College of Engineering and Technology

Mechanical Engineering Department

Hydrogen Diesel Dual Fuel System
Built And Test

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2012

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Chapter one : Introduction

1.1 Introduction

Because of high demand of fuel in the world for its usage in vehicles, it leads to rise its price. Though this resource of fuel is vanishing, the societies and developed countries have the intention to find alternative fuel. This alternative must be available and ought to be economical, in addition it mustn't cause pollution.

Therefore, those who are interested in this field invented vehicles that work on renewable energy such as solar power and electric power. Unfortunately, they found that this new system is not efficient. Also they invented other vehicle that work on fuel cells. This invention found to be more efficient and a good alternative as well. However, it was found expensive and difficult to apply in our developing countries.

Therefore, they looked for other alternative with less cost and easier to handle. So scientists and researchers made experiments and researches on using hydrogen partially in internal combustion engine.

1.2 Previous study

The idea of injecting hydrogen in diesel engine started since 1980s.

1- Experimental investigation on in-cylinder pressure and emission of diesel engine with port injection hydrogen system [1].

In this study, performance and emissions analyses of diesel engine with port injection hydrogen system were carried out experimentally. Hydrogen gas was continuously injected to intake airstreams using port injection technique at a constant rate of 0.10 g/s. The result of performance in the form of pressure versus crank angle was studied. The emissions data acquired from gas analyzer was recorded for the purpose of comparison in diesel engine with and without hydrogen injection system.

- **Result of study**

a- In cylinder Pressure:

The pressure curve has the tendency to shift to the right as hydrogen is added into the cylinder charge since hydrogen with high auto-ignition temperature (858K) ignites after pilot ignition of diesel .Sudden increase in pressure after 20 ATDC indicates auto ignition of hydrogen has been reached parallel to pilot ignition of diesel. This is perhaps due to high flame speed of hydrogen (3.24 to 4.40 ms) causes fast combustion propagation of the in-cylinder charge which was only initiated from pilot ignition ,figure(1-1)shows the result .

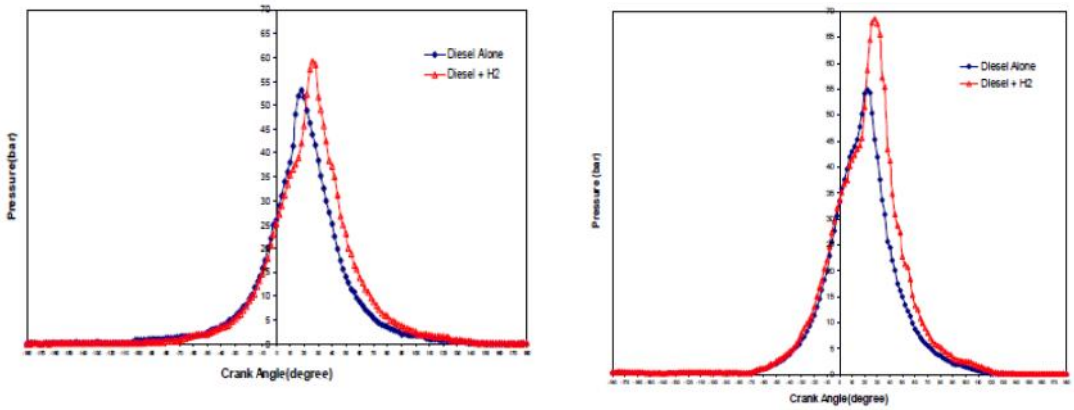

Figure (1-1): Variations of in-cylinder pressure with crank angle at (a) 1500RPM and (b) 3000RPM

b-Emissions:

- **The effect on NOx**

NOx concentration and temperature increases as speed increased until 2500 rpm, further increase in speed drops the temperature and consequently NOx emissions. The hydrogen on combustion temperature leads to increase of NOx emissions ranges between 50 to 200 ppm with port injection hydrogen system. Hydrogen increases the energy release, which has a positive contribution to enhance charge temperature to form NOx (thermal NOx) in both the flame front and the post flame of the charge.

- **The effect on (HC)**

In the dual fuel operation with port injection hydrogen, there was a slight reduction of HC emissions at the average of 15 ppm. One of the possible reasons is the hydrocarbon oxidation. High diffusivity of hydrogen reduces the flame-quenching rate in diesel engine causes wall-quench hydrocarbons apparently diffuse into the burning charge and oxide following the quenching event.

Conclusions of the study

1- Port injection of hydrogen increases the in-cylinder peak pressure ranges between 5 bar to 23 bar comparable to diesel alone operation and the highest peak pressure occurs at 2500 rpm.

2- Higher peak pressure shows better network output of the engine as compared to the engine running on diesel alone.
3- The presence of hydrogen causes a slight decrease in HC emissions at the average of 15 ppm as compared to diesel alone operation due to hydrocarbon oxidation.
4- Hydrogen injection causes CO2 and CO emissions to be increased from 1.1% to 4.2% (by volume) and 420 to 760 ppm, respectively as compared to diesel alone operation.
5- The reduction of O_2emissions at the average of 15 ppm (by volume) is due to hydrocarbon oxidation, crevice effect and formation of local fuel rich region.
6- Hydrogen increases the energy release, which has a positive contribution to enhance charge temperature causes increase in NOx concentration ranges between 50 to 200 ppm and exhaust gas temperature ranges between from 3.1% to 10.2% throughout all engine speeds. [2]

2- An experimental study of a direct injection compression ignition hydrogen engine. [2]

The study is an experimental setup for the testing of a diesel engine in direct injection hydrogen-fuelled mode. Test results showed that the use of hydrogen direct injection in a diesel engine gave a higher power to weight ratio when compared to conventional diesel-fuelled operation, with the peak power being approximately14% higher. The use of inlet air heating was required for the hydrogen-fuelled engine to ensure satisfactory combustion, and a large increase in the peak in-cylinder gas pressure was observed. A significant efficiency advantage was found when using hydrogen as opposed to diesel fuel, with the hydrogen-fuelled engine achieving a fuel efficiency of approximately 43% compared to 28% in conventional, diesel-fuelled mode. A reduction in nitrogen oxides emissions formation of approximately 20% was further observed.

- **results of study**

a- Basic engine performance:

With the inlet air heating system, stable engine operation was achieved in hydrogen direct injection mode. Despite a reduced air mass flow through the engine due to the inlet air heating, an increase of more than 14% in peak power was achieved for the hydrogen-fuelled engine compared to conventional diesel operation. This is due to the higher heating value of hydrogen per standard kg of charge air.

The in-cylinder gas pressure for one cycle in hydrogen-fuelled mode at full load (the graph is produced by the engine monitoring system). The fast combustion process with a rapid pressure rise can be seen, and a very high peak pressure was obtained, more than 30% higher than when operating in conventional, diesel-fuelled mode, which is due to the high engine power output, figure (1-2) show the change .

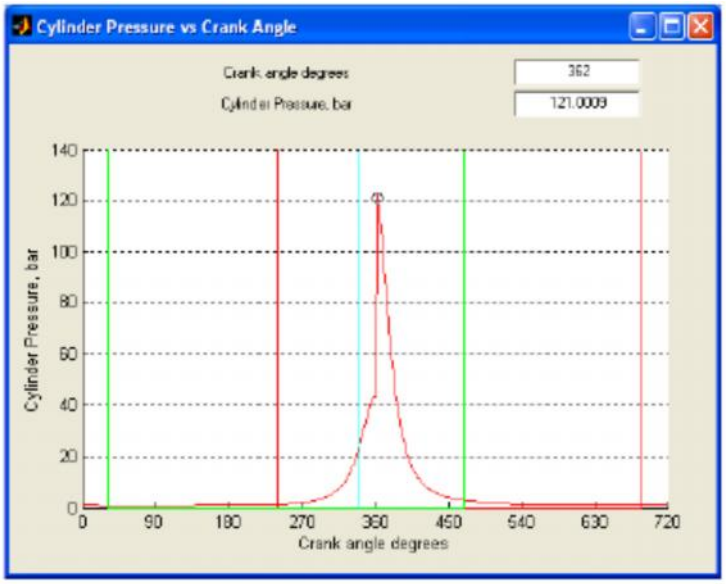

Figure (1-2): The in-cylinder gas pressure

Engine efficiency was significantly higher in hydrogen direct injection (DI) mode, with the engine achieving a brake efficiency of 42.8%, compared with 27.9% when using diesel fuel. As can be seen from the table(1-1), this is mainly due to lower losses to the cooling system, which constitute engine frictional losses and heat transfer losses, mainly to the combustion chamber walls. The frictional losses are not heavily influenced by the choice of fuel, but the increased engine power makes the relative influence of the mechanical losses lower in hydrogen-fuelled mode. Reduced in-cylinder heat transfer losses are expected in the hydrogen-fuelled engine due to the properties of the gaseous fuel, leading to enhanced fuel-air mixing, thereby reducing peak gas temperatures, and the lower inertia of the fuel, reducing the problems associated with spray-wall impingement ,table (1-1) shows the engine efficiency results.

Table (1-1): The engine efficiency results for the different operating mood

	Diesel Dl	Dual fuel (diesel + H_2)	H_2 HCCl	H_2 Dl
Shaft output [%]	27.9	33.9	48.0	42.8
Cooling system [%]	42.2	31.2	20.4	17.3
Exhaust gases [%]	35.3	34.9	31.6	39.9
Shaft power [%]	9000	8950	7076	10280

b- The effect on NOx

As expected, the nitrogen oxides formation is low at low loads, for which the cylinder charge is lean and in-cylinder temperatures are lower, but increases sharply with increasing load. A clear NOx emissions advantage for the hydrogen-fuelled engine can be seen over the full load range, with the NOx levels being approximately 20% lower than those obtained under diesel-fuelled operation. Although the peak gas pressures are higher in hydrogen-fuelled mode due to the higher fuel burn rate, this is seen not to have an adverse effect on NOx formation. This suggests that the peak gas temperatures are lower in hydrogen-fuelled mode due to enhanced fuel-air mixing and more homogeneous conditions within the combustion chamber. High-temperature zones, such as those occurring in the outer regions of the fuel spray in conventional diesel operation are reduced. This is also supported by the results for in-cylinder heat transfer losses presented above ,figure (1-3)shows the measured NOx emissions.

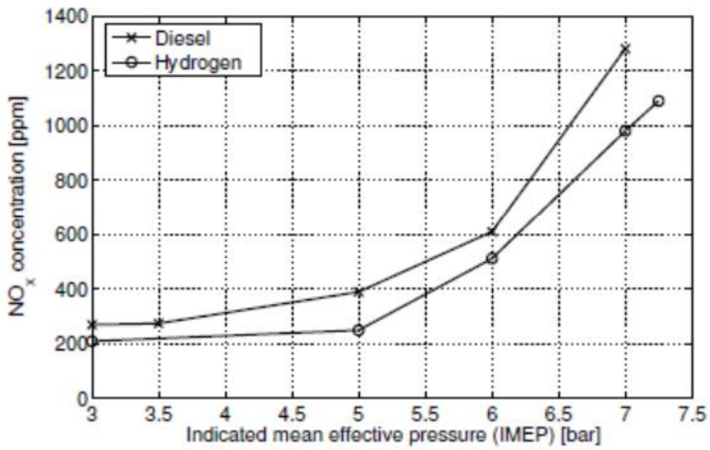

Figure (1-3): The measured NOx emissions

1.3 The main objectives of the project

1. The project has been selected mainly to decrease fuel consumption.
2. Minor to decrease harmful emission.
3. Integrate the engine power.

1.4 The importance of project

The importance of the project for a vehicle can be summarized as follows:

1. Continuance increasing of fuel price.
2. Limited sources of fuel .
3. Reducing emissions from ICE.

1.5 project description

Four cylinder diesel engine will be used in addition to hydrogen injection system. Hydrogen will introduce to the intake manifold by a mixer before entering the combustion chamber. Hydrogen will be passing through a fine control valve to adjust flow rate then through a gas flow meter to meter the flow of hydrogen. The component of the system shows in figure (1-4).

Two different types of tests will be conducted during this investigation. In the first set hydrogen flow rate was maintained constant while the diesel fuel flow rate increased to increase the engine speed.

In the second set the engine again runs at constant speed but the hydrogen flow rate will be varied.

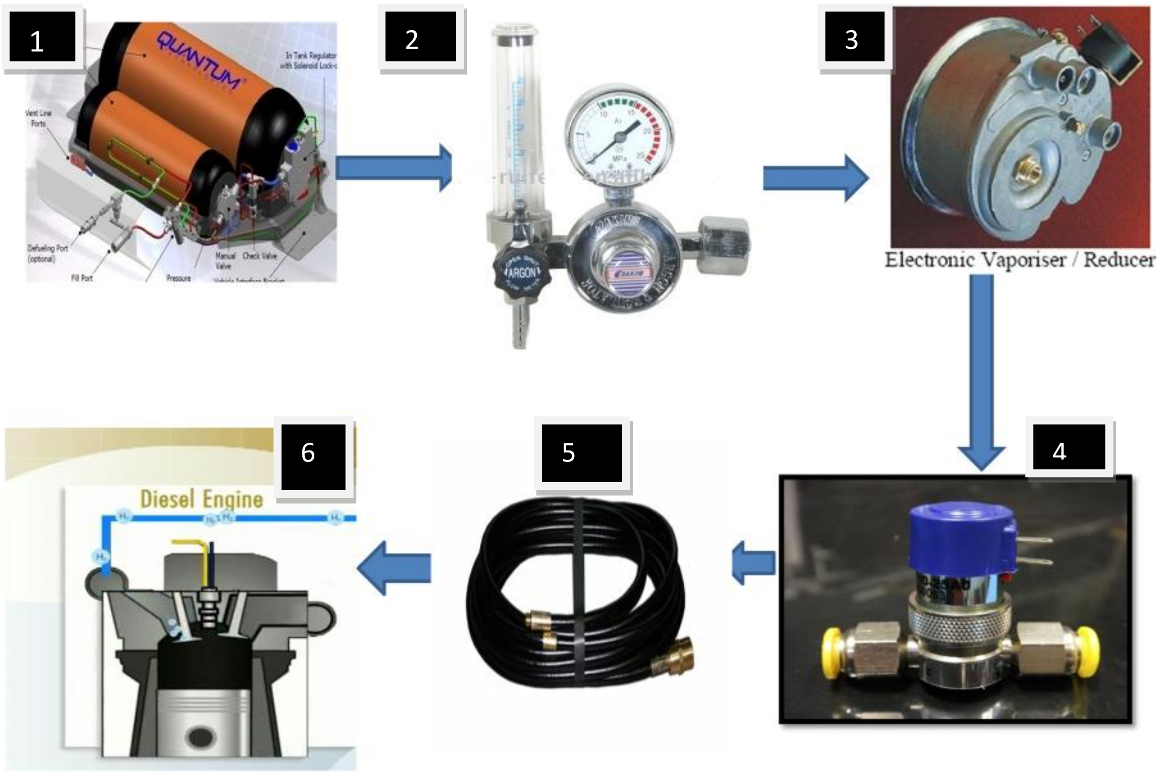

Figure (1-4) system description

- **System content , figure (1-4)**

1. H_2 reservoir.
2. Flow meter.
3. Electronic Vaporizer.
4. Shutoff Valve.
5. Connection pipe.
6. intake manifold.

1.6 Time Planning For The Project

The project time plan follows the time schedules shown below. It includes the related tasks of study and system analysis. Time plan is divided on both first and second semester:

Table (1-2) :Shows the first semester time plan

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choosing project																
Collecting information																
Reading																
Introduction																
Choosing the engine																
Analysis and equation preparing																
Analysis and equation for engine power																
Preparing& printing																
Project Documentation																

Table (1-3): Shows the second semester time plan

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project frame building																
System building																
Accessory Selection																
Operating the apparatus and testing																
Recommendations																
Conclusions																
Project Documentation																

1.7 Budget

Table (1-4):The budget

Task	**#**	**COST (NIS)**	**Total**
First axis	1rf	150	150
Second axis	1	200	200
welding	6	30_50	200
Engine mounting	1	150	150
Plastic pipe	_	100	100
Hydraulic oil	1	20	20
Diesel	2	50	50
bolt	5	20	100
Frame of project	1	350	350
Wheels	8	13	100
Total			

Chapter Two: Characteristics of engine and fuel

2.1 Introduction

This chapter will handle the characteristic of engine, and some of its properties. In addition it will also talk about hydrogen fuel and its properties as well as diesel fuel properties.

2.2 Diesel engine [1]

The development of the internal combustion engine began in the late eighteenth century. Slow but steady progress was made over the next hundred years. By 1892, Rudolf Diesel had received a patent for a compression ignition reciprocating engine. However, his original design, which used coal dust as the fuel, did not work.

Thirty-three years earlier, in 1859, crude oil was discovered in Pennsylvania. The first product refined from crude was lamp oil (kerosene). Because only a fraction of the crude made good lamp oil, refiners had to figure out what to do with the rest of the barrel. Diesel, recognizing that the liquid petroleum byproducts might be better engine fuels than coal dust, began to experiment with one of them. This fuel change, coupled with some mechanical design changes, resulted in a successful prototype engine in 1895. The first commercial diesel engines were large and operated at low speeds.

They were used to power ships, trains, and industrial plants. By the 1930s, diesel engines were also powering trucks and buses. An effort in the late ’30s to extend the engine’s use to passenger cars was interrupted by World War II. After the war, diesel passenger cars became very popular in Europe; but, they have not enjoyed comparable success in the United States yet. Today, diesel engines are used worldwide for transportation, manufacturing, power generation, construction, and farming. The types of diesel engines are as varied as their use – from small, high-speed indirect-injection engines to low-speed direct-injection behemoths with cylinders one meter (three feet) in diameter. Their success comes from their efficiency, economy, and reliability.

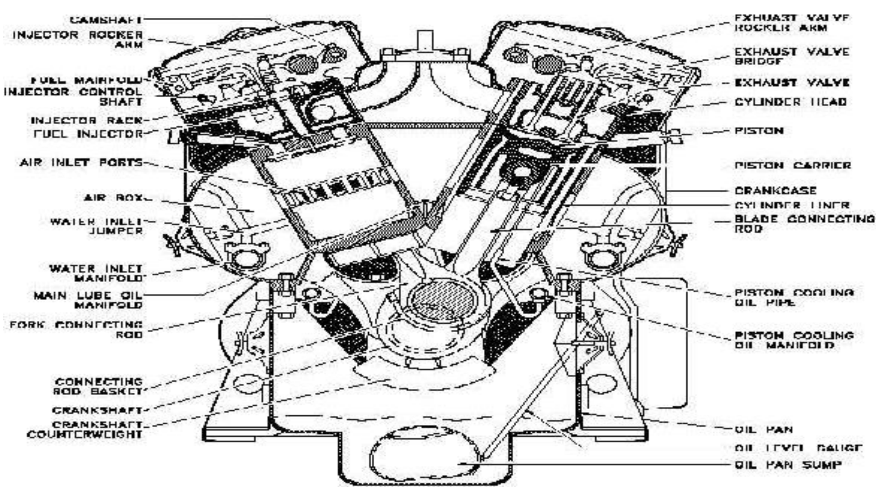

Figure (2-1):The diesel engine and its components (parts)

2.3 Engine characteristics, table (2.1).[2]

Table (2-1):Engine characteristics

Vehicle identification	
No. of cylinders	Type:4/OHC
capacity	Cc:2068
Compression ratio	1:22
Injection system	
Fuel injection pump assembly	Make : Bosch
Fuel injection pump assembly	Type: VA4/9 CL 1163-1
Fuel injection pump assembly	Part No. :0 460394016
Injection sequence	:1-3-4-2
Injector nozzle	Make: Bosch
Nozzle and holder assembly	Part No.:0 432217052
Nozzle opening pressure – new/used	Bar : 125/113
Tuning and emissions	
Plunger travel (pump)	Mm ABDC : 1,17
Adjusting method	Engine pump : pointer / dial gauge
Idle speed	Rpm: 650-750
Rated no load speed	Rpm : 4400
Starting and changing	
Battery	V/RC(Ah): 12
Starter motor	Make :bosch
Starter motor	Type: 0 001 362 071
Alternator	Make :bosch
Alternator	0 120 489 767
Regulated voltage	V : 13, 7-14,5
Glow plugs	
Glow plugs nominal rating	V/A : 11/8,5
Glow plugs activation time	Sesc : 20 max
Glow plugs – part no	Beru : 105 MN
Glow plugs – part no	Bosch : 0 250 200 051
Glow plugs – part no	Champion : CH 63
Glow plugs – part no	Lucas/ CAV : DS006
Service checks and adjustments	
Lubricants and capacities	
Tightening torques	

2.4 Hydrogen [3]

hydrogen is a source of renewable, clean energy, which can be used in fuel cells to generate electricity. Hydrogen can also be used to provide power in another way through a process known as combustion. Hydrogen combustion can provide a source of clean energy to power vehicles and how a hydrogen combustion engine works. [3]

Hydrogen can provide power in two ways: hydrogen fuel cells can be used to create electricity or hydrogen combustion engines can be used to power vehicles. Hydrogen has an advantage over petrol or diesel. When hydrogen is burnt it only produces water.

2.5 Hydrogen properties [3]

Hydrogen is by far the most plentiful element in the universe, making up 75% of the mass of all visible matter in stars and galaxies.

Hydrogen is the simplest of all elements. A hydrogen atom can be visualized as a dense central nucleus with a single orbiting electron, much like a single planet in orbit around the sun. Scientists prefer to describe the electron as occupying a "probability cloud" that surrounds the nucleus some-what like a fuzzy, spherical shell.

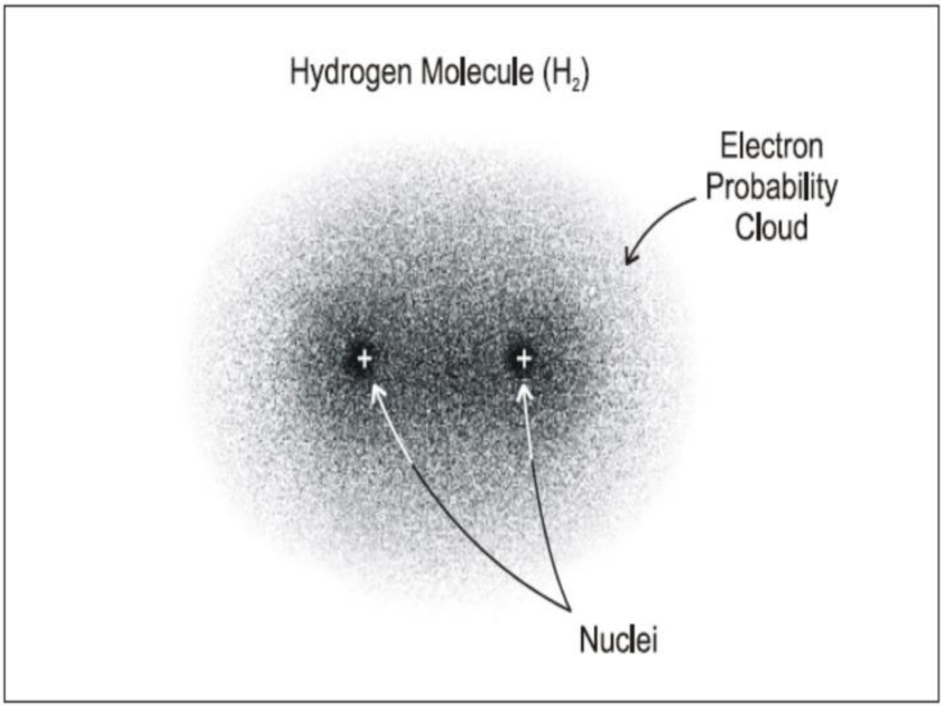

Figure (2-2):The atoms H2

- **State**

All substances exist on earth as either a gas, liquid or solid. Most substances will change from one of these states to another depending on the temperature and pressure of their surroundings. In general, a gas can be changed into a liquid by reducing its temperature, and a liquid to a solid by reducing its temperature further. To some extent, an increase in pressure will cause a substance to liquefy and solidify at higher temperature than would otherwise be required.

The transition from liquid to gas is known as boiling and the transition from liquid to solid as freezing. Accordingly, each substance has a characteristic boiling temperature and freezing temperature (at a given pressure). The opposite transitions, from gas to liquid and solid to liquid, are known as condensation and melting respectively. The condensation temperature is the same as the boiling temperature and the melting temperature is the same as the freezing tempera-true. The process of condensation is also known as liquefaction and the process of freezing is also known as solidification.

Hydrogen has the second lowest boiling point and melting points of all substances, second only to helium. Hydrogen is a liquid below its boiling point of 20 K (–423 ºF; –253 ºC) and a solid below its melting point of 14 K (–434 ºF; –259 ºC) and atmospheric pressure.

- **Odor, Color and Taste**

Pure hydrogen is odorless, colorless and tasteless. A stream of hydrogen from a leak is almost invisible in daylight. Compounds such as mercaptans and thiophene that are used to scent natural gas may not be added to hydrogen for fuel cell use as they contain sulfur that would poison the fuel cells.

- **Toxicity**

Hydrogen is non-toxic but can act as a simple asphyxiate by displacing the oxygen in the air.

- **Density**

Density is measured as the amount of mass contained per unit volume. Density values only have meaning at a specified temperature and pressure since both of these parameters affect the compactness of the molecular arrangement, especially in a gas. The density of a gas is called its vapor density, and the density of a liquid is called its liquid density ,table (2-2)shows the density for different liquids.

Table (2-2):The hydrogen density [4]

substance	Vapor density (at 68º F;20ºC,1 atm)	Liquid density (at normal boiling point,1 atm)
Hydrogen	0.005229 lb/ft^3 (0.08376 kg/m^3)	4.432 lb/ft^3 (70.8 kg/m^3)
Methane	0.0406 lb/ft^3 (0.65 kg/m^3)	26.4 lb/ft^3 (422.8 kg/m^3)
Gasoline	0.275 lb/ft^3 (4.4 kg/m^3)	43.7 lb/ft^3 (700 kg/m^3)

- **Specific volume**

Specific volume is the inverse of density and expresses the amount of volume per unit mass. Thus the specific volume of hydrogen gas is 191.3 ft3/lb (11.9 m3/kg) at 68 ºF (20 ºC) and 1 atom, and the specific volume of liquid hydrogen is 0.226 ft3/lb (0.014 m3/kg) at –423 ºF (–253 ºC) and 1 atm.

- **Expansion Ratio**

When hydrogen is stored as a liquid, is vaporizes upon expansion to atmospheric conditions with a corresponding increase in volume. Hydrogen’s expansion ratio of 1:848 means that hydrogen in its gaseous state at atmospheric conditions occupies 848 times more volume than it does in its liquid state. Figure (2-3).

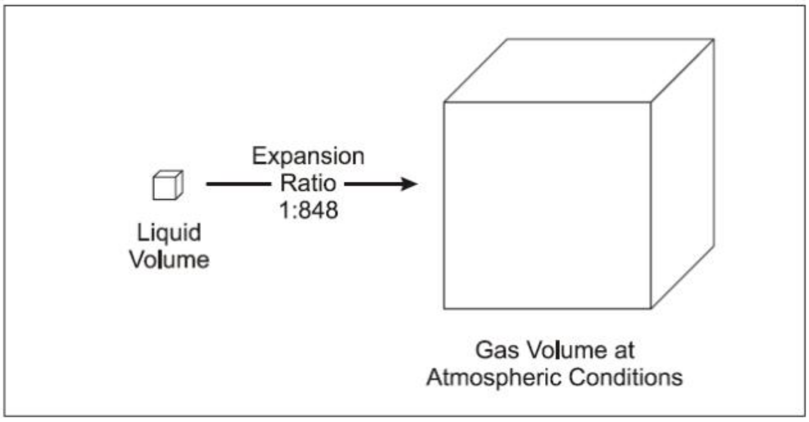

Figure (2-3):The H2 expansion ratio

When hydrogen is stored as a high-pressure gas at 3600 psig (250 bar) and atmospheric temperature, its expansion ratio to atmospheric pressure is 1:240. While a higher storage pressure increases the expansion ratio somewhat, gaseous hydrogen under any conditions cannot approach the expansion ratio of liquid hydrogen.

- **Energy**

Every fuel can liberate a fixed amount of energy when it reacts completely with oxygen to form water. This energy content is measured experimentally and is quantified by a fuel's higher heating value (HHV) and lower heating value (LHV). The difference between the HHV and the LHV is the "heat of vaporization" and represents the amount of energy required to vaporize a liquid fuel into a gaseous fuel, as well as the energy used to convert water to steam.

Flashpoint

All fuels burn only in a gaseous or vapor state. Fuels like hydrogen and methane are already gases at atmospheric conditions, whereas other fuels like gasoline or diesel that are liquids must convert to a vapor before they will burn. The characteristic that describes how easily these fuels can be converted to a vapor is the flashpoint. The flashpoint is defined as the temperature at which the fuel produces enough vapors to form an ignitable mixture with air at its surface.

If the temperature of the fuel is below its flashpoint, it can- not produce enough vapors to burn since its evaporation rate is too slow. Whenever a fuel is at or above its flashpoint, vapors are present. The flashpoint is not the temperature at which the fuel burns, that is the auto ignition temperature.

The auto ignition temperature is the minimum temperature required to initiate self sustained combustion in a combustible fuel mixture in the absence of a source of ignition. In other words, the fuel is heated until it burns into flame

Each fuel has unique ignition temperature. For hydrogen, the auto ignition temperature is relatively high at 1085 ^oF(585 ^oC). This makes it difficult to ignite a hydrogen/air mixture on the basis of heat alone without some additional ignition source. The auto ignition temperatures of comparative fuels are indicated in ,shown table (2-3).

Table (2-3):Flashpoint [5]

Autoignition Temperature	Fuel
1085 ^oF (585 ^oC)	**Hydrogen**
1003 ^{o} F (540 ^oC)	**Methane**
914 ^oF (490 ^oC)	**Propane**
725 ^oF (385^oC)	**Methanol**
450 to 900 ^oF (230 to 480 ^oC)	**Gasoline**

- **Burning Speed**

Burning speed it the speed at which a flame travels through a combustible gas mixture.

Burning speed is different from flame speed. The burning speed indicates the severity of an explosion since high burning velocities have a greater tendency to support the transition from deflagration to detonation in long tunnels or pipes. Flame speed is the sum of burning speed and displacement velocity of the unburned gas mixture.

The burning speed of hydrogen at 8.7–10.7 ft/s (2.65–3.25 m/s) is nearly an order of magnitude higher than that of methane or gasoline (at stoichiometric conditions). Thus hydrogen fires burn quickly and, as a result, tends to be relatively short-lived.

2.6 Diesel prosperities [6]

- **Diesel fuel uses**

Diesel fuel keeps the country moving. From consumer goods moved cross-country, to the generation of electric power, to increased efficiency on the nation's farms, diesel fuel plays a vital role in the nation's economy and standard of living. The major uses:

- On-road transportation
- Off-road uses (mainly mining, construction, and logging)
- Farming
- Rail transportation
- Marine shipping
- Electric power generation
- Military transportation

- **Diesel fuel and driving performance**

There are a number of engine performance characteristics that are generally recognized as important. Their relative importance depends on engine type and duty cycle (truck, passenger car, stationary generator, marine vessel, etc.)

- starting ease
- low wear (lubricity)
- sufficient power
- low temperature operability
- low noise
- long filter life (stability)
- good fuel economy
- low emissions

- **Diesel fuel chemistry**

Diesel fuel is a very complex mixture of thousands of individual compounds, most with carbon numbers between 10 and 22. Most of these compounds are members of the paraffinic, naphthenic, or aromatic class of hydrocarbons. These three classes of hydrocarbons have different chemical and physical properties. Different relative proportions of the three classes is one of the factors that make one diesel fuel different from another.

- **Boiling Point**

For compounds in the same class, boiling point increases with carbon number. For compounds of the same carbon number, the order of increasing boiling point by class is isoparaffin, n-paraffin, naphthene, and aromatic. The boiling point difference (100°–150°F or 60°–80°C) between isoparaffins and aromatics of the same carbon number is larger than the boiling point difference (about 35°F or 20°C) between compounds of the same class that differ by one carbon number. Thus, the middle of the diesel fuel boiling range, might be C12 aromatics, C13 naphthenes, C14 n-paraffin, and C15 isoparaffins.

Table (2-4):Boiling point [7]

compound	Chemical Formula	Hydrocarbon class	Boiling Point, ºC/ºF	Freezing Point, ºC/ºF
Naphthalene	$C_{10}H_8$	**Aromatic**	**218/424**	**80/176**
Tetralin	$C_{10}H_{12}$	**Aromatic**	**208/406**	**-35/-31**
Decane	$C_{10}H_{22}$	**n- paraffin**	**174/358**	**-30/-22**
Anthracene	$C_{14}H_{10}$	**Aromatic**	**341/646**	**215/419**
1-pentylanphthalene	$C_{15}H_{18}$	**Aromatic**	**306/583**	**-24/-11**
n-pentadecane	$C_{15}H_{32}$	**n- paraffin**	**271/520**	**10/50**
1-Decyinaphthalene	$C_{20}H_{28}$	**Aromatic**	**379/714**	**15/59**
Eicosane	$C_{20}H_{42}$	**n- paraffin**	**344/651**	**36/97**
2-Methylnonadecane	$C_{20}H_{42}$	**Isoparaffin**	**339/642**	**18/64**

- **Freezing points**

Freezing points (melting points) also increase with molecular weight, but they are strongly influenced by molecular shape. Molecules that fit more easily into a crystal structure have higher freezing points than other molecules. This explains the high melting points of n-paraffin's and un substituted aromatics, compared to the melting points of isoparaffins and naphthenic of the same carbon number.

- **Density**

Lists density and heat of combustion (heating value) for some representative diesel fuel hydrocarbons. For compounds of the same class, density increases with carbon number. For compounds with the same carbon number, the order of increasing density is paraffin, naphthenic, and aromatic, table (2-5) shows the density for different component.

Table (2-5): Density and Heat of Combustion for representative Diesel fuel Hydrocarbons [8]

Compound	Hydrocarbon class	Carbon Number	Density, 20ºC, g/cm^3	Net Heat of Combustion, 25ºC, MJ/kg	Net Heat of Combustion, 25ºC, Btu/gal
Naphthalene	Aromatic	10	1.175	38,854	163,800
Tetralin	Aromatic	10	0.9695	40,524	140,960
1,3-Diethylbenzene	Aromatic	10	0.8639	41,384	128,270
n-Butylcyclohexane	Naphthene	10	0.7992	42,717	124,500
n-Pentylcyclopentane	Naphthene	10	0.7912	43,585	123,720
Decane	n-Paraffin	10	0.7301	44,236	115,880
2,2-Dimethyloctane	Isoparaffin	10	0.7245	44,145	114,750
Anthracene	Aromatic	14	1.251	38,412	172,410
n-Nonylbenzene	Aromatic	15	0.8558	42,147	129,410
n-Nonylcyclohexane	Napththene	15	0.816	43,431	127,150
n-Decylcyclopentane	Naphthnen	15	0.811	43,545	126,710
n-Pentadencane	n-Paraffin	15	0.7684	43,980	121,250
n-Tetradecylbenzene	Aromatic	20	0.8549	42,4824	130,310
n-Tetradecylcyclohexane	Naphthene	20	0.825	43,445	128,590
n-Pentadecylcyclopentane	Naphthene	20	0.8213	43,524	128,260
Eicosne	n-Paraffin	20	0.7843	43,852	123,400

- **Heating value**

For compounds with the same carbon number, the order of increasing heating value by class is aromatic, naphthene, and paraffin on a weight basis. However, the order is reversed for a comparison on a volume basis, with aromatic highest and paraffin lowest. Lighter (less dense) fuels, like gasoline, have higher heating values on a weight basis; whereas the heavier (more dense) fuels, like diesel, have higher heating values on a volume basis.

Table (2-6):Density and Heating value [9]

Fuel	Density, 15°C, g/cm^3	Net Heating value			
		Btu/lb	Btu/gal	MJ/kg	kJ/L
Regular Gasoline	0.735	18,630	114,200	43,330	31,830
Premium	0.755	18,440	116,200	42,890	32.390
Gasoline	0.795	18,420	122,200	42,850	34,060
Jet Fuel	0.850	18,330	130,000	42,640	36,240
Diesel Fuel					

- **Cetane Number**

Cetane number also varies systematically with hydrocarbon structure (see Table 2-7). Normal paraffins have high cetane numbers that increase with molecular weight. Isoparaffins have a wide range of cetane numbers, from about 10 to 80. Molecules with many short side chains have low cetane numbers; whereas those with one side chain of four or more carbons have high cetane numbers. Naphthenes generally have cetane numbers from 40 to 70. Higher molecular weight molecules with one long side chain have high cetane numbers; lower molecular weight molecules with short side chains have low cetane numbers. Aromatics have cetane numbers ranging from zero to 60. A molecule with a single aromatic ring with a long side chain will be in the upper part of this range; a molecule with a single ring with several short side chains will be in the lower part.

Table (2-7):Cetane number [10]

Compound	Hydrocarbon class	Chemical formula	Cetane number
n-Decane	n-Paraffin	$C_{10}H_{22}$	76
n-Pentadecane	n-Paraffin	$C_{15}H_{32}$	95
n-Eicosane	n-Paraffin	$C_{20}H42$	110
3-Ethyldecane	Isoparaffin	$C_{12}H_{26}$	48
4,5-Diethyloctane	Isoparaffin	$C_{12}H_{26}$	20
7,8-Diethyltetradecane	Isoparaffin	$C_{18}H_{38}$	67
Decalin	Naphthene	$C_{10}H_{18}$	48
3-Cyclohexylhexane	Naphthene	$C_{12}H_{24}$	36
2-Cyclohexyltetradecane	Naphthene	$C_{20}H_{40}$	57
n-Pentylbenzene	Aromatic	$C_{11}H_{16}$	8
Biphenyl	Aromatic	$C_{12}H_{10}$	21
2-Octylnaphthalene	Aromatic	$C_{18}H_{24}$	18

chapter Three: System design

3.1 Introduction

This chapter will talk about the different parts of the system part which were used in the project.

3.2 Reservoir Tank[1]

Storage under pressure is the simplest and most widely applied technology for storing gases. Compressed hydrogen storage was already available at the beginning of the last century, figure (3-1). There are huge number of hydrogen storage tanks of different capacities for different applications installed all over the world. However, barriers still exist for its use in transport applications, where weight and volume considerations are more of a challenge than for stationary applications. On-going developments are around the increase of energy density through the use of advanced materials and cost reduction.

The efficiency of high pressure storage at rated loading is more that 99.9%. The efficiency is almost 100% when checked for leaks and only minor energy losses of <0.1% may be expected due to eventual venting and purging of the lines. Depending on the operating pressure of the application, some of the stored hydrogen could remain in the tank. At part-loading the situation is even better than for rated loading, because the expected losses are lower at lower pressures.

Hydrogen may be stored at any pressure higher than the atmospheric. The storage density increases with increasing storage pressure.

The external volume for a pressure vessel storing 5 kg of hydrogen at 24.8 MPa, which contains the necessary energy for moving a conventional car, is 320 liters, a huge volume for a car. For applications of compressed hydrogen storage in transport, higher densities and pressures are required. At 80 MPa gaseous hydrogen reaches the volumetric energy density of liquid hydrogen.

Regarding transport applications, there is a need for higher densities, and the first storage tanks at 70 MPa made of composite materials have entered the market, It consists of an inner aluminum liner and an outer layer of carbon-fiber reinforced plastic.

For stationary hydrogen storage, GH_2 (Hydrogen gases) also offers the advantages of simplicity and
stable storage (no boil-off losses) but at a considerably greater volume than LH_2 (Liqued hydrogen).

Even accounting for compression costs, high pressure gaseous hydrogen is cheaper than LH_2. However, except of pipeline transmission, GH_2 lacks the bulk transportability of LH_2. Consequently, GH_2 will mostly be employed for storage of limited hydrogen quantities, for long term storage, or when the cost of liquefaction is prohibitive. Remaining issues for GH_2 include its safety perception, and the current high cost of the pressure vessels and hydrogen compressors.

In summary, multiple techniques of hydrogen storage are viable for both vehicular storage and bulk stationary storage. However, no one storage mechanism is ideal. as demand for hydrogen grows, industry must respond by supplying (and storing) hydrogen is always suitable for the new class of consumers and must educate the public in its safe use.

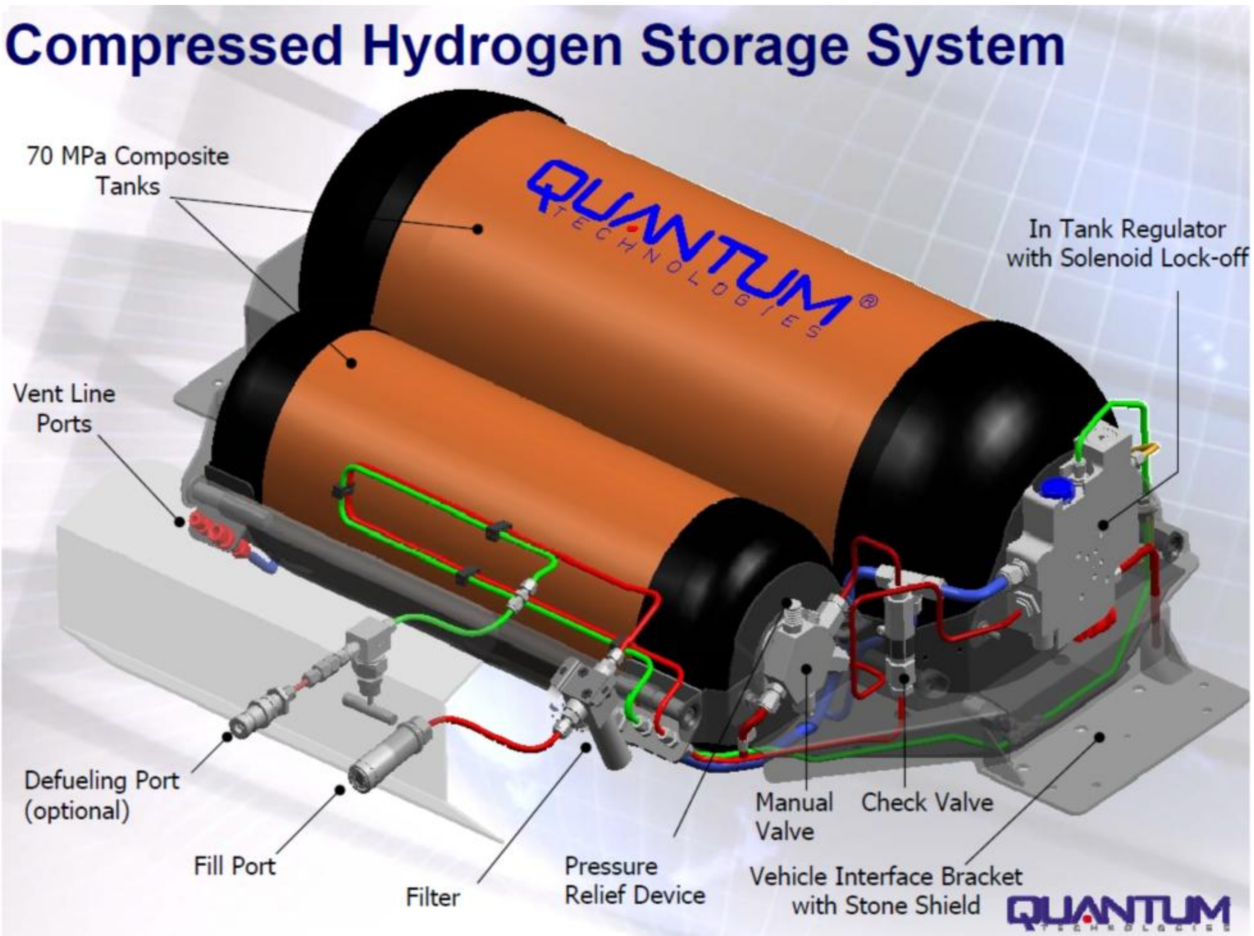

Figure (3-1): Compressed hydrogen storage

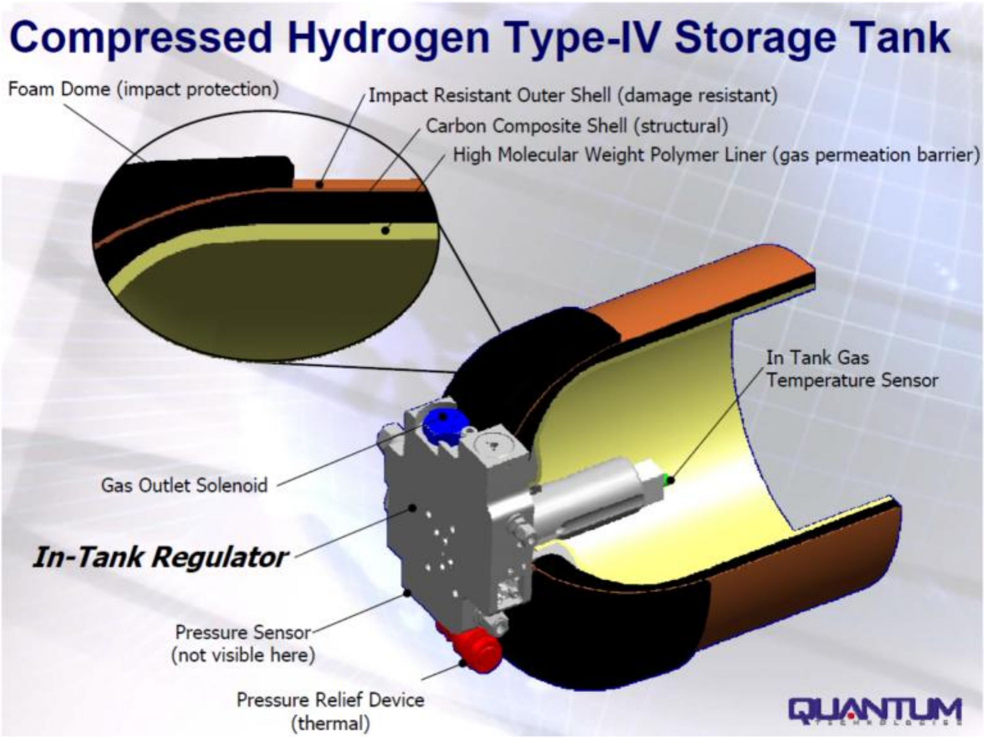

Fig (3-2):Hydrogen tank

Hydrogen tank types:

Type 1:

- Metal tank (steel/aluminum).
- Approximate maximum pressure, aluminum 175 bar or 2,538 psi, steel 200 bar or 2,900 psi.

Type 2:

- Metal tank (aluminum) with filament windings like glass fiber/aramid or carbon fiber around the metal cylinder.
- Approximate maximum pressure, aluminum/glass 263 bar or 3,814 psi, steel/carbon or aramide 299 bar or 4,336 psi.

Type 3:

- Tanks made from composite material, fiberglass/aramid or carbon fiber with a metal liner (aluminum or steel). See metal matrix composite.
- Approximate maximum pressure,aluminum/glass305 bar or 4,423 psi, aluminum/aramide 438 bar or 6,352 psi.

Tybe 4:

- Composite tanks such as carbon fiber with a polymer liner (thermoplastic).
- Approximate maximum pressure, plastic/carbon 661 bar (9,586 psi) and up.

3.3 Flow meter [2]

Flow meters are used in fluid systems (liquid and gas) to indicate the rate of flow of the fluid. They can also control the rate of flow if they are equipped with a flow control valve. Rota meters are a particular kind of flow meter, based on the variable area principle. Figure (3-3)

They provide a simple, precise and economical means of indicating flow rates in fluid systems. This variable area principle consists of three basic elements: A uniformly tapered flow tube, a float, and a measurement scale. A control valve may be added if flow control is also desired. In operation, the rot meter is positioned vertically in the fluid system with the smallest diameter end of the tapered flow tube at the bottom.

This is the fluid inlet. The float, typically spherical, is located inside the flow tube, and is engineered so that its diameter is nearly identical to the flow tube’s inlet diameter. When fluid gas or liquid is introduced into the tube, the float is lifted from its initial position at the inlet, allowing the fluid to pass between it and the tube wall. As the float rises, more and more fluid flows by the float because the tapered tube’s diameter is increasing. Ultimately, a point is reached where the flow area is large enough to allow the entire volume of the fluid to flow past the float. This flow area is called the annular passage.

The float is now stationary at that level within the tube, as its weight is being supported by the fluid forces which caused it to rise. This position corresponds to a point on the tube’s measurement scale and provides an indication of the fluid’s flow rate. One way to change the capacity, or flow range, of a rot meter is to change the float material, and thus its density, while keeping the flow tube and float size constant. Floats which are made from less dense materials will rise higher in the tube and therefore will yield lower flow capacities for the same diameter flow tube.

0

Figure (3-3): Flow meter

3.4 Electronic vaporizer [3]

The vaporizer provides the heat required to turn the liquid gas to vapor. It also regulates the flow of gas in response to engine demand, by sensing the engine vacuum. The vaporizer automatically primes the engine with gas when the ignition is turned on. Various types exist. Generally, there are two adjustments the smaller one control the amount of gas at idle and the larger controls the amount of gas at revs. Some reducers are very sensitive, and may omit the idle adjustment for this reason, as shown in figure (3-4).

Electronic Vaporiser / Reducer

Figure (3-4): Electronic vaporize

3.5 Solenoid valve [4]

The gas solenoid valve shuts off the flow of **Hydrogen gas** when the vehicle is switched to run on petrol. as shown in figure (3-5).

H2 Solenoid Valve

Figure (3-5): The solenoid valve

3.6 EPTS with Vertical Instrument Panel [5]

A **dynamometer** is a load device which is generally used for measuring the power output of an engine. Several kinds of dynamometers are common, some of them being referred to as “breaks” or “break dynamometers”: dry friction break dynamometers, hydraulic or water break dynamometers and eddy current dynamometers. Figure (3-6)

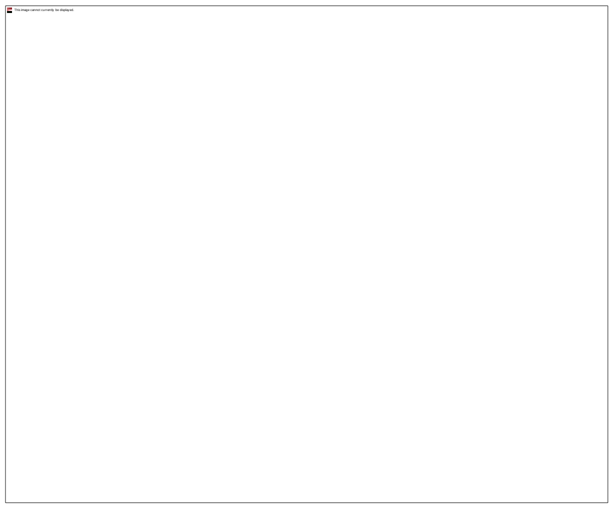

Figure (3-6): The dynamometer with Vertical Instrument Panel

The dynamometer applies a resistance to the rotation of the engine. If the dynamometer is connected to the engine’s output shaft it is referred to as an Engine Dynamometer. When the dynamometer is connected to the vehicles drive wheels it is
called a Chassis Dynamometer. The force exerted on the dynamometer housing is resisted by a strain measuring device The force signal (F) from the strain gage may be converted into a torque (T)
by multiplying by the distance from the center of the shaft to the pivot point of the strain gage (R):

T = R x F [6]

If the units are in Newton-meters and shaft speed (S) is measured in radians per second, then the shaft power or break power (P) of the engine can be calculated by multiplying the speed and the torque:

P = T x S [7]

To test an engine under load and measure its power output it was connected to a dynamometer via the drive shaft sprocket. An eddy current type dynamometer was used for control and measurement of engine power.

Chapter 4: Modeling[1]

In this chapter, simple based model for hydrogen and diesel mixture formation in the intake manifold is flow to engine cylinder. Its enough simple and accurate to take the intake manifold as single capacity. For modeling, closed volume was used around the intake manifold to account flow to the engine cylinder, the mass and energy flow the receiver store mass and thermal energy, and there level change with pressure and temperature, if we assume that no heat transfer through the wall ,and no change with potential and kinetic energy, the flow occur.

The rate of mass, energy change inside the capacity can be given by the continuity equation given by:

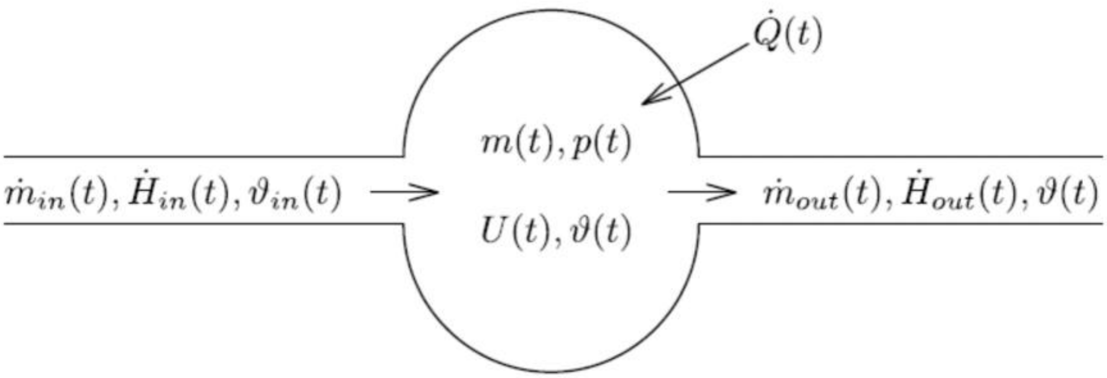

Figure (4-1):The energy change inside intake

$$\frac{dm_m}{dt} = m_{in} - m_{out} \quad (1)$$

$$\frac{dU(t)}{dt} = H_{in} + H_{out} + Q_{in} \quad (2)$$

$$H_{in} = cp_{in} * m_{in} * T_{in} \quad (3)$$

$$H_{out} = cp_{out} * m_{out} * T_{out} \quad (4)$$

where m_m is the intake mass inside intake manifold, m_{in} is the input mass flow to the intake manifold, and m_{out} is the out flow rate to engine cylinder, $U(t)$ is internal energy in receiver,H_{in} is enthalpy flow in,H_{out} is enthalpy flow out.

Assuming that all gases hydrogen, air, exhaust gas recirculation flow in intake manifold is perfect gas, so the mass in this case given by:

$$m_m = \frac{P_m * V_m}{R_m * T_m} \tag{5}$$

Where $P_m$is the pressure in the intake manifold, $V_m$is volume of intake manifold, $T_m$is the temperature inside intake, and $R_m$is constant gas of manifold mixture. The pressure rate change inside the intake manifold is given by:

$$\frac{dPm}{dt} = \frac{Rm * Tm}{Vm}(min - mout) \tag{6}$$

$R_m$and T_m of the mixture at the intake manifold, can be given in eq.4 and eq.5, respectively, the two equations based on implicit assume that gases perfect and adiabatic mixing in the intake manifold.

$$Rm = \frac{ma * Ra + mh * Rh + me * Re}{ma + mh + me} \tag{7}$$

$$Tm = \frac{ma * cp,a * Ta + mh * cp,h * Th + me * cp,e * Te}{ma * cp,a + mh * cp,h + me * cp,e} \tag{8}$$

Where $m_a$is the air mass flow rate, $m_h$is the hydrogen flow rate.T_a, $T_h$are the air, hydrogen temperature, respectively. $cp_a$and $cp_h$is air, hydrogen gas constant specific heats, respectively.R_a, $R_h$are the air, hydrogen gas constant respectively.

The total mass flow rate into intake manifold depends on the pressure differences between the source and the intake manifold, which given by:

$$mi = mi,a + mi,h + mi,e \tag{9}$$

Where mi_a is the air mass flow rate, mi_h is the hydrogen mass flow rate.

In this case of study, it is sufficiently accurate to adopt subsonic flow, to account the flow into the intake manifold. For subsonic flow the air, hydrogen flow, exhaust flow rate can given by the flowing expression:

$$mi,a = \frac{cd,a * Av,a * Pa}{\sqrt{Ra * Ta}} * \left(\frac{Pm}{Pa}\right)^{\frac{1}{Ka}} * \left(\frac{2Ka}{Ka-1}\left[1-\left(\frac{Pm}{Pa}\right)^{\frac{Ka-1}{Ka}}\right]\right)^{\frac{1}{2}} \tag{10}$$

$$mi,h = \frac{cd,h * Av,h * Ph}{\sqrt{Rh * Th}} * \left(\frac{Pm}{Pa}\right)^{\frac{1}{Kh}} * \left(\frac{2Kh}{Kh-1}\left[1-\left(\frac{Pm}{Pa}\right)^{\frac{Kh-1}{Kh}}\right]\right)^{\frac{1}{2}} \tag{11}$$

$$mi,e = \frac{cd,e * Av,e * Pe}{\sqrt{Re * Te}} * \left(\frac{Pe}{Pa}\right)^{\frac{1}{Ke}} * \left(\frac{2Ke}{Ke-1}\left[1-\left(\frac{Pm}{Pa}\right)^{\frac{Ke-1}{Ke}}\right]\right)^{\frac{1}{2}} \tag{12}$$

Where cd_a, cd_h, cde are the coefficient of discharge for air, hydrogen, exhaust gas recirculation respectively.Av_a,$Av_h$are the restriction flow areas for air ,hydrogen respectively.P_a,P_h are the air, hydrogen is the sources pressure, respectively.K_a, K_h,Ke are the air, hydrogen, exhaust gas recirculation specific heat ratio, respectively.

The following picture shows hydrogen before it enters to intake manifold.

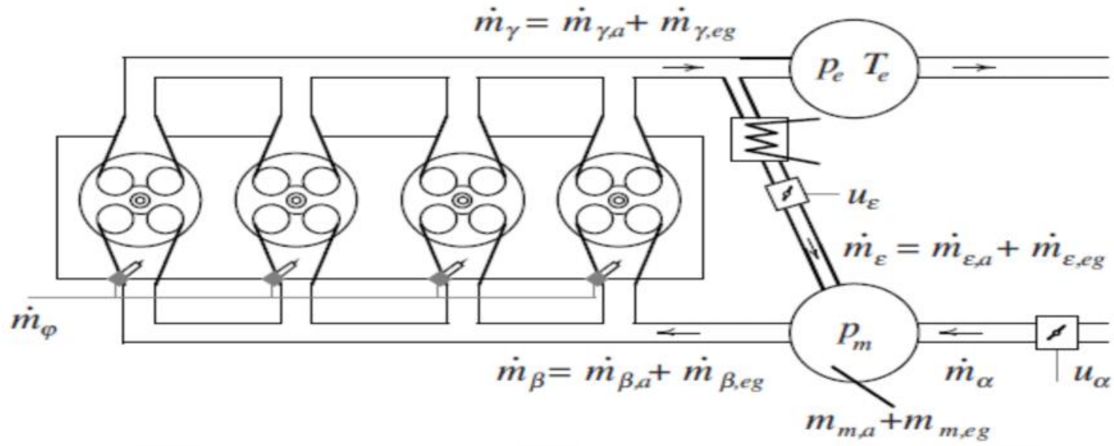

Figure (4-2): Mass flow rate inside intake

Where m_γ is total mass flow exhaust, $m_{\gamma,a}$ is excess air of engine output, $m_{\gamma,eg}$ is exhaust mass flow, m_ϵ is the exhaust gas recirculation, m_α is air mass flow to the intake manifold, m_β is air, exhaust mass flow to engine cylinder respectively.

For the mass flow rate from intake manifold to the engine cylinder, the following equation presents it.

$$m_{out} = \eta v * \rho m * Vd * \frac{N}{120} \tag{13}$$

Where ρm is the intake manifold density, ηv is the volumetric efficiency, V_a is the displacement volume, and N is the engine speed in rpm.

The density ρm can be found by the following equation.

$$\rho m = \frac{Pm}{Rm * Tm} \tag{14}$$

For compression engine the volumetric efficiency, ηv can be calculated by the following equation assuming perfect gases with constant specific heat ratio and isentropic processes, the volumetric efficiency can be considered by depending on the pressure.

$$\eta v = \frac{Vc + Vd}{Vd} - \frac{Vc}{Vd} * \left(\frac{Pe}{Pm}\right)^{\frac{1}{k}} \qquad (15)$$

Where P_e is the exhaust gas source pressure, and V_d is the combustion chamber volume.

For this study, it is assumed that there no exhaust recirculation, $me = 0$, it is possible to relate hydrogen flow to airflow inside the intake manifold by the following.

$$ma = AFRh * mh = \lambda h * AFRs, h * mh \qquad (16)$$

Where AFR_h is the air/hydrogen fuel mass flow ratio, $AFR_{s,h}$ is the air/hydrogen fuel stoichiometric ratio, λ_h is the excess air factor inside intake manifold.

If the fuel temperature, specific heat, gas constant is known, the expression of air mass flow can be calculated by the following equation.

$$mair = \frac{\frac{\eta v * Vd * Pm * N}{120}\left(cp, a + \frac{cp, h}{AFRh}\right)}{cp, a * Ra * Ta + \frac{cp, h * Ra * Th + cp, h * Rh * Ta}{AFRh} + \frac{cp, h * Rh * Th}{AFRh^2}} \qquad (17)$$

The air mass flow rate trapped to engine cylinder, which is for combustion of the injected diesel fuel, it's possible if assume that all hydrogen flow to engine cylinder that burned at stoichiometric condition. All air trapped to engine cylinder used for diesel combustion.

$$mair = AFRd * md + AFRs, h * mh \qquad (18)$$

To account the diesel fuel mass that proportional to air mass flow to engine cylinder can be given.

$$md = ma\left(\frac{\lambda_d - 1}{\lambda h * \lambda d * AFRs,d}\right) \tag{19}$$

Where λ_d is the excess air factor inside the engine cylinder that required for stoichiometric hydrogen combustion.

To account the total fuel energy that trapped to engine cylinder, the following equation can be used.

$$Qc = md * LHv,d + mh * LHv,h \tag{20}$$

To simulate the effects of adding hydrogen to the air mean value engine modeling will be used. The effect on the air mass flow rate at various hydrogen concentration begins in the effect of adding hydrogen on the air mass flow rate at various hydrogen concentration.

The engine speed is kept constant as its main effect on volumetric efficiency, and for not complicating result analysis. Table 4-1 gives the main parameter used.

Table (4-1): Diesel engine and working fluids parameter [2]

Table (4 Engine		and workin Diesel		Hydrogen	
V_d (cm)^3	2000	AFRs	12.5	AFRs	34.3
N (rpm)	800-3000	$C_{10.8}H_{18.7}$		Cp (kJ/kg k)	14.21
rc	19:1	LHV (MJ/kg)	42.5	LHV (MJ/kg)	120.0

Figure (4-3) shows the variation hydrogen flow rate with air flow rate, increases of adding hydrogen reduces the air flow to engine cylinder, which reduces the possibility of burning diesel fuel. Diesel engine always needs excess of air, that limits smoke. However, experimentation result that presents hydrogen improves and helps to reduce the duration of combustion process.

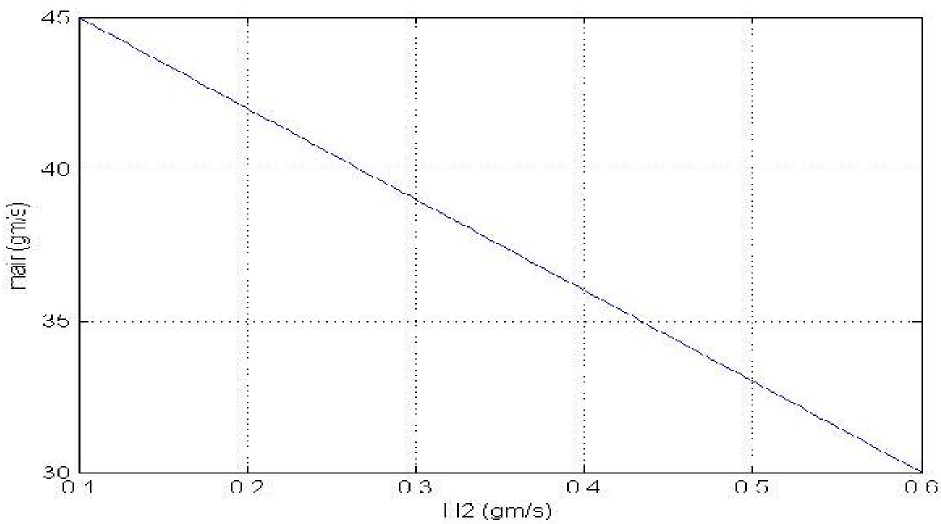

Figure (4-3):H_2 flow & mass air flow rate [3]

Figure (4-4) gives that diesel fuel increases with increase air flow, thus gives in other hand that, if the air mass flow rate decreases by adding hydrogen, the diesel flow reduces. because when adding hydrogen we have higher torque, therefore decrease adding hydrogen. This could increase engine power as the brake mean effective pressure increases with percentage of hydrogen begin increase.

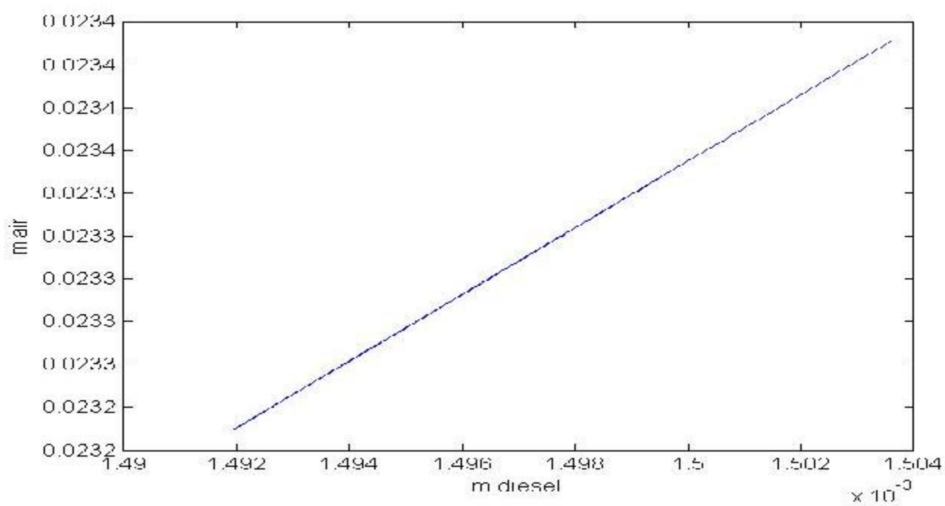

Figure (4-4):Mass diesel & Mass air flow rate [4]

Figure (4-5) shows the variation of trapped hydrogen to the engine cylinder, the total fuel energy is increased at constant speed of engine, shows that diesel keeps constant or reduces diesel flow at lower excess air factor. Reduction of diesel flow, lower of hydrogen concentration at the same load the energy trapped shifted to rise.

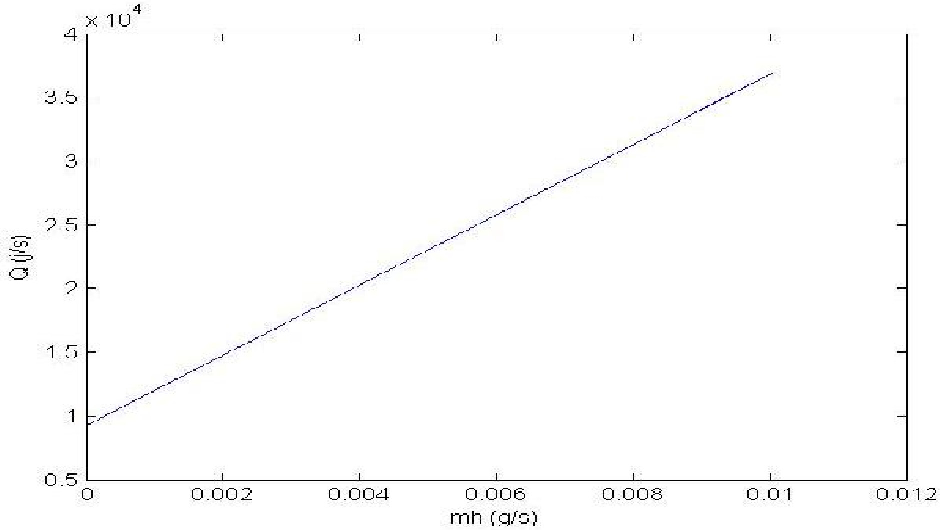

Figure (4-5): Mass H2 &Fuel energy flow [5]

Figure (4-6) gives that increases intake manifold pressure allows the hydrogen mass flow rate to rise, that affects engine power, increases in mass flow rate of hydrogen, that helps hydrogen for complete combustion, in addition that limits of smoke and emission.

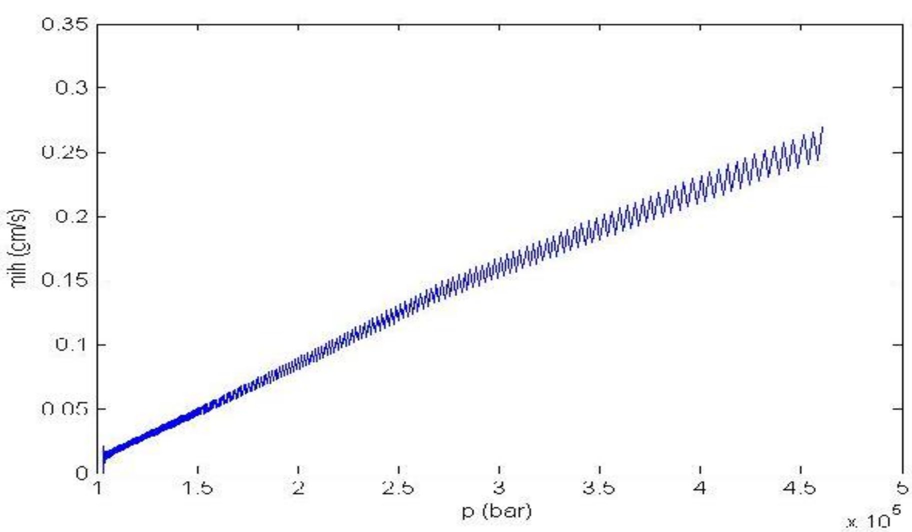

Figure (4-6):Pressure &Mass flow rate H2 [6]

The chemical reaction is given by the flowing equation, which is based on complete combustion for introduced fuel (Diesel and Hydrogen) in the presence of excess air.

- $n_d C_{10.8} H_{18.7} + n_d H_2 + \left\{\left(10.8 + \frac{18.7}{4}\right) n_d \lambda_d + n_h\right\} (O_2 + 3.76 N_2)$
  $\xrightarrow{yields} 10.8 n_d \quad + \left(\frac{18.7}{4} n_d + n_h\right) H_2O + 3.76 \left\{\left(10.8 + \frac{18.7}{4}\right) n_d \lambda_d + n_h\right\} N2 +$
  $\left\{(\lambda_d - 1)\left(10.8 + \frac{18.7}{4}\right) n_d O_2\right\}$ [7]

Where n_d is number of mole diesel, n_h number of hydrogen mole.

The previous equation is also considered for evaluating adiabatic flame temperature, when excess air is reduced, that's allowing for more hydrogen flow at part-load, this helps to increase power output and reduces carbon emissions.

Chapter 5: Experiments and Conclusion [1]

5.1 Introduction

This chapter will discuss achievements, the procedure of the experiment, obstacles were faced during working, as well as results and conclusion.

5.2 Cut the cover of Flywheel

The case, which covers the flywheels that holds the engine fixes the motor with stands. Therefore, if the cover is removed difficulties will be faced with engine. This means, that it should be fixed, but this contradicts the presence of shaft that connects the flywheel engine and the dynamometer. As we were are obliged to cut the cover, keeping the engine fixed, half of it was cut and the other kept fixed to the motor, the fixed one was the lower part.

Figure (5-1): The cut cover

It seems that cutting the cover make it unstable. This instability can be solved by fixing a portion connected to the motor and stand, and add a dumber below the portion, without any contradiction with shaft. By making a trial to get the result the motor was switched on and it was found that vibration level enhanced.

5.3 Repairing the pump

Before the project procedures we started, all tools needed were collected to help make the needed checking. As the most important part of the project is the motor, the first step was to check the motor itself, and it was found that it wasn't working.

Figure (5-2): Repairing the pump

It seems that the motor wasn't on operation for a long time, in addition to the weakness of battery, the battery was charged more than once in order to put on the motor, unfortunately it didn't work. So the pipes that were connected to the injector and pump were disjointed. This is to test the strength of the pump; which was found not working, because it wasn't clean and full of air and dust.

To remove air from the pump the speed of the motor we accelerated. Therefore, air was out of the pump which enhanced its work. However, the pump had to be cleaned. To have a good result a special liquid was put in the diesel tank. An hour later the pump was found to work efficiently and in a quiet good mode.

5.4 The Motor Stand Design

The motor which was used was fixed on old stand. This stand is quite good, and steady, designed to move the motor easily and make the motor rotate according to clock rotate wise and counter clock wise through a mechanical connection between stand motor and gear.

Figure (5-3): gear stand

The stand which was used didn't help. Because the gear contradicts with the dynamotor device that was fixed to the motor, a new stand was designed.

Figure (5-4): Stand on hydraulic jack

In the new design of the stand the weight, the vibration of the motor, and its mobility were taken in consideration

Suitable wheels have been added to the stand to facilitate mobility. By finishing these steps, motor has to be fixed on the stand. Therefore, a hydraulic jack was used to lift up the motor from the old stand to the new one.

5.5 Fixing Dynameters to the Stand

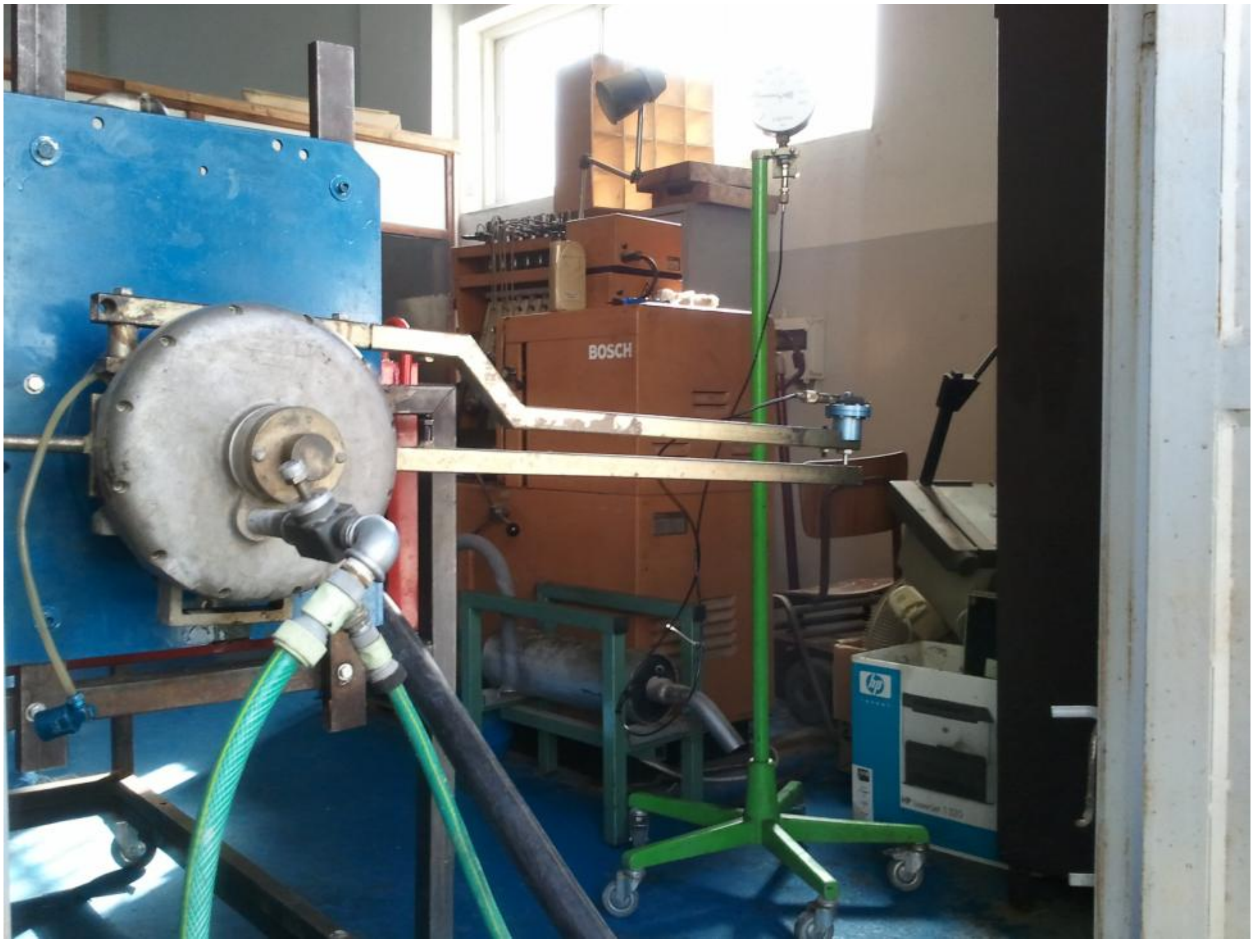

Figure (5-5): Fixing Dynameters

The Dynamiter must be centralized opposite to flywheel. To fix it to the stand a hydraulic jack was used to connect the rigid shaft and the centralized dynamiter with centralized flywheel to make sure the dynameters is truly fixed centralized opposite to flywheel. To measure centralization of the dynamiter a parameter scale was used to make sure it was balanced. So bolts were used to fix it after the shaft was removed.

5-6 Choosing Shaft

After fixing the dynameters still need to fix the shaft that connect the engine with dynameters.

- **Characteristics of Shaft:**

It should resist the torque output from engine, and the vibration of motor. A shaft with velocity joint was chosen to damp the inclination of the joint.

- **Shaft is composed of three parts:**

1**.** The first step is an adaptor flange that connects to dynameters that contains eight holes each hole equal to 8 ml. The flange radius 30 ml.

Figure (5-6):Adapter flange 1

2. The second part, shaft itself.

Figure (5-7): Axis part

3. The third part adopter Flange that connect to fly wheel.

Figure (5-8): Adapter flange 2

4- The complete shaft

Figure (5-9):The all shaft

While motor on operation, shaft exposed to shear force and bending moment as a result of torque and vibration, which results in breaking the old shaft. Therefore a new one was used to make a new design with the same specification , without using welding because it weaken the shaft.

The design for the adopter flange was used to fix the shaft without welding, instead bolts were used.

A new Shaft was being fixed, and was also tested, doing this the motor was found to be stable. As a result it was discovered that the old shaft wasn't fixed probably which means that there was deformation of its structure.

Through the motor operation, shaft exposed to shear force and bending moment as a result of torque and vibration, which resulted in breaking the shaft.

Therefore a new one has to be used, and for this a new design with some specification was used, welding wasn't used as it weakens the shaft.

Figure (5-10):Broken shaft

The adapter flange was designed to be fixed on shaft without welding and was fixed by belts.

Shaft is being fixed and tested, stability of motor was noticed, the old shaft wasn't fixed in a proper way as there was deformation in its structure.

On a rotating shaft, the torque is doing the work, and the shaft's rotational speed is time-dependent, so shaft power is the product of its rotational speed and its torque. Using arbitrary units, the power formula for a rotating shaft is:

Power Shaft = Rotating Speed × 2π × Torque

5-7 Fixing vaporizer to the engine

The evaporator was drilled to the stand in a very near point to water pipe, and was checked by operating engine for half an hour. This was done to increase the temperature of the engine for us to know the pipe line that was heated. This operation is to indicate how water system is working to see when hot pipe is located and then the pipe was cut to connect it at the entrance of evaporator to raise its temperature, while the cut pipe is connected to the exit of the evaporator.

Figure (5-11): Fixing evaporator

The other part of the pipe is connected from the evaporator to the intake Mani volte. This operation is to raise temperature of hydrogen that passes through evaporator.

5.8 Electrical circuit

It is used to control with valves of evaporator. When this circle is in operation it allows opening closing valves to pass hydrogen. We connect the two negative valves with earth, which the positive one has been connect to switch.

5.9 Speed Changer

This tool helps in modifying the speed system in motor. It is graduated to help the speed needed. It has a characteristic to control speed and fixed the speed needed. This is needed for the project to see the speed of each level of the motor. And identify at each level of the change the acceleration of the motor. By using a telescope, which is used to measure the rotation of motor.

The telescope is fixed beside the flywheel which have been already have marked. The telescope sends a light radiation on this mark to measure rotation of motor. The light measure the level graduated speed of motor. Thus we get to know at each level, how far the speed is.

5.10 Experimental method and test data

- **Diesel testing procedure**

1- The velocity of the motor was fixed on an exact rate.

2-Then a load was being added on the motor ,therefore, note speed degree of engine movement was noticed.

3-Then after speed constant speed, data was recorded after the speed constant speed.

4-By increasing the load on motor, another decrease to engine velocity was noticed.

5- Another reading to the result was made .

6-The different experiment made on different load indicated speed constant according to load on motor and pump, pump fixed fuel quantity.

7- The test was made on other speed for different times.

- **Test hydrogen with diesel procedure**

1-By fixing the motor speed through fixing the diesel pump on constant flow of diesel.

2-A load was added on motor, that leads to decrease the velocity of motor rotation.

3-A reading to the motor speed and torque was taken at this level.

4- The increasing of the motor velocity was noticed when some hydrogen was injected.

5-To return the velocity of speed back to get the reading that was taken at the last point before H_2 was injected, more load was added on the motor.

6- A another read of torque was taken due to hydrogen injected.

7-Some readings to motor torque were made at injecting the it with different flow of hydrogen.

8-The steps were made completely in different constant speeds on the engine.

Table (5-1): The Recorded Data and the Calculating Diesel and hydrogen

	Diesel		Diesel&H2			
Speed Rpm	**Torque N.m**	**Power kw**	**Speed Rpm**	**Mass Flow cm^3/s**	**Torque N.m**	**Power Kw**
950	20	1.98	950	2.1	24	2.38
				5.25	28	2.78
				7.36	33	3.28
1200	34	4.27	1200	2.1	39	4.9
				5.25	41	5.15
				7.36	45	5.65
1600	45	7.53	1600	2.1	49	8.21
				5.25	56	9.38
				7.36	58	9.71

Table (5-1) shows the result data of torque at different speeds with injected diesel alone, and was compared with test hydrogen & diesel in different flow rate of hydrogen.

Figure (5-12) shows the result of testing and comparing torque output from diesel, and hydrogen diesel at 2 cm^3/s. we show that by injecting hydrogen at part load we can get higher torque with less diesel flow. At this point the object of the project was got, that is to get better efficiency at part load.

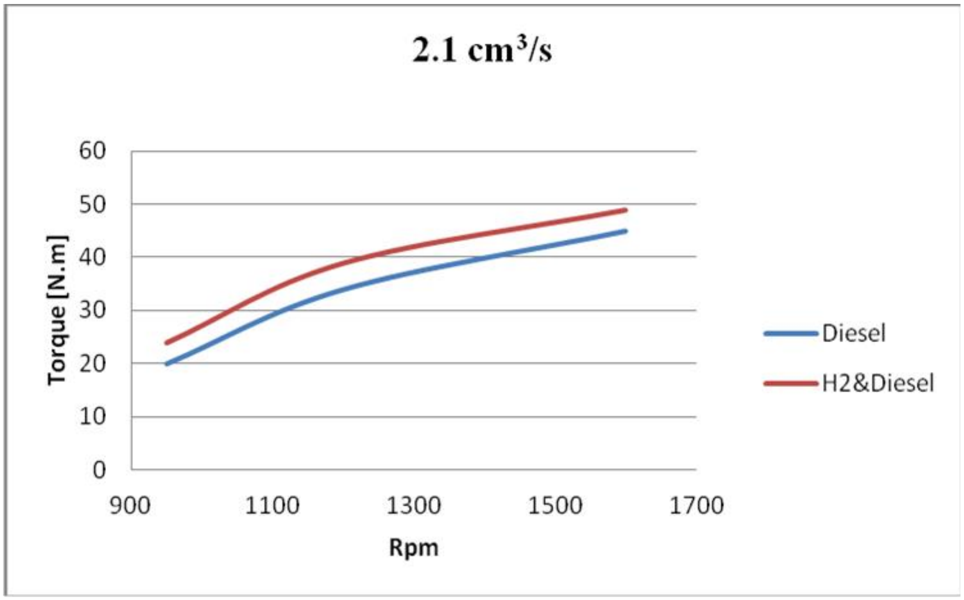

Figure (5-12): The torque vs Rpm

Figure (5-13) shows the result of the testing and comparing torque output from diesel and hydrogen diesel at 5 cm^3/s.

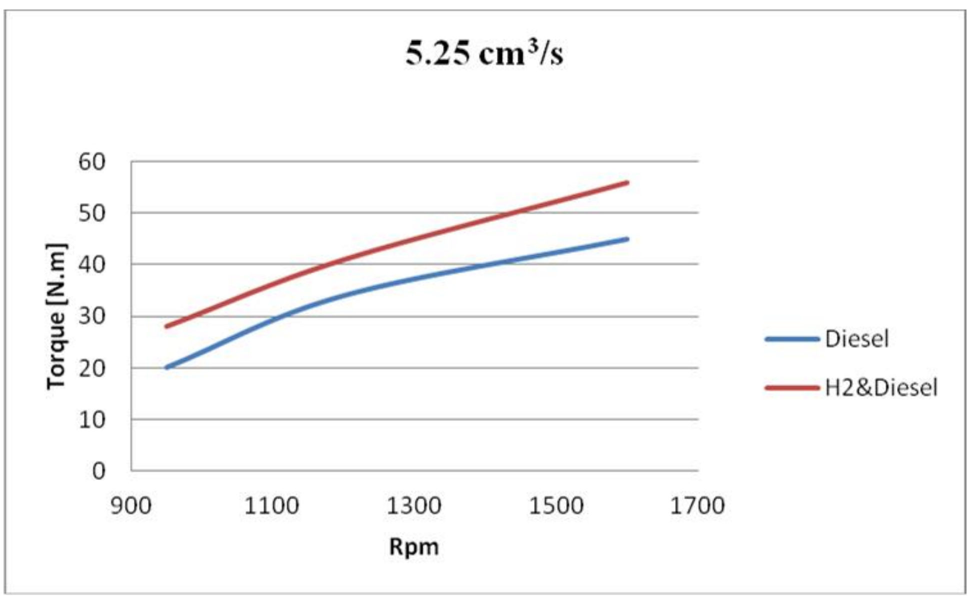

Figure (5-13): The torque vs. Rpm

Figure (5-14) show the result testing ,and comparing torque output from diesel, and hydrogen diesel at 7.36 [cm^3/s.]

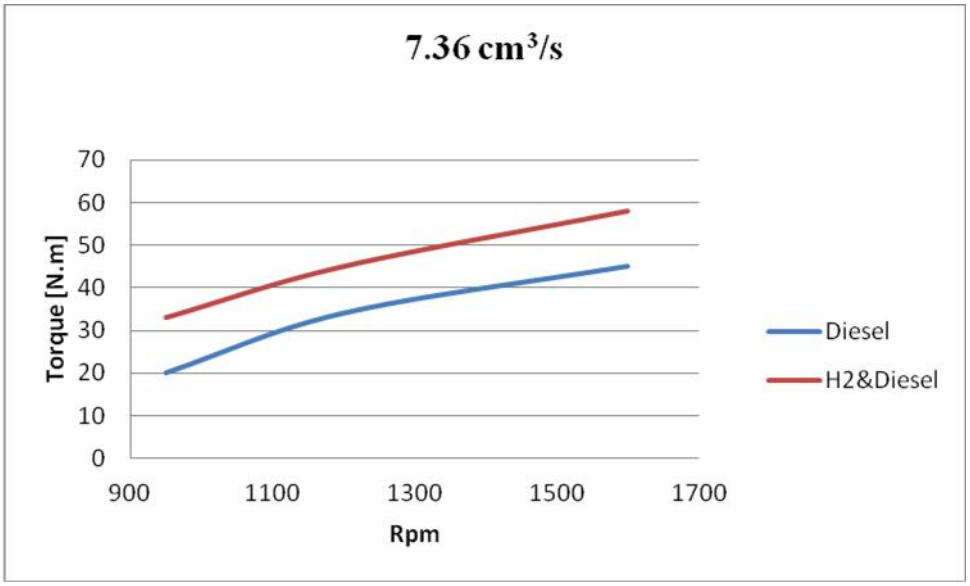

Figure (5-14): The torque vs. Rpm

The figure (5-15) compare the torque outout from engine, with differen flow rate of hydrogen.

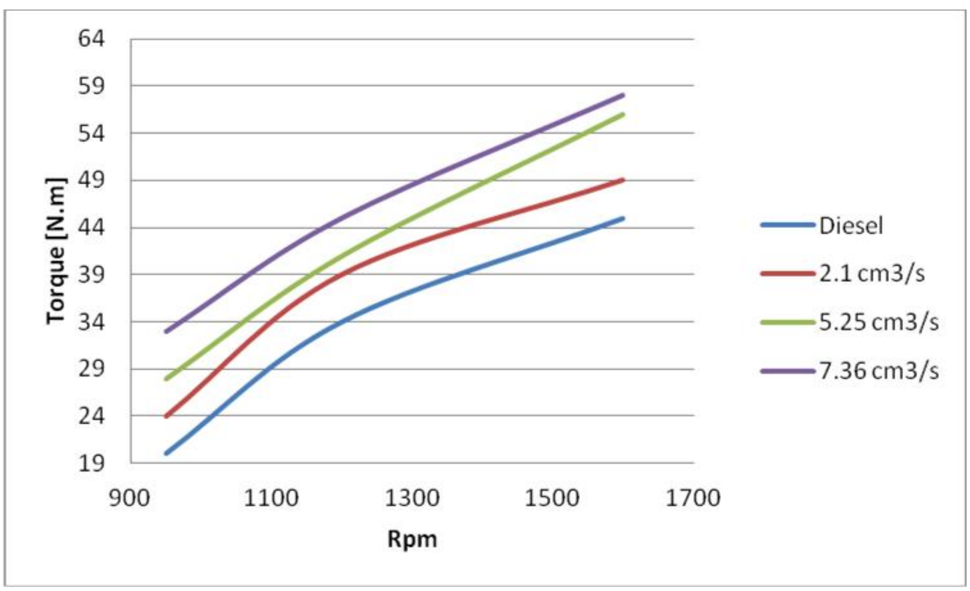

Figure (5-15): The torque vs. Rpm

- **Explanation**

Through the test the speed of engine was fixed at 1100 Rpm through speed changer, to make sure of speed through scholmeter device. When a load was put on motor the speed of motor decrease to reach 1025. Then a reading for torque was taken 7 [N.m]. The load was increased step by step and each time a reading had been taken for torque. The experiment was being done at different speeds and the read was taken.

The engine was operated for sometime until it reached to a natural heat level. After injecting the hydrogen with hydrogen injected system, and making sure that the pipes totally have no leaks in the connection, the motor was fixed on 1500 Rpm without hydrogen injection. Then engine load was given until the speed reached 1200, after that a reading of torque that resulted from motor load was taken. Another reading was taken after the gage fixed.

When 2.1 **[cm^3/s]** of hydrogen were injected, the speed of motor accelerated. Then a reading of the torque was taken when the motor was loaded to reach the speed of 1200 Rpm.

It was noticed that the acceleration increase when hydrogen was injected by 5.25 **[cm^3/s].** Load was applied on motor until speed rotation reached a constant of 1200 Rpm, torque reading was taken as well. Same steps were made on 7.36 **[cm^3/s]** of hydrogen.

- **Obstacle:**

1-The most important problem that was faced was bring and buying the hydrogen gase, because hydrogen is very dangerous gases, people are not used to bring this gases and sell it. Also the occupation authority doesn't allow to bring this gas to the Palestinian territories only under its supervision.

2-The engine that was used was an old one, and the previous experiment used oil food to operate the engine. Therefore most of its parts weren’t working well.

3-High vibration from engine, due to dirty injection system which caused to break the axis many time.

4-The engine was old and there was no control unit to connect the diagnostic device on it. To get the data needed such as diesel quantity and speed, an external device (schlolmeter) was used to know the speed in Rpm

5-The laboratory wasn't equipped with safety system that was needed to operate the hydrogen experiment, so the experiment was done and readings were taken in a narrow range of speed and at a very short time .

5.11 Conclusion

The design, build and testing of the project was completed successfully within the specified project time frame. The breadth of this project was extensive and encompassed all three stages of an engineering project: a feasibility study, design and manufacture and testing.

In the experimentation stage of the project, several design variables were tested. This included investigating the effect of varying the mass flow of hydrogen , load, speed of engine and study the performance of the engine.

- **Review of project goals**

  Concluding the project, we can say that the trial was done successfully, achieving most of the goals we were looking forward to. Some were partially achieved.

- **Future work**

Based on the project outcomes the possible future directions of this project was identified:

1. Same test procedure can be used in addition to measure emission that couldn’t be tested.
2. Using the test procedure to test effect inject hydrogen on engine knock.
3. Repeat the test procedure with high safety technology.

Chapter six : Safety features [1]

6.1 Introduction

All fuels burn and pose fire and explosion risks if their combustion is not controlled, so safety is always an issue with fuels. Most people are familiar with hydrocarbon fuels such as gasoline, propane, and natural gas. Tens of millions of people pump gasoline into their cars every day. The risks associated with the use of these fuels is accepted because systems that use them achieve sufficient levels of safety. Hydrogen as a fuel is a new idea to most people, but like most other fuels, hydrogen is flammable, and potentially hazardous if handled incorrectly. It is no more hazardous than other fuels, It is not uncommon for the layperson to think of hydrogen as dangerous because of erroneous connotations with the hydrogen bomb or may make the life of people around this fuel in danger.

Type of hazard:

1- Industrial and Aerospace Accidents.
2- Ignition.
3- Fire and Explosions.
4- Leaks.
5- Hydrogen Dispersion.
6- Storage Vessel Failure.
7- Vent and Exhaust System.

Figure (6-1): Hazards Elimination

6.2 Use of inherent safety features [1]

1- Hazards Elimination:

Regardless of quantity, all hydrogen systems and operations must be devoid of hazards by providing adequate ventilation, designing and operating to prevent leakage, and eliminating potential ignition sources.

Figure (6-2): Hazards Elimination

2- Barriers:

Barriers or safeguards should be provided to minimize risks and control failures.

3- Safety Systems:

Safety systems should be installed to detect and counteract or control the possible effects of such hazards as vessel failures, leaks and spills embrittlement, collisions during transportation, vaporization system failures, ignitions, fires and explosions, cloud dispersions, and the exposure of personnel to cryogenic or flame temperatures.

4- Safe Interface:

A safe interface must be maintained under normal and emergency conditions so at least two failures occur before hazardous events could lead to personal injury, loss of life, or major equipment or property damage.

6.3 CONTROL [2]

1- Warning Systems:

Warning systems should be installed to detect abnormal conditions, measure malfunctions, and indicate incipient failures. Warning system data transmissions with visible and audible signals should have sufficient redundancy to prevent any single-point failure from disabling the system.

Figure (6-3) :warning sensor

2- Flow Controls:

Safety salving and flow regulation should be installed to adequately respond for protection of personnel and equipment during hydrogen storage, handling, and use.

4- Safety Features:

System and equipment safety features should be installed to automatically control the equipment required to reduce the hazards suggested by the triggering of the caution and warning systems. Manual controls within the systems should be constrained by automatic limiting devices to prevent over-ranging.

Referance

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