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The Use of Hydrogen as an Alternative Fuel in Internal Combustion Engines

Kareem A. Dakhil
Department of Mechanical Engineering, Energy Conversion, College of Engineering, Iraq
Corresponding author email: kareemalawi1983@gmail.com

Abstract-Globalization and the rising demand for energy have certainly led to ever greater needs in fossil fuel. Certainly several nations are researching new sources of energy, and hydrogen is a fuel that burns cleanly. Meanwhile in the transportation industry, hydrogen-powered cars being developed aim at once for maximum fuel efficiency and for significantly less poisonous vapors in the air for people to breathe but also caused by their partial exhausts--because these are now eliminated entirely thanks to complete conversion of hydrocarbons into water vapor plus some extra CO2.Using this review, the author wants to do a summary of how hydrogen is a internal combustion engine fuel, covering both spark-ignition [SI] and compression-ignition [CI] motors.Using hydrogen as a fuel for internal combustion engines lowers the torque, output, and brake thermal efficiency of them while their brake-specific fuel consumption changes little. There is data that indicates that by using hydrogen, emission of CO, UHC, CO2 and soot from an engine can be reduced. On the other hand, NOx is expected to increase because more air enters into the combustion chamber to pick up a large amount of water vapor in addition.Hydrogen fuel, as an energy source, is clean and renewable which can promote sustained development of the environment for everyone to enjoy.
Keywords: hydrogen fuel ; Hydrogen ICE; renewable energy; efficiency; emissions

1. INTRODUCTION

Perhaps the most eloquent human invention which ever had a profound effect on society, prosperous economy and flourishing, natural environment is the reciprocating internal combustion engine, known generally as IC engines[1]. Hydrogen is widely recognised as an energy carrier with much promise for transportation applications. Hydrogen may be used as an energy carrier in a variety of technologies, the most advanced products being fuel cells and internal combustion engines (ICE).[2] Although many scholars made noteworthy contributions to the development of engines that rely on internal combustion of fuel, this historical breakthrough by Nicolaus Otto(1876) and his counterpart Rudolf Diesel(1892) in the development of Spark Ignition(SI) engine and Compression Ignitiona(CI) engine is world-renowned[2, 3]. For decades their inspiring creations held a prominent place in the automotive system, used almost universally up to the present time. However, there now exists a pressing need to develop advanced combustion engines that maximize engine efficiency as well as completely eliminate exhaust emissions[4]. As a result, Hydrogen-fueled internal combustion engines stand at the center of future transportation systems when integrated with hybrid electric vehicles, they are considered one of the key parts due to their ability to substantially decrease emissions and raise energy efficiency[5]. Moreover, Hydrogen-powered ICEs-as they are naturally abbreviated-have the advantage of being able to handle different types of fuels, long life and comparatively low cost [6]. Therefore an alternative fuel today must not only be technically feasible and economically viable to produce, but above all must mitigate harmful emissions for the environment, including CO2 as much as possible. Alternative fuels now being used such as ethanol, methanol, biodiesel, propane, natural gas, and hydrogen can all to varying degrees reduce engine emissions compared with the output levels associated with mainstream liquid hydrocarbon fuels. Among these hydrogen, as an energy carrier, is the only fuel that may be entirely free of hydrocarbons; carbon monoxide and carbon dioxide emissions. Hydrogen has a high combustion velocity in an engine combustion chamber [about 6 times greater than petrol], lending itself to high engine efficiency[7]. Hydrogen also has a wide range of flammability, allowing it to burn in engines when mixed with air in many different combinations (4--75%). This enables very lean mixtures to be used. On the evidence of research so far, a hydrogen-consumed reciprocating internal combustion engine has a higher efficiency of more than 5% than a diesel-consumed ZS engine (about 44.5% for a prototype engine was already realized on 8, 9 occasions)[8]. Consequently hydrogen is considered one of the most important fuels for the future. It will enable us to meet ever-stricter emissions standards. Thus hydrogen is one of the most important candidates for meeting future energy demands (it will also be applied as an engine fuel for future vehicles) and is one of the main aspects in most government's plans[10, 11]. Hydrogen, as an energy resource for the future, will reduce worldwide dependence on fossil fuel reserves and the exhaust level from vehicles emitted by individual carriers[12, 13]. The emissions however are greatly dependent on the method of hydrogen production, [14, 15]

At present, various methods are being tried out to produce hydrogen（16）. However, the only emission-free system is the solar–hydrogen method. This one of great cost and expense indeed frightened away many potential users but brought postwar peace(pf2). First, in 2016, 96% of hydrogen was produced from fossil fuels [13]. But when fossil hydrocarbons are used, reforming produces Co2. This is harmful to the environment and will bring disaster if it continues[17, 18].In order to immobilize it against release into the atmosphere, it must be captured and stored[17]. Using hydrogen as a fuel to power ICEs offers significant advantages over FC technology. Most importantly, it allows for greater toleration of contamination, has mature ICE technology, saves widely used but scarce materials, and even the ICE can adapt easily to running on hydrogen[9, 19].Hydrogen-fueled ICEs, however,[H2ICEs] have been the subject of research since the last century [20, 21]. 1 [21, 22].

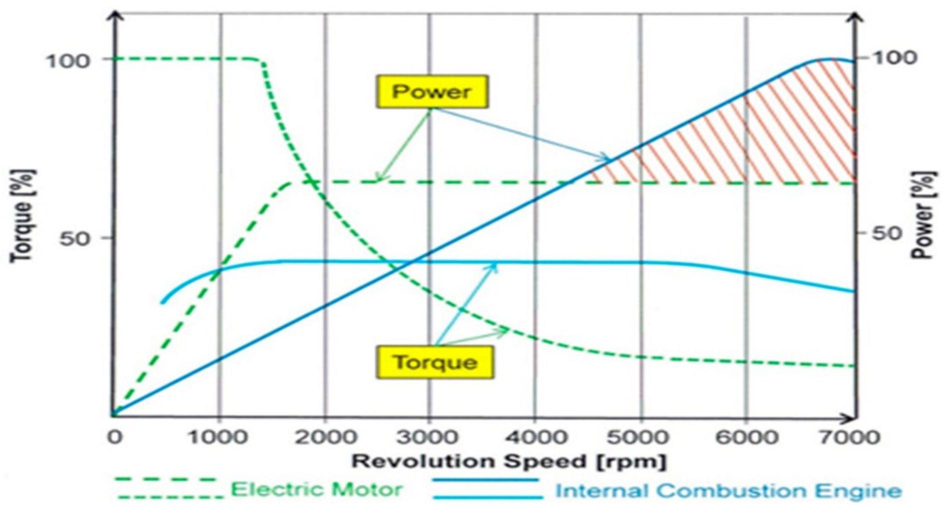

Figure 1. Comparison of ICE and electric motors (BEVs and FCEVs).

2. METHODS OF USING HYDROGEN IN ENGINES

While a hydrogen-fueled engine is feasible provided there are minor changes in its structure, the way the fuel is burned demands certain alterations to the design. The use of hydrogen in an internal combustion engine is much like using it anywhere else. In separate investigations on hydrogen use in automobile industry internal combustion petrol engines [22], hydrogen enters the motor's combustion chamber via either injection or carburetor systems from the premixed company

2.1. Use of Hydrogen as a Direct Fuel

As engines do until now, traditional ones run on liquid fuels such as gasoline and diesel fuel. A few make use of alternative ones like natural gas. Unless their combustion systems are actually modified, you cannot take traditional engines and run them using hydrogen. So to be able to combine various kinds of electricity and hydrogen together, something new has got to be thought up [24]

2.2. Use of Hydrogen as a Secondary Fuel

Hydrogen can be used as a main or secondary fuel in internal combustion engines. Although there are certain disadvantages to employing hydrogen as a single fuel source, it is more suited in the current scenario[25]. Even if this technique does not eliminate reliance on fossil fuels, hydrogen will be utilized in conjunction with an economic shift in the fuel framework, and harmful exhaust emissions will be minimized[26].

3. HYDROGEN USE IN INTERNAL COMBUSTION ENGINES

Hydrogen can be used in spark ignition (SI) as well as compression ignition (CI) engines.

3.1.Spark Ignition Engines

Hydrogen fuel is used widely both in spark ignition engine and high performance practices.Here hydrogen's good properties--its speedy propagation of flames, its low ignition energy requirement, and wide flammability limits--all demonstrably help in optimizing and improving this process. What this means is that hot working-temperature releases of compounds will be greatly diminished. Even to the point that just NOx will come out[27, 28]. In such ways can hydrogen be used in SI engines[28, 29]: -Collector induction Into the collector is injected some low-temperature hydrogen from a controlled valve orifice. -Direct entry Cryogenic cylinders are used to hold hydrogen. A liquid hydrogen system is cooled by gas rad; turning it to cold hydrogen. Remain airborne also come through fuel injectors boeing 707 engines would be giving off combustible mixtures and burning them up with the high-octane Nox residues[28].With hydrogen fuel mixed in Air: a flammable mixture, it can be burnt in conventional SI engines with an equivalent ratio on the lean A flame temperature below that of gasoline–air flammability limits This amounts to or lean combustion. This directly leads at lower walls, raising engine efficiency and lowering No emissions[30].And hydrogen-powered SI engines have a further advantage: their unwanted emissions are lower than in hydrocarbon-fueled engines. As earlier studies have demonstrated, NOx is the prime pollutant from engines using hydrogen. Hydrogen-fueled ICEs produce higher emissions of NOx than petrol-fueled ICEs because the temperature in combustion is high when using hydrogen. With lifting from stoichiometric fuel-air mixture temperature [to avoid poor combustion and thus excessive NOx output] high NOx emissions result. Dropping the air–fuel ratio decreases combustion temperature and NOx emissions[31].The hydrogen combustion process is very similar to that of gasoline. If you run an engine on hydrogen, the cylinders can endure up to 340 bar or even more in peak pressure, and burning speed is higher than with methane alone. There is virtually no hydrocarbon or carbon monoxide emissions. Only minute traces of each come from evaporation and combustion of the protective oil secretion on engine cylinder walls [29].The performance of a hydrogen engine is superior to that of a petrol engine, especially when the engine is operating at part load. Hydrogen can also be used as an admixture in natural gas or gasoline. In this way, fuel that is very lean [equivalent ratio of 0.1] may be combusted. But spark ignited engines are not as good a solution where high levels of torque are needed at low engine speeds. In such cases those more capable engines operating at higher compression ratios, like Diesels, are used instead [32].

3.2.Compression Ignition Engines

As a diesel fuel additive in compression ignition engines, there are many reasons that hydrogen could be used.The small addition of hydrogen into a CI IC engine can improve the mixture homogeneity of fuel when it is spray.Certainly, this is owed, at least in part, to the great diffusivity of hydrogen.The whole 33 Combustible mixture has been mixed associated framing energy jes while combustion products arise [2.5O AsSoonOnceAt present, oil suspensions originate mainly from partial combustion of lubricating oil.31 32With hydrogen-fueled CI engines, a high-pressure hydrogen injector injects into the cylinder.Accordingly, the design of engine structure is one important matter and designing the injector nozzle to control how pressurized hydrogen enters the combustion chamber is another[134].For this reason hydrogen cannot be used as a standalone fuel for compression ignition engines. As the temperature of compression is not sufficiently high to cause combustion due to the high autoignition temperature required [137, 138].So that to burn hydrogen in a CI engine requires the aid of either a spark plug or a glow plug.With a dual fuel engine, a pilot burn of a small amount (hydrogen) carried an intake air or carburator. Combustion is brought about by standard diesel fuel standing in ignition source Hence it is possible to mix up to %~20 of the main fuel (hydrogen) into intake or injection of other hydrocarbons[39].Hydrogen-fuled dual-fuel CI engines, like SI engines, have a serious problem with NOx. Since there is less oxygen in the intake charge, EGR will reduce these things out. However, as you put in more EGR, volumetric efficiency falls off fast. A reduction of approximately 15% is observed when compared to hydrogen dual-fuel propulsion systems not employing EGR[40].Besides, in hydrogen dual-fuel operation with EGR, particulate emissions are increased.9XPW^29-D In this mode of operation, a bi-fuel engine with H2and EGR will make about the same amount of smoke as a Ci ICE. At the same time, the emission rates of both unburned HC and CO also rise with EGR addition.There is also a way to reduce nitrogen oxide (Nox) emissions -- using liquid water inside the engine.Meanwhile, water can alleviate unstable combustion and premature ignition when hydrocarbons are burned.The function of W is similar to that of EGR, which dilutes the exhaust gas and makes it cool enough for combustion. That virtually eliminates the smog.Liquid water as well may produce smoke levels typical for a CI IC if H2gas is burned with EGR in a dual fuel engine. However, EGR also adds two kinds of emission: nitrogen oxides and unburned hydrocarbons. It would(copy)[5]

4. IMPACT OF HYDROGEN FUELS ON THE PERFORMANCE OF INTERNAL COMBUSTION [IC] ENGINES

The use of hydrogen in gasoline engines has been thoroughly explored, and different changes to these engines are necessary owing to hydrogen's characteristics[38].

4.1. Power and Torque

Hydrogen has more impact on the volumetric efficiency of engines under lower heat value (LHV) (120 MJ/kg) than diesel (43.6 MJ/kg) and gasoline (43.4 MJ/kg), because it is can be an additive in spark ignition (SI) or compression ignition (CI) engines [42].Compared with liquid fuels, hydrogen expands more within engines and therefore its volumetric efficiency is reduced as a result.Hence the intake manifold often heats up for more effective liquid fuel evaporation in the case of diesel and gasoline fuels [47]If a hydrogen–air mixture burns just to completion at stoichiometric ratios(ie the ratio of hydrogen to air is about 30% by volume), then consumed per litre of normal gasoline will correspond to a equivalent consumption in engine displacement of at least 20% greater[48].As the percentage of hydrogen in the fuel within a diesel engine increases, the volumetric efficiency will decrease at a higher rate[44]: This was demonstrated in Figure 2.To avoid any distortions, it seems reasonable that if methane replaces gasoline as the baseline fuel and has an LHV value close to that of gasoline [50], then what we wish to determine is indeed how much volumetric efficiency for methane will be lost accordingly with any rise in engine load[45].As can be seen clearly from both graphs in Figures 2 and 3, larger amounts of hydrogen in the fuel lead to lower volumetric efficiencies of engines, and similarly less amounts mean higher efficiencies.

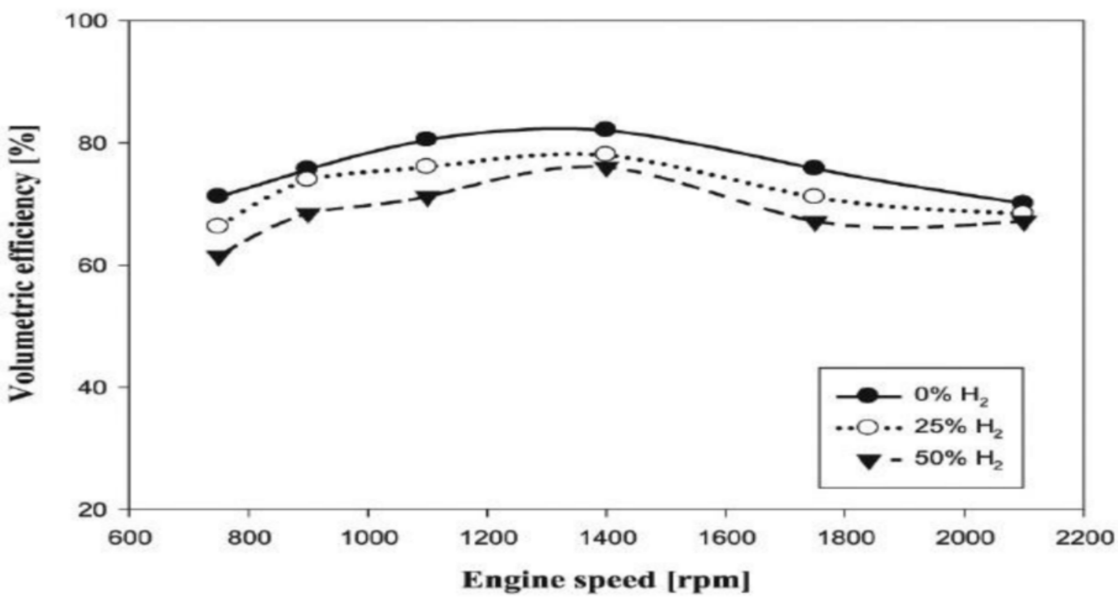

Figure 2. Volumetric efficiency changes with different percentages of hydrogen in the CI engine[44].

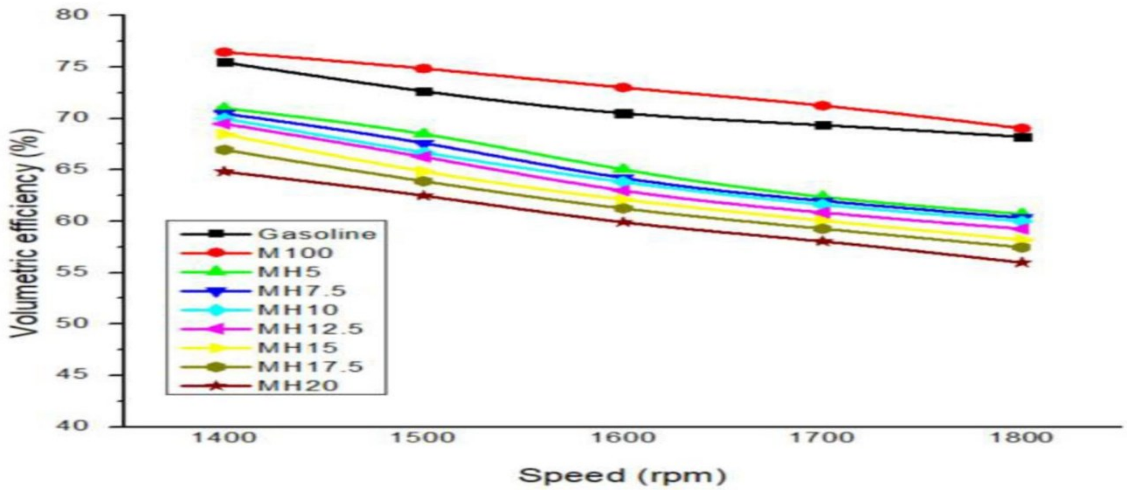

Figure 3. Volumetric efficiency changes with different percentages of hydrogen in the SI engine[45].

This reduction in volumetric efficiency will reduce engine power and torque. **Figure 8** shows the amount of power and torque reduction in a CI engine using 25 and 50% hydrogen[44]. As can be seen from the diagrams, with an increasing percentage of hydrogen, engine power and torque decrease. This power and torque reduction has also been reported for gasoline engines using hydrogen[46].

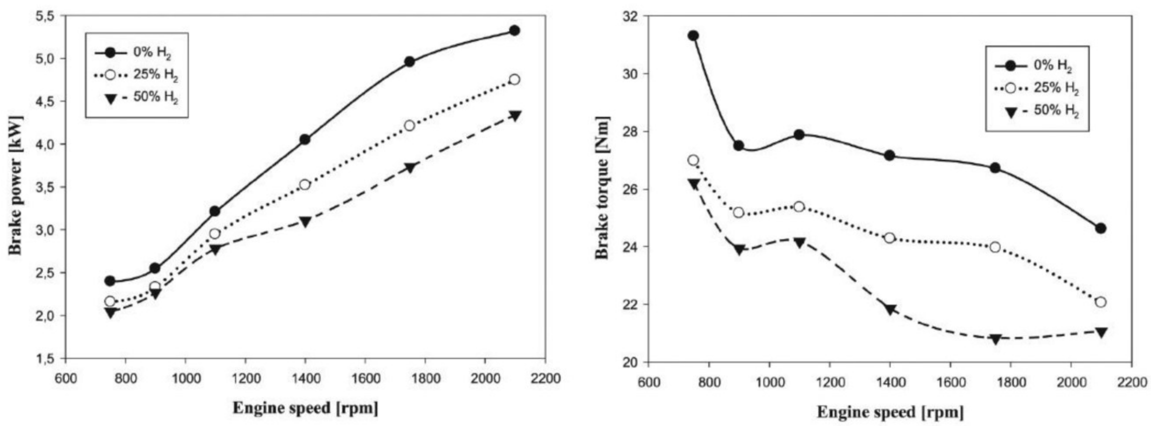

Figure 4. Brake power and brake torque changes with different percentages of hydrogen in the CI engine [47].

4.2. Brake Thermal Efficiency

Because of hydrogen's huge molecular thermal capacity and the fact that adding hydrogen to internal combustion engines causes the combustion phase to shift, which affects combustion efficiency [44], as hydrogen is added to SI and CI engines, the fuel brake thermal efficiency (BTE) drops. Figure 5 shows the reduction in the amount of BTA in a CIA engine by adding hydrogen to the base fuel, which is diesel. Similar results have been reported by other researchers for the reduction of BTE in these engines [48, 49].

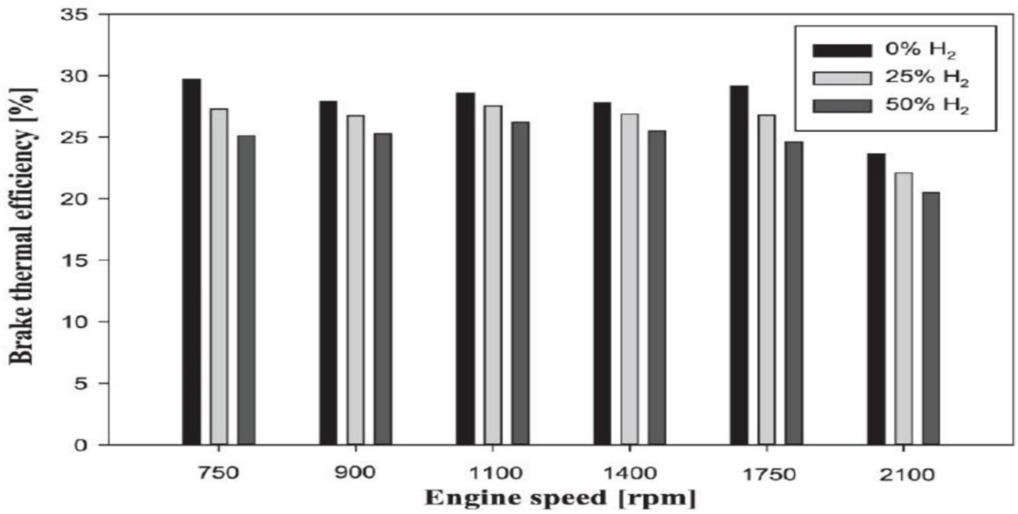

Figure 5. Brake thermal efficiency with different percentages of hydrogen in the CI engine[44].

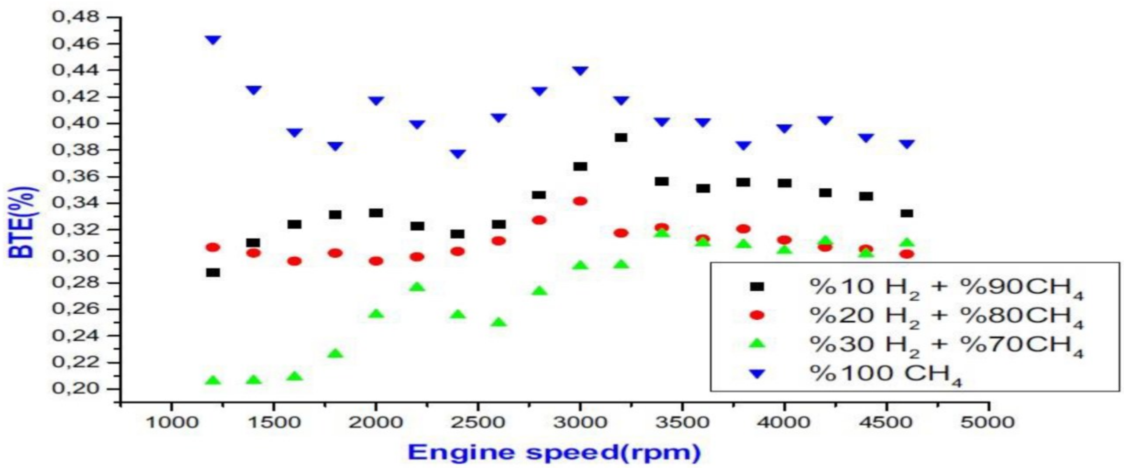

Figure 6. Brake thermal efficiency with different percentages of hydrogen in the SI engine[42].

Several aspects of hydrogen fuel are being investigated, including the addition of hydrogen to various fuels with varying operating characteristics. However, one of the essential characteristics to evaluate in a performance study is the change in compression ratio. Engines with greater operational compression ratios offer better thermal efficiency and higher power output according to prior research [50, 51]. The hydrogen engine's power loss can be minimized by raising the compression ratio [52]. Other researchers have reported an increase in BTE as the compression ratio increases [53].

4.3. Brake-Specific Fuel Consumption

In a diesel dual-fuel engine, hydrogen burns faster and has a nine-fold higher flame speed. The rate of heat release increases as the load and hydrogen substitution increase[54]. As a result, mixing hydrogen with diesel fuel in a CI engine raises the brake-specific fuel consumption. Figure 7 demonstrates how adding hydrogen to diesel fuel increases the quantity of BSFC produced at various speeds.

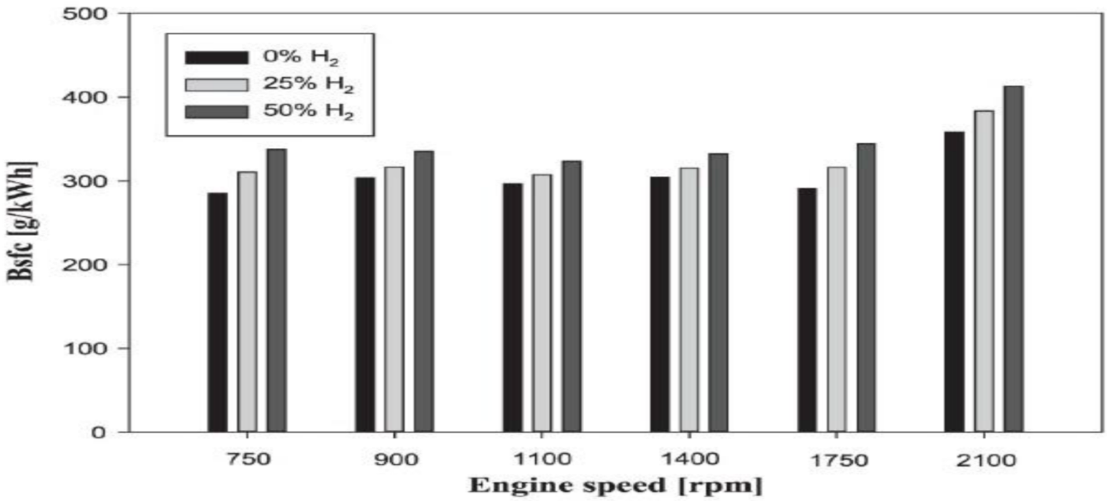

Figure 7. Brake thermal efficiency with different percentages of hydrogen in the SI engine[44].

By injecting hydrogen in varied hydrogen ratios, the equivalent brake-specific fuel consumption (BSFC) increases compared to what observed when using gasoline, due to the reduction in engine power (when hydrogen injection methods that lower engine power are utilized). Changing water injection and ignition times, on the other hand, can eliminate the degradation caused by hydrogen injection and successfully lower BSFC [55-58].

5. CONCLUSION

Energy should become cleaner and more efficient in the future. When compared to other alternative fuels, hydrogen is the most successful at reducing or eliminating hazardous vehicle emissions and environmental impact. Because hydrogen is one of the numerous elements found in the atmosphere, it is readily available and one of the most useful alternatives to fossil fuels today. Currently, the most used technique for hydrogen generation is steam–methane reforming.

In this review, the effect of adding hydrogen as a fuel on the performance and exhaust emissions of spark ignition (SI) and compression ignition (CI) engines was investigated.

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