values and correction factors derived in this study provide a necessary baseline for proper engine calibration prior to testing. Subsequent work will focus on implementing these reference values during carburetor adjustment and lambda-based control, followed by real-time measurements of exhaust gas composition, AFR, and engine operating parameters under steady-state and transient conditions. Such experiments will enable validation of the theoretical AFR predictions and assessment of deviations resulting from fuel vaporization dynamics, oil distribution, scavenging efficiency, and thermal effects specific to two-stroke engines. Conducting measurements on a real engine will also allow evaluation of the practical usefulness of the proposed correction factors in diagnostic systems and will support the development of more accurate calibration procedures for engines operating on ethanol-blended, oil-containing fuels.

Although the present study is strictly theoretical and based on stoichiometric modeling, the proposed AFR values and correction coefficients can be directly subjected to experimental validation. A natural continuation of this work would involve controlled test-bench measurements on a representative two-stroke engine equipped with a wideband lambda sensor and exhaust gas analyzer, enabling comparison between corrected and uncorrected AFR or λ readings under steady-state and transient conditions. Such validation could include systematic variation of ethanol content (E5 vs E10) and fuel-to-oil ratio, combined with measurements of exhaust composition, combustion stability, and engine response. Experimental confirmation would not only verify the quantitative accuracy of the proposed correction factors but also support their integration into practical diagnostic and calibration procedures for modern ethanol-containing two-stroke fuels.

From an engineering perspective, the magnitude of the observed AFR differences should be interpreted in relation to the practical resolution of carburetor adjustment and diagnostic instrumentation. In small two-stroke engines, typical carburetor mixture screw adjustments correspond to AFR changes significantly larger than ±0.05, and repeatability of manual tuning under workshop conditions rarely allows discrimination below approximately ±0.1 AFR units. Therefore, the variations associated with oil type (≤ 0.06) and fuel-to-oil ratio (≤ 0.03) can be considered practically negligible for routine carburetor calibration.

In contrast, the AFR shift of approximately 0.3 observed between E5 and E10 fuels exceeds typical mechanical adjustment tolerances and directly affects the λ value calculated by analyzers calibrated to AFR = 14.7. Without applying correction coefficients (0.98 for E5 and 0.96 for E10), systematic measurement bias may occur, leading to misinterpretation of mixture richness during service diagnostics or laboratory testing. Consequently, ethanol content constitutes the dominant factor requiring calibration correction in AFR or λ analyzers, whereas differences resulting from oil formulation remain within engineering tolerance for most practical applications.

The main practical value of this study is the provision of corrected stoichiometric AFR reference values for two-stroke engines operating on E5 and E10 fuels with oil admixture. Since most AFR or λ diagnostic systems are calibrated for pure gasoline (AFR = 14.7), applying them without correction introduces systematic bias in mixture assessment. By quantifying the actual AFR values and proposing correction factors (0.98 for E5 and 0.96 for E10-based blends), the study reduces this bias and improves the accuracy of carburetor calibration and exhaust diagnostics under real operating conditions.

CONCLUSIONS

The present study aimed to determine the theoretical AFR for ternary fuel mixtures composed of gasoline, ethanol (E5 and E10), and lubricating oils (mineral, semi-synthetic, and synthetic) used in two-stroke engines. The research question focused on how ethanol addition and oil type influence the stoichiometric AFR values relevant for engine calibration and exhaust gas analysis. The calculations demonstrated that the theoretical stoichiometric AFR decreases with increasing ethanol content due to the oxygen present in ethanol molecules. For pure gasoline, the AFR equals 14.7, while for E5 and E10 blends it drops to 14.33 and 13.95, respectively. When mineral, semi-synthetic, or synthetic oils are introduced at typical ratios of 1:25, 1:50, and 1:100, the resulting AFR values range from 14.42 (E5 + mineral oil 1:25) to 14.07 (E10 + synthetic oil 1:25). The influence of oil type and fuel-to-oil ratio on the theoretical AFR was found to be negligible. The AFR variation between mineral, semi-synthetic, and synthetic oils does not exceed 0.06, while changing the fuel-to-oil ratio from 1:25 to 1:100 alters AFR by no more than 0.03. In contrast, increasing the ethanol content from E5 to E10 reduces AFR by 0.29–0.33 for oil-containing blends and by 0.38 for the base fuel, confirming that ethanol concentration is the dominant factor affecting the stoichiometric AFR. The main contribution of this study lies in providing stoichiometric AFR reference values for multicomponent two-stroke engine fuels. These values enable improved calibration and more accurate correction of λ readings in diagnostic systems. These results extend the existing literature by quantifying the combined effect of ethanol and lubricating oil content on AFR and by introducing correction factors that can be directly implemented in measurement devices and control algorithms. The obtained results should be interpreted considering certain limitations. The AFR values depend on the actual densities and compositions of fuels, which vary with temperature and production batch. Gasoline is a variable mixture, ethanol is hygroscopic, and oils differ in molecular structure and oxygen content, which affects the results. In calculations, volumetric proportions must consistently be converted into mass ratios, applying unified density assumptions and equivalent molecular models. For precise calibration, theoretical assumptions should be verified through exhaust gas analysis and observation of engine behavior under real operating conditions. Future work should include experimental verification of the calculated AFR values using exhaust gas analyzers, evaluation of engine performance with varying oil-to-fuel ratios, and validation of correction coefficients under transient operating conditions typical for portable two-stroke engines.

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