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Effect of alcohol-based fuel on the performance, combustion and emission characteristics of spark-ignition engine: A review

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Abstract

The spark ignition (SI) engine is a significant energy device. Alcohol-based alternative fuels have been used to investigate SI engines' performance, combustion, and emission. Using alternative fuels in SI engines, such as alcohol, natural gas, and biodiesel, aims to reduce air pollution and energy costs. Investigations into alternative fuels operating on SI engines have been carried out, and most of the research is focused on performance, combustion, and emission characteristics. This review intends to reveal SI engines' performance, combustion, and emission characteristics using alternative fuels, such as alcohol, natural gas, and biodiesel. The effects of alternative fuels on performance, combustion characteristics, and emissions, such as NOx, CO, and HC, were also investigated. The results presented here showed that the use of alcohol fuel blends such as butanol, n-butanol, tert-butanol, iso-butanol, bio-ethanol, isopropanol, propanol, and ethanol-methanol-gasoline can improve engine performance and NOx, CO, and HC emissions. Increased performance and emissions have reduced the combustion characteristics. On the contrary, when combustion increases, engine performance and emissions decrease. The engine combustion decreased due to the lower heating value (LHV), lower cetane number, and lower molecular weight of alcohol fuel than gasoline.

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	Combustion characteristics

1. Introduction

The spark-ignition (SI) engine is a significant energy device for public transportation and private vehicles because it costs less than diesel engines. 30% of the world's greenhouse emissions currently comes from the transportation sector [1–3]. The SI engine is environmentally friendly because fewer emissions come out form the combustion chamber [4–6]. There are several types of substances that are very dangerous in these inhaled suspended particles, such as elemental carbon, inorganic ions, organic carbon and trace elements [7–9]. These chemical compounds can threaten the health and ecosystem [10–15].

The effect of adding iso-butanol-bio-methanol to gasoline can improve the performance of engines such as EGT, BP, Torque and ICP by 0.9%, 2.6%, 1.47% and 6.2% respectively [16]. Meanwhile, the addition of ethanol to gasoline shows a reduction in carbon dioxide (CO2), carbon monoxide and nitrogen oxide

(NOx) emissions without significantly reducing the power. However, the temperature reduction in the cylinder increases hydrocarbon (HC) emissions [17–20]. NOx emissions are scattered in urban environments and mostly come from private vehicles or public transportations which lead to smog, thinning of the ozone layer and acid rain [16,21,22]. Thus, emission reduction from the combustion engine is focused on to reduce environmental and air pollutions [23]. The automotive industry has attempted to devote all its resources with the aim of achieving the requirements for standard emission reductions derived from their vehicles. In this regard, the use of sustainable fuel alternatives such as alcohol, natural gas and biodiesel is the most appropriate method to reduce NOx, CO, HC, CO2 emissions [24,25]. In recent studies, some researchers suggested alternative fuels such as alcohol, natural gas and biodiesel as the main keys to reduce greenhouse gases and harmful pollutants sourced from the combustion chamber [26–31].

Demand for fuel that continues to increase from customers in recent years has resulted in the depletion of fossil fuels [32–34]. Investigations about alternative fuels have been explained in the literature, where reservoirs can meet the demand for fuels such as oil, coal and natural gas [35,36]. The growth of the automotive industry which continues to increase has had an impact on energy scarcity. The increasing demand for alternative fuels and the use of petroleum are the biggest challenges because people want to be ensured of energy security globally. Alternative fuels have been widely used in SI and internal combustion engines with the aim of overcoming the diminishing fossil fuels and rising prices of natural gas. Alcohol fuel, biodiesel and natural gas are alternative fuels that are very promising as a substitute for fossil fuels that have attracted users' interest because they are easily stored and very easy to handle [28,37–40]. SI can be operated by using various mixtures of alcohol fuels with multiple ratios, both through modification and without modification to the engine [17,41–44]. In the blended mode, the alcohol fuel is mixed first with gasoline before being injected into the cylinder [16,21,45–47]. Blended stability with additive fuel is very necessary. The long carbon chain and also the normal HLB (Hydrophile-Lipophile Balance) of 1.6 to 6 contained in fatty alcohols are emulsifiers and co-solvents. The SI engine needs a little modification to add a separate fuel tank, fuel injector, low pressure, the channel and the control system [48–52]. However, in this case, there is no need to use fuel additives because all load conditions and speed of the engine being tested can directly use alcohol fuel [53–57].

Another alternative that can be used for combustion engines as a substitute for fossil fuels is natural gas [49,58–63]. Natural gas has various mixtures of hydrocarbon molecules such as butanol, methanol, ethanol and inert diluents such as nitrogen and carbon dioxide molecules. However, the availability of natural gas throughout the year and geographically varies greatly. In addition, it requires special care during production and operation [24,64–69]. It can be mixed with air to form a homogeneous fuel/air mixture for combustion engines and significantly reduce emissions from the engine exhaust [69–72]. Raw materials such as corn, vegetables, sugar and wheat can be produced into biodiesel fuel [31,49,73–76]. The difference between biodiesel and fossil fuels lies in the oxygen content [77–79]. Clean energy can be produced from biodiesel fuel because it is a renewable energy. Thus, renewable and sustainable fuels such as biodiesel are more promising and also very environmentally friendly [80–82].

This review intends to reveal the performance, combustion and emission characteristics of SI engines using alternative fuels (such as alcohol, natural gas and biodiesel. The effects of alternative fuels on the performance, combustion characteristics and emissions such as NOx, CO, HC, and CO2 were also investigated.

2. Literature review

Alcohol fuel on SI Engine

Alcohol fuel has been widely studied (especially ethanol and methanol) because it is an alternative fuel that can be mixed into gasoline. Alcohol is a renewable energy source and has oxygen properties that can reduce emissions from the combustion chamber [83,84]. Comparison of alcohol and gasoline is shown in **Table 1**, where alcohol density is higher than that of gasoline. Oxygen, latent heat of evaporation and self-ignition temperature are not present in gasoline; however, the octane number of gasolines is higher than alcohol as the number of carbon molecules increases. As an important parameter in engine combustion, low latent heat evaporation and carbon in higher alcohols are not considered. Ethanol and methanol are more desirable than other alcohols as alternative fuels because the resulting emissions are lower and more affordable [85–87]. In a recent study, ethanol-methanol fuel operated on a combustion engine with full load conditions significantly reduced emissions because it has a lower amount of carbon [42,88]. Moreover, the use of ethanol-methanol-propanol, HC and CO emissions was found to decrease because alcohol tolerates higher exhaust-gas recirculation ratio (EGRs) [89–91].

Table 1 - Comparison properties of gasoline and alcohol-based [6,44,46]

Properties	Methanol	Ethanol	Butanol	Propanol	Gasoline
Chemical formula	CH_3OH	C_2H_5OH	C_4H_9OH	C_3H_7OH	C_8H_{15}
Cetane number	2	8	17	12	10-15
Molecular weight (g/mol)	32.04	46.07	-	60.10	96.5
Density (kg/m^3)	791.3	789.4	-	803.7	746
Boiling point (°C)	65	79	117	97	25-215
Lower heating value (MJ/kg)	20.01	26.08	32.01	29.82	42.7
Vaporization latent heat (kJ/kg)	1162.64	918.42	-	727.88	-
Self-ignition temperature (°C)	385	363	-	350	-
Oxygen (%) (wt.)	49.93	34.73	21.6	26.62	-
Latent heating (kJ/kg) 25 °C	1162	904	585	728	380-500
Viscosity (mm2/s) 40 °C	0.59	1.13	2.22	1.74	0.4-0.8[a]

Natural gas

Natural gas is one of the most important energy sources for use in combustion engines among other alternative fuels [24,92]. There are several advantages to natural gas in terms of the prices that are relatively cheaper and lower greenhouse gas emissions than other alternative fuels. **Table 1** shows the properties found in natural gas. Natural gas fuels can be used in combustion engines with high compression ratios, especially for diesel engines, because the octane is high.

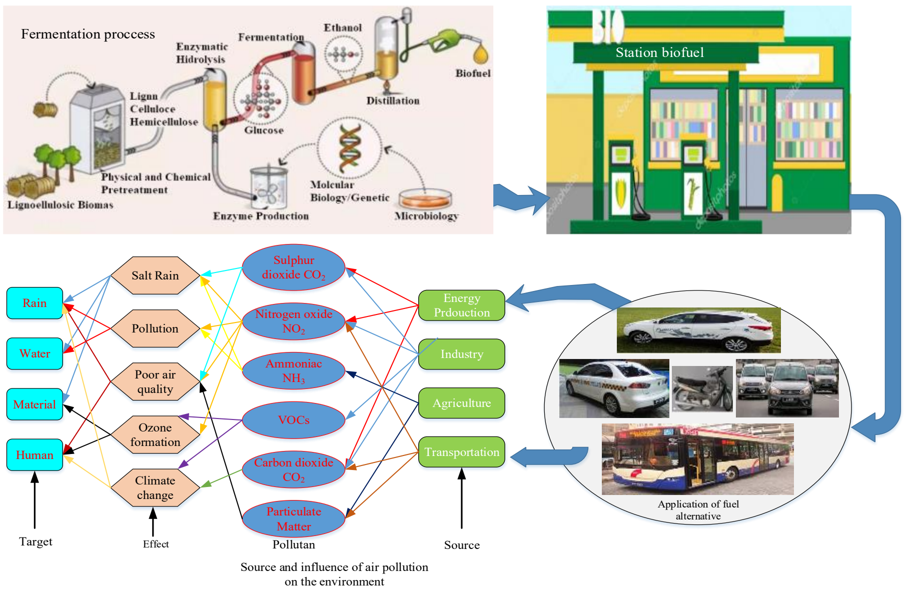

Figure 1: Fermentation, station biofuel, application and source and influence of air pollution on the environment

In recent decades, environmental pollution and energy depletion have attracted the attention of governments around the world to use natural gas as an alternative to stationary machines, etc. [93,94]. This is because the induction to the intake or the cylinder directly uses natural gas where fresh air can form homogeneous blends, and which are then ignited by a spark plug or fuel pilot [15,95–97]. Therefore, emission reductions derived from reduced exhaust gases and efficient combustion can be achieved. Moreover, modifications do not have to be carried out on vehicles when using natural gas, and thus giving important economic and environmental benefits [98,99].

Table 2: Properties of natural gas [6,100]

Component	v/v (%)
C_5H_{12}	0.03 ± 0.03
Density(kg/m^3)	0.788
Lower heating value (MJ/kg)	49.5 ± 0.2
Stoichiometric air/fuel ratio	17.20
CH_4	91.72 ± 1.7
C_3H_8	1.98 ± 0.8
C_4H_{10}	0.44 ± 0.5
C_2H_6	5.5 ± 1.6
CO_2	0.03 ± 0.03
N_2	0.322 ± 0.3

Biodiesel fuel

Biodiesel alternative fuels are more prominent than others and biodiesel production can be refined from various vegetable oils; for example, cotton seeds, soybeans, sunflowers, peanuts, palm oil and rapeseeds. Biodiesel fuel has been widely used for combustion engines, especially in heavy-duty vehicles and marine engines [101–103]. Table 3 shows the properties of biodiesel fuels. Vegetable oil reacted with alcohol can produce biodiesel and can also be obtained from alkali catalysts (KOH and NaOH) with the transesterification process. This process aims to reduce the viscosity of vegetable oils and oxygen content. The organic substances contained in biodiesel have high molecules such as alcohol, ketones, phenols and ether [104–106]. Biodiesel has a lower density than water because the stability of biodiesel can be stored for a longer duration [55,107–109]. Biodiesel does not have aromatic hydrocarbons and the sulphur content is lower than diesel. Thus, emissions from the production of biodiesel do not endanger human health and are also more environmentally friendly. Moreover, biodiesel has a lower amount of cetane than diesel fuel which further improves engine combustion performance [6,55,110].

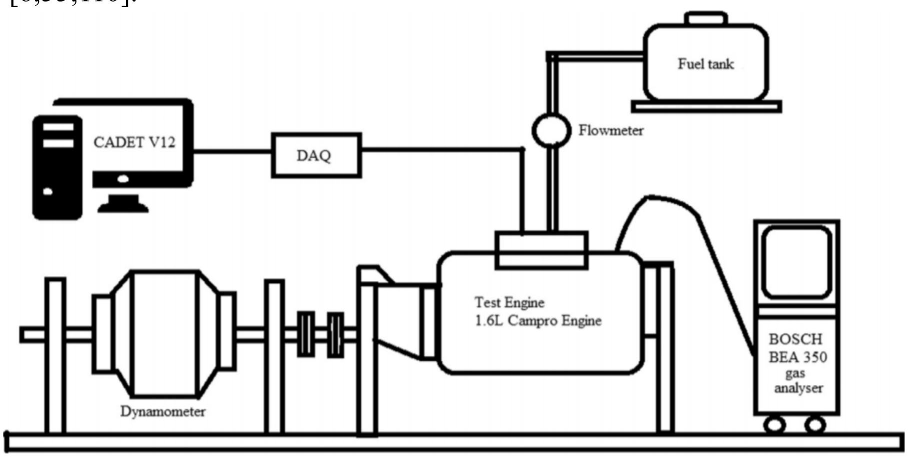

Figure 2: Schematic diagram used of the engine test set-up [111]

Table 3: Properties of biodiesel fuel

Properties	Biodiesel fuel
Carbon content (wt%)	77.0
Specific gravity at 15 °C	896
Flash point (°C)	105

Properties	Biodiesel fuel
Stoichiometric air/fuel ratio	12.33
Oxygen content (wt%)	10.32
Hydrogen content (wt%)	12.18
Gross heating value (MJ/kg)	40
Cetane number	53
Viscosity at 40 °C (cSt)	2.99

A schematic diagram for fuel blend modes used by previous researchers is shown in **Figure 2**. This is illustrated from the Campro PROTON engine four-cylinder used to operate alternative fuels. During the experiment, this machine operated at a speed of 1,000 to 5,000 rpm, with 20% butanol and 80% gasoline ratio of fuel. The schematic diagram shown in **Figure 3** is an illustration of the Mitsubishi 4G93 SOHC four-cylinder engine. This machine can be operated using a variety of alternative fuels with speeds of 500 to 6,500 rpm and full engine load conditions.

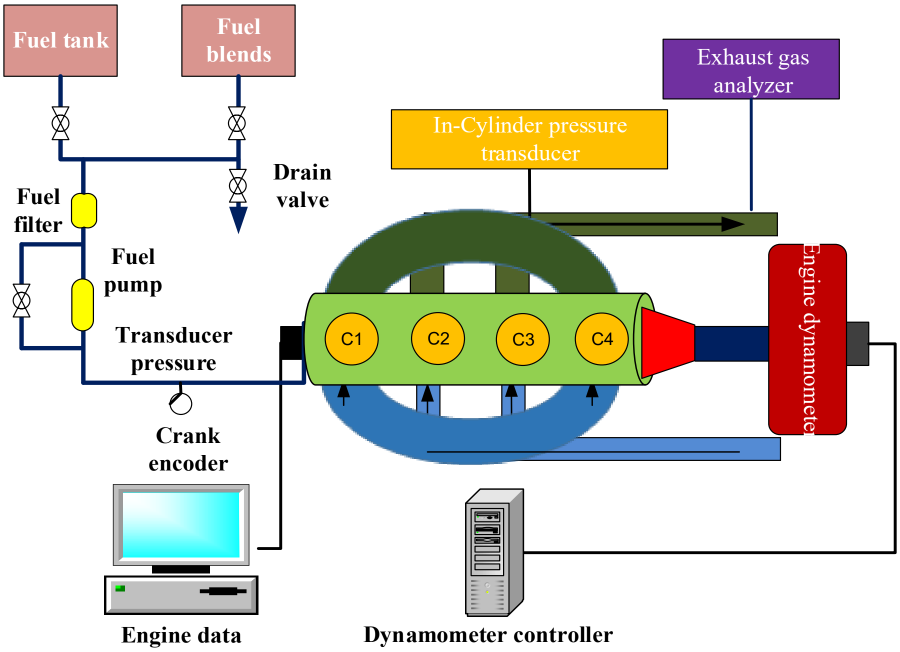

Figure 3: Schematic diagram four-cylinder SI engine

3. Methodology

Application mode of alcohol fuel on SI Engine

Inside the combustion engine, there are two main application modes used for alternative fuels: combustion mode for mixed fuels and dual fuel combustion mode [112–114]. In this review, the experiments carried out generally used the mixed combustion mode, while alternative fuels used for testing included methanol, ethanol, butanol, propanol, n-butanol, n-propanol, isopropanol, natural gas and biodiesel [115–117]. The purpose of this review is to investigate the effect of using alcohol-based fuels on performance, combustion and emission characteristics of the SI engine. In addition, alternative fuels were used to overcome fossil fuels that are constantly decreasing and prices that are continuously increasing all over the world [118]. The average monthly retail fuel price in the United States (US) from 2000 to 2018 can be seen in the graph shown in **Figure 4**. Gasoline and diesel fuel are the primary drivers for the price of liquid fuels. This is because vehicles that use liquid fuels cannot be replaced and are not dedicated to fuel oil, while electric vehicles are high in cost and not made to reach the lower income and middle-class groups of drivers. However, even electricity and natural gas fuels are denied from drivers because only a small portion is marketed for transportation.

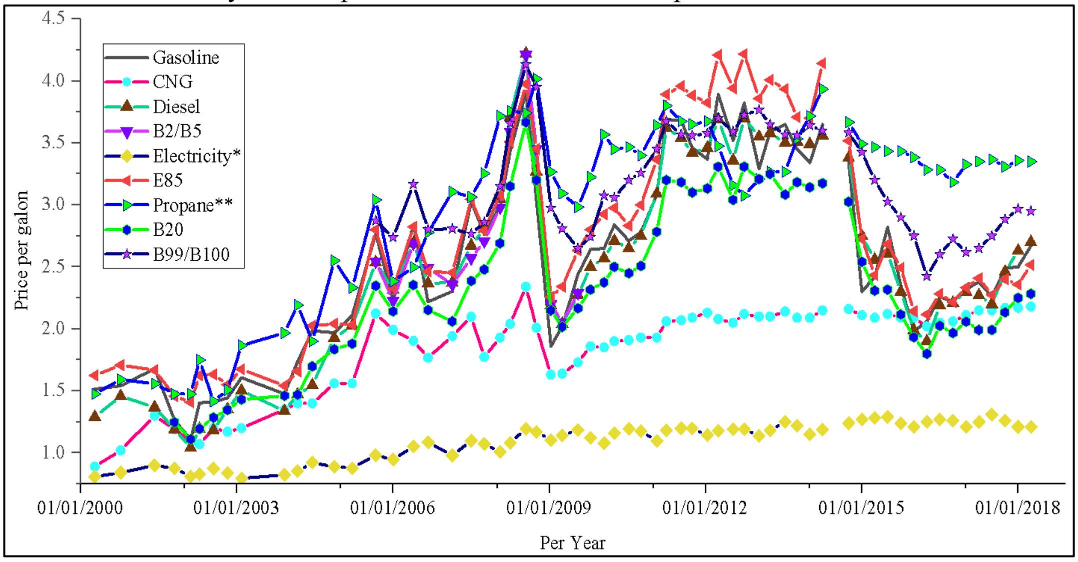

Figure 4: Alternative fuel vehicles in use, 2000 to 2018

Worldwide commercial vehicle use from 2006 to 2015 is as shown in **Figure 5**. More than 335 million commercial vehicles were used globally in 2015. One of the largest markets using commercial vehicles is in the United States. As a rapid increase in commercial vehicle use also has an impact on fuel, the United States has used alternative fuels to avoid scarcity and increasing demand for fossil fuels.

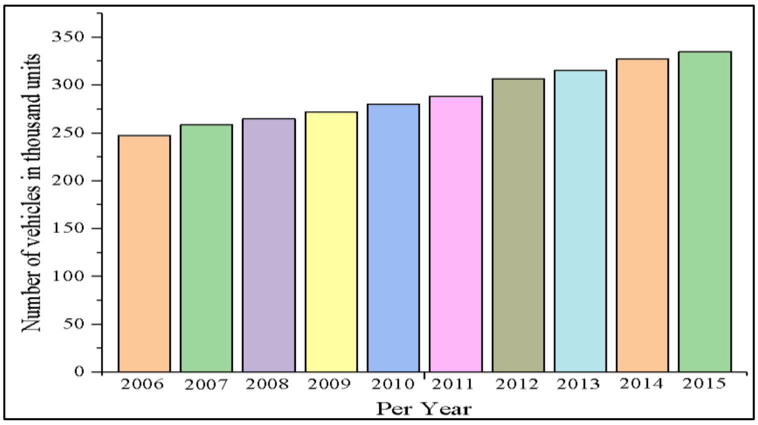

Figure 5: Number of vehicles in thousand units

Fuel blend mode for engine combustion

Liquid alternative fuels such as alcohol and biodiesel are very suitable using the mixed fuel mode because they can be dissolved into gasoline [24,119,120]. Meanwhile, alcohol-based alternative fuels such as ethanol, methanol, butanol and propanol can be mixed with gasoline with emulsifiers and solvents [47,51]. The schematic diagram of blended fuel mode is shown in **Figure 3**. The phase separation of alternative fuels for engine combustion is a problem faced by the mixed fuel modes. However, this problem can be overcome by using solvents into the mixed fuels. Moreover, some ignition fuels such as methanol can be added to mixed fuels so that the fuel cetane number can be compressed. By realizing this application, the fuel and engine supply systems do not need to be modified because the concentration of these alternative fuels is lower. The use of alternative fuels mixed with gasoline in spark ignition engines and the effects on engine performance, combustion and exhaust gas emissions have been investigated in several previous studies [41,43,62,83,92,121–123]. In this study, the percentage of different mixed fuels was chosen as an experiment. With the addition of alcohol to gasoline alternative fuels, engine performance and NOx, CO and HC emissions increased. However, the combustion characteristics in the engine decreased, while CO_2 emissions were found to increase depending on the concentration of alternative fuel-gasoline used. Moreover, the load and speed of the engine when using alternative-gasoline mixed fuels affected engine performance and NOx, CO and HC emissions.

Mode dual fuel

The dual fuel combustion mode has several advantages and has been extensively studied by previous researchers [86,124–126]. Fig. 2 shows a schematic diagram of a dual fuel combustion mode system. The mixing of alternative fuels was done by inducing into the manifold mixed with fresh air so that a homogeneous mixture can be formed [86]. Furthermore, the alternative fuel mixture was ignited with a spark plug or diesel pilot, when the piston was at the top dead center. The amount of diesel fuel remained constant when the operating load conditions were different, while the amount of alternative fuel injections varied according to the output power of the engine [127]. Alcohol fuel, natural gas and biodiesel were included in the alternative fuels used in the dual fuel combustion mode. In previous research [28,128–133], the use of dual fuel modes was very suitable for alternative alcohol-based fuels such as ethanol as engine combustion fuels. This dual fuel mode can reduce NOx emissions compared to using conventional combustion engines. However, dual fuel modes have several difficulties when the combination is performed. The combustion efficiency is much lower when the engine is operated in low and medium engine load conditions. Consequently, it significantly increases NOx, CO and HC emissions that do not burn when using a dual fuel combustion mode [134–137]. Therefore, further research is needed to evaluate the effects of engine combustion using dual fuel combustion modes.

4. Result & Discussion

The performance a spark-ignition engine

Brake specific fuel consumption (BSFC)

The brake specific fuel consumption (BSFC) using alcohol-gasoline mixed fuels requires an increase compared to gasoline for different engine loads and speeds. This shows an increase in BSFC when using alcohol-gasoline mixed fuels compared to pure gasoline. This increase occurred for all engine speeds tested; in the review, it can be reported that increasing BSFC also increased emissions. However, the characteristics of combustion decreased and vice versa; if the combustion increased, this did not apply to BSFC and emissions. The maximum BSFC was obtained from the strength of the brakes when testing the engine using gasoline. Of course, the use of alcohol fuel is more stable because alcohol fuel has a lower energy content than gasoline. Significant increase in BSFC was also due to the increase in engine speed and the results of this review clearly proved the different values of alcohol fuel and gasoline. Comparison of use of alcohol and gasoline is shown in Table 1, and the graph is shown in Table 5.

Brake torque and brake power

The main performance parameters on the engine are important to be investigated so that performance in the engine can be estimated. These parameters included the brake specific fuel consumption (BSFC), brake power (BP) and engine brake torque (BT). The brake torque in the engine is a rotational force resulting from the cylinder press from the piston crankshaft inside the engine. The average effective cylinder pressure, stroke length and engine load have an impact on engine torque. The engine torque varies greatly when alternative fuels are operated at constant engine loads, due to the nature of the fuel and the effective pressure generated. BSFC calculations can be done with the following equation:

$$\text{BSFC} = \frac{Fuel\ cosmptio}{Power\ output} \qquad (1)$$

Some studies [16,41,111,138,139], stated that the torque curve of alternative fuels has the same results. The effects of using various types of alternative fuels for BSFC, brake power and brake torque are shown in Table 4. The use of alternative alcohol-based fuels generally improves engine performance. However, when using alternative fuels with a low volume ratio, the engine performance decreases [140]. Increasing the amount of carbon in alcohol fuel has significantly reduced engine losses. The use of alcohol fuel operated in the combustion engine results in increased brake torque, brake power and brake specific fuel consumption [16]. Moreover, the use of alcohol-gasoline fuel with a high ratio resulted in deteriorating engine behaviour. Findings from several previous studies on the performance of machines such as BSFC, BP and BT have no significant impact when using alcohol fuel. However, compared to pure gasoline, alcohol fuel slightly increases engine performance [43,141–143]. As for natural gas, the total variation of BSFC is directly calculated from the ratio between the amount of fuel mass flow rate and engine output power. When the engine is operated in low and medium engine load conditions, engine performance, such as BSFC, is higher. This increase occurs when using the mixed fuel combustion mode compared to conventional combustion mode due to the low combustion temperature and the fuel-air ratio in the combustion chamber which decrease the combustion rate in the engine. However, in conditions with high engine loads, the engine performance decreases for the combustion mode using natural gas fuel on dual fuel modes. The increased combustion temperatures and more mixtures are the two main factors that increase the conversion of natural gas to decrease the total BSFC [24,94,144,145].

Table 4: Effect of alcohol on the engine performance.

Speed RPM	Using fuel	Volume fraction	Engine test	BSFC	Power	Torque	Ref.
1000-5000	Butanol isomers; n-butanol, sec-butanol, tert-butanol and iso-butanol and gasoline	All fuel 20%	SI-Gasoline	High ↑	N/A	N/A	[146]
2600-3400	Iso-butanol–bio-methanol–gasoline and n-butanol–bio-ethanol–gasoline	3%, 7% and 10%	SI-Gasoline	High ↑	High ↑	High ↑	[111]
2600-3400	n-butanol–methanol–gasoline	0%, 3%, 7% and 10%	SI-Gasoline	N/A	High ↑	High ↑	[16]
1500-5000	Ethanol and gasoline	10% and 20%	SI-Gasoline	Lower ↓	Lower ↓	N/A	[147]
1500	n-Octanol-Diesel	10%, 20% and 30%	SI-Gasoline	Lower ↓	Lower ↓	Lower ↓	[41]
1000-5000	Propanol-gasoline	0%, 5%, 10%, 15% and 20%	SI-Gasoline	High ↑	Lower ↓	N/A	[138]
2600-3400	Bio-ethanol–iso-butanol–gasoline	0.8%, 1.2%, 0.4% and 0.6%	SI-Gasoline	High ↑	High ↑	High ↑	[46]
1200	Methanol, ethanol and butanol	N/A	SI-Gasoline	Lower ↓	High ↑	High ↑	[139]
2600-3400	n-butanol–methanol–gasoline	1.5%, 3%, 3.5%, 5% and 7%	SI-Gasoline	Lower ↓	Lower ↓	Lower ↓	[148]
3000	iso-octane/n-butanol	10%, 20 and 30%	SI-Gasoline	High ↑	Lower ↓	N/A	[147]
N/A	1-pentanol	5%, 10%, 20%, and 40%	Kirloskar	N/A	N/A	N/A	[149]
1200	Acetone-n-butanol-ethanol and isopropanol-n-butanol-ethanol	30% and 60%	SI-Gasoline	High ↑	High ↑	High ↑	[150]
1500	Methanol, ethanol, 2-propanol, 1-butanol and diesel	15%, 30%, 45%, 55% and 70%	CI-engine	Lower ↓	Lower ↓	Lower ↓	[151]
2000	Ethanol/gasoline	10% and 20%	SI-Gasoline	High ↑	High ↑	High ↑	[124]

Speed RPM	Using fuel	Volume fraction	Engine test	BSFC	Power	Torque	Ref.
2000	isopropanol-n-butanol-ethanol and gasoline	N/A	SI-Gasoline	High ↑	High ↑	High ↑	[152]

Engine combustion characteristics

The effects of combustion such as cylinder pressure and heat release rates from various types of alternative fuels were calculated. The ignition delay is well-defined as the variation of the crank angle in the ignition time and the start of the injection. The zero-braking angle placement was made to determine the ignition time of the second derivative of the cylinder pressure. The collected heat release rate was definite for the crank angle of 90% (CA90), and the variation of the crank angle between CA90 and ignition time was defined for the duration of combustion. The effect of release rate and pressure in the cylinder from the use of alternative alcohol fuels is presented in Table 6. There are many differences in the rate of heat release and in-cylinder pressure from the use of alcohol fuels operated in mixed fuel modes and conventional fuels. Significantly, compression pressure decreased as the alcohol content in the fuel increased, compared to conventional combustion mode [152–155]. This decrease was caused by the latent heat of vaporization in alcohol which is higher than gasoline. So, when intake ports were injected with alcohol fuels such as methanol and ethanol, they absorbed heat and evaporated from the incoming air, so that the cylinder pressure and temperature decreased. When the engine was operated under low load and engine speed conditions, the maximum cylinder pressure changed slightly with the low and medium ratios of premix alcohol; however, the premix was high when the alcohol ratio decreased. Increasing the latent vaporization of alcohol decreased the combustion temperature and cylinder pressure in delaying the excessive combustion phase. The ratio of pre-paste alcohol fuel increased when the engine load and speed were operated. While for natural gas, when operated in a mixed fuel mode with natural gas fuels, a decrease was shown in combustion pressure compared to conventional fuels [156–158]. When the engine was operated with a low load using a mixture of natural gas, the combustion pressure in the cylinder decreased. This was due to the increased specific heat capacity of the cylinder combustion, gas-air mixture leanness and lower ignition delay. At the beginning of combustion, heat cannot be released efficiently because of the amount of steam collected during the ignition; however, after that, it improved. After experiencing an ignition delay, the fuel-air mixture burnt very quickly. Moreover, engine load conditions can cause more accumulation of gas fuel in the combustion chamber and a decrease in ignition delay. The addition of biodiesel can accelerate the initial combustion for all test engine loads because the cylinder pressure increased rapidly in the pressure trace at the end of compression [159,160].

Furthermore, the combustion of the engine with biodiesel mixture was carried out earlier than conventional fuels, especially diesel. The value of the biodiesel fuel mixture occurred a little earlier in the crank angle due to the bulk modulus, higher density and viscosity. By adding a biodiesel mixture, the rate of heat release decreased in the combustion phase and this occurred when the engine was operated in low and high engine load conditions. This decrease also occurred because the injector of the amount of fuel was lower so that the ignition delay was shorter, thus the biodiesel fuel mixture had a low heating value.

In-Cylinder

Pistons do all the work during compression and produce energy gas through the combustion process in the engine. In an SI engine, when the cylinder gas pressure increases, it can significantly increase combustible fuel. Because the enthalpy of combustion has increased, the fuel energy increases. The combustion characteristics of mixed alcohol fuels can be compared with gasoline fuel through the use of gas pressure in the cylinder. The peak combustion pressure was significantly faster than the gasoline achieved in the cylinder because the octane value in the fuel was lower as shown in the results in Table 5. The higher the octane value, the greater the compression ratio that can be charged in the engine without observing the knock phenomenon in the engine. Thus, a significant increase in engine performance output can be provided with similar amounts in the use of test fuels. This is a fairly positive aspect, while the engine efficiency is lacking in terms of the current gasoline engine that can be handled.

Heat release rate

Combustion can produce the rate of heat release in the engine and provide precise information on fuel combustion. The calculation of heat release rate was carried out to try to get information from the combustion process inside the engine. The alcohol fuel mixture was tested to investigate combustion characteristics and compared with gasoline, then compared with the rate of heat release during their combustion process [140]. The increase in heat shown by the heat release pattern can be released by using a gasoline-alcohol fuel mixture. This observation was carried out when the piston has reached the top dead centre. The increase in the amount of heat released in the engine was the result of greater enthalpy in the mixed fuel. Gasoline fuels had a higher level of heat release compared to alcohol-based fuels for all engine speeds and tested loads. This was also found at the location of the peak level of heat release which was wider when using alcohol-gasoline mixed fuels compared to pure gasoline fuel. The main reason in this case was that oxygen contained in alcohol fuel can increase combustion, depending on the concentration given. In addition, combustion using a larger fuel mixture occurred in areas near the dead centre. Therefore, the release of increased heat in the engine can reduce emissions; in the beginning, if the combustion decreased, the emissions increased. This can be influenced by several factors, especially the heat value of gasoline which was higher than alcohol. More details about combustion characteristics are shown in **Table 5**.

Table 5: Combustion characteristic

Speed RPM	Using fuel	Volume fraction	Engine test	Pressure	HRR	Temperature	Ref.
1000-5000	Butanol isomers; n-butanol, sec-butanol, tert-butanol and iso-butanol and gasoline	All fuel 20%	SI-Gasoline	N/A	N/A	High ↑	[146]
2600-3400	Iso-butanol–bio-methanol–gasoline and n-butanol–bio-ethanol–gasoline	3%, 7% and 10%	SI-Gasoline	N/A	N/A	High ↑	[111]
2600-3400	n-butanol–methanol–gasoline	0%, 3%, 7% and 10%	SI-Gasoline	High ↑	N/A	High ↑	[16]
1500-5000	Ethanol and gasoline	10% and 20%	SI-Gasoline	Lower ↓	N/A	Lower ↓	[147]
1500	n-Octanol-Diesel	10%, 20% and 30%	SI-Gasoline	High ↑	N/A	**N/A**	[41]
1000-5000	Propanol-gasoline	0%, 5%, 10%, 15% and 20%	SI-Gasoline	N/A	High ↑	High ↑	[138]
2600-3400	Bio-ethanol–iso-butanol–gasoline	0.8%, 1.2%, 0.4% and 0.6%	SI-Gasoline	N/A	N/A	**N/A**	[46]
1200	Methanol, ethanol and butanol	N/A	SI-Gasoline	Lower ↓	N/A	High ↑	[139]
2600-3400	n-butanol–methanol–gasoline	1.5%, 3%, 3.5%, 5% and 7%	SI-Gasoline	High ↑	N/A	**N/A**	[148]
3000	iso-octane/n-butanol	10%, 20 and 30%	SI-Gasoline	High ↑	N/A	High ↑	[147]
N/A	1-pentanol	5%, 10%, 20%, and 40%	Kirloskar	High ↑	N/A	High ↑	[149]
1200	Acetone-n-butanol-ethanol and	30% and 60%	SI-Gasoline	Lower ↓	Lower ↓	**N/A**	[150]

Speed RPM	Using fuel	Volume fraction	Engine test	Pressure	HRR	Temperature	Ref.
	isopropanol-n-butanol-ethanol						
1500	Methanol, ethanol, 2-propanol, 1-butanol and diesel	15%, 30%, 45%, 55% and 70%	CI-engine	High ↑	**N/A**	High ↑	[151]
2000	Ethanol/gasoline	10% and 20%	SI-Gasoline	High ↑	High ↑	High ↑	[124]
2000	isopropanol-n-butanol-ethanol and gasoline	N/A	SI-Gasoline	**N/A**	**N/A**	High ↑	[152]

Engine emission characteristic for alcohol fuel

The use of ethanol led to lower HC and CO emissions from the engine and also decreasing the NOx emission. In addition, the blends had lower content of toxicity, since they were reported to be much cleaner after comparing the emissions with the conventional fuels. A detailed literature outcome, depicting the influence of ethanol blends on the various constituents of emissions, has been done in a previous study [35].

Nitrogen monoxide (NOx)

Several studies reviewed in this paper mentioned that NOx emissions vary greatly and sometimes increase but reduce combustion in the engine. Conversely, if engine combustion increases and NOx emissions decrease, this applies to all engine loads and fuel mixtures. Compared to the alcohol content, the water content of the fuel can significantly reduce emissions; however, it affects the loss of torque from the engine output. Investigations into the use of the fuel mixture have been done. NOx emissions do not linearly increased significantly with the compression ratio because the combustion temperature runs throughout the engine. This is because the water content in the fuel has an influence on reducing NOx emissions. Furthermore, the peak combustion temperature in the cylinder decreases. As reported, the reaction of nitrogen with engine fuel can form NOx emissions. Moreover, it can create greenhouse gases which are very dangerous, because they cannot ignore oxidation from a fuel-rich environment with a lower temperature during the combustion process [17,21,140,161,162].

The exhaust gas temperatures and a comparative graph of various speed and loads of the test engine have provided significant insight into the extent to which the fuel mixture can emit NOx emission gas. From several studies reviewed, it was stated that the addition of alcohol fuel to various ratios could reduce NOx emissions. However, there are also different studies that stated adding alcohol to gasoline can increase NOx emissions. Meanwhile, the amount of gas emitted to gasoline burned enough for certain engine speeds. Conversely, a greater alcohol content in the fuel can produce NOx emission levels even at higher exhaust temperatures. This is a determining factor for the level of NOx emission stressed from the engine. The increase and decrease of NOx emissions in machines that are operated using a mixture of alcohol to gasoline with different engine loads and speeds are shown in Table 6.

The reduction in CO content to zero cannot be done because each combustion is imperfect and there is always a little of the fuel contained in the engine. The concentration of CO emissions in the engine is also affected by the combustion temperature when the engine is operated. In some cases, the amount of CO increases significantly in the exhaust because the combustion temperature in the engine is lower. The changes in the compression ratio in the engine show highly varied emission levels. Every addition of alcohol fuel such as ethanol by 10% to gasoline can reduce CO emissions by 30% [41,163]. In this review, several proven statements that the use of alcohol fuels can reduce CO from various mixtures were tested [16,41,46,111,124,138,139,147]. However, CO emissions also increased in some research, and more details can be shown in Table 6 [115,146–148,150–152]. The CO emission graph clearly illustrated that an increase in alcohol fuel can reduce CO; however, the combustion characteristics decrease slightly and vice versa; if the combustion characteristics of the engine increase, CO emissions decrease. CO emission levels can also be affected by the low latent heat contained in alcohol fuel.

Hydrocarbon (HC)

HC that are not burned out are hydrocarbons emitted after burning fossil oil in the engine. Some of the air-fuel mixtures inside the engine piston is hiding from the combustion of fire in the cracks available on the piston ring grooves. Moreover, it is possible that from some combustion chambers, the flames are very weak, and the combustion temperatures are low. As a result, when the fuel is not burned, the steam emitted from HC is formed. The HC emission from alcohol fuel is larger compared to gasoline. This is because the calorific value and molecular weight in alcohol fuel are lower than gasoline [6,44,46]. The effect of an alcohol-based alternative fuel mixture on hydrocarbon emissions is significantly increased. However, from some previous studies, not all HC experienced an increase, as shown in **Table 6**. Non-combustible HC emissions are one of the emissions in the engine discussed in this review. The engine efficiency decreases with the increasing HC emissions; on the contrary, if engine combustion increases, HC emissions decrease. The wasteful use of fuel in the engine also causes an increase in pollution levels. In the case of a fuel mixture, it can provide better combustion and is quite clear because it can limit the unburned fuel trapped in a particular engine location. Alcohol fuels with B20 and B40 fuel mixtures increase HC emissions due to the lower cetane number which causes ignition delays [150,152]. Meanwhile, a mixture of gasoline-ethanol and methanol HC emission was found to decrease, while the HC methanol-gasoline mixture increased. The increasing HC uses methanol-gasoline because too much fuel is injected, resulting in ignition delays [148]. The addition of ethanol fuel with a mixture ratio of E10W and E20W to gasoline reduces\d HC emissions compared to E20W, E10W [41]. The effect of iso-butanol-n-butanol-gasoline mixture produced the lowest HC emissions compared to pure gasoline when the engine load was high [111]. The effect of oxygenated fuel tested on dual fuels showed that HC emissions were increased compared to conventional fuel modes [124]. An alcohol fuel mixture of 10% (IBE10%) increased UHC emissions by 12.4-25.1 and 4.4-6.1% compared to ABE. However, deteriorating combustion quality can increase UHC emissions [151]. HC emissions decreased by 14.18% from the use of propanol-gasoline fuel mixture. In addition, vehicle fuel consumption increased with decreasing hydrocarbons [46].

Table 6: Emission Characteristic

Speed RPM	Using fuel	Volume fraction	Engine test	NOx	CO	HC	CO_2	Ref.
1000-5000	Butanol isomers; n-butanol, sec-butanol, tert-butanol and iso-butanol and gasoline	All fuel 20%	SI-Gasoline	High ↑	High ↑	High ↑	N/A	[146]
2600-3400	Iso-butanol–bio-methanol–gasoline and n-butanol–bio-ethanol–gasoline	3%, 7% and 10%	SI-Gasoline	Lower ↓	Lower ↓	Lower ↓	High ↑	[111]
2600-3400	n-butanol–methanol–gasoline	0%, 3%, 7% and 10%	SI-Gasoline	N/A	Lower ↓	Lower ↓	Lower ↓	[16]
1500-5000	Ethanol and gasoline	10% and 20%	SI-Gasoline	N/A	High ↑	High ↑	Lower ↓	[147]
1500	n-Octanol-Diesel	10%, 20% and 30%	SI-Gasoline	Lower ↓	Lower ↓	Lower ↓	N/A	[41]
1000-5000	Propanol-gasoline	0%, 5%, 10%, 15% and 20%	SI-Gasoline	Lower ↓	Lower ↓	Lower ↓	N/A	[138]
2600-3400	Bio-ethanol–iso-butanol–gasoline	0.8%, 1.2%, 0.4% and 0.6%	SI-Gasoline	High ↑	Lower ↓	Lower ↓	N/A	[46]
1200	Methanol, ethanol and butanol	N/A	SI-Gasoline	N/A	Lower ↓	Lower ↓	High ↑	[139]
2600-3400	n-butanol–methanol–gasoline	1.5%, 3%, 3.5%, 5% and 7%	SI-Gasoline	Lower ↓	High ↑	Lower ↓		[148]
3000	iso-octane/n-butanol	10%, 20 and 30%	SI-Gasoline	N/A	Lower ↓	Lower ↓	High ↑	[147]

Speed RPM	Using fuel	Volume fraction	Engine test	NOx	CO	HC	CO_2	Ref.
N/A	1-pentanol	5%, 10%, 20%, and 40%	Kirloskar	N/A	N/A	N/A	N/A	[149]
1200	Acetone-n-butanol-ethanol and isopropanol-n-butanol-ethanol	30% and 60%	SI-Gasoline	High ↑	High ↑	High ↑	N/A	[150]
1500	Methanol, ethanol, 2-propanol, 1-butanol and diesel	15%, 30%, 45%, 55% and 70%	CI-engine	High ↑	High ↑	High ↑	N/A	[151]
2000	Ethanol/gasoline	10% and 20%	SI-Gasoline	High ↑	Lower ↓	High ↑	Lower ↓	[124]
2000	isopropanol-n-butanol-ethanol and gasoline	N/A	SI-Gasoline	High ↑	High ↑	High ↑	N/A	[153]

The use of alcohol-based fuel with fumigation and mixtures in combustion engines has been widely investigated. Alcohol fuels, such as methanol, ethanol, butanol and biodiesel, have several advantages. Alcohol fuel is suitable for cleaning machines such as SI engines and the like, both through fumigation and mixture into conventional ingredients. The disadvantages of using alcohol fuels such as methanol are mainly for diesel engines because of lower calorific value, low flash point and smaller cetane number. The advantages and disadvantages of alcohol-based fuels are described in **Table 7** [31,42]. Among several alternative fuels used for combustion engines, biodiesel has more advantages that can support some unique qualities and features. Biodiesel fuel has been tested, and all the requirements for health effects have been successfully passed, unlike other alternative fuels, as standardized by the Amendment to the Clean Water Act in 1990.

Table 7: Comparative study of alcohol, natural gas and biodiesel

Advantages Methanol	• Higher cooling, hence less compression work • The high latent heat of vaporisation • The high stoichiometric fuel-air ratio • The high stoichiometric fuel-air ratio • High oxygen content, high hydrogen to the car bon ratio and low sulfur content • Reduced soot and smoke
Disadvantages Methanol	• Poor combustion characteristics • Lower energy content • Longer ignition delay • More corrosive • Lower flash point
Advantages biodiesel	• Biodiesel fuel is a renewable energy source unlike petroleum-based diesel • One of the main biodiesel fuel advantages is that it is less polluting than petroleum diesel • Excessive production of soybeans in the world makes it an economical way to utilise this surplus for manufacturing the Biodiesel fuel • The lack of sulfur in 100% biodiesel extends the life of catalytic converters • Another of the advantages of biodiesel fuel is that it can also be blended with other energy resources and oil • It can also be distributed through existing diesel fuel pumps, which is another biodiesel fuel advantage over other alternative fuels • The lubricating property of the biodiesel may lengthen the lifetime of engines • Biodiesel fuel can also be used in existing oil heating systems and diesel engines without making any alterations

Disadvantages of biodiesel	• It requires energy to produce biodiesel fuel from soy crops, plus there is the energy of sowing, fertilizing and harvesting • At present, Biodiesel fuel is bout one and a half times more expensive than petroleum diesel fuel • Another biodiesel fuel disadvantage is that it can harm rubber hoses in some engines • Biodiesel fuel distribution infrastructure needs improvement, which is another of the biodiesel fuel disadvantages • As Biodiesel cleans the dirt from the engine, this dirt can then get collected in the fuel filter, thus clogging it. So, filters have to be changed after the first several hours of biodiesel use.
Advantages Ethanol	• The use of ethanol as opposed to petroleum could reduce carbon dioxide emissions, provided that a renewable energy resource was used to produce crops required to obtain ethanol and to distil fermented ethanol • Unlike petroleum, ethanol is a renewable resource • Ethanol burns more cleanly in the air than petroleum, producing less carbon (soot) and carbon monoxide
Disadvantages Ethanol	• Large amounts of arable land are needed to produce the necessary plants to purchase ethanol, leading to problems such as soil erosion, deforestation, fertiliser run-off and salinity • Typical current engines would require modification to use high concentrations of ethanol • Ethanol has a lower heat of combustion (per mole, per unit of volume, and per unit of mass) that petroleum • Major environmental problems would arise out of the disposal of waste fermentation liquors.
Advantages Butanol	• Biomass is readily available for making butanol, and the process is simple enough that it can be wholly regionalized (from biomass production to fuel). • Butanol is much like gasoline so that it can be distributed through the same infrastructure, and it's much more comfortable on the atmosphere and planet that is petroleum-based fuel. • Butanol is very water tolerant, so it can mix easily with gasoline or diesel without the separation issues that water can bring to ethanol mixtures. • It can also be burned in most combustion engines made for it without the need of water separation (as with diesel) or dehydration (as with ethanol).
Disadvantages Butanol	• Butanol has less energy density than gasoline and a lower octane rating than gas, ethanol, or methanol. • It has an air-fuel ratio similar to gasoline (11.1 vs 14.6) but outputs less energy overall. • While the making of butanol is not new, producing it correctly as a fuel is, so no real commercialization has happened yet.

5. Conclusion

This review presents the effects of alcohol mixture on the performance, combustion and emission characteristics on spark ignition (SI) engines. The addition of alcohol fuel to gasoline can result in more varied engine operations. The increased combustion has an impact on the reduction in performance and emissions in the engine. The conclusions that can be drawn from this paper are as follows:

- The fuel with more octane numbers has far better implications for engine efficiency; more octane contained in the fuel can provide better engine combustion.
- The percentage of alcohol fuel increases NOx, CO, HC emissions and performance in the engine. However, it reduces the combustion characteristics; otherwise, if the combustion in the engine increases, emissions and engine performance decrease.
- The use of new and clean alternative fuels in engines such as alcohol-based fuels can offer longer injection delay, shorter ignition delays and lower pressure ratios. The properties offered are contrary to what is found in conventional fuels.

- Clean alternative fuels for machines such as alcohol, biodiesel and natural gas have enormous potential in the future to overcome the depletion of energy worldwide.

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Nomenclature			
BSFC	Brake Specific Fuel Consumption	LHV	Low Heat Value
BTE	Brake Thermal Efficiency	BMEP	Brake Mean Effective Pressure
HCCI	Homogeneous Charge Compression Ignition	PCCI	Premixed Charge Compression Ignition
E	Engine's speed surface	PAH	Polycyclic Aromatic Hydrocarbon
NOx	Nitrogen Oxides	HC	Hydrocarbon
CO	Carbon monoxide	PM	Particulate Matter
HLB	Hydrophile Lipophile Balance	EGR_s	Exhaust Gas Recirculation
BP	Brake power	BT	Brake torque
SI	Spark ignition	CO_2	Carbon dioxide
HRR	Heat release rate	CH_3OH	Methanol
C_2H_5OH	Ethanol	C_3H_7OH	Propanol
C_4H_9OH	Butanol	C_8H_{15}	Gasoline

References

[1] L. Wright, Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities. Module 3b: Bus Rapid Transit, (2004).

[2] H. Dalkmann, C. Brannigan, Transport and climate change, module 5e, sustainable transport, a sourcebook for policy-makers in developing cities, GTZ global, Fed. Eschborn, Ger. Minist. Econ. Coop. Dev. (2007).

[3] O.I. Awad, R. Mamat, T.K. Ibrahim, A.T. Hammid, I.M. Yusri, M.A. Hamidi, A.M. Humada, A.F. Yusop, Overview of the oxygenated fuels in spark ignition engine: Environmental and performance, Renew. Sustain. Energy Rev. 91 (2018) 394–408.

[4] J.M. Bergthorson, M.J. Thomson, A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines, Renew. Sustain. Energy Rev. 42 (2015) 1393–1417. https://doi.org/10.1016/j.rser.2014.10.034.

[5] S. Lal, R.S. Patil, Monitoring of atmospheric behaviour of NOx from vehicular traffic, Environ. Monit. Assess. 68 (2001) 37–50.

[6] P. Geng, E. Cao, Q. Tan, L. Wei, Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review, Renew. Sustain. Energy Rev. 71 (2017) 523–534. https://doi.org/10.1016/j.rser.2016.12.080.

[7] K.L. Cheung, L. Ntziachristos, T. Tzamkiozis, J.J. Schauer, Z. Samaras, K.F. Moore, C. Sioutas, Emissions of particulate trace elements, metals and organic species from gasoline, diesel, and biodiesel passenger vehicles and their relation to oxidative potential, Aerosol Sci. Technol. 44 (2010) 500–513.

[8] L. Francioso, D.S. Presicce, M. Epifani, P. Siciliano, A. Ficarella, Response evaluation of TiO2 sensor to flue gas on spark ignition engine and in controlled environment, Sensors Actuators B Chem. 107 (2005) 563–571.

[9] J.C. Chow, Diesel engines: Environmental impact and control, J. Air Waste Manage. Assoc. 51 (2001) 1258–1270.
[10] C.C. Lim, R.B. Hayes, J. Ahn, Y. Shao, D.T. Silverman, R.R. Jones, C. Garcia, G.D. Thurston, Association between long-term exposure to ambient air pollution and diabetes mortality in the US, Environ. Res. 165 (2018) 330–336.
[11] X. Wang, L. Zhang, Z. Yao, S. Ai, Z.M. Qian, H. Wang, R. BeLue, T. Liu, J. Xiao, X. Li, Ambient coarse particulate pollution and mortality in three Chinese cities: Association and attributable mortality burden, Sci. Total Environ. 628 (2018) 1037–1042.
[12] M. Zhou, G. He, Y. Liu, P. Yin, Y. Li, H. Kan, M. Fan, A. Xue, M. Fan, The associations between ambient air pollution and adult respiratory mortality in 32 major Chinese cities, 2006–2010, Environ. Res. 137 (2015) 278–286.
[13] Y. Tong, K. Luo, R. Li, L. Pei, A. Li, M. Yang, Q. Xu, Association between multi-pollutant mixtures pollution and daily cardiovascular mortality: An exploration of exposure-response relationship, Atmos. Environ. 186 (2018) 136–143.
[14] B. Done, Experimental investigations of LASER ignition use at spark ignition engine, Procedia Manuf. 22 (2018) 659–666.
[15] C. Gong, Z. Li, Y. Chen, J. Liu, F. Liu, Y. Han, Influence of ignition timing on combustion and emissions of a spark-ignition methanol engine with added hydrogen under lean-burn conditions, Fuel. 235 (2019) 227–238.
[16] A. Elfasakhany, Exhaust emissions and performance of ternary iso-butanol–bio-methanol–gasoline and n-butanol–bio-ethanol–gasoline fuel blends in spark-ignition engines: assessment and comparison, Energy. (2018).
[17] B. Doğan, D. Erol, H. Yaman, E. Kodanli, The effect of ethanol-gasoline blends on performance and exhaust emissions of a spark ignition engine through exergy analysis, Appl. Therm. Eng. 120 (2017) 433–443. https://doi.org/10.1016/j.applthermaleng.2017.04.012.
[18] A. Peters, B. Veronesi, L. Calderón-Garcidueñas, P. Gehr, L.C. Chen, M. Geiser, W. Reed, B. Rothen-Rutishauser, S. Schürch, H. Schulz, Translocation and potential neurological effects of fine and ultrafine particles a critical update, Part. Fibre Toxicol. 3 (2006) 13.
[19] J.D. McDonald, M.D. Reed, M.J. Campen, E.G. Barrett, J. Seagrave, J.L. Mauderly, Health effects of inhaled gasoline engine emissions, Inhal. Toxicol. 19 (2007) 107–116.
[20] M. Jerrett, R. McConnell, C.C.R. Chang, J. Wolch, K. Reynolds, F. Lurmann, F. Gilliland, K. Berhane, Automobile traffic around the home and attained body mass index: a longitudinal cohort study of children aged 10–18 years, Prev. Med. (Baltim). 50 (2010) S50–S58.
[21] P. Iodice, G. Langella, A. Amoresano, Ethanol in gasoline fuel blends: Effect on fuel consumption and engine out emissions of SI engines in cold operating conditions, Appl. Therm. Eng. 130 (2018) 1081–1089. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2017.11.090.
[22] S. Ramalingam, S. Rajendran, P. Ganesan, M. Govindasamy, Effect of operating parameters and antioxidant additives with biodiesels to improve the performance and reducing the emissions in a compression ignition engine–A review, Renew. Sustain. Energy Rev. 81 (2018) 775–788.
[23] P. Tamilselvan, N. Nallusamy, S. Rajkumar, A comprehensive review on performance , combustion and emission characteristics of biodiesel fuelled diesel engines, Renew. Sustain. Energy Rev. 79 (2017) 1134–1159. https://doi.org/10.1016/j.rser.2017.05.176.
[24] F. Yan, L. Xu, Y. Wang, Application of hydrogen enriched natural gas in spark ignition IC engines: from fundamental fuel properties to engine performances and emissions, Renew. Sustain. Energy Rev. (2017).
[25] A.K. Thakur, A.K. Kaviti, R. Mehra, K.K.S. Mer, Progress in performance analysis of ethanol-gasoline blends on SI engine, Renew. Sustain. Energy Rev. 69 (2017) 324–340. https://doi.org/https://doi.org/10.1016/j.rser.2016.11.056.
[26] M.M.E. Moula, J. Nyári, A. Bartel, Public acceptance of biofuels in the transport sector in Finland, Int. J. Sustain. Built Environ. 6 (2017) 434–441.
[27] M. Li, J. Xu, H. Xie, Y. Wang, Transport biofuels technological paradigm based conversion approaches towards a bio-electric energy framework, Energy Convers. Manag. 172 (2018) 554–

566.
[28] H. Chen, J. He, X. Zhong, Engine combustion and emission fuelled with natural gas: A review, J. Energy Inst. 92 (2019) 1123–1136. https://doi.org/https://doi.org/10.1016/j.joei.2018.06.005.
[29] R. Sathiyamoorthi, G. Sankaranarayanan, T. Chiranjeevi, D.D. Kumar, Experimental investigation on performance, combustion and emission characteristics of a single cylinder diesel engine fuelled by biodiesel derived from Cymbopogon Martinii, Renew. Energy. 132 (2019) 394–415.
[30] J.P. Bhasker, E. Porpatham, Effects of compression ratio and hydrogen addition on lean combustion characteristics and emission formation in a Compressed Natural Gas fuelled spark ignition engine, Fuel. 208 (2017) 260–270.
[31] M.A. Ghadikolaei, C.S. Cheung, K.-F. Yung, Study of combustion, performance and emissions of diesel engine fueled with diesel/biodiesel/alcohol blends having the same oxygen concentration, Energy. 157 (2018) 258–269. https://doi.org/https://doi.org/10.1016/j.energy.2018.05.164.
[32] N. Abas, A. Kalair, N. Khan, Review of fossil fuels and future energy technologies, Futures. 69 (2015) 31–49. https://doi.org/https://doi.org/10.1016/j.futures.2015.03.003.
[33] M. David, The role of organized publics in articulating the exnovation of fossil-fuel technologies for intra-and intergenerational energy justice in energy transitions, Appl. Energy. 228 (2018) 339–350.
[34] T. Jia, Y. Dai, R. Wang, Refining energy sources in winemaking industry by using solar energy as alternatives for fossil fuels: A review and perspective, Renew. Sustain. Energy Rev. 88 (2018) 278–296. https://doi.org/https://doi.org/10.1016/j.rser.2018.02.008.
[35] D.G. Kessel, Global warming—facts, assessment, countermeasures, J. Pet. Sci. Eng. 26 (2000) 157–168.
[36] J.J. Zucchetto, Reflections on Howard T. Odum's paper: Energy, Ecology and Economics, Ambio, 1973, Ecol. Modell. 1 (2004) 195–198.
[37] M. Hoseinpour, H. Sadrnia, M. Tabasizadeh, B. Ghobadian, Evaluation of the effect of gasoline fumigation on performance and emission characteristics of a diesel engine fueled with B20 using an experimental investigation and TOPSIS method, Fuel. 223 (2018) 277–285.
[38] I.M. Yusri, R. Mamat, G. Najafi, A. Razman, O.I. Awad, W.H. Azmi, W.F.W. Ishak, A.I.M. Shaiful, Alcohol based automotive fuels from first four alcohol family in compression and spark ignition engine: a review on engine performance and exhaust emissions, Renew. Sustain. Energy Rev. 77 (2017) 169–181.
[39] D.K. Jamuwa, D. Sharma, S.L. Soni, Experimental investigation of performance, exhaust emission and combustion parameters of stationary compression ignition engine using ethanol fumigation in dual fuel mode, Energy Convers. Manag. 115 (2016) 221–231.
[40] M.S.M. Zaharin, N.R. Abdullah, G. Najafi, H. Sharudin, T. Yusaf, Effects of physicochemical properties of biodiesel fuel blends with alcohol on diesel engine performance and exhaust emissions: A review, Renew. Sustain. Energy Rev. 79 (2017) 475–493.
[41] X. Deng, Z. Chen, X. Wang, H. Zhen, R. Xie, Exhaust noise, performance and emission characteristics of spark ignition engine fuelled with pure gasoline and hydrous ethanol gasoline blends, Case Stud. Therm. Eng. 12 (2018) 55–63. https://doi.org/10.1016/j.csite.2018.02.004.
[42] Y. Li, Y. Chen, G. Wu, J. Liu, Experimental evaluation of water-containing isopropanol-n-butanol-ethanol and gasoline blend as a fuel candidate in spark-ignition engine, Appl. Energy. 219 (2018) 42–52. https://doi.org/10.1016/j.apenergy.2018.03.051.
[43] M.A. Ghadikolaei, Effect of alcohol blend and fumigation on regulated and unregulated emissions of IC engines—a review, Renew. Sustain. Energy Rev. 57 (2016) 1440–1495.
[44] X. Liu, H. Wang, Z. Zheng, J. Liu, R.D. Reitz, M. Yao, Development of a combined reduced primary reference fuel-alcohols (methanol/ethanol/propanols/butanols/n-pentanol) mechanism for engine applications, Energy. 114 (2016) 542–558.
[45] P. Iodice, A. Senatore, G. Langella, A. Amoresano, Effect of ethanol–gasoline blends on CO and HC emissions in last generation SI engines within the cold-start transient: An experimental investigation, Appl. Energy. 179 (2016) 182–190.

https://doi.org/10.1016/j.apenergy.2016.06.144.
[46] M. Mourad, K.R.M. Mahmoud, Performance investigation of passenger vehicle fueled by propanol/gasoline blend according to a city driving cycle, Energy. 149 (2018) 741–749.
[47] B. Zhang, S.M. Sarathy, Lifecycle optimized ethanol-gasoline blends for turbocharged engines, Appl. Energy. 181 (2016) 38–53.
[48] İ. Yilmaz, M. Taştan, Investigation of hydrogen addition to methanol-gasoline blends in an SI engine, Int. J. Hydrogen Energy. 43 (2018) 20252–20261.
[49] Y. Chen, J. Ma, B. Han, P. Zhang, H. Hua, H. Chen, X. Su, Emissions of automobiles fueled with alternative fuels based on engine technology: A review, J. Traffic Transp. Eng. (English Ed. (2018).
[50] B. Wu, L. Wang, X. Shen, R. Yan, P. Dong, Comparison of lean burn characteristics of an SI engine fueled with methanol and gasoline under idle condition, Appl. Therm. Eng. 95 (2016) 264–270.
[51] I.M. Yusri, A.P.P. Abdul Majeed, R. Mamat, M.F. Ghazali, O.I. Awad, W.H. Azmi, A review on the application of response surface method and artificial neural network in engine performance and exhaust emissions characteristics in alternative fuel, Renew. Sustain. Energy Rev. 90 (2018) 665–686. https://doi.org/10.1016/j.rser.2018.03.095.
[52] G. Najafi, B. Ghobadian, A. Moosavian, T. Yusaf, R. Mamat, M. Kettner, W.H. Azmi, SVM and ANFIS for prediction of performance and exhaust emissions of a SI engine with gasoline-ethanol blended fuels, Appl. Therm. Eng. 95 (2016) 186–203. https://doi.org/10.1016/j.applthermaleng.2015.11.009.
[53] O.I. Awad, R. Mamat, O.M. Ali, N.A.C.C. Sidik, T. Yusaf, K. Kadirgama, M. Kettner, Alcohol and ether as alternative fuels in spark ignition engine: A review, Renew. Sustain. Energy Rev. 82 (2018) 2586–2605. https://doi.org/https://doi.org/10.1016/j.rser.2017.09.074.
[54] R. Sathiyamoorthi, G. Sankaranarayanan, The effects of using ethanol as additive on the combustion and emissions of a direct injection diesel engine fuelled with neat lemongrass oil-diesel fuel blend, Renew. Energy. 101 (2017) 747–756. https://doi.org/10.1016/j.renene.2016.09.044.
[55] C.W.M. Noor, M.M. Noor, R. Mamat, Biodiesel as alternative fuel for marine diesel engine applications: A review, Renew. Sustain. Energy Rev. 94 (2018) 127–142.
[56] C. Bae, J. Kim, Alternative fuels for internal combustion engines, Proc. Combust. Inst. 36 (2017) 3389–3413. https://doi.org/https://doi.org/10.1016/j.proci.2016.09.009.
[57] E. Jiaqiang, M. Pham, D. Zhao, Y. Deng, D. Le, W. Zuo, H. Zhu, T. Liu, Q. Peng, Z. Zhang, Effect of different technologies on combustion and emissions of the diesel engine fueled with biodiesel: A review, Renew. Sustain. Energy Rev. 80 (2017) 620–647.
[58] S. Nocera, F. Cavallaro, The competitiveness of alternative transport fuels for CO2 emissions, Transp. Policy. 50 (2016) 1–14.
[59] I.M. Gogolev, J.S. Wallace, Performance and emissions of a compression-ignition direct-injected natural gas engine with shielded glow plug ignition assist, Energy Convers. Manag. 164 (2018) 70–82.
[60] W. Du, Q. Zhang, Z. Zhang, J. Lou, W. Bao, Effects of injection pressure on ignition and combustion characteristics of impinging diesel spray, Appl. Energy. 226 (2018) 1163–1168.
[61] C. Liu, F. Li, H. Song, Z. Wang, Effects of H 2/CO addition on knock tendency and lean limit in a natural gas SI engine, Fuel. 233 (2018) 582–591.
[62] G. Li, Z. Liu, T.H. Lee, C.F. Lee, C. Zhang, Effects of dilute gas on combustion and emission characteristics of a common-rail diesel engine fueled with isopropanol-butanol-ethanol and diesel blends, Energy Convers. Manag. 165 (2018) 373–381.
[63] R.K. Mehra, H. Duan, R. Juknelevičius, F. Ma, J. Li, Progress in hydrogen enriched compressed natural gas (HCNG) internal combustion engines - A comprehensive review, Renew. Sustain. Energy Rev. 80 (2017) 1458–1498. https://doi.org/10.1016/j.rser.2017.05.061.
[64] J. Ogden, A.M. Jaffe, D. Scheitrum, Z. McDonald, M. Miller, Natural gas as a bridge to hydrogen transportation fuel: Insights from the literature, Energy Policy. 115 (2018) 317–329.
[65] W. Mazyan, A. Ahmadi, H. Ahmed, M. Hoorfar, Market and technology assessment of natural

gas processing: A review, J. Nat. Gas Sci. Eng. 30 (2016) 487–514.
[66] D.R. Johnson, R. Heltzel, A.C. Nix, N. Clark, M. Darzi, Greenhouse gas emissions and fuel efficiency of in-use high horsepower diesel, dual fuel, and natural gas engines for unconventional well development, Appl. Energy. 206 (2017) 739–750.
[67] V. Korsakas, M. Melaika, S. Pukalskas, P. Stravinskas, Hydrogen addition influence for the efficient and ecological parameters of heavy-duty natural gas si engine, Procedia Eng. 187 (2017) 395–401.
[68] T. Grigoratos, G. Fontaras, G. Martini, C. Peletto, A study of regulated and green house gas emissions from a prototype heavy-duty compressed natural gas engine under transient and real life conditions, Energy. 103 (2016) 340–355.
[69] A. Hegab, A. La Rocca, P. Shayler, Towards keeping diesel fuel supply and demand in balance: Dual-fuelling of diesel engines with natural gas, Renew. Sustain. Energy Rev. 70 (2017) 666–697.
[70] M. Imran Khan, Policy options for the sustainable development of natural gas as transportation fuel, Energy Policy. 110 (2017) 126–136. https://doi.org/https://doi.org/10.1016/j.enpol.2017.08.017.
[71] M.I. Khan, Identifying and addressing barriers for the sustainable development of natural gas as automotive fuel, Int. J. Hydrogen Energy. 42 (2017) 25453–25473.
[72] Q. Wang, C. Yao, Z. Dou, B. Wang, T. Wu, Effect of intake pre-heating and injection timing on combustion and emission characteristics of a methanol fumigated diesel engine at part load, Fuel. 159 (2015) 796–802.
[73] N.N. Ramli, F.M. Epplin, Cost to produce liquid biofuel from invasive eastern redcedar biomass, Biomass and Bioenergy. 104 (2017) 45–52.
[74] A.P. Saravanan, T. Mathimani, G. Deviram, K. Rajendran, A. Pugazhendhi, Biofuel policy in India: a review of policy barriers in sustainable marketing of biofuel, J. Clean. Prod. 193 (2018) 734–747.
[75] P. Dimitriou, T. Tsujimura, A review of hydrogen as a compression ignition engine fuel, Int. J. Hydrogen Energy. 42 (2017) 24470–24486.
[76] Z. Şahin, İ.Z. Akcanca, O. Durgun, Experimental investigation of the effects of ammonia solution (NH 3 OH) on engine performance and exhaust emissions of a small diesel engine, Fuel. 214 (2018) 330–341.
[77] J.L. Trumbo, B.E. Tonn, Biofuels: A sustainable choice for the United States' energy future?, Technol. Forecast. Soc. Change. 104 (2016) 147–161.
[78] D.F. Dominković, I. Bačeković, A.S. Pedersen, G. Krajačić, The future of transportation in sustainable energy systems: Opportunities and barriers in a clean energy transition, Renew. Sustain. Energy Rev. (2017).
[79] H.A. Baloch, S. Nizamuddin, M.T.H. Siddiqui, S. Riaz, A.S. Jatoi, D.K. Dumbre, N.M. Mubarak, M.P. Srinivasan, G.J. Griffin, Recent advances in production and upgrading of bio-oil from biomass: a critical overview, J. Environ. Chem. Eng. (2018).
[80] P.D. Patel, A. Lakdawala, S. Chourasia, R.N. Patel, Bio fuels for compression ignition engine: A review on engine performance, emission and life cycle analysis, Renew. Sustain. Energy Rev. 65 (2016) 24–43.
[81] S.K. Thangavelu, A.S. Ahmed, F.N. Ani, Review on bioethanol as alternative fuel for spark ignition engines, Renew. Sustain. Energy Rev. 56 (2016) 820–835. https://doi.org/10.1016/j.rser.2015.11.089.
[82] S.Z. Abbas, A. Kousar, S. Razzaq, A. Saeed, M. Alam, A. Mahmood, Energy management in South Asia, Energy Strateg. Rev. 21 (2018) 25–34. https://doi.org/https://doi.org/10.1016/j.esr.2018.04.004.
[83] I. Schifter, U. González, L. Díaz, G. Sánchez-Reyna, I. Mejía-Centeno, C. González-Macías, Comparison of performance and emissions for gasoline-oxygenated blends up to 20 percent oxygen and implications for combustion on a spark-ignited engine, Fuel. 208 (2017) 673–681. https://doi.org/10.1016/j.fuel.2017.07.065.
[84] H. Yerrennagoudaru, K. Manjunatha, A. Raza, B.R. Kantharaj, A. Mujahed, K. Irshad, Analysis

and comparison of performance and emissions of compression ignition engine fuelled with diesel and different bio-fuels blended with Methanol, Mater. Today Proc. 5 (2018) 5175–5185. https://doi.org/https://doi.org/10.1016/j.matpr.2017.12.099.

[85] J. Benajes, A. García, J. Monsalve-Serrano, R.L. Sari, Fuel consumption and engine-out emissions estimations of a light-duty engine running in dual-mode RCCI/CDC with different fuels and driving cycles, Energy. 157 (2018) 19–30.

[86] D. Ramasamy, C.Y. Goh, K. Kadirgama, F. Benedict, M.M. Noor, G. Najafi, A.P. Carlucci, Engine performance, exhaust emission and combustion analysis of a 4-stroke spark ignited engine using dual fuel injection, Fuel. 207 (2017) 719–728.

[87] P.X. Pham, D.Q. Vo, R.N. Jazar, Development of fuel metering techniques for spark ignition engines, Fuel. 206 (2017) 701–715.

[88] E.J. Barrientos, J.E. Anderson, M.M. Maricq, A.L. Boehman, Particulate matter indices using fuel smoke point for vehicle emissions with gasoline, ethanol blends, and butanol blends, Combust. Flame. 167 (2016) 308–319.

[89] K. Liu, Y. Li, J. Yang, B. Deng, R. Feng, Y. Huang, Comprehensive study of key operating parameters on combustion characteristics of butanol-gasoline blends in a high speed SI engine, Appl. Energy. 212 (2018) 13–32. https://doi.org/https://doi.org/10.1016/j.apenergy.2017.12.011.

[90] S. Polat, An experimental study on combustion, engine performance and exhaust emissions in a HCCI engine fuelled with diethyl ether–ethanol fuel blends, Fuel Process. Technol. 143 (2016) 140–150.

[91] I.M. Yusri, R. Mamat, W.H. Azmi, G. Najafi, N.A.C. Sidik, O.I. Awad, Experimental investigation of combustion, emissions and thermal balance of secondary butyl alcohol-gasoline blends in a spark ignition engine, Energy Convers. Manag. 123 (2016) 1–14. https://doi.org/10.1016/j.enconman.2016.05.082.

[92] G. Gonca, Influences of different fuel kinds and engine design parameters on the performance characteristics and NO formation of a spark ignition (SI) engine, Appl. Therm. Eng. 127 (2017) 194–202. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2017.08.002.

[93] S. Szwaja, E. Ansari, S. Rao, M. Szwaja, K. Grab-Rogalinski, J.D. Naber, M. Pyrc, Influence of exhaust residuals on combustion phases, exhaust toxic emission and fuel consumption from a natural gas fueled spark-ignition engine, Energy Convers. Manag. 165 (2018) 440–446. https://doi.org/https://doi.org/10.1016/j.enconman.2018.03.075.

[94] M.S. Boulahlib, F. Medaerts, M.A. Boukhalfa, Experimental study of combustion performances and emissions of a spark ignition cogeneration engine operating in lean conditions using different fuels, Int. J. Hydrogen Energy. 43 (2018) 3586–3596. https://doi.org/https://doi.org/10.1016/j.ijhydene.2017.10.041.

[95] I.M.M. Elsemary, A.A.A. Attia, K.H. Elnagar, M.S. Elsaleh, Spark timing effect on performance of gasoline engine fueled with mixture of hydrogen–gasoline, Int. J. Hydrogen Energy. 42 (2017) 30813–30820. https://doi.org/https://doi.org/10.1016/j.ijhydene.2017.10.125.

[96] H. Feng, W. Zhang, J. Zhang, X. Wang, X. Zhang, Availability analysis of a coke oven gas fueled spark ignition engine, Int. J. Hydrogen Energy. 43 (2018) 1835–1845. https://doi.org/https://doi.org/10.1016/j.ijhydene.2017.11.125.

[97] T. Su, C. Ji, S. Wang, L. Shi, J. Yang, X. Cong, Effect of spark timing on performance of a hydrogen-gasoline rotary engine, Energy Convers. Manag. 148 (2017) 120–127. https://doi.org/https://doi.org/10.1016/j.enconman.2017.05.064.

[98] S. Moon, Potential of direct-injection for the improvement of homogeneous-charge combustion in spark-ignition natural gas engines, Appl. Therm. Eng. 136 (2018) 41–48. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2018.01.068.

[99] Z. Wang, Z. Zhao, D. Wang, M. Tan, Y. Han, Z. Liu, H. Dou, Impact of pilot diesel ignition mode on combustion and emissions characteristics of a diesel/natural gas dual fuel heavy-duty engine, Fuel. 167 (2016) 248–256. https://doi.org/https://doi.org/10.1016/j.fuel.2015.11.077.

[100] L. Wei, C.S. Cheung, Z. Huang, Effect of n-pentanol addition on the combustion, performance and emission characteristics of a direct-injection diesel engine, Energy. 70 (2014) 172–180.

https://doi.org/https://doi.org/10.1016/j.energy.2014.03.106.
[101] P. Verma, M.P. Sharma, Review of process parameters for biodiesel production from different feedstocks, Renew. Sustain. Energy Rev. 62 (2016) 1063–1071. https://doi.org/https://doi.org/10.1016/j.rser.2016.04.054.
[102] Z. Amini, Z. Ilham, H.C. Ong, H. Mazaheri, W.-H. Chen, State of the art and prospective of lipase-catalyzed transesterification reaction for biodiesel production, Energy Convers. Manag. 141 (2017) 339–353. https://doi.org/https://doi.org/10.1016/j.enconman.2016.09.049.
[103] A. Arumugam, V. Ponnusami, Biodiesel production from Calophyllum inophyllum oil a potential non-edible feedstock: An overview, Renew. Energy. 131 (2019) 459–471. https://doi.org/https://doi.org/10.1016/j.renene.2018.07.059.
[104] P. Adewale, M.-J. Dumont, M. Ngadi, Recent trends of biodiesel production from animal fat wastes and associated production techniques, Renew. Sustain. Energy Rev. 45 (2015) 574–588. https://doi.org/https://doi.org/10.1016/j.rser.2015.02.039.
[105] J. Chen, J. Li, W. Dong, X. Zhang, R.D. Tyagi, P. Drogui, R.Y. Surampalli, The potential of microalgae in biodiesel production, Renew. Sustain. Energy Rev. 90 (2018) 336–346. https://doi.org/https://doi.org/10.1016/j.rser.2018.03.073.
[106] S.C. da Silva Filho, A.C. Miranda, T.A.F. Silva, F.A. Calarge, R.R. de Souza, J.C.C. Santana, E.B. Tambourgi, Environmental and techno-economic considerations on biodiesel production from waste frying oil in São Paulo city, J. Clean. Prod. 183 (2018) 1034–1042. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.02.199.
[107] B. Sajjadi, A.A.A. Raman, H. Arandiyan, A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models, Renew. Sustain. Energy Rev. 63 (2016) 62–92. https://doi.org/10.1016/j.rser.2016.05.035.
[108] V.B. Veljković, M.O. Biberdžić, I.B. Banković-Ilić, I.G. Djalović, M.B. Tasić, Z.B. Nježić, O.S. Stamenković, Biodiesel production from corn oil: A review, Renew. Sustain. Energy Rev. 91 (2018) 531–548. https://doi.org/https://doi.org/10.1016/j.rser.2018.04.024.
[109] Y. Wang, H. Liu, C.-F.F. Lee, Particulate matter emission characteristics of diesel engines with biodiesel or biodiesel blending: A review, Renew. Sustain. Energy Rev. 64 (2016) 569–581. https://doi.org/https://doi.org/10.1016/j.rser.2016.06.062.
[110] M.F. Othman, A. Adam, G. Najafi, R. Mamat, Green fuel as alternative fuel for diesel engine: A review, Renew. Sustain. Energy Rev. 80 (2017) 694–709. https://doi.org/10.1016/j.rser.2017.05.140.
[111] M.N.A.M. Yusoff, N.W.M. Zulkifli, H.H. Masjuki, M.H. Harith, A.Z. Syahir, M.A. Kalam, M.F. Mansor, A. Azham, L.S. Khuong, Performance and emission characteristics of a spark ignition engine fuelled with butanol isomer-gasoline blends, Transp. Res. Part D Transp. Environ. 57 (2017) 23–38. https://doi.org/10.1016/j.trd.2017.09.004.
[112] B. Yang, M. Yao, W.K. Cheng, Y. Li, Z. Zheng, S. Li, Experimental and numerical study on different dual-fuel combustion modes fuelled with gasoline and diesel, Appl. Energy. 113 (2014) 722–733. https://doi.org/https://doi.org/10.1016/j.apenergy.2013.07.034.
[113] N.N. Mustafi, R.R. Raine, S. Verhelst, Combustion and emissions characteristics of a dual fuel engine operated on alternative gaseous fuels, Fuel. 109 (2013) 669–678. https://doi.org/https://doi.org/10.1016/j.fuel.2013.03.007.
[114] F.Z. Aklouche, K. Loubar, A. Bentebbiche, S. Awad, M. Tazerout, Predictive model of the diesel engine operating in dual-fuel mode fuelled with different gaseous fuels, Fuel. 220 (2018) 599–606. https://doi.org/https://doi.org/10.1016/j.fuel.2018.02.053.
[115] Y. Li, L. Meng, K. Nithyanandan, T.H. Lee, Y. Lin, C. fon F. Lee, S. Liao, Combustion, performance and emissions characteristics of a spark-ignition engine fueled with isopropanol-n-butanol-ethanol and gasoline blends, Fuel. 184 (2016) 864–872. https://doi.org/10.1016/j.fuel.2016.07.063.
[116] P. Verma, M.P. Sharma, G. Dwivedi, Impact of alcohol on biodiesel production and properties, Renew. Sustain. Energy Rev. 56 (2016) 319–333. https://doi.org/https://doi.org/10.1016/j.rser.2015.11.048.
[117] M.A. Akar, Performance and emission characteristics of compression ignition engine operating

with false flax biodiesel and butanol blends, Adv. Mech. Eng. 8 (2016) 1–7. https://doi.org/10.1177/1687814016632677.
[118] P.N.E.A. Agency, Trends in global carbon dioxide emissions 2013 report, 2013. https://doi.org/10.1016/j.jvir.2009.04.003.
[119] C. Yao, W. Pan, A. Yao, Methanol fumigation in compression-ignition engines: A critical review of recent academic and technological developments, Fuel. 209 (2017) 713–732. https://doi.org/https://doi.org/10.1016/j.fuel.2017.08.038.
[120] A. Turkcan, M.D. Altinkurt, G. Coskun, M. Canakci, Numerical and experimental investigations of the effects of the second injection timing and alcohol-gasoline fuel blends on combustion and emissions of an HCCI-DI engine, Fuel. 219 (2018) 50–61. https://doi.org/https://doi.org/10.1016/j.fuel.2018.01.061.
[121] X. Yu, Z. Guo, L. He, W. Dong, P. Sun, W. Shi, Y. Du, F. He, Effect of gasoline/n-butanol blends on gaseous and particle emissions from an SI direct injection engine, Fuel. 229 (2018) 1–10. https://doi.org/https://doi.org/10.1016/j.fuel.2018.05.003.
[122] S. Verma, B. Sharma, J. Ahmad, G. Dwivedi, G. Nandan, Impact assessment of Ethanol as Fuel for Engine operation, Mater. Today Proc. 5 (2018) 6115–6120. https://doi.org/https://doi.org/10.1016/j.matpr.2017.12.217.
[123] M.N.A.M. Yusoff, N.W.M. Zulkifli, H.H. Masjuki, M.H. Harith, A.Z. Syahir, L.S. Khuong, M.S.M. Zaharin, A. Alabdulkarem, Comparative assessment of ethanol and isobutanol addition in gasoline on engine performance and exhaust emissions, J. Clean. Prod. 190 (2018) 483–495. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.04.183.
[124] A. Jamrozik, W. Tutak, M. Pyrc, M. Gruca, M. Kočiško, Study on co-combustion of diesel fuel with oxygenated alcohols in a compression ignition dual-fuel engine, Fuel. 221 (2018) 329–345. https://doi.org/https://doi.org/10.1016/j.fuel.2018.02.098.
[125] M.R. Saxena, R.K. Maurya, Effect of premixing ratio, injection timing and compression ratio on nano particle emissions from dual fuel non-road compression ignition engine fueled with gasoline/methanol (port injection) and diesel (direct injection), Fuel. 203 (2017) 894–914.
[126] Z. Zheng, M. Xia, H. Liu, X. Wang, M. Yao, Experimental study on combustion and emissions of dual fuel RCCI mode fueled with biodiesel/n-butanol, biodiesel/2, 5-dimethylfuran and biodiesel/ethanol, Energy. 148 (2018) 824–838.
[127] X. Wang, H. Liu, Z. Zheng, M. Yao, Development of a reduced n-butanol/biodiesel mechanism for a dual fuel engine, Fuel. 157 (2015) 87–96.
[128] A. Thiruvengadam, M. Besch, V. Padmanaban, S. Pradhan, B. Demirgok, Natural gas vehicles in heavy-duty transportation-A review ☆, Energy Policy. 122 (2018) 253–259. https://doi.org/10.1016/j.enpol.2018.07.052.
[129] V.B. Pedrozo, I. May, W. Guan, H. Zhao, High efficiency ethanol-diesel dual-fuel combustion: A comparison against conventional diesel combustion from low to full engine load, Fuel. 230 (2018) 440–451. https://doi.org/https://doi.org/10.1016/j.fuel.2018.05.034.
[130] D. Feng, H. Wei, M. Pan, L. Zhou, J. Hua, Combustion performance of dual-injection using n-butanol direct-injection and gasoline port fuel-injection in a SI engine, Energy. 160 (2018) 573–581.
[131] J. Pan, N. Li, H. Wei, J. Hua, G. Shu, Experimental investigations on combustion acceleration behavior of methane/gasoline under partial load conditions of SI engines, Appl. Therm. Eng. 139 (2018) 432–444.
[132] H. Song, C. Liu, Y. Li, Z. Wang, L. Chen, X. He, J. Wang, An exploration of utilizing low-pressure diesel injection for natural gas dual-fuel low-temperature combustion, Energy. 153 (2018) 248–255.
[133] B. Yang, C. Xi, X. Wei, K. Zeng, M.-C. Lai, Parametric investigation of natural gas port injection and diesel pilot injection on the combustion and emissions of a turbocharged common rail dual-fuel engine at low load, Appl. Energy. 143 (2015) 130–137.
[134] T. Sarjovaara, M. Larmi, Dual fuel diesel combustion with an E85 ethanol/gasoline blend, Fuel. 139 (2015) 704–714.

[135] M.S. Kumar, G. Nataraj, S.A. Selvan, A comprehensive assessment on the effect of high octane fuels induction on engine's combustion behaviour of a Mahua oil based dual fuel engine, Fuel. 199 (2017) 176–184.
[136] H. Liu, Z. Wang, Y. Long, S. Xiang, J. Wang, S.W. Wagnon, Methanol-gasoline Dual-fuel Spark Ignition (DFSI) combustion with dual-injection for engine particle number (PN) reduction and fuel economy improvement, Energy. 89 (2015) 1010–1017.
[137] H. Liu, Z. Wang, Y. Long, S. Xiang, J. Wang, M. Fatouraie, Comparative study on alcohol–gasoline and gasoline–alcohol Dual-Fuel Spark Ignition (DFSI) combustion for engine particle number (PN) reduction, Fuel. 159 (2015) 250–258.
[138] B.R. Kumar, S. Saravanan, D. Rana, V. Anish, A. Nagendran, Effect of a sustainable biofuel–n-octanol–on the combustion, performance and emissions of a DI diesel engine under naturally aspirated and exhaust gas recirculation (EGR) modes, Energy Convers. Manag. 118 (2016) 275–286.
[139] A. Elfasakhany, Engine performance evaluation and pollutant emissions analysis using ternary bio-ethanol–iso-butanol–gasoline blends in gasoline engines, J. Clean. Prod. 139 (2016) 1057–1067.
[140] B.M. Masum, H.H. Masjuki, M.A. Kalam, S.M. Palash, M. Habibullah, Effect of alcohol–gasoline blends optimization on fuel properties, performance and emissions of a SI engine, J. Clean. Prod. 86 (2015) 230–237. https://doi.org/10.1016/j.jclepro.2014.08.032.
[141] A. Imran, M. Varman, H.H. Masjuki, M.A. Kalam, Review on alcohol fumigation on diesel engine: A viable alternative dual fuel technology for satisfactory engine performance and reduction of environment concerning emission, Renew. Sustain. Energy Rev. 26 (2013) 739–751. https://doi.org/10.1016/j.rser.2013.05.070.
[142] V. Thangavel, S.Y. Momula, D.B. Gosala, R. Asvathanarayanan, Experimental studies on simultaneous injection of ethanol–gasoline and n-butanol–gasoline in the intake port of a four stroke SI engine, Renew. Energy. 91 (2016) 347–360.
[143] M.İ. İlhak, S.O. Akansu, N. Kahraman, S. Ünalan, Experimental study on an SI engine fuelled by gasoline/acetylene mixtures, Energy. 151 (2018) 707–714.
[144] R. Amirante, E. Distaso, S. Di Iorio, P. Sementa, P. Tamburrano, B.M. Vaglieco, R.D. Reitz, Effects of natural gas composition on performance and regulated, greenhouse gas and particulate emissions in spark-ignition engines, Energy Convers. Manag. 143 (2017) 338–347.
[145] W.C. Nadaleti, G. Przybyla, Emissions and performance of a spark-ignition gas engine generator operating with hydrogen-rich syngas, methane and biogas blends for application in southern Brazilian rice industries, Energy. 154 (2018) 38–51.
[146] X.H. Yan, P. Gao, G. Zhao, L. Shi, J.B. Xu, T.S. Zhao, Transport of highly concentrated fuel in direct methanol fuel cells, Appl. Therm. Eng. 126 (2017) 290–295.
[147] A. Elfasakhany, A.-F. Mahrous, Performance and emissions assessment of n-butanol–methanol–gasoline blends as a fuel in spark-ignition engines, Alexandria Eng. J. 55 (2016) 3015–3024.
[148] Y. Li, J. Gong, Y. Deng, W. Yuan, J. Fu, B. Zhang, Experimental comparative study on combustion, performance and emissions characteristics of methanol, ethanol and butanol in a spark ignition engine, Appl. Therm. Eng. 115 (2017) 53–63. https://doi.org/10.1016/j.applthermaleng.2016.12.037.
[149] H. Feng, D. Liu, X. Yang, M. An, W. Zhang, X. Zhang, Availability analysis of using iso-octane/n-butanol blends in spark-ignition engines, Renew. Energy. 96 (2016) 281–294.
[150] V.M. Raj, L.R.G. Subramanian, S. Thiyagarajan, V.E. Geo, Effects of minor addition of aliphatic (1-pentanol) and aromatic (benzyl alcohol) alcohols in Simarouba Glauca-diesel blend fuelled CI engine, Fuel. 234 (2018) 934–943.
[151] Y. Li, Y. Chen, G. Wu, C.F. Lee, J. Liu, Experimental comparison of acetone-n-butanol-ethanol (ABE) and isopropanol-n-butanol-ethanol (IBE) as fuel candidate in spark-ignition engine, Appl. Therm. Eng. (2018). https://doi.org/10.1016/j.applthermaleng.2017.12.132.
[152] A.O. Hasan, H. Al-Rawashdeh, A.H. Al-Muhtaseb, A. Abu-jrai, R. Ahmad, J. Zeaiter, Impact of changing combustion chamber geometry on emissions, and combustion characteristics of a single cylinder SI (spark ignition) engine fueled with ethanol/gasoline blends, Fuel. 231 (2018)

197–203. https://doi.org/https://doi.org/10.1016/j.fuel.2018.05.045.
[153] H.R. Fajri, M.J. Jafari, A.H. Shamekhi, S.A. Jazayeri, A numerical investigation of the effects of combustion parameters on the performance of a compression ignition engine toward NOx emission reduction, J. Clean. Prod. 167 (2017) 140–153.
[154] S. Pischinger, M. Günther, O. Budak, Abnormal combustion phenomena with different fuels in a spark ignition engine with direct fuel injection, Combust. Flame. 175 (2017) 123–137.
[155] Z. Wang, H. Liu, Y. Long, J. Wang, X. He, Comparative study on alcohols–gasoline and gasoline–alcohols dual-fuel spark ignition (DFSI) combustion for high load extension and high fuel efficiency, Energy. 82 (2015) 395–405. https://doi.org/10.1016/j.energy.2015.01.049.
[156] L. Tarabet, M.S. Lounici, K. Loubar, K. Khiari, R. Bouguessa, M. Tazerout, Hydrogen supplemented natural gas effect on a DI diesel engine operating under dual fuel mode with a biodiesel pilot fuel, Int. J. Hydrogen Energy. 43 (2018) 5961–5971.
[157] N.Y. Dudareva, R.D. Enikeev, V.Y. Ivanov, Thermal Protection of Internal Combustion Engines Pistons, Procedia Eng. 206 (2017) 1382–1387.
[158] M. Feidt, Finite Physical Dimensions Optimal Thermodynamics 1: Fundamentals, Elsevier, 2017.
[159] S. Dharma, H.C. Ong, H.H. Masjuki, A.H. Sebayang, A.S. Silitonga, An overview of engine durability and compatibility using biodiesel–bioethanol–diesel blends in compression-ignition engines, Energy Convers. Manag. 128 (2016) 66–81.
[160] H. Yerrennagoudaru, K. Manjunatha, K.R.V. Kumar, M.D. Basavanagouda, Investigation and assessment of performance and emissions of an IC engine fuelled with diesel and different bio-fuels blended with Ethanol, Mater. Today Proc. 5 (2018) 6238–6246.
[161] M. Canakci, A.N. Ozsezen, E. Alptekin, M. Eyidogan, Impact of alcohol–gasoline fuel blends on the exhaust emission of an SI engine, Renew. Energy. 52 (2013) 111–117. https://doi.org/10.1016/j.renene.2012.09.062.
[162] R. Suarez-Bertoa, A.A. Zardini, H. Keuken, C. Astorga, Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the Worldwide Harmonized Light duty Test Cycle (WLTC), Fuel. 143 (2015) 173–182. https://doi.org/https://doi.org/10.1016/j.fuel.2014.10.076.
[163] P. Chansauria, R.K. Mandloi, Effects of Ethanol Blends on Performance of Spark Ignition Engine-A Review, Mater. Today Proc. 5 (2018) 4066–4077. https://doi.org/https://doi.org/10.1016/j.matpr.2017.11.668.