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Chapter

Alternative Fuels for Internal Combustion Engines

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Abstract

Researchers have studied on alternative fuels that can be used with gasoline and diesel fuels. Alternative fuels such as hydrogen, acetylene, natural gas, ethanol and biofuels also uses in internal combustion engines. Hydrogen in the gas phase is about 14 times lighter than the air. Moreover, it is the cleanest fuel in the world. On the other hand because of its high ignition limit (4–75%), low ignition energy, needs special design to use as pure hydrogen in internal combustion engines. It is proved that hydrogen improves the combustion, emissions and performance, when is added as 20% to fuels. Natural gas is generally consisting of methane (85–96%) and it can be used in both petrol and diesel engines. Ethanol can be used as pure fuel or mixed with different fuels in internal combustion engines. In this section, the effects of natural gas, hydrogen, natural gas + hydrogen (HCNG), ethanol, ethanol + gasoline, ethanol + hydrogen, acetylene, acetylene + gasoline mixtures on engine performance and emissions have been examined.

Keywords: internal combustion engines, hydrogen, acetylene, natural gas, ethanol

1. Introduction

Oil is the undisputed largest source of energy for internal combustion engines (ICE). However, rapid depletion of the oil due to the increasing number of vehicles, the pollutant emissions within its combustion products that threaten the ecological system and the concerns about the security of supply due to the oil reserves unevenly distributed over the globe, of which about 50% is located in the Middle East, encourages the exploration of fuel sources that are more environmentally friendly and have widespread reserves in the world [1].

Gasoline and diesel fuels that are produced from crude oil can also be produced synthetically from CO and H_2 gases with the method found by the German chemists Franz Fischer and Hans Tropsch in 1923. Fischer-Tropsch synthesis, a patented method since 1926, provides obtaining synthetic liquid fuel from many different kinds of carbon and hydrogen-derived raw materials. Generally, coal, natural gas and methane are used to obtain large amounts of CO and H_2 gases that are necessary for synthesis reactions. Today, Germany, India, China and South Africa that have major coal reserves produce commercially synthetic fuels with Fischer-Tropsch synthesis [2–4]. However, because the compositions of the synthetic gasoline and diesel fuels are similar to the natural

gasoline and diesel fuels, their effects on the pollutant emissions resulting from vehicles are also similar.

In this chapter, for the purpose of reducing pollutant emissions resulting from internal combustion engines, the characteristics of hydrogen, natural gas, acetylene and ethanol, which are alternative fuels and can be used without requiring a structural change in SI and CI engines, and their effects on engine performance and exhaust emissions are mentioned. The physical and chemical characteristics

Properties	Acetylene	Hydrogen	CNG	Ethanol	Gasoline	Diesel
Formula	C_2H_2	H_2	CH_4	C_2H_5OH	C_4–C_{12}	C_8–C_{20}
Density (1 atm, 20°C (kg/m^3))	1.092	0.08	0.65	809.9	720–780	820–860
Auto ignition temperature (°C)	305	572	540	363	257	254
Stoichiometric ratio (kg/kg)	13.2	34.3	17.2	9	14.7	14.5
Motor octane number	45–50	130	105	89.7	95–97	–
Flammability limits in air (%Vol.)	2.5–81	4–74.5	5.3–15	3–19	1.4–7.6	0.6–5.5
Adiabatic flame temperature (K)	2500	2400	2320	2193	2300	2200
Min. quenching diameter (mm)	0.85	0.9	3.53	2.97	2.97	–
Min. ignition energy (MJ)	0.019	0.02	0.29	0.23	0.23	–
Maximum flame speed (m/s)	1.5	3.5	0.42	0.61	0.5	0.3
Lower heating value (kJ/kg)	48.225	120.000	49.990	26.700	43.000	42.500

Table 1.
Physical and combustion properties of fuels [146–153].

Fuels	Resource	Expended energy [MJ/MJ fuel]	Greenhouse emissions [g CO_2/MJ]
Gasoline	Crude oil	0.18	13.8
Diesel	Crude oil	0.20	15.4
Natural gas	EU-mix NG	0.17	13.0
	Imported NG 7000 km	0.29	22.6
	Imported NG 4000 km	0.21	16.1
	LNG*	0.28	19.9
	Shale gas	0.10	7.8
	Synthetic from wind electricity	1.05	3.3
Ethanol	Sugar*	1.20	28.4
	Wheat*	1.31	55.6
	Other*	1.66	41.4
Hydrogen	Natural Gas*	1.10	118
	Coal*	1.45	237
	Biomass*	1.05	14.6
	Electricity*	3.11	190

**Average value.*

Table 2.
Energy and greenhouse gas balance in WTT analyses for EU (2010–2020+) [154].

of gasoline, diesel fuel and alternative fuels that are mentioned in this chapter are shown in **Table 1**.

Fuels used in ICE are generally produced from primary resources. To convert a source to a fuel and bring this fuel to a vehicle, well to tank (WTT) analyzes are made in terms of energy consumption and greenhouse gas emissions. The energy and greenhouse gas balances obtained from WTT analyses based 2010–2020+ years for the alternative fuels in EU are shown in **Table 2**. When **Table 2** is investigated according to fuel types, the maximum energy is consumed for the production of hydrogen gas and the minimum energy is expended for gasoline fuel. On the other hand when **Table 2** has been compared in terms of resources, the highest energy consumption is obtained as 3.11 MJ/MJ by the using of electrolysis in hydrogen production, while the lowest energy consumption occurs as 0.1 MJ/MJ in the producing of shall gas removed from EU geography. It is seen from **Table 2** that the highest CO_2 value is produced in the obtaining of hydrogen gas and the least emission value is emitted for gasoline fuel. In terms of resources, while the highest greenhouse emissions value is obtained as 237 g CO_2/MJ in hydrogen production from coal, the lowest greenhouse gas produce is 3.3 g CO_2/MJ in the producing of synthetic natural gas from wind electricity.

2. Acetylene

Acetylene was used as fuel in internal combustion engines in the early 1900s. Gustave Whitehead used a 15 kW engine powered by acetylene on his flying machine in 1901. Towards the year 1940s, acetylene began to be used in automobiles. In those years, about 4000 licenses for the conversion of vehicles to alternate fuels had been issued, and more than half of them were for conversion to acetylene [5]. Nowadays acetylene is only used in metal and chemical industries and it is not used in vehicles. Nevertheless, experimental studies on the use of acetylene in ICE have gained momentum in recent years due to high flame speed and energy density.

Acetylene was first discovered by Edmund Davy in 1836. But thereafter it was forgotten. Marcellin Berthelot rediscovered this hydrocarbon compound in 1860. He coined the name "acetylene" to this compound [6].

Acetylene, the first member of the alkynes (C_nH_{2n-2}), is a colorless and odorless gas but with an odor similar to garlic if produced from calcium carbide. Acetylene gas does not occur in quantities in nature but it is commonly obtained from the reaction of calcium carbide with water [7]. Calcium carbide (CaC_2) is produced by heating the mixture of quicklime and coke in electric arc furnaces to 2000–2100°C. Quicklime (CaO) is produced by heating calcium carbonate ($CaCO_3$) about at 900°C. **Figure 1** shows a schematic representation of an integrated facility for the production of calcium carbide [8]. Moreover, the processes are seen in Eqs. (1) and (2) [8–10].

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2 \quad (1)$$

$$CaO + 3C \rightarrow CaC_2 + CO \quad (2)$$

Acetylene has higher flame speed and energy density than gasoline and diesel [11] hence acetylene engines could more approach thermodynamically ideal engine cycle efficiency. But the octane number of acetylene is lower than other fuels which use in internal combustion engines [12]. Therefore the maximum amount of acetylene consumption is limited to the onset of knock. Lower ignition energy,

high flame speed, wide flammability limits and lower octane number leads to premature ignition and undesirable combustion phenomenon called knock [13, 14]. These are the main problems encountered in using acetylene as a fuel in internal combustion engines.

In SI engines, acetylene and gasoline are either injected into the intake manifold or directly into the cylinder and the mixture is ignited by spark plug at the end of the compression stroke. In diesel engines, acetylene is either inducted along

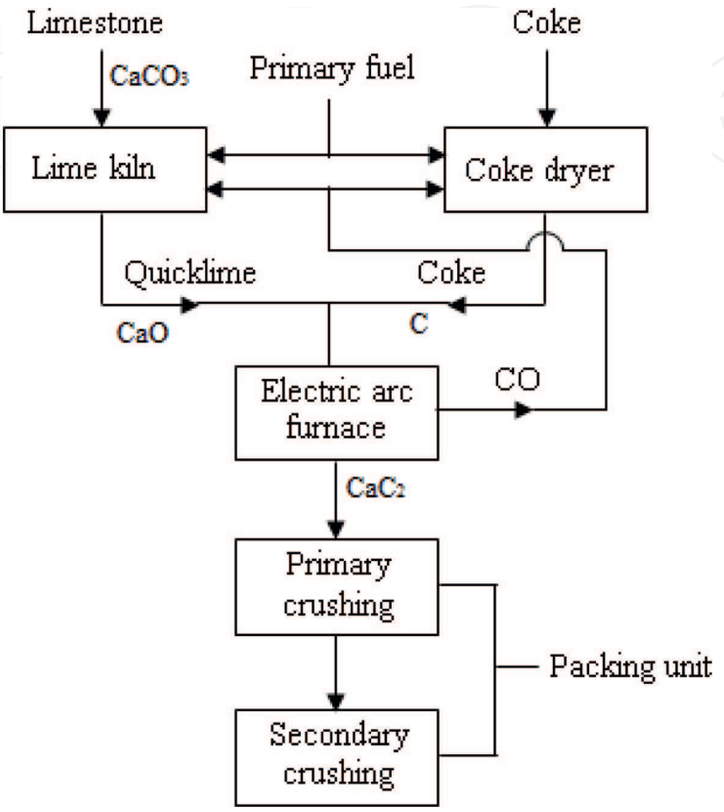


Figure 1.
Integrated calcium carbide production facility [8].

Load (%)	Gasoline (g/h)	Acetylene (g/h)	Acetylene (%)	Peak Pressure (bar)	Spark Advance (CA BTDC)
25	1877 1320 840	0 500 1000	0 27.5 54.3	16.6 16.5 15.6	21 13 2
50	2805 2145 1800	0 500 1000	0 18.9 35.7	25.4 26.5 20.9	18 11 1
75	3730 3250 2750	0 500 1000	0 13.3 26.7	31.5 24.6 23.8	15 3 0
100	4265 3890 3390	0 500 1000	0 11.6 22.8	40.6 30.9 29.0	11 1 -2*

**2 CA After Top Dead Center*

Table 3.
Mass flows of fuels, peak pressure and spark advance [18].

with intake air or injected directly into the cylinder and compressed. However, the mixture of acetylene-air does not auto-ignite due to its very high self-ignition temperature. A small amount of diesel fuel called pilot fuel is injected into the mixture towards the end of the compression stroke. The pilot diesel fuel auto-ignites first and ignites the acetylene-air mixture such as spark plug. So, dual fuel diesel engines combine the features of both SI and CI engines [15–17].

The main advantages of using acetylene as gasoline-acetylene mixtures in SI engines [5, 18–21]:

- Acetylene-gasoline mixtures can be used in SI engines at every load from low load to full load. However, it can be also used as a single fuel at partial loads.

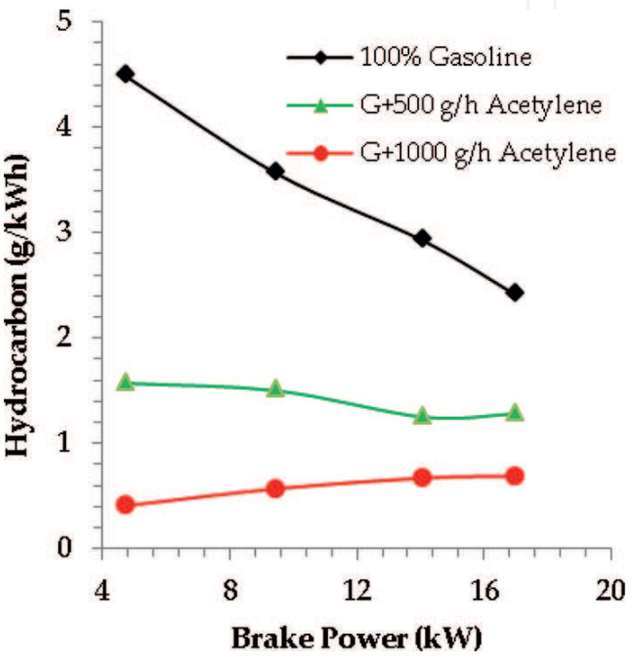


Figure 2.
Variety of HC with brake power (1500 rpm, different loads) [18].

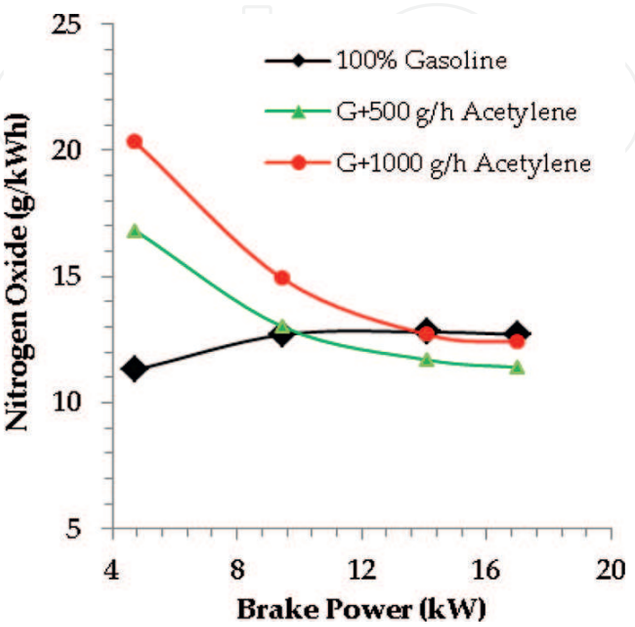


Figure 3.
Variety of NO with brake power (1500 rpm, different loads) [18].

- If acetylene is mixed with gasoline under stoichiometric conditions, it causes a decrease in gasoline consumption at constant output power as seen in **Table 3**. At the same time, as can be seen **Figure 2**, hydrocarbon emissions were significantly reduced at all loads and as can be seen **Figure 3**, NO emissions were reduced at full loads according to working with gasoline [18]. Experimental studies [18] were realized at 1500 rpm and stoichiometric ratio under 25, 50, 75% and full load conditions. The acetylene was injected into the intake manifold of test engine through the gas injector 500 and 1000 g/h gas flow rates.

- Acetylene increases the poor combustion limit in partial loads in SI engines. The engine can be operated in leaner conditions with gasoline-acetylene mixtures. As seen in **Figures 4** and **5** the brake thermal efficiency of the engine increases and the specific fuel consumption decreases. Further, at high equivalence ratios, the fairly reduced exhaust emissions are observed. NO emissions are almost non-existent as in-cylinder temperatures decrease in lean fuel-air

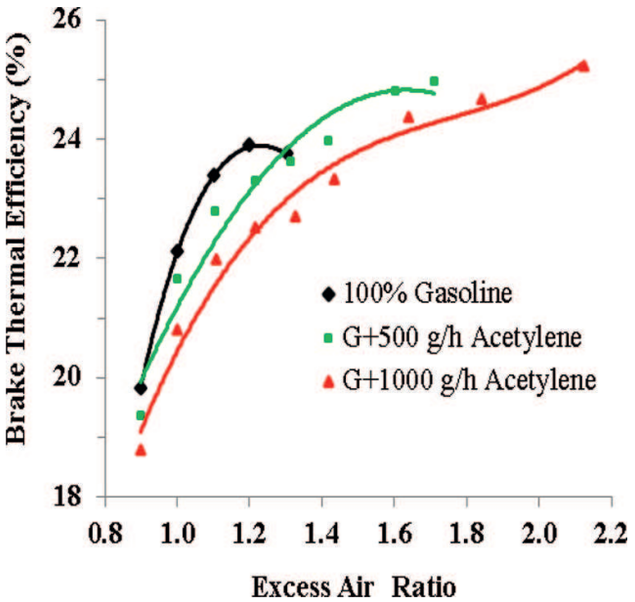


Figure 4.
The variation of BTE with excess air ratio (1500 rpm, 25% load) [19].

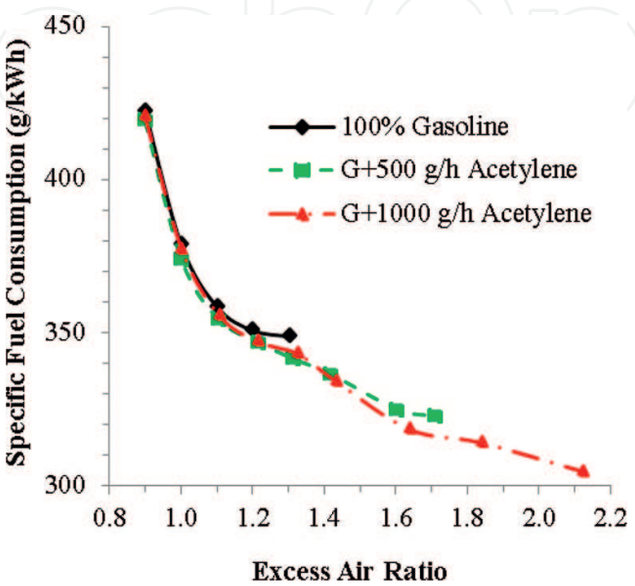


Figure 5.
The variation of BSFC with excess air ratio (1500 rpm, 25% load) [19].

mixtures and unburned hydrocarbon emissions are quite reduced when compared gasoline operation in SI engines as can be seen **Figures 6** and 7. With the use of acetylene as an alternative fuel in SI engines, air pollution from SI engine vehicles in large cities can be significantly reduced [19].

- Acetylene operates in diesel engines with dual fuel mode by a little engine modification and while reduces NOx, HC, CO and CO_2 emissions, contributing to a significant reduction in diesel fuel consumption [16]. Acetylene cannot be used as a single fuel in diesel engines due to the high compression ratio. In that study, the tests were conducted on a four-stroke diesel engine with a rated power output of 4.4 kW at 1500 rpm, with slight modification in intake manifold for holding the gas injector. The gas flow rates of 110, 180 and 240 g/h and optimized injection timings were arranged by ECU's. **Table 4** gives energy share ratio of diesel and acetylene at 240 g/h flow rate [16].

- In countries with large coal reserves and little or no oil reserves acetylene can be used in automobiles that form the largest part of vehicle traffic. Thus the country's need for oil can be reduced.

The main disadvantages of acetylene as alternative motor fuel [22–26]:

- Acetylene is a very explosive gas which sensitive to pressure and temperature. For this reason, in vehicles that use acetylene as fuel should be security precautions taken seriously and should not be parked in closed areas.

- Acetylene is a fuel with very low ignition energy and may cause backfire in intake manifold.

- As the knock resistance of acetylene is low, the air-fuel ratio must be precisely adjusted to avoid knock.

- Acetylene can be used as the only fuel in SI engines only under very lean air-fuel mixture conditions. In very lean conditions, we cannot get maximum power out of the engine.

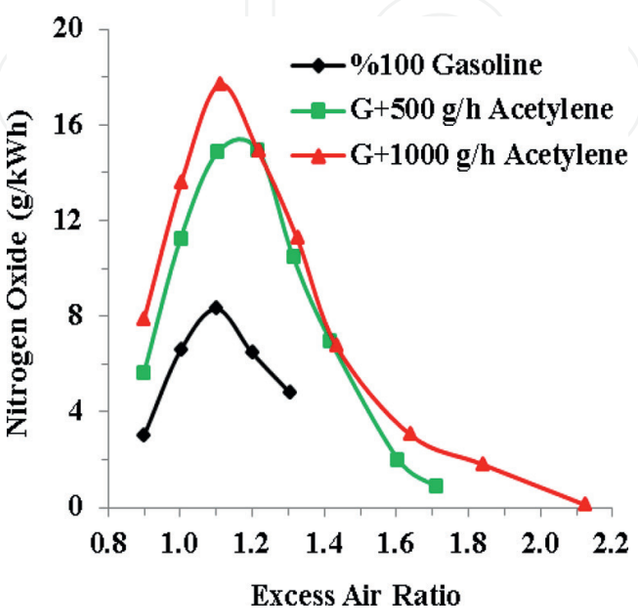


Figure 6.
The variation of NO with excess air ratio (1500 rpm, 25% load) [19].

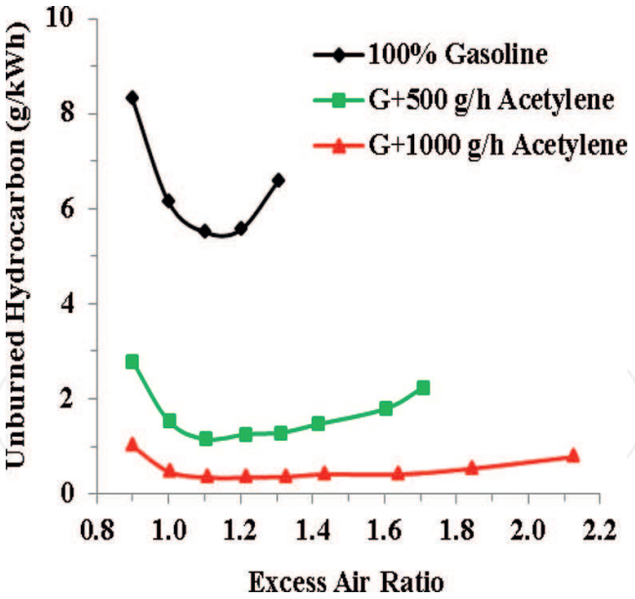


Figure 7.
The variation of UHC with excess air ratio (1500 rpm, 25% load) [19].

Load (%)	Energy equivalent of diesel fuel (kW)	Energy equivalent of acetylene fuel (kW)	Energy share of gas (%)	Energy share of diesel (%)
0	4.01	3.21	44	56
25	5.31	3.21	38	62
50	7.79	3.21	29	71
75	9.33	3.21	26	74
100	10.39	3.21	24	76

Table 4.
Energy share ratio of diesel and acetylene at 240 g/h [16].

- Storage of acetylene in vehicles is an unsolved problem yet. As acetylene is decomposed at a pressure of 2.5 bar, it cannot be stored as compressed gas like other gases. Acetylene is stored dissolved in acetone contained in a metal cylinder with a porous filling material under 18 bar pressure. When acetylene cylinders are empty, on-site filling is not possible. Therefore, disassembly and montage the cylinder is a major disadvantage. Although manufactured in different sizes, cylinders that can be stored 8.7 m^3 acetylene have a volume of about 60 liters and average weighs (full) 70 kg [27]. This situation causes great difficulties in practice.

- Another method is to produce acetylene from carbide as in the 1940s and to use it without storage. This method requires a complex system as shown in **Figure 1**. Disposal of the residue called calcium hydroxide is another important problem of an on-board fuel generating system

3. Natural gas

Natural gas is a fossil fuel found in nature reserves, associated or not with petroleum [28]. The cost of obtaining from nature is lower than other fossil fuels. Natural gas consists of about 90% methane, 3% ethane, 3% nitrogen, 2% propane and other trace gases. Methane which is the always dominant component of natural gas is the

first member of alkane's family. Since it has a high H/C ratio, natural gas is known as the cleanest fuel in fossil fuels. Due to its ecological benefits, city buses operate with natural gas engines in many countries. CO_2 gas, which should normally be between 180 and 280 ppm in the atmosphere, reached 405 ppm as of September 2018 due to overuse of fossil fuels [29]. Therefore, many countries encourage the use of natural gas instead of petrol and diesel fuel in vehicles. Because, natural gas mixes perfectly with air, it is easy to ignite, provides clean combustion and gives high heat. The thermal efficiency of natural gas engines is higher than that of gasoline engines due to these engines have a higher compression ratio than gasoline engines [28–35].

Unlike gasoline and diesel engines, natural gas-powered internal combustion engines do not require fuel enrichment in cold start, and exhaust emissions are not affected by low temperatures. Natural gas vehicles (NGV) produce emission values lower than the EURO 6 standard according to vehicles using petroleum-derived fuel [30].

According to NGV Global's report, the number of NGV and filling stations in the world is increasing rapidly (**Figures 8** and **9**). China ranks first in the NGV Park with 6,080,000 vehicles and 8400 filling stations, according to 2018 data. In the number of NGV, Iran, India and Pakistan are the countries that come after China. The total number of NGVs reached to 26,130,000 as of June 2018 [31].

The biggest disadvantage for the NGV transportation sector comes from the storage challenge of natural gas. Natural gas is a lighter gas than air. While the density of air at sea level at 15°C is 1.225 kg/m^3, although the density of natural gas varies according to its composition, it is about 0.71 kg/m^3. As natural gas is a light gas the energy density per unit volume is low and in order to ensure a reasonable driving distance the storage volume should be chosen large. Fortunately, technology has developed and the natural gas has been begun to storage in steel or carbon tubes at a pressure of 200 bar with high pressure compressors. Parking of natural gas vehicles in enclosed spaces is dangerous for safety reasons. Nowadays, cars with natural gas engines have a range of more than 300 miles with a single filling. Also, natural gas is not a renewable energy source, like other fossil fuels [35–37].

High knock resistance of natural gas allows it to be used in engines with higher compression ratios as compared to gasoline engines. Operation of natural gas vehicles at higher compression ratios than gasoline vehicles increases the thermal

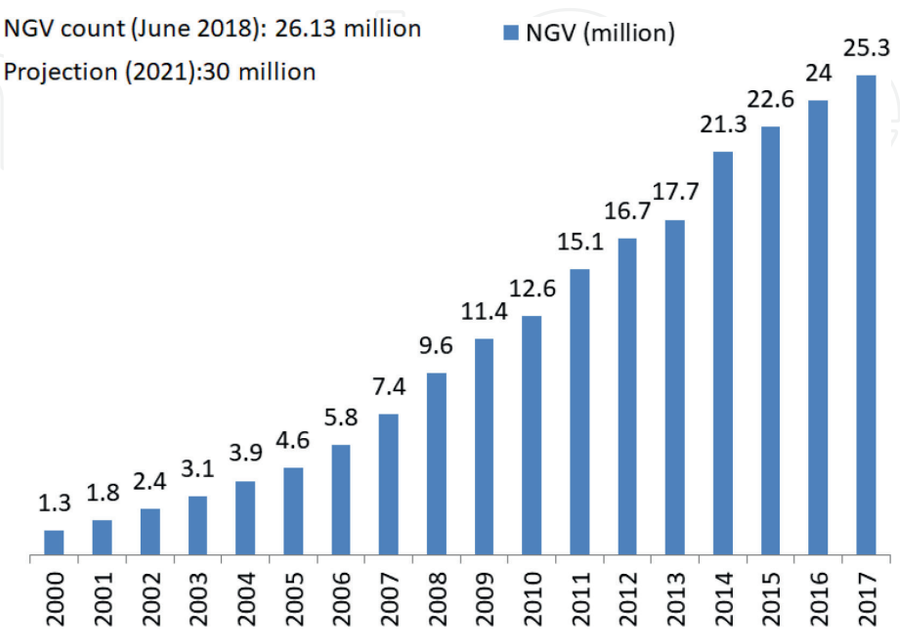


Figure 8.
Number of natural gas vehicles worldwide by years [31].

efficiency. As seen in **Figure 10**, in the tests carried out at different compression ratios with natural gas and natural gas-hydrogen mixtures (HCNG), the minimum fuel consumption for the compression ratio of 12.5 was obtained. **Figure 11** shows that, THC emissions are lower than the Euro VI standards in all compression ratios [30]. The experiments have been carried out using a modified diesel engine having 9.6, 12.5 and 15 different compression ratios at 1500 rpm under full load conditions fueled by hydrogen enriched compression natural gas blends (100% CNG, 95% CNG + 5% H_2, 90% CNG + 10% H_2 and 80% CNG + 20% H_2). Engine performances

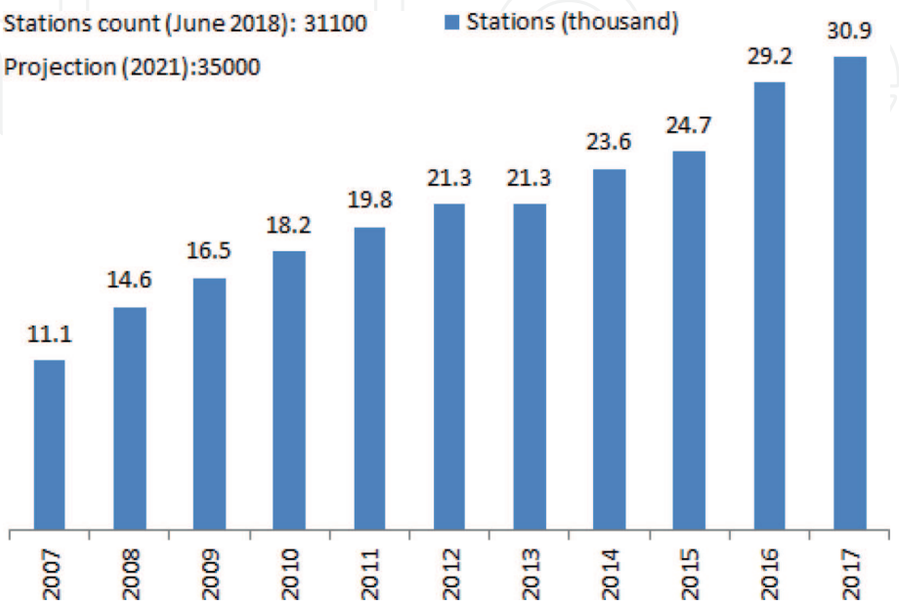


Figure 9.
Number of natural gas fueling stations worldwide by years [31].

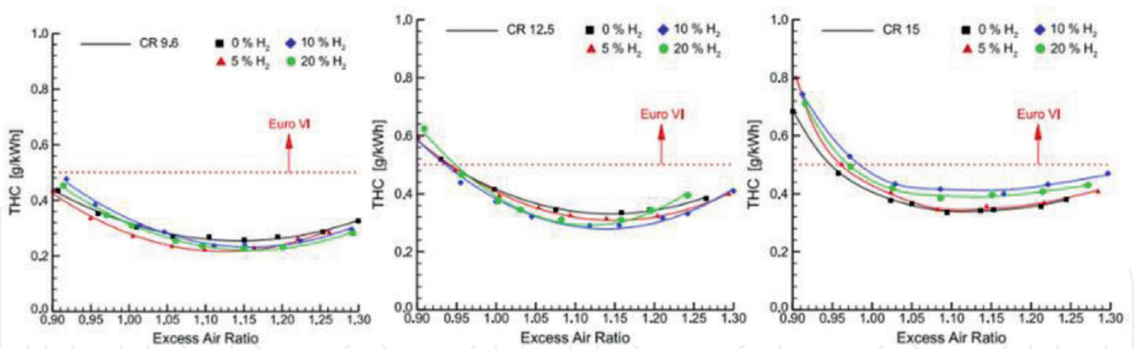


Figure 10.
The THC values versus excess air ratio using different compression ratios [30].

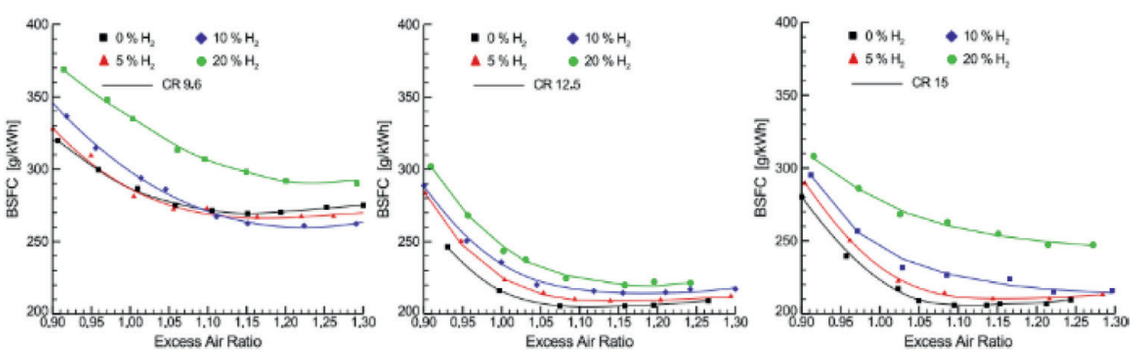


Figure 11.
The BSFC values versus excess air ratio using different compression ratios [30].

CR	H_2 (%)	λ = 1.0	λ = 1.15
9.6	0	2000	3620
	5	2100	3825
	10	1710	4185
	20	1535	4225
12.5	0	2040	4410
	5	1940	4200
	10	2260	4520
	20	2210	4695
15	0	2045	4465
	5	2570	4700
	10	2660	4565
	20	3030	4350

Table 5.
NO_X values (ppm) for λ = 1.0 and λ = 1.15 [30].

and emissions parameters have been realized at 10°CA BTDC ignition timing and different excess air ratios (λ = 0.9–1.3).

NO_X values for λ = 1.0 and λ = 1.15 show in **Table 5**. As seen in the table, increasing of compression ratio and hydrogen fraction values lead to an increase in NO_X values.

4. Ethanol

Ethanol is generally produced from renewable sources such as biomass and agricultural feedstock [38, 39]. So, ethanol has been used widely as alternative fuel in internal combustion engines. The octane number of ethanol is higher than the octane number of the gasoline. The high octane number of ethanol allows the use of ethanol as fuel in an SI engine with a higher compression ratio [40]. The latent vaporization heat of ethanol increase cooling effect in the cylinder, this situation leads to an increase in volumetric efficiency [41]. Ethanol burns cleaner than gasoline and diesel fuels and it produce less CO, CO_2 and NO_x. It has low diffusivity and ignition difficulty at low temperature, therefore combustion is not completed at low temperature and HC increases compared to gasoline in ethanol use. Ethanol chemical formulation is C_2H_5OH. Hydrogen percentage of ethanol is higher than gasoline.

Recently environmental authorities in large urban centers have expressed their concerns on the true effect of using ethanol blends of up to 20% in-use vehicles without any modification in the setup of the engine control unit (ECU), and on the variations of these effects along the years of operation of these vehicles [40].

Pure ethanol can be used internal combustion engines but there are some problems [42–45]. These problems are;

1. Ethanol has a low flame speed. So it has a bad cold-starting function. The using as fuel is hard in the winter months.

2. There is no passenger car designed for 100% ethanol. The use of pure ethanol can damage engines. Even engines that can work with gasoline-ethanol mixtures can reach up to 85% ethanol.

3. Ethanol is a corrosive fuel. So, the materials and surfaces of parts of combustion chamber, all plastic materials having contact with fuel and fuel injection system must be improved.

5. Hydrogen

Although hydrogen the most common element in the world and it does not exist in nature in its pure state, so it has to be produced from sources like water and natural gas. The environmental impact and energy efficiency of hydrogen depends on how it is produced [46, 47].

Hydrogen has been studied as an alternative gas fuel for a long time. Hydrogen has not some problems associated with liquid fuels, such as vapor lock, cold wall quenching, inadequate vaporization and lean mixing. Hydrogen has clean burning behaviors. As hydrogen is burned, it products mainly water. The combustion of hydrogen does not bring out toxic products such as hydrocarbons, carbon monoxide and carbon dioxide [48]. The most important advantage of hydrogen is that it does not produce CO_2 gas, which is one of the most important sources of global warming. In addition, hydrogen has a wider limit of flammability than gasoline, diesel and natural gas [49, 50]. Moreover, hydrogen has high flame speed and it has high self-ignition temperature [51]. Also, hydrogen can easily burn in ultra-lean mixtures [52]. The energy required to ignite the hydrogen-air mixture is only 0.02 MJ. Therefore, it is ideal for poor mixed burns [50]. Finally, hydrogen can be used at wide compression rates in internal combustion engines as the self-ignition temperature of hydrogen is too high [53]. Due to these properties, many studies have been carried out on the use of hydrogen in internal combustion engines [54–56].

Due to the low energy required for the ignition of hydrogen, the mixture immediately ignites when it comes into contact with a hot spot in the cylinder. As a result, knock may occur [56, 57]. As can be seen from **Figure 12**, another disadvantage of hydrogen is its low energy density [58]. In addition, the formations of NO_X emissions are increased by hydrogen combustion due to high flame temperature [59, 60]. The increasing of NO_X with hydrogen can be seen from **Figure 13**.

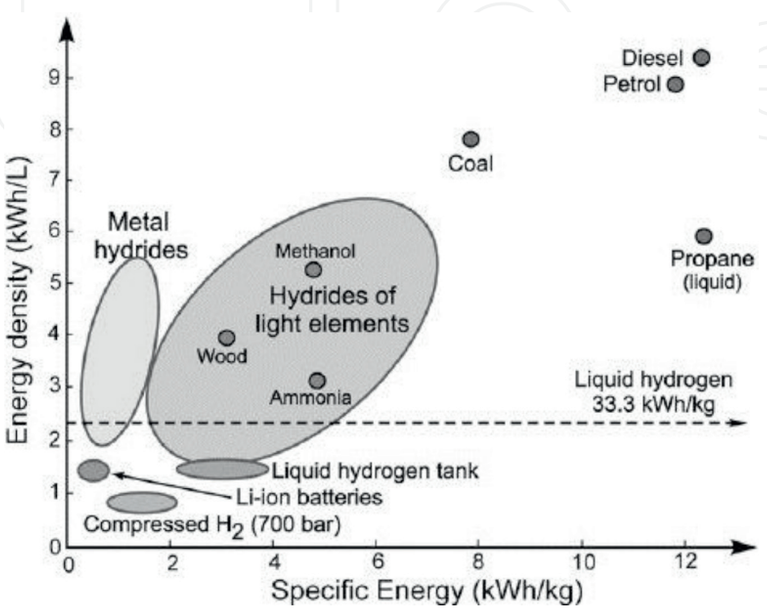
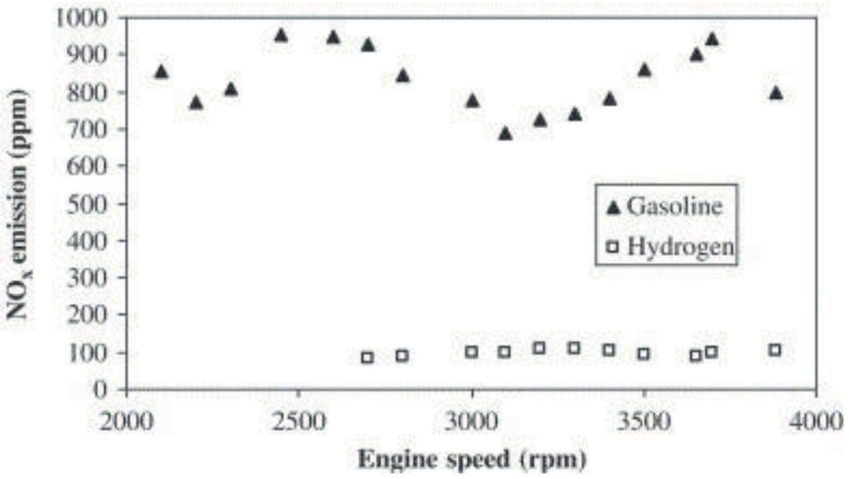
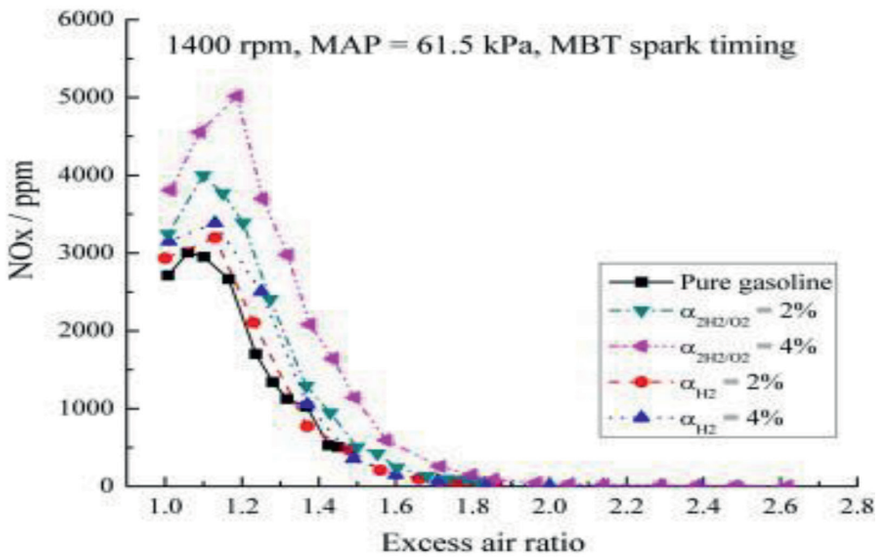


Figure 12.
The energy density of some fuels [145].



(a)



(b)

Figure 13.
NO_X variations at different engine speeds (a) [61] and different excess air ratio (b) [62] with addition of hydrogen to gasoline.

The experiments in the study fueled by pure hydrogen and gasoline [61], in which **Figure 13** was taken, carried out on a four-cylinder, four stroke, SI engine with carburetor, having 8.8:1 compression ratio. The ignition timing was set to 10° before top dead center (BTDC). The engine was run between 2600 and 3800 rpm engine speeds. In the experimental study [62], the tests were carried out at 1400 rpm engine speed, 61.5 kPa manifold air pressure, MBT spark timing and different excess air ratios (1.0–2.6). In this study, to simulate the hydroxygen, the hydrogen-to-oxygen mole ratio was fixed at 2:1 through adjusting the injection durations of hydrogen and oxygen. Moreover, three standard hydroxygen volume fractions in the total intake gas of 0, 2 and 4% were adopted in the tests.

6. Hydrogen mixture

Because of hydrogen has some negative effects on internal combustion engine, it is used as a mixture rather than pure. The most widely mixture of hydrogen is

HCNG. The mixture has been formed by the blending of natural gas. Natural gas-hydrogen mixtures (HCNG), which are considered as alternative fuels for conventional engines, are mixtures formed to combine the superior properties of natural gas and hydrogen. There are many studies [63–70] using HCNG as an alternative fuel.

As can be seen in **Figure 14**, the hydrogen adding causes an increase in thermal efficiency and causes an expansion of the flammability limits. In addition, when the figures are examined, it is seen that the addition of hydrogen increases the stability of combustion and the value of brake power and reduces the specific fuel consumption.

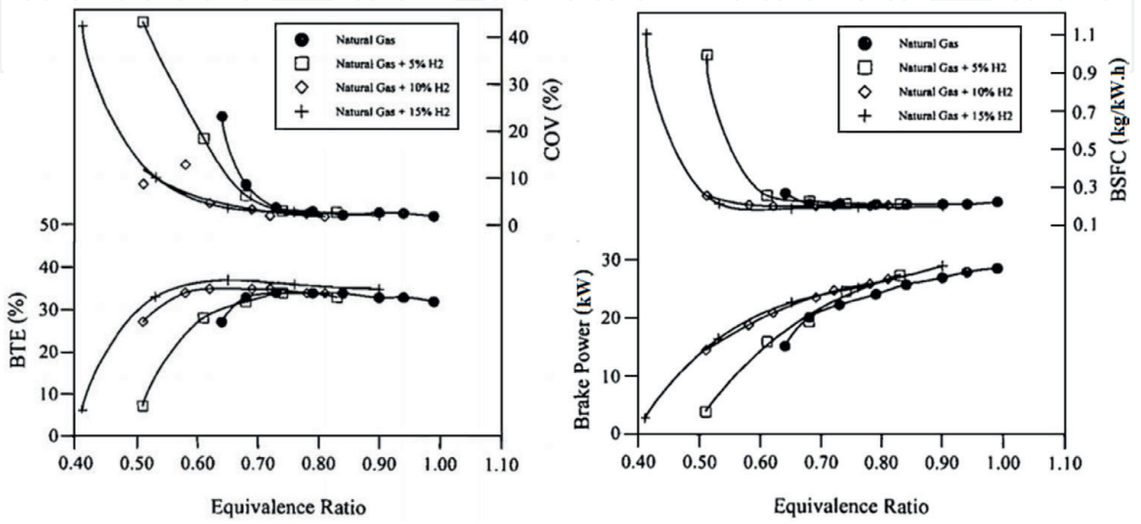


Figure 14.
BTE, COV, power and BSFC values versus equivalence ratio at 2200 rpm, 50% WOT with MBT timing and different hydrogen percent [69].

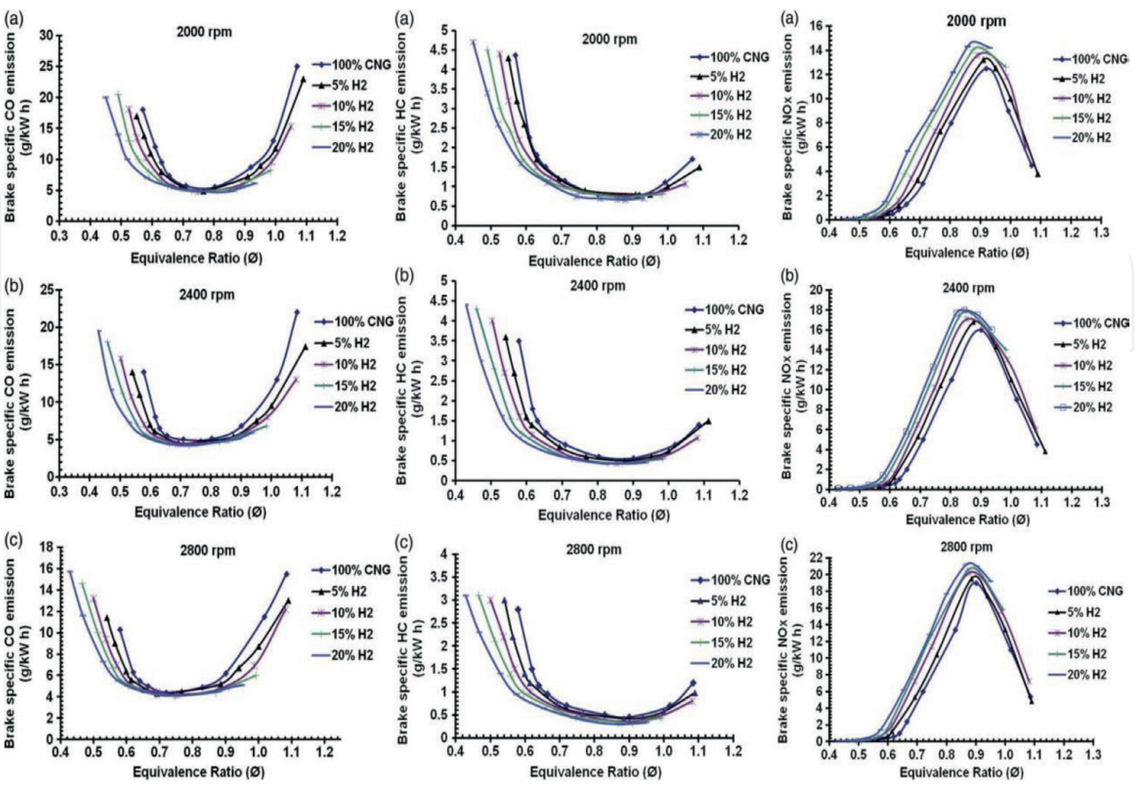


Figure 15.
Emission values versus equivalence ratio at 2000 rpm (a), 2400 rpm (b) and 2800 rpm (c) and different hydrogen rates [70].

Moreover, as can be seen in **Figure 15**, the addition of hydrogen to natural gas leads to a decrease in CO and HC emissions and an increase in NO_X values. In the experimental study, in which **Figure 15** was taken, the experiments were performed at 2000, 2400 and 2800 rpm with wide open throttle and varying the equivalence ratio. The engine with single-cylinder having 7.25:1 compression ratio was fueled by compressed natural gas, and mixtures of hydrogen in CNG as 5, 10, 15 and 20% by energy.

Another mixture made using hydrogen is the ethanol-hydrogen mixture. In the literature, it can be found many studies on the use of hydrogen and ethanol in internal combustion engines [71–85].

In the experimental study [85], in which **Figure 16** was taken, the experiments were carried out on a compression ignition engine modified to run on spark ignition mode fueled with hydrogen-ethanol dual fuel combination with different percentage of hydrogen (0–80%) under compression ratio conditions of 7:1, 9:1 and 11:1 by varying the spark ignition timing at a constant speed of 1500 rpm.

In a study conducted with a mixture of hydrogen-acetylene, Sampath Kumar et al. [86] have been investigated the performance and the emission behaviors of SI

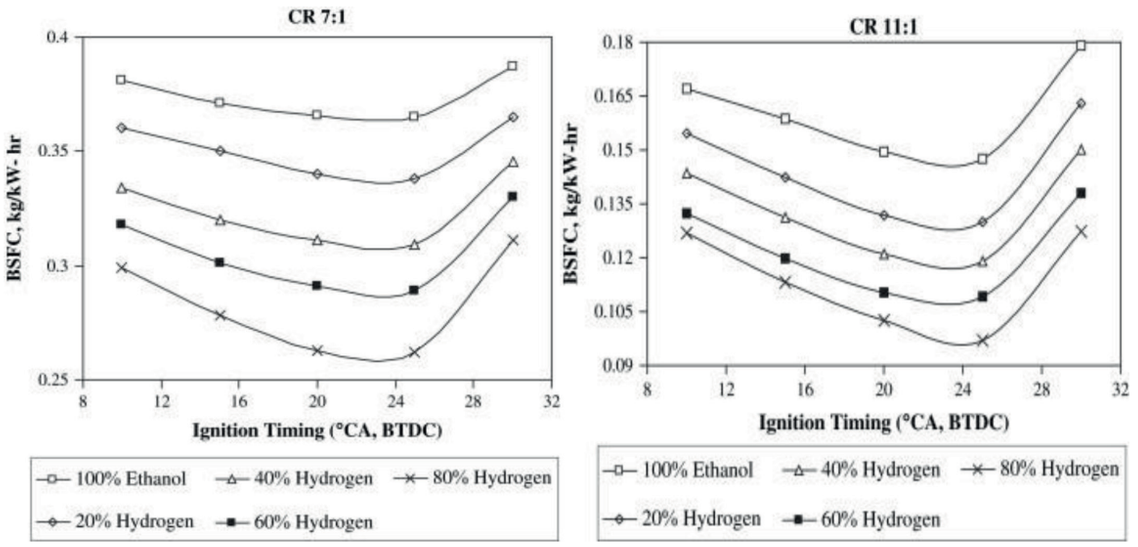


Figure 16.
The BSFC variations versus ignition timings at 7:1 and 11:1 compression ratios for different ethanol-hydrogen blend [85].

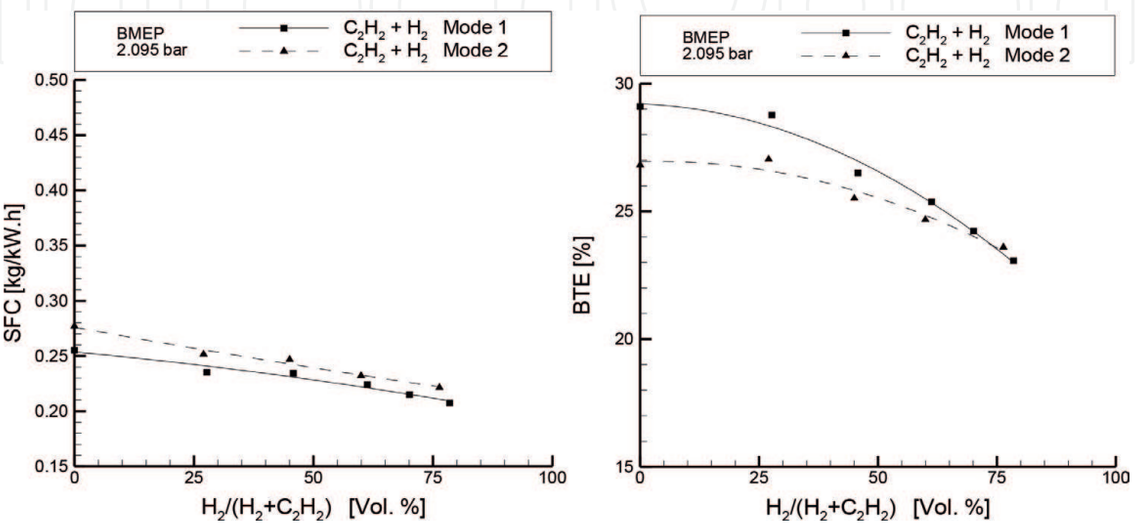


Figure 17.
SFC and BTE values versus different fractions of hydrogen [87].

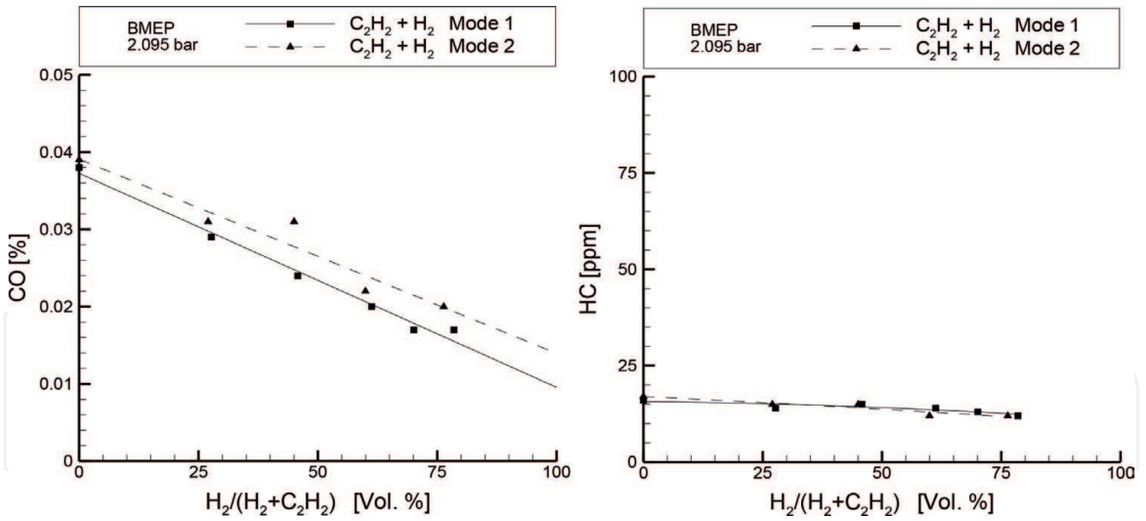


Figure 18.
CO and HC emissions versus different fractions of hydrogen [87].

engine fueled by hydrogen-acetylene fuel. The results indicated that brake thermal efficiency raised and emissions values descended when compare to gasoline.

In the another study, Tangöz et al. [87] have been analyzed the performance and emission values of an SI engine fueled by acetylene-hydrogen at a fixed BMEP value of 2.095 bar, a load of 30 Nm and an engine speed of 1500 rpm under lean mixture conditions (λ = 1.3–2.8). As can be seen from **Figures 17** and **18**, the experimental results showed that the values of specific fuel consumption are declined between 18.5 and 20.1% by hydrogen addition in the blend. The values of brake thermal efficiency are declined between 6.2 and 3.3% with the addition of hydrogen in the blend. The curves of cylinder pressure and heat release rate are advanced to top dead center by the adding of hydrogen to acetylene. The adding of hydrogen in acetylene leads to a decrease in CO and HC emissions and an increase in NO_X values for fixed lambda.

7. Alternative fuels for new ICE applications

Today, one of the most important problems in the use of internal combustion engines is the production of harmful emission gases. For this reason, many studies have been carried out to reduce the emissions while maintaining of engine performances, with the new ICE applications such as HCCI, RCCI, PCCI and PPC. Moreover, for the purpose of reducing emissions, some of these studies focused on the using of alternative fuels. In the new engine applications have a process in which a homogeneous mixture of air and fuel is compressed under the conditions in which auto ignition occurs close to the end of the compression stroke, followed by combustion, which is significantly faster than conventional diesel or Otto combustion. The auto-ignition and combustion phasing in cylinder are controlled by mixture stratification and fuel injection timing [88–93]. These engine applications compared to conventional engines allows to reduce nitrogen oxide and soot emissions and to achieve higher thermal efficiency [94–98]. However, it is very difficult to control the auto ignition in these engines. Many studies were carried out to control the auto ignition process in the engines by using alternative fuels having high auto ignition temperature or low reactivity or high octane number.

One of the most important new ICE applications is homogeneous charge compression ignition (HCCI). To control the auto ignition process in HCCI engine, some fuels having high auto ignition temperature use as alternative fuel. When these studies are examined, it is seen that the studies focused on the natural

gas [99–104], ethanol [105–108], acetylene [109–114] and hydrogen [115–122]. Reactivity controlled compression ignition (RCCI), premixed charge compression ignition (PCCI) and partially premixed combustion (PPC) are other new ICE applications. In the engine applications, the low reactivity fuel is introduced from port injection to form a homogeneous mixture in the cylinder, and the high cetane number fuel is injected directly into the cylinder to control the combustion phasing and duration. High octane fuels or low reactivity with resistance to spontaneous ignition are more favorable for RCCI, PCCI and PPC combustion. For this reason, most of the studies carried out on RCCI, PCCI and PPC engines are focused on natural gas [89, 123–133] and ethanol [134–144] as an alternative fuel.

As a result, the operation parameters such as fuel type, fuel composition, air fuel ratio and inlet temperature were observed to significantly affect working regime of the new ICE applications. However, it is considered that a complete framework for the each ICE application modes has been not provided. Moreover, in spite of significant reduction in NO_X and soot emissions is observed in the applications fueled by the alternative fuels, significant amounts of HC and CO emissions forming still remain problematic.

8. Conclusion

Acetylene has some suitable properties such as high energy density, high flame temperature, high flame speed and low emission production. For this reason, it is considered to can be use an important contribution fuel or alternative fuel in the future for internal combustion engine. It increases brake thermal efficiency while contribute to decrease fuel consumption and all emission values. However, some studies should be carried out to increase the knock resistance of acetylene. Moreover, efficient production methods and new storage methods need to be developed in order to use acetylene as an alternative fuel in vehicles. Finally, in order to determine whether acetylene is economical or not, well to tank analysis should be performed.

Looking at today's applications, it is seen that natural gas fuel is a suitable fuel especially for SI engines having high compression ratio due to high knock resistance. Operation of natural gas vehicles at higher compression ratios than gasoline vehicles decreases the BSFC. On the other hand, natural gas, the cleanest fossil fuel due to having high H/C ratio, provides more reduction in THC emission values than Euro VI standard when suitable compression ratio is met. However, the storage problem must be eliminated in order to be used in all engines. Moreover, studies should also be done to increase the energy density.

Ethanol has high octane number. However, it is expensive than fossil fuels and it has corrosive property. In addition, even engines that can work with gasoline-ethanol mixtures can reach up to 85% ethanol. Ethanol can be blended to other alternative fuel to improve the energy density. Ethanol burns cleaner than gasoline and diesel fuels and produces less CO, CO_2 and NO_x but HC increases due to it has low diffusivity and ignition difficulty at low temperature.

Hydrogen is a clean fuel and the mass energy density is very high. Fast burning characteristics of hydrogen permits high speed engine operation and less heat loss occurs for hydrogen than gasoline. NO_x emission of hydrogen fuelled engine is about 10 times lower than gasoline fuelled engine if it works lean conditions. Because of hydrogen has some disadvantages such as very low ignition energy and volume energy density, it is mixed with other fuels especially natural gas to use in SI engines.

Intensive studies such as the use of hydrogen in a liquid state should be done to solve the storage problems in order to achieve the desired level of use in internal combustion engines. Also, the methods or mixtures that reduce NO_x formation should be studied.

In spite of significant reduction in NO_X and soot emissions is observed in the new ICE applications such as HCCI, RCCI, PCCI and PPC fueled by the alternative fuels, significant amounts of HC and CO emissions forming still remain problematic.

Consequently, each fuel has positive and negative properties for use in internal combustion engines. There are differences in the effects of each alternative fuel on emissions and engine performance. The future studies could be carried out to obtain an appropriate hybrid fuel by making a comparison between these alternative fuels to reduce all emissions and to improve engine performance.

Abbreviations

BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CA BTDC	crank angle before top dead center
CI	compression ignition engine
COV	coefficient of variation
CR	compression ratio
EU	European Union
HCNG	natural gas-hydrogen mixtures
ICE	internal combustion engine
MBT	maximum brake torque
NGV	natural gas vehicles
SI	spark ignition
WOT	wide open throttle
WTT	well to tank

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