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Study and Comparison of Carnot Engine with Hydrogen Fuel Cells and Hydrogen Fuel Engines.

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Abstract: *Today we are facing a crisis of fossil fuels and gasoline prices are at an all-time high due to various reasons. The rapid depletion and soaring prices of fossil fuels have forced us to discover new renewable resources to be used as fuels. With being renewable our energy systems should be sustainable, safe, and cost-effective. We can look forward to Hydrogen as one of the significant energy resources. The thermal efficiency of the Carnot engine is maximum. A comparison is made of Carnot efficiency and the efficiencies of other neat fuel and hydrogen-enriched fuel in engines as well as the fuel cells. For the same, we have studied hydrogen fuel cells, hydrogen use as primary fuel, and hydrogen used as secondary fuel in gasoline, diesel, and CNG engine. The outcome of this research was found to be a significant rise in the thermal efficiency of these engines in comparison with neat lean fuel mixtures.*

Keywords: Hydrogen, Fuel Cells, Engine, Carnot Engine, Efficiency

I. INTRODUCTION

Today maximum power generation and propulsion are done by fossil fuels. Using these fuels creates a lot of pollution and does not follow stringent emission norms. They emit various poisonous and greenhouse gases like Carbon Monoxide (CO), Carbon Dioxide (CO_2). To tackle this, various other fuels are being discovered and used one of which is Hydrogen. The reasons in use Hydrogen as fuel lie in its properties which we are going to discuss in detail. There exist many ways in which Hydrogen can be used as fuel.

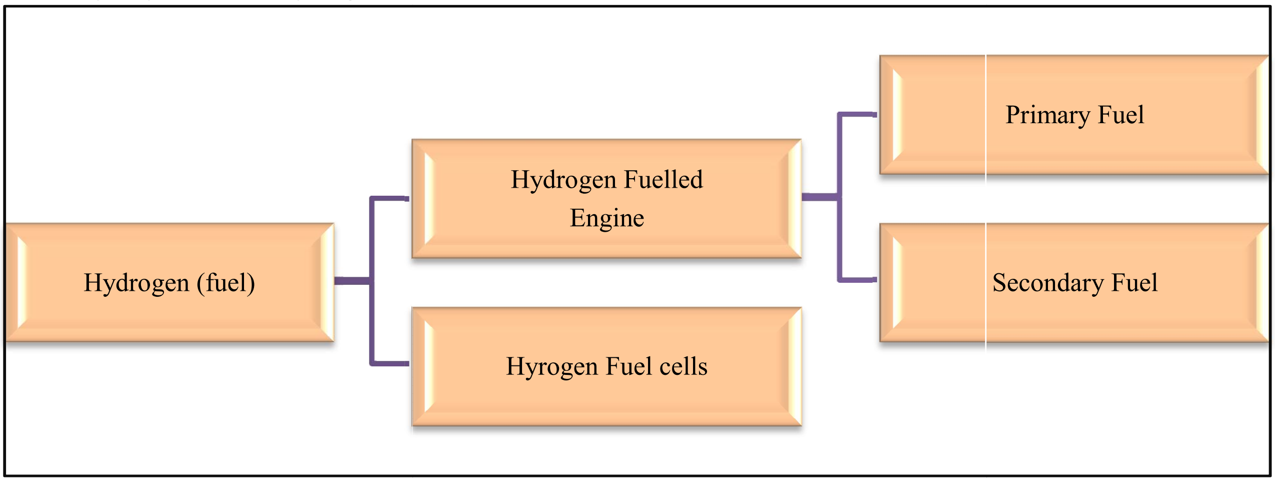

FIG 1: Shows methods in which Hydrogen can be used as fuel.

In fig 1 we see that Hydrogen can be used in engines as well as in fuel cells. Hydrogen fuel cells are an electrochemical cell that converts the chemical energy of a fuel and an oxidizing agent into electricity through a pair of redox reactions.[1]

The other type in which Hydrogen fuel can be used is in Engines. These engines are of two types that are Spark Ignition engine and Compression Engine.The spark-ignition engine uses a spark plug to create a spark in the Hydrogen and hence burn the fuel. Various research has been done on this matter and pure Hydrogen can be used in this engine is also proved. The other way Hydrogen can be used is by mixing it with other fuels like Natural Gas, Diesel, and Gasoline. On the other hand, in a compression engine Hydrogen is mixed with diesel and the ignition is done by compression stroke with the required pressure.

Hydrogen when used as fuel emits some amount of water without CO_2. This makes it environmentally friendly but it emits NO_x in some amount. [2] NO_x is a poisonous gas for human beings. It is emitted in small quantities which can be eliminated by some methods.

II. METHODOLOGY

We are going to study these engines, their efficiencies, and performance and compare them with the Carnot engine which is an ideal engine. When comparing the efficiencies of the Carnot engine and direct hydrogen fuel cell vehicles (DHFCV) in this study precaution needs to be taken to keep vehicle parameters identical. In simulating vehicles analyzed, it is important to check all the parameters. The mechanical properties of vehicles like aerodynamic drag coefficient, frontal area, tire diameter, and tire friction are invariable while the overall mass of the vehicle varies. For the battery hybrids, these fuel cell system designs include two additional components, a dc-dc converter, a large battery pack, and an additional controller to manage these additional components together with the fuel cell assemblage. These additional components enable regenerative braking to be implemented at the vehicle level and provide for the storage and reuse of this regenerative energy.[3]

In a gasoline engine, we analyzed the thermal efficiency of gasoline, gasoline-ethanol, and gasoline-ethanol-hydrogen blend. The tests were carried out at stoichiometric conditions at 1500rpm engine speed at different loads. Later the tests were done with 80% gasoline and 20% ethanol at the same conditions. In the final step, we added hydrogen in 10.7%, 21.3%, 33.8%, and 45.1% different mass fractions to the gasoline-ethanol blend. The last experiment was studied at 1500 rpm.[4]

A 4-stoke water-cooled single-cylinder direct injection CI engine was used in a diesel engine. It was coupled with an eddy current dynamometer to supply and measure the torque. Constant speed was kept at 1500 rpm. Hydrogen was directly supplied from a hydrogen storage tank and the thermal efficiencies were recorded for lean diesel engines and hydrogen-enriched diesel engines.[5]

The setup of a CNG engine consists of a single-cylinder engine coupled with an AC dynamometer. The experiments were performed at a constant speed of 1500rpm. The engine load and HCNG mass fractions were varied. A capacitive discharge ignition system was used to start the combustion of the fuel-air mixture in an engine. HCNG mixture of desired quality was pre-bottled before each experiment. The mixture was made using Dalton's law of partial pressure.[6]

III. RESULT AND DISCUSSIONS

3.1 Reasons for use of Hydrogen as fuel

A. Wide Range of Flammability

When we compare the flammability of all other fuels Hydrogen has a very wide flammability range (4% - 75% vs 1.4% - 7.6% volume in the air of gasoline) This raises some concerns about safety for handling Hydrogen. But if there is a lean mix which means the fuel-air mixture in which stoichiometric or chemically ideal amount. When the engine is run on a lean mix then it will increase the fuel economy due to the complete combustion of fuel.[7]

B. Low Ignition Energy

The amount of energy required to ignite hydrogen is less than other fuels. For Hydrogen air mix the ignition energy is 0.02 mJ and that of Gasoline is 0.24 mJ for petrol. This may increase the risk of premature ignition and flashback. [2]

C. Small Quenching Distance

Hydrogen has a small quenching distance which is about 0.6mm for Hydrogen and 2.0mm for Gasoline. A small Quenching Distance means that it will be more difficult to quench the Hydrogen flame than other fuels which will increase backfire.[7]

D. High Flame Speed

It is seen that when Hydrogen burns with a high flame speed it makes the hydrogen engine closer to the ideal engine. But when we use lean mix, it is seen the high flame speed is reduced to some extent.[7]

E. High Diffusivity

Hydrogen disperses quickly into the air which makes the fuel more homogeneous and uniform that reduces safety issues occurring by Hydrogen leaks.[7]

F. Low Density

Hydrogen has a very low density. It implies that without compression or changing its state to liquid a large volume may be necessary to store Hydrogen for an adequate driving range. Low Density means that in a lean mix there will be low energy density which will require more power.[7]

3.2 Carnot Engine

A Carnot Heat engine is a theoretical heat engine that works on the principle of the Carnot Cycle. The efficiency of the Carnot engine is not 1 which implies that any kind of engine could not have the efficiency of 1. The efficiency of any kind of heat engine is given by

$$h = 1 - Q_L/Q_H$$

Where Q_H is the heat transferred to the engine from the high-temperature reservoir at T_H and Q_L is the heat rejected to a low-temperature reservoir at T_L. For Reversible engines, the Carnot efficiency can be given by

$$h = 1 - T_L/T_H$$

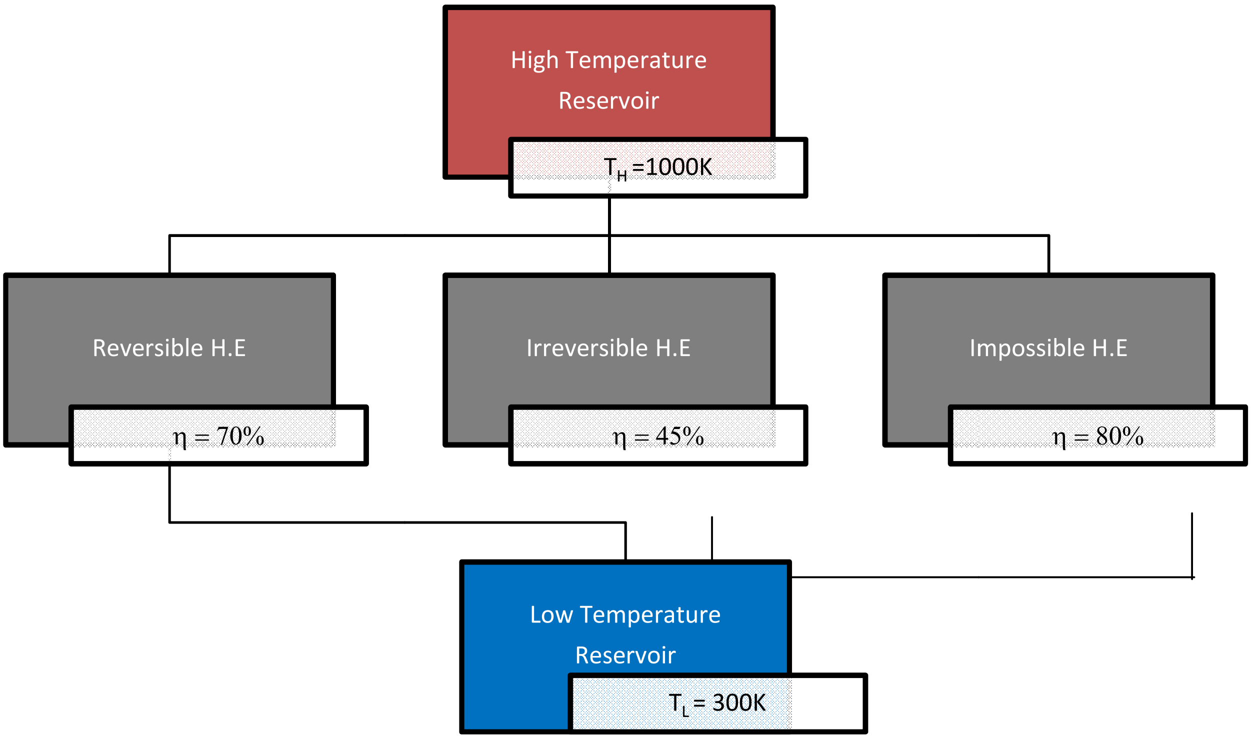

Fig 2: No heat engine can have higher efficiency than a reversible heat engine operating between the same high and low temperature.

Fig 2 explains the efficiencies of various heat engines. The maximum efficiency a Carnot heat engine can obtain is 70%. This is because the Carnot engine is a reversible heat engine. The engines we use in our daily life like Diesel engines, Petrol or gasoline engines, CNG engines, and others are irreversible engines. The maximum ideal efficiency they can attain is only 45%. Most working engines today have efficiencies under 40%. It seems very low compared to

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100% but we consider the maximum efficiency of the heat engine as the efficiency of a reversible heat engine because it is the true upper limit for the efficiency. The thermal efficiency of a real heat engine can be increased by supplying maximum heat at the highest possible temperature and minimizing the rejection of heat at the lowest possible temperature. In this paper, we will be comparing the efficiencies of other heat engines with the efficiency of the Carnot engine in the irreversible process which would be 45%.[8]

3.3 Comparison of Carnot Efficiency with the Existing Heat Engines.

In the given table below, we are going to compare the efficiencies of Petrol, Diesel, CNG, LPG, and electric engines to that of the Carnot Engine

Table I: Shows the Comparison of the efficiencies of various Heat Engines and that of the Carnot Heat Engine. [9-10-11-12-13]

SR NO	Type of Engine	Carnot Efficiency	Efficiency of Engine
1	Electric	-	77%
2	Hydrogen	45%	33%
3	Gasoline	45%	20% - 26%
4	Diesel	45%	25% - 30%
5	CNG	45%	25% - 30%

A. Hydrogen Fuel Cells

As discussed earlier, Hydrogen fuel cells are electrochemical cells that convert energy from Hydrogen to electrical energy. There are three ways in which Hydrogen Fuel Cells could be used. The three mixtures that can be used are hydrogen-oxygen, hydrogen-air, and methane-air.

B. Ideal Hydrogen Cell

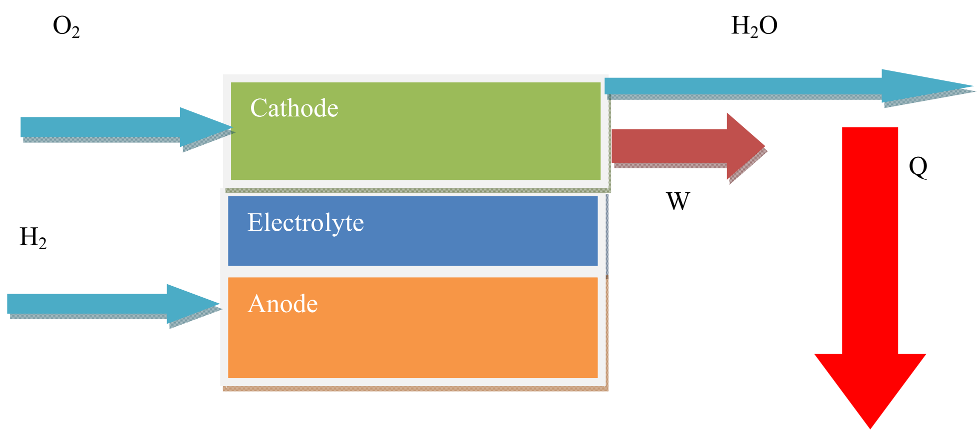

Fig 3: Schematics of Hydrogen Fuel Cells.

Fig 3 shows the schematic of an ideal hydrogen-oxygen fuel cell in which the anode is hydrogen and the cathode is oxygen. The operation of this fuel cell is steady-state, adiabatic, and isobaric. It is discussed in many thermodynamics textbooks that the Carnot efficiency limit is not applicable in the case of fuel cells while some counter it. But it is seen that the theoretical efficiency of Hydrogen fuel cells exceeds that of the Carnot efficiency. The lowest maximum efficiency of Hydrogen fuel cells is 79.3%, 75.7%, and 82.1%, and the highest maximum efficiency is 92.7%, 82.7%, and 82.7% for hydrogen-oxygen, hydrogen-air, and methane-air respectively. These values are obtained by applying the conservation of energy and entropy balance equation.[14] Several studies have found that the theoretical value ofthe fuel economy of this hydrogen fuel cell is going to be2.2-2.4 times the fuel economy of a gasoline engine.[15] According to the GM study, at a 50% likelihood point, the fuel economy of Hydrogen fuel cells would be 2.1 times greater than that of gasoline engines for the year 2005 and beyond.[16]So the fuel economy of hydrogen fuel cells is much greater than any other kind of internal combustible engine.

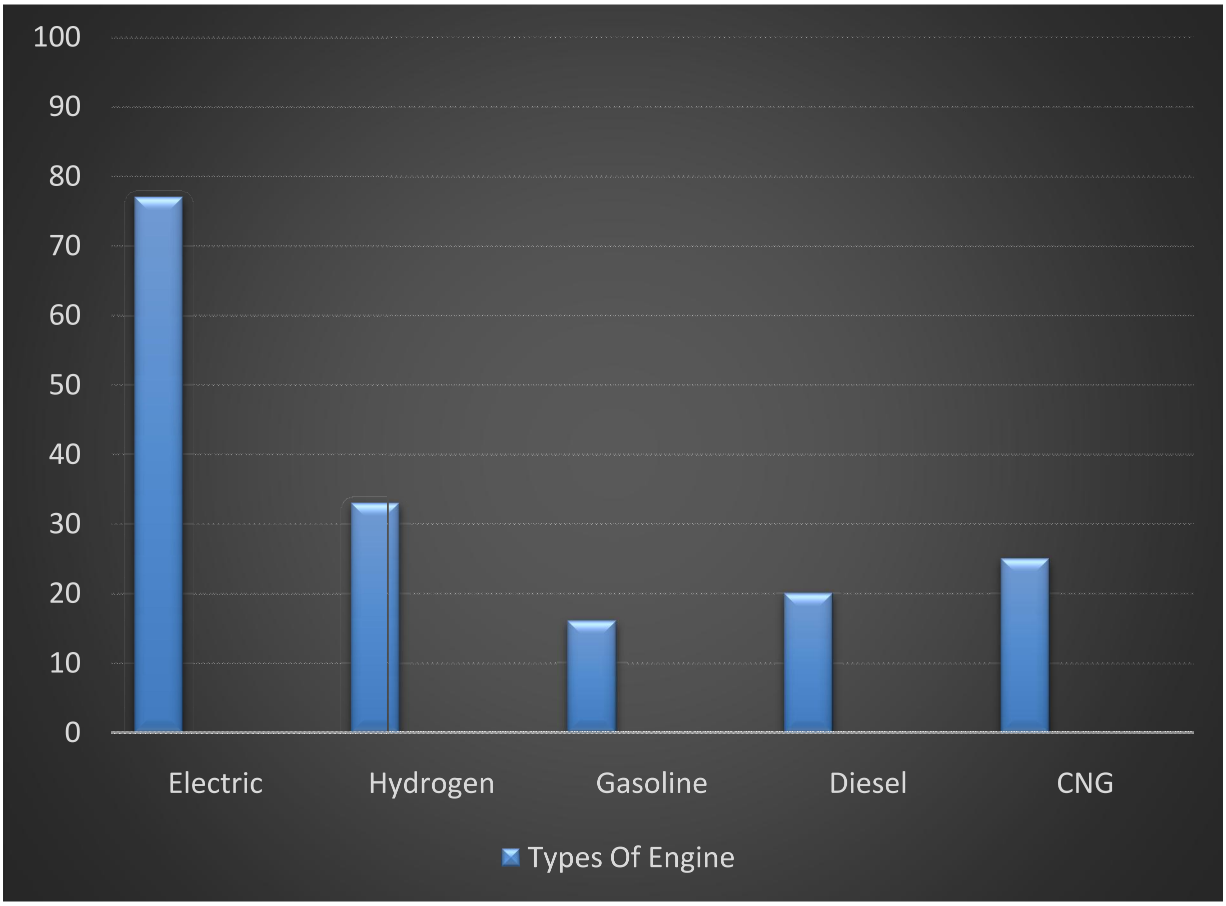

Fig 4: Graph representing the efficiencies of various engines by different fuel types.

In fig 4 we can see the comparison between the efficiencies of engines by direct electrification, hydrogen fuel cells, petrol, and diesel. Maximum efficiency is obtained by direct electrification. There is a loss in fuel production efficiency and overall efficiency of hydrogen fuel cells, diesel, and petrol engines.[13]

The efficiencies of hydrogen engines give us an efficiency of 33%. The efficiency of a hydrogen engine is greater than gasoline and diesel engine excluding mechanical loss.

The issue with direct electrification is that it is not environmentally friendly. In most countries, electricity generation is done by thermal energy that is by using coal and other harmful substances. Furthermore, the batteries which are used in cars are lithium-ion batteries. The extraction of lithium from mines is very difficult and causes a lot of pollution. So electric cars are not the best possible option for gasoline and diesel in terms of environmental effects.

The advantage of using a hydrogen engine is that hydrogen is easily available. It causes less pollution as it does not emit carbon dioxide and carbon monoxide. These are versatile to use. Hence hydrogen engines could be a better alternative.

3.4 Hydrogen use in International Internal Combustible Engine

There could be two possible ways in which Hydrogen can be used in an internal combustible engine. One way would be Hydrogen as primary fuel and the other way would be Hydrogen as secondary fuel.

A. Hydrogen as Direct Fuel

Various kinds of fuel are used in an internal combustible engines like Petrol, Diesel, LPG, and CNG. These fuels have different chemical properties and fuel-air mixture ratios. Therefore, it would be necessary to make modifications to the existing engines for using Hydrogen as a fuel. Touse hydrogen as direct fuel various car manufacturers have designed some engines. For example, BMW and Mercedes have created their “sole hydrogen engine”. The material selected for these engines was made with the greatest caution due to the low ignition energy of hydrogen, its flammability limits, and the high pressure and temperature caused by combustion. Also, the spark plugs have been designed uniquely according to the properties of Hydrogen.[17]

B. Hydrogen as Secondary Fuel

Hydrogen can be used in an internal combustion engine in two ways. The first way is to use it as direct fuel and the other way is to use it as additional fuel. There exist many problems while using hydrogen as direct fuel specifically due to its chemical properties. Another important problem is although hydrogen is light in nature the equipment used for its storage weighs high which increases the cost of modifications and other additional costs.

In the current scenario, it would be wise to use Hydrogen as secondary fuel in internal combustion engines. This does not make us independent from fossil fuels it would be an economic and eco-friendly change in the fuel system.[18]

Hydrogen can be used in different ways with different combustion techniques than other fuels like gasoline and diesel. For this to happen a reactor system should be installed in the vehicle. By this method, low ignition energy is obtained with heat recovery that benefits from the exhaust gases released from the engine, and the emissions that are harmful to the environment are reduced significantly. The use of Hydrogen as secondary fuel would be a transition from fossil fuels to Hydrogen as a direct fuel. [19]

C. Hydrogen use in a Gasoline Engine

Tremendous research has been done to use Hydrogen in Gasoline engines. Based on various properties of Hydrogen, several changes have to be done in an existing gasoline engine. The thermal efficiency of a hydrogen engine is nearly the same as that of a gasoline engine. It was observed that the efficiency increases together with a reduction in harmful exhaust emissions in engines using Hydrogen as a fuel.[20]

When a lean mixture of Hydrogen- Gasoline- Ethanol blend was taken. The experiment was done with 1500rpm with Hydrogenin a gasoline-ethanol blend(G80E20)and the performance was analyzed. The thermal efficiency of the gasoline-ethanol blend (G80E20) was found to be 25.7% and 31% under 50% and 100% engine loads at 1500 rpm. The addition of ethanol in gasoline reduces the energy density of the fuel. So, the thermal efficiency falls by ethanol addition. The thermal efficiency value for different H_2 mixtures and 1500 rpm. The thermal efficiency values measured 25.6, 28.7, 29.5, 31.1, and 30.9% for 0,10.7, 21.3, 33.8, and 45.1% of hydrogen mass fractions respectively. The thermal efficiency is increased from 25.6% to 30.9% with Hydrogen addition to 45.1% to the gasoline-ethanol blend.[4]

D. Hydrogen use in a CNG engine

As we know that CNG is seen as an alternative to gasoline and diesel engines. The reason for it lies in its property of low emission of carbon dioxide (CO_2) and carbon monoxide (CO). Also, it produces fewer particulates. But it also emits methane gas (CH_4) in large quantities. Methane gas has a 21times higher global warming potential than CO_2. So, a proper after-treatment system is required. The engine speed was constant at 1500rpm.[21]

Break Thermal Efficiency (BTE) demonstrates the overall conversion efficiency of fuel’s chemical energy to mechanical energy, which is available at the engine shaft. CNG showed low brake thermal efficiency than HCNG due to relatively higher combustion efficiency and superior combustion stability. When Brake Mean Effective Pressure(BMEP) was 5.3 bar CNG showed 25.7% BTE while 10HCNG, 20HCNG, 30HCNG showed 27.2%, 28.1% and, 28.5% BTE respectively. Similarly, when the BMEP was increased to 6.18 bar CNG, 10HCNG, 20HCNG, and 30HCNG showed BTE of 28%, 28.6%, 29.3%, and 29.7% respectively.

As the BMEP increased the BTE also increased and more fuel was consumed resulting in the fuel-air mixture becoming richer.[6]

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E. Hydrogen use in Diesel Engine

The diesel engine is a Compression ignition (CI) engine. The ignition occurs due to the compression of the air-diesel mixture. The addition of hydrogen in the diesel engine would ensure more rapid ignition than normal due to the low ignition energy of hydrogen. A 1500 rpm engine was taken.

The flow of Hydrogen was kept constant at 0.15kg/h. The variation in brake thermal efficiency (BTE) with load for neat diesel engine and diesel with 0.15kg/h hydrogen enrichment was observed. The BTE of the neat diesel engine was observed to be 30.2% while that of the hydrogen-enriched diesel engine was 34.1%. It is observed that the flow rate of hydrogen starts increasing and that of diesel starts decreasing which indicates that hydrogen is being consumed in this reaction. The increase in thermal efficiency is a result of enhanced combustion rate due to the high flame speed of hydrogen. It was also observed that the combustion efficiency of hydrogen in the presence of diesel is maximum when the load is between 20% to 40%.[22]

3.5 Result Table

Table II: Depicts the result of this research

SR NO	Type of Engine	Carnot Efficiency	Engine Efficiency	Engine Efficiency + Hydrogen	Percentage Rise
1	Electric	-	77%	-	-
2	Hydrogen fuel cells	-	79.3%	-	-
3	Hydrogen	45%	33%	-	-
4	Gasoline	45%	25.6%	30.9%	20.7%
5	Diesel	45%	30.2%	34.1%	12.91%
6	CNG	45%	28%	29.7%	6.07%

IV. CONCLUSION

- The thermal efficiency of all kinds of engines increased after the addition of hydrogen in all the fuels.
- The highest thermal efficiency was found to be of Hydrogen enriched Diesel engine to be followed by hydrogen enriched Gasoline engine to be followed by a CNG engine.
- The thermal efficiency of hydrogen fuel cells was maximum. It cannot be compared to Carnot's efficiency because it is not a heat engine.
- Use of Hydrogen fuel cells and hydrogen-enriched fuels is highly recommended to increase the efficiency of vehicles as well as to control emissions.
- Hydrogen cannot be used as direct fuel because many modifications are required in an existing engine.

REFERENCES

[1]. https://en.wikipedia.org/wiki/Fuel_cell

[2]. Murat CİNİVİZ, Hüseyin KÖSE, HYDROGEN USE IN INTERNAL COMBUSTION ENGINE:A REVIEW, International Journal of Automotive Engineering and Technologies Vol.1, Issue 1, pp. 1-15, 2012

[3]. R.M. Moore, K.H. Hauer, S. Ramaswamy, J.M. Cunningham, Energy utilization and efficiency analysis for hydrogen fuel cell vehicles, Journal of Power Source, https://doi.org/10.1016/j.jpowsour.2005.12.083

[4]. Selahaddin Orhan Akansu, Selim Tangoz ,Nafiz Kahraman,Mehmet Ilhan Ilhak , Salih Acikgoz, Experimental study of gasoline-ethanol-hydrogen blends combustion in an SI engine, International Journal of Hydrogen Energy, http://dx.doi.org/10.1016/j.ijhydene.2017.07.014.

[5]. Balaji Subramanian, Venugopal Thangavel, Experimental investigations on performance, emission and

combustion characteristics of Diesel- Hydrogen and Diesel-HHO gas in a Dual fuel CI engine, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2020.06.280

[6]. Tadveer Singh Hora, Avinash Kumar Agarwal, Experimental study of the composition of hydrogen-enriched compressed natural gas on engine performance, combustion and emission characteristics, Fuel, http://dx.doi.org/10.1016/j.fuel.2015.07.078.

[7]. Gillingham K., Hydrogen Internal Combustion Engine Vehicles: A Prudent Intermediate Step or a Step in the Wrong Direction? Department of Management Science & Engineering Global Climate and Energy Project, Precourt Institute for Energy Efficiency, Stanford University, Pages 1-28, 2007

[8]. YUNUS A. ÇENGEL, MICHAEL A. BOLES, MEHMET KANOĞLU, Thermodynamics: An Engineering Approach, Ninth Edition.

[9]. D. Splitter, V. Boronat, F. Chuahy, and J.Storey, Performance of Direct Injected Propane and Gasoline in a High 1Stroke-to-Bore ratio SI Engine: Pathways to Diesel Efficiency Parity with Ultra-Low Soot, THIESEL 2020 Conference on Thermo- and Fluid Dynamic Processes in Diesel Engines.

[10]. Aiman ALBATAYNEH, Mohammad N. ASSAF, Dariusz ALTERMAN, Mustafa JARADAT, Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles, Environmental and Climate Technologies 2020, vol. 24, no. 1, pp. 669–680.

[11]. https://en.wikipedia.org/wiki/Engine_efficiency

[12]. https://rentar.com/efficient-engines-thermodynamics-combustion-efficiency

[13]. https://cleantechnica.com/2021/02/01/chart-why-battery-electric-vehicles-beat-hydrogen-electric-vehicles-without-breaking-a-sweat/

[14]. Y. Haseli, Maximum conversion efficiency of hydrogenfuel cells, International Journal of Hydrogen Energy 2018.

[15]. Rajesh K. Ahluwalia∗, X. Wang, A. Rousseau, R. Kumar, Fuel economy of hydrogen fuel cell vehicles, Journal of Power Sources 130 (2004) 192–201.

[16]. Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems—North American Analysis, vol. 2, General Motors Corporation, June 2001

[17]. Murcak A. Experimental analysis of the effect of hydrogen fuel on diesel engine performance and exhaust emissions G.U¨ . Mater Thesis. Automotive Department; 2003.

[18]. Birsen EB. Use of hydrogen fuel in internal combustion engines, Erciyes University. Master Thesis. Kayseri: Natural Sciences Institute; 2008. p. 1e5.

[19]. Akal D et al., A review of hydrogen usage in internal combustion engines (gasoline-Lpg-diesel) from a combustion performance aspect, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2020.02.001

[20]. Vorst W, Finegold JG. Automotive hydrogen engines, and Onboard storage Methods, Hydrogen energy Fundamentals, Miami Beach, Florida U.S.A. 1975.

[21]. Sunyoup Lee, Changgi Kim, Young Choi, Gihun Lim, Cheolwoong Park, Emissions and fuel consumption characteristics of an HCNG-fueled heavy-duty engine at idle, International Journal of Hydrogen Energy, http://dx.doi.org/10.1016/j.ijhydene.2014.03.079

[22]. Probir Kumar Bose*, Dines Maji, An experimental investigation on engine performance and emissions of a single cylinder diesel engine using hydrogen as inducted fuel and diesel as injected fuel with exhaust gas recirculation, International Journal of Hydrogen Energy, doi:10.1016/j.ijhydene.2008.10.077.