

Impact of Isopropanol Addition on Engine Performance and Emissions [†]

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Abstract: As global energy consumption grows and environmental concerns intensify, the demand for alternative fuels is becoming increasingly significant. This study investigates the properties and effects of isopropanol when added to gasoline as an alternative fuel. The overall analysis focusing on engine performance and emissions shows the impact of isopropanol as a fuel additive. From the results, an improvement in engine efficiency was observed due to isopropanol's high-octane number and improved combustion characteristics when added. There are also disadvantages associated with increased fuel consumption due to the lower energy density. Emissions analysis shows that there is a reduction in hydrocarbon and nitrogen oxide emissions with the addition of isopropanol, although with different trends depending on the concentration. The results of the study present the complex relationship between fuel composition and engine performance, offering insights into the possibility of using isopropanol as an alternative fuel in the search for sustainable energy solutions. The results showed that for this engine, it is most effective to add isopropanol in the range of 5–15%, relative to which emissions are prioritized to be reduced. The lower energy density of isopropanol reduces the overall energy density, which increases fuel consumption to achieve efficiency over gasoline-only operation.

Keywords: isopropanol; isopropanol–gasoline blends; engine emissions; engine efficiency



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1. Introduction

A growing population is experiencing increasing energy needs in transport and industry, but environmental problems associated with the extraction and use of petroleum fuels are worsening. Starting in the 1970s, the rate of demand for primary energy has been increasing. Today, potential alternatives to replace traditional ones are being thoroughly explored in order to reduce damage to the environment and human health. The main consideration in the use of alternative fuels is the evaluation of their physico-chemical properties, the way they are obtained and stored, and, finally, their impact on engine performance [1,2].

The group of alcohols is often considered as an alternative fuel. In the 1980s, alcohol was seen as a source of energy at its peak, as its combustion reduced emissions and greenhouse gases. Alcohols are seen as an alternative to fossil fuels as are usable in the liquid state, and their high octane number, wide flammability limit, and high combustion rate only aid in engine performance [3,4].

2. Properties of Isopropanol

Isopropyl alcohol is one of the common representatives of alcohols. It was the first synthetic alcohol created for commercial use. Isopropanol, or 2-propanol, is a colorless, flammable liquid with a salty odor. Isopropyl alcohol has the property of being a good

solvent for oils and resins. Unlike ethanol and methanol, isopropyl alcohol does not mix with salt solutions and can be separated from aqueous solutions by adding sodium chloride. Isopropyl alcohol is commonly used in households, and it is added to antiseptics, detergents, and various disinfectants [5,6].

Isopropyl alcohol's molecular formula is C_3H_8O . It is a second isomer of propanol. In propanol, each of the terminal carbons has alcohol functionality, and in isopropyl alcohol, the middle carbon is bonded to the -OH group [7,8]. The isopropanol molecule is highly hygroscopic. It can absorb moisture from the air. This property of isopropanol is useful when it is used as an additive to fossil fuels. Table 1 presents the properties of gasoline and isopropanol.

Table 1. Comparing fuel properties.

Fuel Characteristic	Gasoline	Isopropanol
Chemical formula	C_8H_{15}	C_3H_7OH
Molecular weight, [g/mol]		60.1
Density [kg/m ³]	715–765	800
Octane number (MON)	81–89	112
Octane number (RON)	91–99	
Melting point, °C	−57	−90
Boiling point, °C		117
Flash point, °C	~−43	~11.7
Laminar flame speed (cm/s)	33–44	45
Auto-ignition temperature, °C	280	399
Kinematic viscosity (200 °C), cSt	0.6	2.65
Stoichiometric air–fuel ratio (AFR)	14.7	10.4
Heat of combustion (250 °C), [kJ/mol]		2021
Heat of vaporization (250 °C), [kJ/mol]	36	45

2.1. Octane Number

Octane number is a characteristic of fuel that gives information about its resistance to detonation combustion, which can be caused by high temperature or high pressure in the cylinder. Detonation combustion is an undesirable effect as it can cause serious engine damage. Octane-boosting gasoline additives allow the engine to run at a higher compression ratio. The high-octane characteristics of alcohols allows improved power and environmental performance of the engine [9].

2.2. Fuel Density

The fuel density is related to the quantity to be fed to the combustion chamber. A denser fuel contains more mass per unit volume under the same conditions of temperature and pressure as a lighter fuel. For the same amount of energy in the form of fuel to be delivered to the engine, the denser fuel must be smaller in volume [10].

2.3. Fuel Viscosity

Fuel viscosity can also affect the combustion efficiency of the fuel mixture in the cylinder. High-viscosity fuel can affect good atomization in the cylinder, resulting in incomplete combustion of the fuel mixture. When the fuel mixture is incompletely burned, engine efficiency decreases and emissions increase. Viscosity has an effect on the cold starting of the engine, with higher-viscosity fuels being less sensitive to ambient temperature change.

2.4. Laminar Combustion Velocity

Laminar combustion velocity is an index describing the velocity of the flame front as the fuel mixture burns in the cylinder. A higher laminar velocity results in more efficient fuel combustion and better engine performance. Higher speed promotes faster and more complete combustion, which reduces the heat loss of internal combustion engines, thus improving efficiency. The laminar velocity of the fuel–air mixture depends on the octane

number of the fuel, the fuel and air content of the mixture, and the combustion conditions in the cylinder—temperature and pressure.

3. Experimental Setup

The present study aimed to investigate the variation of emissions with fuel mixture and engine power. The study was conducted in a laboratory environment (Figure 1).

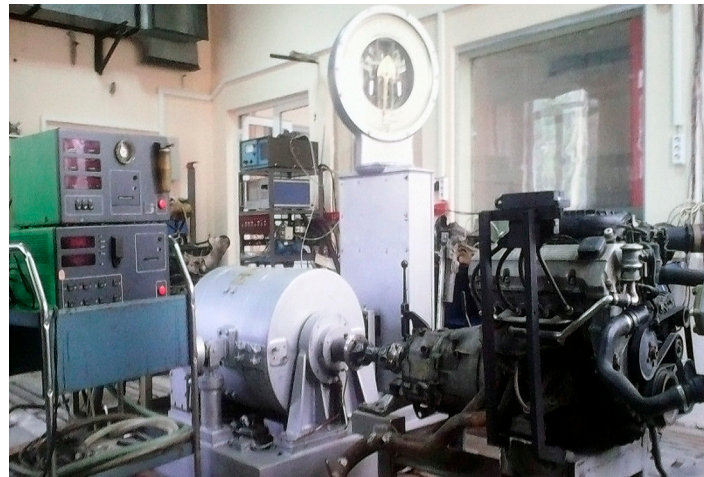


Figure 1. Laboratory equipment.

3.1. Fuel Mixture

The study was conducted with different gasoline and isopropanol ratios. Table 2 presents the ratios and the notations used in the paper.

Table 2. Fuel mixture.

Characteristics	Value
Manufacturer	BMW
Year of manufacture	2002
Number of cylinders	4
Number of strokes	4
Fuel system	Port Fuel Injection
Cooling system	Water cooled
Displacement	1895 cm ³
Compression ratio	9.7:1
Power output	118 hp at 5500 rpm
Cylinder bore	85 mm
Piston stroke	83.5 mm

3.2. Engine Characteristics

The study was conducted on a 4-stroke, 4-cylinder gasoline engine at a speed of 2500 rpm from a BMW concern. The technical characteristics of the engine are presented in Table 3.

Table 3. Engine Characteristics.

Gasoline, %	Isopropanol, %	Naming
100	0	Gasoline
95	5	5% IPA
90	10	10% IPA
85	15	15% IPA
80	20	20% IPA

4. Results and Discussion

4.1. Engine Performance

4.1.1. Brake-Specific Fuel Consumption

Specific fuel consumption is a measure of the amount of fuel consumed by an engine to produce a certain amount of power or perform a certain amount of work.

Specific fuel consumption is an important indicator of engine efficiency. A lower specific fuel consumption means that the engine uses less fuel to produce the same power or perform the same work, which is a desirable property for fuel-efficient and environmentally friendly operation.

Some of the characteristics of fuels, such as octane number and energy content, are important in determining specific fuel consumption.

By increasing the octane number when alcohols are added to the fuel mixture, higher engine operational speed can be achieved, eliminating the possibility of detonation combustion. This results in reduced specific consumption in some operating modes. On the other hand, the lower energy content of alcohols can increase fuel consumption. When alcohols are added to the fuel–air mixture, a greater amount of fuel is required to perform a given amount of work relative to gasoline operation.

The results for brake specific fuel consumption (BSFC) obtained by addition of isopropanol and gasoline are shown in Figure 2.

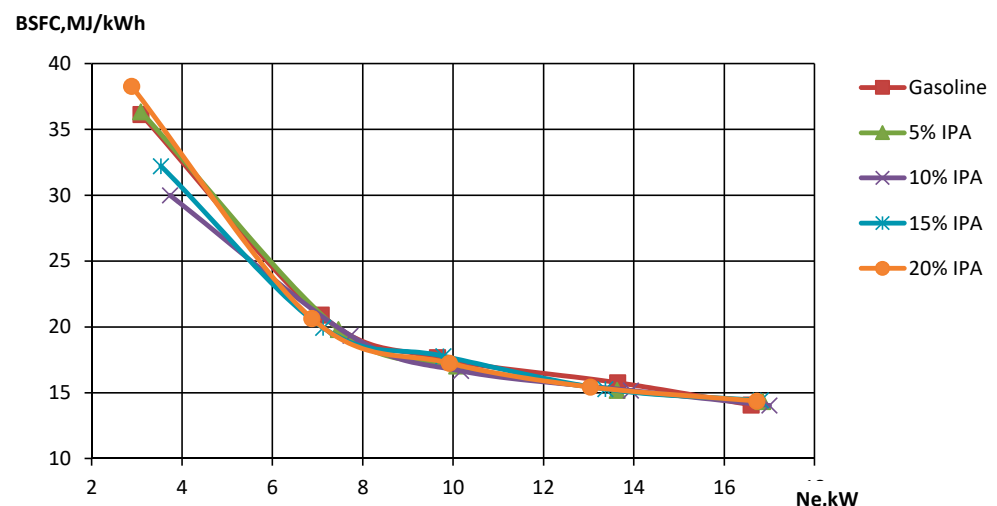


Figure 2. Change in brake-specific fuel consumption addition of isopropanol.

4.1.2. Effective Efficiency

Effective efficiency is a measure of the conversion of energy derived from fuel into useful work. Effective efficiency is defined as the ratio of the input energy from the fuel to the power output of the engine.

A higher effective efficiency means that the engine is operating more efficiently and there are lower losses in the engine when using energy from the fuel to generate mechanical power. The factors that affect the effective efficiency of an engine are the design features of the engine, the way the fuel–air mixture is mixed, the combustion process, and the mechanical and thermal losses. The results for brake thermal efficiency obtained by addition of isopropanol and gasoline are shown in Figure 3.

When 5, 10, or 15% isopropanol is added to gasoline there is an increase in effective efficiency, and when 20% isopropanol is added there is a decrease in effective efficiency compared to the 5, 10, or 15% additives operation.

The addition of isopropanol increases the octane number of the fuel mixture, and this allows an operation at a higher compression ratio without the presence of detonation combustion. This mode of operation increases the effective efficiency. Another reason for the increase in efficiency with the addition of alcohol additives is their ability to improve

mixing and combustion in the cylinder. The laminar combustion rate of alcohols is also one of the reasons for the increased effective efficiency of engines when added to the fuel mixture. In some cases, the addition of alcohol to the fuel mixture can reduce engine efficiency and increase fuel consumption due to their lower energy content compared to that of traditional fuels.

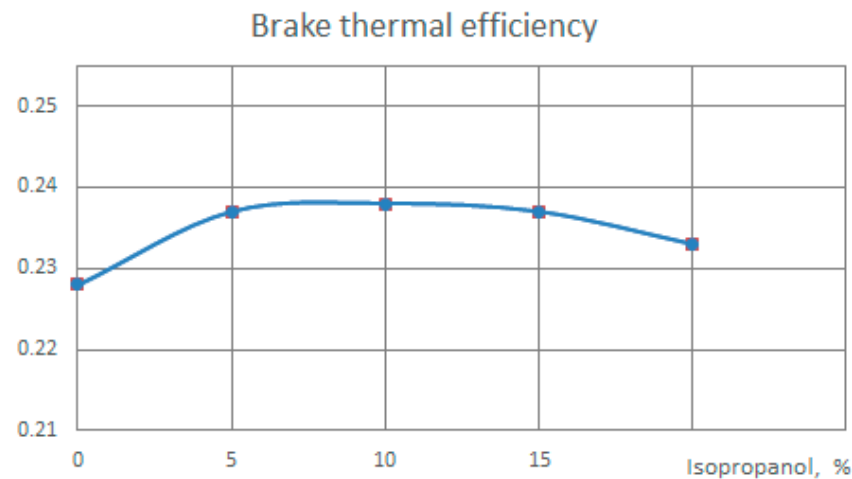


Figure 3. Change in Brake thermal efficiency addition of isopropanol.

4.2. Emissions

Internal combustion engines produce various harmful emissions as part of their operation. These emissions can have a negative impact on the environment and human health. Some of the main types of harmful emissions are as follows: Carbon monoxides (CO and CO₂); CO is a toxic gas hazardous to human health and CO₂ is a greenhouse gas responsible for climate change. Nitrogen oxides (NO_x); NO_x contributes to smog formation and acid rain, and also have a negative impact on nature and human health. Hydrocarbons (HC), hydrocarbons that are not fully burned, pose a risk to human health and, when mixed with nitrogen oxides, contribute to ozone formation in the lower atmosphere [11,12].

4.2.1. Hydrocarbon Content in Exhaust Gas

The results for CH emissions obtained by addition of isopropanol and gasoline are shown in Figure 4.

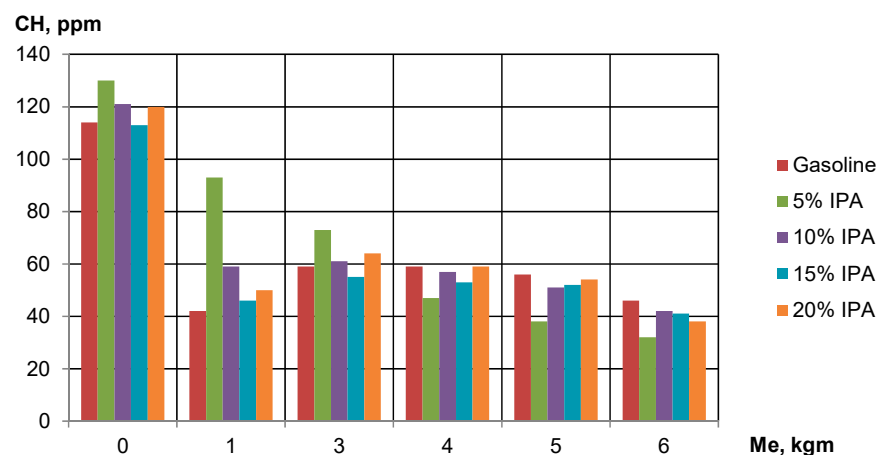


Figure 4. Change in the amount of hydrocarbons evolved during engine operation with isopropanol additives.

When isopropanol is added to the fuel mixture, the octane number changes and with it the combustion rate and temperature of the fuel mixture. The addition of alcohol to

the fuel mixture contributes to lowering the autoignition temperature of the fuel mixture. Depending on the combustion process, the emissions are also changed. The hydrocarbons are oxidized to CO_2 and H_2O as alcohol is added to the fuel mixture for faster and more uniform combustion. Another property influencing emissions is the effect of alcohols to better mix the fuel with air and to burn the fuel mixture more efficiently.

In the study conducted, it was observed that in terms of hydrocarbons for the test engine, optimum performance was achieved with the addition of 10 and 15% isopropanol.

4.2.2. Nitrogen Oxides Content in Exhaust Gas

Nitrogen oxides are formed in the combustion process. For their formation, nitrogen is required from the air entering the cylinder and a sufficiently high temperature. The main source of NO_x is internal combustion engines. Nitrogen oxides are considered to be a major contributor to smog formation and acid rain, and their effects adversely affect human health and the environment.

The results for NO_x emissions obtained by addition of isopropanol and gasoline are shown in Figure 5.

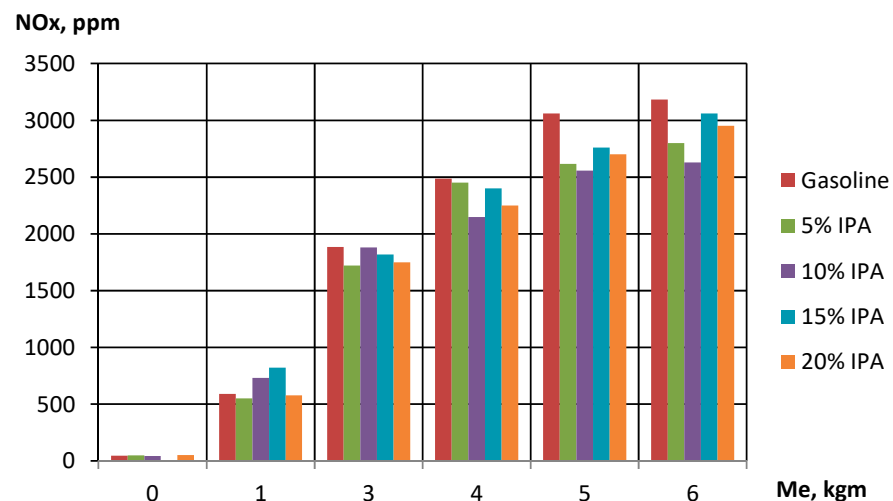


Figure 5. Variation of the amount of nitrogen oxides emitted during engine operation with isopropanol additives.

The addition of isopropyl alcohol to the fuel mixture affects the formation of nitrogen oxides (NO_x). The addition of isopropanol allows operation at higher compression, which would raise the combustion chamber temperature and consequently NO_x formation would increase. On the other hand, the addition of alcohol additives reduces the temperature in the cylinder, and hence the formation of nitrous oxides is reduced. The property of isopropanol to mix readily with air improves mixing, which is a major factor in complete combustion and reduced exhaust emissions.

Different trends were observed with respect to engine performance and the amount of isopropanol added in the study. At higher loads, reduced nitrogen oxide emissions were observed for the different isopropanol additions to the fuel mixture compared to operation on gasoline alone. It can be seen from Fig. that the results are most optimum when isopropanol is added in the range of 5–10%.

4.2.3. Carbon Monoxide Content in Exhaust Gas

Carbon monoxide (CO) is a colorless, tasteless gas that is extremely harmful to humans. It is formed by the incomplete combustion of the fuel entering the combustion chamber. It is formed when there are unburnt carbons left in the combustion chamber after the combustion process. Another factor in its formation is insufficient oxygen to complete oxidation and form carbon dioxide.

As with the formation of other emissions, good mixing, combustion temperature and velocity, and the chemical composition of the fuel mixture play an important role.

The addition of isopropanol to the fuel mixture can promote better combustion of the fuel mixture and thus reduce CO emissions but increase CO₂ emissions. CO₂ is a greenhouse gas that damages the environment.

The results for CO emissions obtained by addition of isopropanol and gasoline are shown in Figure 6.

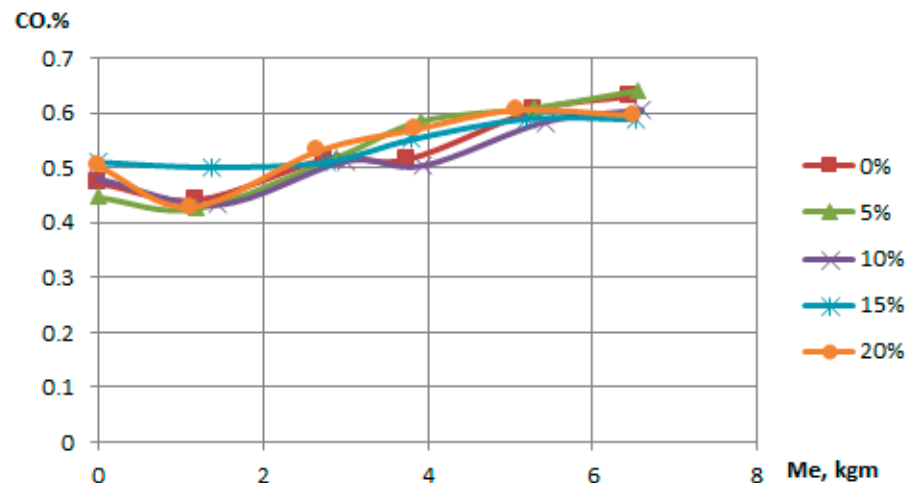


Figure 6. Change in the amount of carbon monoxide evolved during engine operation with isopropanol additives.

Different CO emission values were observed during the test depending on the operating mode and the isopropanol addition to the fuel. It is difficult to determine what amount of isopropanol, in which operating mode, is most appropriate, but when 10% is added to the fuel mixture, a reduction in emissions is observed compared to gasoline operation in all operating modes.

5. Conclusions

The high-octane number of isopropanol, increases the overall octane number of the fuel mixture and promotes better combustion, which increases engine efficiency and reduces emissions.

The lower energy density of isopropanol reduces the overall energy density, which increases fuel consumption to achieve efficiency over gasoline-only operation. Higher laminar combustion velocity affects the combustion rate and temperature in the cylinder, which affects the efficiency and emissions release of engine operation.

For the engine tested, the highest effective efficiency was observed when a 10% isopropanol additive was added. The lowest specific efficiency was observed when 10% isopropanol was added to 90% gasoline. In terms of emissions, for this engine and its mode of operation, it is most effective to add isopropanol in the range of 5–15%, relative to which emissions are prioritized to be reduced.

Future work will continue with the investigation of larger amounts of isopropanol in the fuel mixture.

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References

1. Moka, S.S.; Pande, M.; Rani, M.; Gakhar, R.; Sharma, M.; Rani, J.; Bhaskarwar, A.N. Alternative fuels: An overview of current trends and scope for future. *Renew. Sustain. Energy Rev.* **2014**, *32*, 697–712. [\[CrossRef\]](#)
2. Kasibhatta, S. Alcohol Fuels as an Alternative Fuels—Bringing New Heights in Sustainability. In *Alcohol Fuels—Current Technologies and Future Prospect*; IntechOpen: London, UK, 2020. [\[CrossRef\]](#)
3. Agilan; Riyaz, M.; Sheety, P.P.; Shaheer, M. Efficient and Cost-effective Production of Isopropyl Alcohol using Tokuyama Soda Process: Design and Analysis of a Chemical Engineering Plant. *Eng. Arch.* **2023**. [\[CrossRef\]](#)
4. PubChem, Isopropyl Alcohol. Available online: <https://pubchem.ncbi.nlm.nih.gov/compound/Isopropyl-Alcohol> (accessed on 20 February 2024).
5. Iliev, S. Investigation of the gasoline direct injection engine working with ethanol and gasoline in different compression ratios. *AIP Conf. Proc.* **2022**, *2557*, 060007. [\[CrossRef\]](#)
6. Gainey, B.; Yan, Z.; Moser, S.; Lawler, B. Lean flammability limit of high-dilution spark ignition with ethanol, propanol, and butanol. *Int. J. Engine Res.* **2021**, *23*, 638–648. [\[CrossRef\]](#)
7. Sivasubramanian, H.; Pochareddy, Y.K.; Dhamodaran, G.; Esakkimuthu, G.S. Performance, emission and combustion characteristics of a branched higher mass, C3 alcohol (isopropanol) blends fuelled medium duty MPFI SI engine. *Eng. Sci. Technol. Int. J.* **2017**, *20*, 528–535. [\[CrossRef\]](#)
8. Altun, S.; Oner, C.; Firat, M. Exhaust emissions from a spark-ignition engine operating on iso-propanol and unleaded gasoline blends. *Technology* **2010**, *13*, 183–188.
9. Iliev, S.; Ivanov, Z.; Dimitrov, R.; Mihaylov, V.; Ivanov, D.; Stoyanov, S.; Atanasova, S. An Experimental Investigation into the Performance and Emission Characteristics of a Gasoline Direct Injection Engine Fueled with Isopropanol Gasoline Blends. *Machines* **2023**, *11*, 1062. [\[CrossRef\]](#)
10. Awad, O.I.; Mamat, R.; Ali, O.M.; Sidik, N.C.; Yusaf, T.; Kadirgama, K.; Kettner, M. Alcohol and ether as alternative fuels in spark ignition engine: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2586–2605. [\[CrossRef\]](#)
11. Iliev, S. A Comparison of Ethanol, Methanol, and Butanol Blending with Gasoline and Its Effect on Engine Performance and Emissions Using Engine Simulation. *Processes* **2021**, *9*, 1322. [\[CrossRef\]](#)
12. Li, D.; Yu, X.; Guo, Z.; Zhang, J.; Wang, T.; Li, Y. Effects of isopropanol ratio at different excess air ratios on combustion and emissions characteristics of an isopropanol/gasoline dual-fuel combined injection SI engine. *Fuel* **2023**, *333*, 126507. [\[CrossRef\]](#)

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