CHAPTER II

THEORIES AND RELATED LITERATURE

Introduction to internal combustion engine

An internal combustion engine (IC) is one in which the heat transfer to the working fluid occurs within the engine itself, usually by the combustion of fuel with the oxygen of air. In external combustion engines heat is transferred to the working fluid from the combustion gases via such as heat exchanger, steam engines or sterling engines. IC engines include spark ignition (SI) engines using gasoline as a fuel, and compression ignition (CI) engines (usually referred to as diesel engines) using petroleum diesel or biodiesel as a fuel [1].

In these engines, there is a sequence of processes starting from compression, combustion, expansion and finally exhaust process. Fundamentally, four or six stroke basic mechanical designs are the most common designs to achieve these four processes in most common passenger vehicles and light duty vehicles; either in gasoline or diesel passenger vehicles and most pick up diesel trucks in the world. The basic difference between the petrol engine and the diesel engine is in the method of ignition and the combustion process [1].

The diesel engine uses the heat of compression to initiate ignition and burn the fuel that has been injected into the combustion chamber. This contrasts with gasoline engine or gas engine that uses a gaseous fuel as opposed to gasoline, which use a spark plug to ignite an air-fuel mixture. To be more specific, the diesel internal combustion engine differs from the gasoline powered Otto cycle by using highly compressed hot air to ignite the fuel rather than using a spark plug. Gasoline engine is illustrated in figure 1 and diesel engine is illustrated in figure 2.

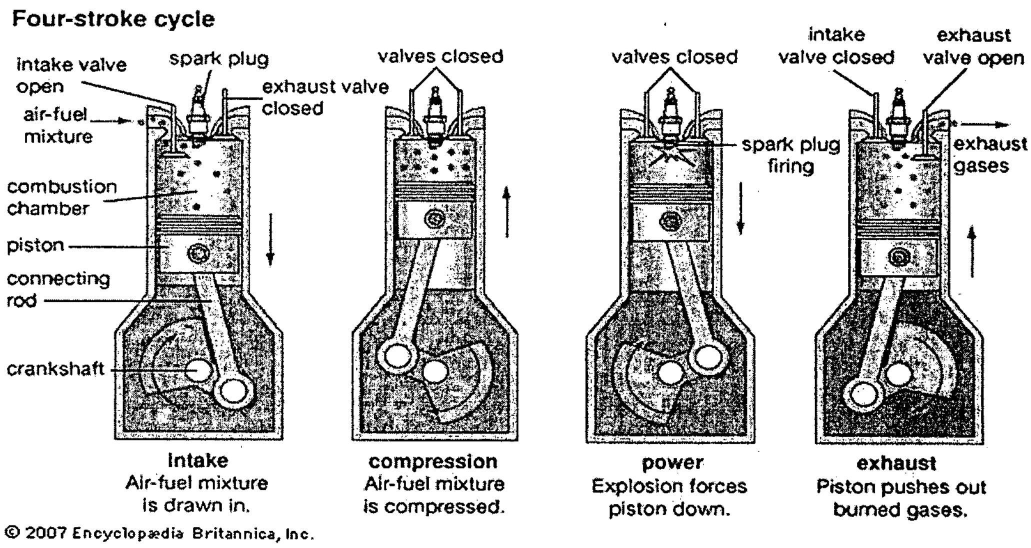

Figure 1 shows basic four stroke processes in gasoline engine

Source: internal-combustion engine: four-stroke cycle. Art. Britannica Online for Kids, June 12, 2014, http://kids.britannica.com/comptons/art-89315

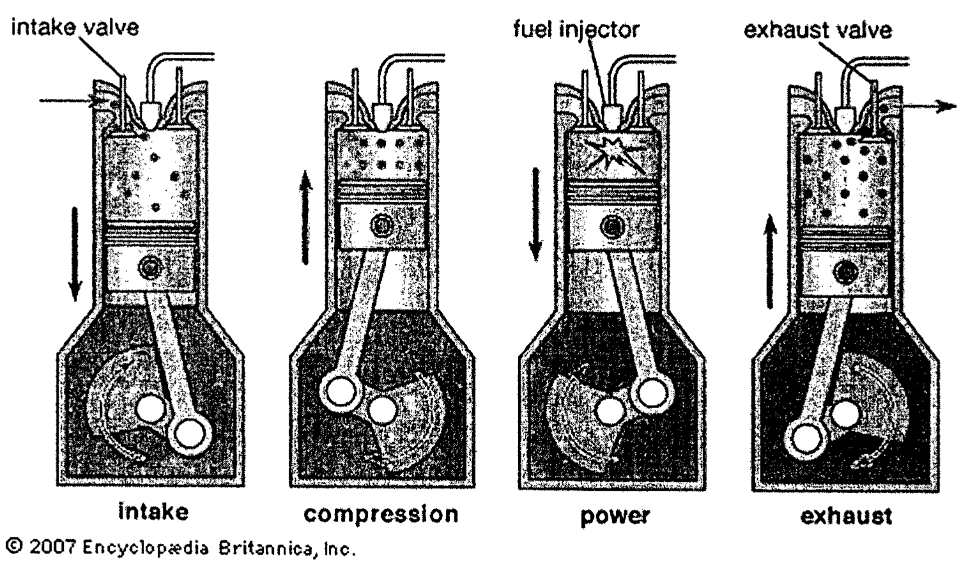

Figure 2 shows basic four stroke processes in diesel engine

Source: diesel engine. Art. Britannica Online for Kids, June 12, 2014, http://kids.britannica.com/comptons/art-167213

Diesel engine technology

In the original diesel engine, only air is initially introduced into the combustion chamber. The air is then compressed with a compression ratio typically between 15:1 and 22:1 resulting in 40-bar pressure compared to 8 to 14 bars in the petrol engine [2]. This high compression heats the air to 550 °C (1,022 °F) [2]. At about the top of the compression stroke, fuel is injected directly into the compressed air in the combustion chamber. This may be into a typically toroidal void in the top of the piston or a pre-chamber depending upon the design of the engine. The fuel injector ensures that the fuel is broken down into small droplets, and that the fuel is distributed evenly. The heat of the compressed air vaporizes fuel from the surface of the droplets. The vapour is then ignited by the heat from the compressed air in the combustion chamber, the droplets continue to vaporize from their surfaces and burn, getting smaller, until all the fuel in the droplets has been burnt completely. The start of vaporization causes a delay period during ignition and the characteristic diesel knocking sound as the vapour reaches ignition temperature and causes an abrupt increase in pressure above the piston. The rapid expansion of combustion gases then drives the piston downward, supplying power to the crankshaft [2].

As well as the high level of compression allowing combustion to take place without a separate ignition system, a high compression ratio greatly increases the engine's efficiency. Increasing the compression ratio in a spark-ignition engine where fuel and air are mixed before entry to the cylinder is limited by the need to prevent damaging pre-ignition [2]. Since only air is compressed in a diesel engine, and fuel is not introduced into the cylinder until shortly before top dead center (TDC) point, premature detonation is not an issue and compression ratios are much higher than the spark-ignition engine [2].

Diesel's original engine injected fuel with the assistance of compressed air, which atomized the fuel and forced it into the engine through a nozzle. The nozzle opening was closed by a pin valve lifted by the camshaft to initiate the fuel injection before top dead center (TDC) point. This is called an air-blast injection. Driving the three stage compressor used some power but the efficiency and net power output was more than any other combustion engine at that time [2].

Diesel engines in service today raise the fuel to extreme pressures by mechanical pumps and deliver it to the combustion chamber by pressure-activated injectors without compressed air. With direct injected diesels, injectors spray fuel through 4 to 12 small orifices in its nozzle [2]. The early air injection diesels always had a superior combustion without the sharp increase in pressure during combustion. Research is now being performed and patents are being taken out to use some form of air injection to reduce the nitrogen oxides and pollution, reverting to Diesel's original implementation with its superior combustion and possibly quieter operation [2]. In all major aspects, the modern diesel engine holds true to Rudolf Diesel's original design that of igniting fuel by compression at an extremely high pressure within the cylinder [2].

A vital component of all diesel engines is a mechanical or electronic governor which regulates the idling speed and maximum speed of the engine by controlling the rate of fuel delivery. Mechanically governed fuel injection systems are driven by the engine's gear train. These systems use a combination of springs and weights to control fuel delivery relative to both load and speed. Modern electronically controlled diesel engines control fuel delivery by use of an electronic control module (ECM) or electronic control unit (ECU) [3]. The ECM or ECU receives an engine speed signal, as well as other operating parameters such as intake manifold pressure and fuel temperature, from a sensor and controls the amount of fuel and start of injection timing through actuators to maximize power, efficiency and minimize emissions. Controlling the timing of the start of injection of fuel into the cylinder is a key to minimizing emissions, and maximizing fuel economy of the engine. The timing is measured in degrees of crank angle of the piston before top dead center. Optimal timing will depend on the engine design as well as its speed and load, and is usually 4° BTDC in 1,350-6,000 HP [3].

Advancing the start of injection results in higher in-cylinder pressure and temperature, and higher efficiency, but also results in increased engine noise due to faster cylinder pressure rise and increased oxides of nitrogen (NO_x) formation due to higher combustion temperatures [3]. Delaying start of injection causes incomplete combustion, reduced fuel efficiency and an increase in exhaust smoke, containing a considerable amount of particulate matter and unburned hydrocarbons [3].

Today, previous diesel engines use a mechanical single plunger high-pressure fuel pump driven by the engine crankshaft. For each engine cylinder, the corresponding plungers of the fuel pump measure out the correct amount of fuel and they determine the timing of each injection. These engines use injectors that are very precise spring-loaded valves that open and close at a specific fuel pressure. Separate high-pressure fuel lines connect the fuel pump with each cylinder. Fuel volume in each cylinder is controlled by a slanted groove in the plunger which rotates only a few degrees releasing the pressure and is controlled by a mechanical governor, consisting of weights rotating at engine speed constrained by springs and a lever [3]. The injectors are held open by the fuel pressure. On high-speed engines the plunger pumps are together in one unit. The length of fuel lines from the pump to each injector is normally the same for each cylinder in order to obtain the same pressure delay [3].

A cheaper configuration on high-speed engines with fewer than six cylinders is to use an axial-piston distributor pump, consisting of one rotating pump plunger delivering fuel to a valve and line for each [3].

Many modern diesel engine systems have a single fuel pump which supplies fuel constantly at high pressure with a common rail to each injector. Each injector has a solenoid operated by an electronic control unit, resulting in more accurate control of injector opening times that depend on other control conditions, such as engine speed and loading, and providing better engine performance and fuel economy [3].

Both mechanical and electronic injection systems can be used in either direct or indirect injection configurations [3].

An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber, where combustion begins and then spreads into the main combustion chamber; assisted by turbulence created in the chamber. This system allows for a smoother and quieter running engine. Mechanical injection systems allowed high-speed running suitable for road vehicles. Indirect injection engines are cheaper to build and it is easier to produce smooth, quiet-running vehicles with a simple mechanical system. In previous diesel engine vehicles, many diesel engine manufacturers most prefer the greater efficiency and better controlled emission levels of direct injection diesel applications [3].

In the past decades, design of diesel engine has included direct injection diesel engines that have injectors mounted at the top of the combustion chamber. The injectors are activated using one of two methods. The first one is hydraulic pressure from the fuel pump, or an electronic signal from an engine controller [3]. Fuel consumption is about 15–20% lower than indirect injection diesels. The extra noise is generally not a problem for industrial uses of the engine, but for automotive industry; buyers have to decide whether or not the increased fuel efficiency would compensate for the extra noise. Electronic control of the fuel injection transformed the direct injection engine by allowing much greater control over the combustion [3].

The most advanced diesel engine today is the common rail diesel engine. In common rail diesel engine systems, the separate pulsing high-pressure fuel line to each cylinder's injector has been eliminated for greater fuel economy and better controlled of the environmental pollutants. A high-pressure pump pressurizes fuel at up to 2,500 bar [3]. The common rail is a tube that supplies each computer-controlled injector containing a precision-machined nozzle and a plunger driven by a solenoid or piezoelectric actuator [3].

Dual Fuel Engine

Dual fuel engine is engine with multi-fuel capability that runs on two fuels or more. On internal combustion engines, dual fuel can be applied to either gasoline engine or diesel engine with a simple conversion system. Dual fuel engine runs on either pure gasoline or pilot diesel and the other is an alternate fuel such as natural gas (CNG), LPG, bio-diesel or hydrogen. The two fuels are stored in separate tanks and the engine runs on one fuel at a time in gasoline engine, or in both fuels for diesel engine. Dual fuel vehicles have the capability to switch back and forth from gasoline or diesel to the other fuel, manually or automatically. The most common technology and alternate fuel available in the market for bi-fuel gasoline cars is Autogas (LPG), followed by natural gas (CNG) and hydrogen. For diesel engine, various alternative fuels such as LPG, CNG, hydrogen and many other alternative fuels are widely used as secondary source of fuel all over the world. Moreover, more researchers have tested possibility of using more alternatives fuels more than two source of fuels that provided higher performance and cleaner emission levels [4][5]. Some new technologies are also being developed daily from available local resources and wasted for the use of dual fuel engine [6]. Many institutions worldwide and major oil companies developed new technology to develop dual fuel for their local production and local market available locally [7, 8].

Worldwide Automobile Emission Standards

Automobile emission standards are requirements that set specific limits to the amount of pollutants that can be released into the environment from an automobile. Many emissions standards focus on regulating pollutants released by automobiles and other powered vehicles but they can also regulate emissions from industry, power plants, small equipment such as lawn mowers and diesel generators [9]. The emission standards are different in many countries around the world but the most widely acceptable standards are from the European Union.

In the United States, emissions standards are managed by the environmental protection agency (EPA). The state of California has special dispensation to promulgate more stringent vehicle emissions standards, and other states may choose to follow either the national or California standards. California's emission standards are set by the California Air Resources Board (CARB) [9]. Given that California's automotive market is one of the largest in the world, CARB wields enormous influence over the emissions requirements that major automakers must meet if they wish to sell into that market. In addition, several other U.S. states also choose to follow the CARB standards, so their rulemaking has broader implications within the U.S. CARB's policies have also influenced EU emissions standards.

Federal tier 1 regulations went into effect starting in 1994, and tier 2 standards were being phased in from 2004 to 2009. Automobiles and light trucks such as SUVs, pickup trucks, and minivans are treated differently under certain standards [9]. California was attempting to regulate greenhouse gas emissions from automobiles, but faces a court challenge from the federal government [9]. The EPA had separated regulations for small engines, such as grounds keeping equipment. The states must also promulgate miscellaneous emissions regulations in order to comply with the national ambient air quality standards (NAAQS) started in 2009 [9].

Major standard for automotive emission controlled is the EURO standard. EURO standard is a major standard of reference for emissions of most common vehicle around the world. The European Union has its own set of emissions standards that all new vehicles must meet these requirements. Currently, standards are applied to all road vehicles, trains, barges and tractors. European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in EU member states and many other part of the world. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards. Currently, emissions of nitrogen oxides (NO_x), total hydrocarbon (THC), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types, including cars, lorries, trains, tractors and similar machinery, barges, but excluding seagoing ships and airplanes [9]. For each vehicle type, different standards will be applied accordingly. Compliance to the standard is determined by running the engine at a standardized test cycle. Non-compliant vehicles cannot be sold in the EU and many other countries, but new standards do not apply to vehicles already on the roads. No use of specific technologies is mandated to meet the standards, though available technology is considered when setting the standards. New models introduced must meet current or planned standards, but minor lifecycle model revisions may continue to be offered with pre-compliant engines [9].

European Union automobile emission standards are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6. The corresponding series of standards for heavy duty vehicles use Roman, rather than Arabic numeral numbers. These series of standards consists of a specific list which the EU directives provide the definition of the standard for different classification of vehicle ranging from different category of weight and different types of engine.

Emission standards for passenger cars and light commercial vehicles are summarized in the following tables from table 1 to table 4. Since the Euro 2 stage, EU regulations introduce different emission limits for diesel and petrol vehicles. Diesels have more stringent CO standards but are allowed higher NO_x emissions. Petrol vehicles are exempted from particulate matter (PM) standards at the Euro 4 stage, but vehicles with direct injection engines will be subject to a limit of 0.005 g/km for Euro

5 and Euro 6 [10]. A particulate number standard (P) or (PN) is part of Euro 5 and 6, but it is not a final tier on the EU standard. The standard will be defined in the near future and at the latest upon entry into force of Euro 6 [10].

Table 1 EURO emission standards for passenger cars (Category M), g/km

Tier	Date	CO	THC	NMHC	NO_X	HC	PM
Diesel							
Euro 1	July 1992	2.72	-	-	-	0.97	0.14
Euro 2	1 January 1996	1	-	-	-	0.7	0.08
Euro 3	1 January 2000	0.64	-	-	0.5	0.56	0.05
Euro 4	January 2005	0.5	-	-	0.25	0.3	0.025
Euro 5	1 September 2009	0.5	-	-	0.18	0.23	0.005
Euro 6	1 September 2014	0.5	-	-	0.08	0.17	0.005
Petrol (Gasoline)							
Euro 1	July 1992	2.72	-	-	-	0.97	-
Euro 2	1 January 1996	2.2	-	-	-	0.5	-
Euro 3	1 January 2000	2.3	0.2	-	0.15	-	-
Euro 4	January 2005	1	0.1	-	0.08	-	-
Euro 5	1 September 2009	1	0.1	0.068	0.06	-	0.005
Euro 6	1 September 2014	1	0.1	0.068	0.06	-	0.005

Table 2 EURO emission standards for light commercial vehicles of less than 1,305 kg (Category N1), g/km

Tier	Date	CO	THC	NMHC	NO_X	HC	PM
Diesel							
Euro 1	July 1992	2.72	-	-	-	0.97	0.14
Euro 2	1 January 1996	1	-	-	-	0.7	0.08
Euro 3	1 January 2000	0.64	-	-	0.5	0.56	0.05
Euro 4	January 2005	0.5	-	-	0.25	0.3	0.025
Euro 5	1 September 2009	0.5	-	-	0.18	0.23	0.005
Euro 6	1 September 2014	0.5	-	-	0.08	0.17	0.005
Petrol (Gasoline)							
Euro 1	July 1992	2.72	-	-	-	0.97	-
Euro 2	1 January 1996	2.2	-	-	-	0.5	-
Euro 3	1 January 2000	2.3	0.2	-	0.15	-	-
Euro 4	January 2005	1	0.1	-	0.08	-	-
Euro 5	1 September 2009	1	0.1	0.068	0.06	-	0.005
Euro 6	1 September 2014	1	0.1	0.068	0.06	-	0.005

Table 3 EURO emission standards for light commercial vehicles between 1,305 kg to 1,760 kg (Category N1-II), g/km

Tier	Date	CO	THC	NMHC	NO_X	HC	PM
Diesel							
Euro 1	July 1992	5.17	-	-	-	1.4	0.19
Euro 2	1 January 1996	1.25	-	-	-	1	0.12
Euro 3	1 January 2000	0.8	-	-	0.65	0.72	0.07
Euro 4	January 2005	0.63	-	-	0.33	0.39	0.04
Euro 5	1 September 2010	0.63	-	-	0.235	0.295	0.005
Euro 6	1 September 2015	0.63	-	-	0.105	0.195	0.005
Petrol (Gasoline)							
Euro 1	July 1992	5.17	-	-	-	1.4	-
Euro 2	1 January 1996	4	-	-	-	0.6	-
Euro 3	1 January 2000	4.17	0.25	-	0.18	-	-
Euro 4	January 2005	1.81	0.13	-	0.1	-	-
Euro 5	1 September 2010	1.81	0.13	0.09	0.075	-	0.005
Euro 6	1 September 2015	1.81	0.13	0.09	0.075	-	0.005

Table 4 EURO emission standards for light commercial vehicles weight more than 1,760 kg to maximum weight of 3,500 kg (Category N1-III), g/km

Tier	Date	CO	THC	NMHC	NO_X	HC	PM
Diesel							
Euro 1	July 1992	6.9	-	-	-	1.7	0.25
Euro 2	1 January 1996	1.5	-	-	-	1.2	0.17
Euro 3	1 January 2000	0.95	-	-	0.78	0.86	0.1
Euro 4	January 2005	0.74	-	-	0.39	0.46	0.06
Euro 5	1 September 2010	0.74	-	-	0.28	0.35	0.005
Euro 6	1 September 2015	0.74	-	-	0.125	0.215	0.005
Petrol (Gasoline)							
Euro 1	July 1992	6.95	-	-	-	1.7	-
Euro 2	1 January 1996	5.22	-	-	-	0.7	-
Euro 3	1 January 2000	2.27	0.29	-	0.21	-	-
Euro 4	January 2005	2.27	0.16	-	0.11	-	-
Euro 5	1 September 2010	2.27	0.16	0.108	0.082	-	0.005
Euro 6	1 September 2015	2.27	0.16	0.108	0.082	-	0.005

Automobiles in other parts of the world are also using and referring automobile emission to the EURO emission standards. In the UK, taxis and licensed private hire vehicles must be using Euro IV or Euro V standard complied vehicle to operate their fleets [10]. For Germany, cars in Germany mostly conform to the Euro IV standard as of January 2009 onward [10]. China adopted Euro III standards and the standards went into effect on July 1, 2007. In January of 2008, China implemented Euro IV standards. Beijing became the first city in mainland China to adopt this standard [10]. In Hong Kong, all new passenger cars must meet either Euro IV or US EPA Tier 2 Bin 5 standard. This legislation in Hong Kong was implemented since Jan 1, 2006 [10]. For India, Euro IV standard was applied since the beginning of 2010 [10]. Stricter emission standards are being applied in Israel. Since January 2012 all vehicles which do not comply with Euro V emission values are not allowed to be imported to Israel [10].

Unlike South Africa's own emission standard, the emission regulations are very much different from other countries. South Africa's first clean fuels program was implemented in 2006 with the banning of lead from petrol and the reduction of sulphur levels in diesel from 3000 parts per million (ppm) to 500 ppm, along with a niche grade of 50 ppm. The Clean Fuels 2 standard, expected to begin in 2017, includes the reduction of sulphur to 10 ppm; the lowering of benzene from 5 percent to 1 percent of volume; the reduction of aromatics from 50 percent to 35 percent of volume; and the specification of olefins at 18 percent of volume [10].

Lastly, Japanese automobile emission standards are fairly interesting to study because Japan is the largest automobile manufacturer in the world. Historically, the Japanese emissions standards started in June 10, 1968, when the Japanese Government passed the Japanese air pollution control act which regulated all sources of air pollutants [10]. As a result of the 1968 law, dispute resolutions were passed under the 1970 Japanese air pollution dispute resolution act. As a result of the 1970 law, in 1973 the first four sets of new emissions standards were introduced in that year. Interim standards were introduced on January 1, 1975 and again in 1976. The final Japanese emission standards were introduced in 1978 [10]. While the standards were introduced they were not made immediately mandatory, instead tax breaks were offered for cars which passed them. The standards were based on those adopted by the original US clean air act of 1970, but the test cycle included more slow city driving to correctly reflect the Japanese situation. The 1978 limits for mean emissions during a hot start test of CO, hydrocarbons, and NO_x were 2.1 grams per kilometer (3.38 g/mi) of CO, 0.25 grams per kilometer (0.40 g/mi) of HC, and 0.25 grams per kilometer (0.40 g/mi) of NO_x respectively [10]. Maximum limits are 2.7 grams per kilometer (4.35 g/mi) of CO, 0.39 grams per kilometer (0.63 g/mi) of HC, and 0.48 grams per kilometer (0.77 g/mi) of NO_x [10]. The 10 - 15 Mode Hot Cycle test, used to determine individual fuel economy ratings and emissions observed from the vehicle being tested, use a specific testing regime [10].

In 1992, to cope with NO_x pollution problems from existing vehicle fleets in highly populated metropolitan areas, the Ministry of the Environment adopted the Japanese law concerning special measures to reduce the total amount of nitrogen oxides emitted from motor vehicles in specified areas, called in short the motor vehicle NO_x Law [10]. The regulation designated a total of 196 communities in the Tokyo, Saitama, Kanagawa, Osaka and Hyogo prefectures as areas with significant air pollution due to nitrogen oxides emitted from motor vehicles [10]. Under the law, several measures had to be taken to control NO_x from in-use vehicles, including enforcing emission standards for specified vehicle categories. The regulation was amended in June 2001 to tighten the existing NO_x requirements and to add PM control provisions [10]. The amended rule is called the law concerning special measures to reduce the total amount of nitrogen oxides and particulate matter emitted from motor vehicles in specified areas or in short the automotive NO_x and PM law.

These NO_x and PM law introduces emission standards for specified categories of in-use highway vehicles including commercial goods vehicles such as trucks and vans, buses, and special purpose motor vehicles, irrespective of the fuel type. The regulation also applies to diesel powered passenger cars. In-use vehicles in the specified categories must meet 1997/98 emission standards for the respective new vehicle type [10]. Also, the 1997 and the 1998 new vehicle standards are retroactively applied to older vehicles already on the road [10]. Vehicle owners have two methods to comply with the new law. First, vehicle owners can replace old vehicles with newer cleaner models. Second, vehicle owners can retrofit old vehicles with approved NO_x and PM control devices.

Furthermore, Japanese vehicles have a grace period between 8 and 12 years from the initial registration [10]. The grace period depends on the vehicle type. Light commercial vehicles with gross vehicle weight lesser than 2500 kg have an 8 years limit. Heavy commercial vehicles with gross weight lesser than 2500 kg have a 9 years limit. Micro buses between 11 to 29 seats have a 10 years grace period. Large buses with lesser than 30 seats have 12 years grace period. Special vehicles such as large cargo truck or bus have a 10 years limited. Diesel passenger cars only allow 9 years grace period. The regulation allows fulfillment of its requirements to be postponed by an additional 0.5 to 2.5 years, depending on the age of the vehicle [10]. This delay was introduced in part to harmonize the NO_x and PM Law with the Tokyo diesel retrofit program. The NO_x and PM Law are enforced in connection with Japanese vehicle inspection program, where non-complying vehicles cannot undergo the inspection in the designated areas.

Fuel Economy in automobiles

The fuel economy of an automobile is the fuel efficiency relationship between the distance traveled and the amount of fuel consumed by the vehicle. Consumption can be expressed in terms of volume of fuel to travel a distance, of the distance travelled per unit volume of fuel consumed. Since fuel consumption of vehicles is a great factor in air pollution, and since importation of fuel for transportation sector can be a large part of a nation's foreign trade; many countries impose requirements for fuel economy. Different measurement tests are used to approximate the actual performance of the vehicle. The energy in fuel is required to overcome various losses such as wind resistance, tire drag, and many others in propelling the vehicle, and in providing power to vehicle systems such as ignition or air conditioning.

Generally, fuel economy of a vehicle is mainly losses by many factors. Firstly, engine efficiency; which varies with engine type, the mass of the automobile and its load, and engine speed usually measured in RPM. Secondly, the aerodynamic drag force, which increases roughly by the square of the car's speed and rolling friction. Thirdly, braking is another major cause of higher fuel consumption. Furthermore, losses in the transmission; the manual transmissions can be up to 94% efficient whereas the older automatic transmissions may be as low as 70% efficient

[11]. Automatically controlled shifting of gearboxes that have the same internals as manual boxes will give the same efficiency as a pure manual gearbox. Air conditioning is also another critical cause of fuel economy loss because the power required for the engine to turn the compressor decreases the fuel-efficiency [11]. Moreover, power steering is another major cause. With older hydraulic power steering systems are powered by a hydraulic pump constantly engaged to the engine. Power assistance required for steering is inversely proportional to the vehicle speed so the constant load on the engine from a hydraulic pump reduces fuel efficiency. More modern designs improve fuel efficiency by only activating the power assistance when needed; this is done by using either direct electrical power steering assistance or an electrically powered hydraulic pump.

Also, older cooling systems that used a constantly engaged mechanical fan to draw air through the radiator at a rate directly related to the engine speed can also lower fuel economy. The constant load reduces efficiency. More modern systems are now using electrical fans to draw additional air through the radiator when extra cooling is required by the vehicle.

Vehicle electrical systems are certainly another key factor that effect fuel economy. Turning off headlights, battery charging, active suspension, circulating fans, defrosters, media systems, speakers, and other electronics can also significantly increase fuel consumption because the energy to power these devices causes increased load on the alternator. Since alternators are commonly only 40–60% efficient, the added load from electronics on the engine can be as high as 3 horsepower or approximately about 2.2 kW at any speed including idle [11]. Headlights, for example; consume 110 watts on low and up to 240 watts on high [11]. These electrical loads can cause much of the discrepancy between real world and normal manufacturer tests, which only include the electrical loads required to run the engine and basic climate control.

Fuel-efficiency decreases from electrical loads are most pronounced at lower speeds because most electrical loads are constant while engine load increases with speed. So at a lower speed a higher proportion of engine horsepower is used by electrical loads. Hybrid cars see the greatest effect on fuel-efficiency from electrical loads because of this proportional effect. Various measures can be taken to reduce losses at each of the conversions between chemical energy in fuel and kinetic energy of the vehicle [11]. Driver behavior can also affect fuel economy, even sudden acceleration and heavy braking also wastes energy as well.

Generally, fuel economy can be expressed in two ways. One is the units of fuel per fixed distance and the other one is units of distance per fixed fuel unit. Commonly, unit of expression is miles per gallon (mpg) which is used in the United States, the United Kingdom and Canada. Kilometers per liter (km/L) is more commonly used elsewhere in Europe, Asia and many other parts of Africa.

Many fuel economy standards and testing procedures vary in many part of the world. For example, in Australia from October 2008; all new cars had to be sold with a sticker on the widescreen showing the fuel consumption and the CO2 emission [11]. Fuel consumption figures are expressed as urban, extra urban and combined, measured according to UN ECE Regulations 83 and 101 which are based on the European driving cycle [11]. Australia also uses a star rating system, from one to five stars, that combines greenhouse gases with pollution, rating each from 0 to 10 with then being best [11]. To get 5 stars a combined score of 16 or better is needed to fulfill the test requirement, so a car with a 10 for fuel economy and a 6 for emission or 6 for economy and 10 for emission, or anything in between would get the highest 5 star rating [11].

Most of the vehicles being sold to Thailand and the ASEAN countries are mainly Japanese automobiles. Japan has 10-15 mode driving cycle test which is the official fuel economy test and emission certification test for new light duty vehicles [11]. For the Japanese vehicle, fuel economy is expressed in km/L (kilometers per liter) and emissions are expressed in gram per kilometer [11]. The test is carried out on a dynamometer and consist of 25 tests which cover idling, acceleration, steady running and deceleration, and simulate typical urban and expressway driving patterns. The running pattern begins with a warm start, lasts for 660 seconds and runs at speeds up to 70 km/h. The distance of the cycle is 6.34 km with average speed of 25.6 km/h, and duration 892 seconds, including the initial 15 mode segment [11]. In December, 2006, Japan automobile manufacturer implemented a new test for setting a new standard of fuel economy testing [11]. It was called the JC08. This test was supposed to go into effect in 2015 but it is already being used by most of the car manufacturers for new cars at this stage [11]. The JC08 test is significantly longer and more rigorous than the 10-15 mode test. The running pattern with JC08 stretches out to 1200 seconds and there are both cold and warm start measurements and top speed is 82 km/h. The economy ratings of the JC08 are lower than the 10-15 mode cycle, but they are expected to be more appropriate for the real usages [11].

For the European Union, the standard for fuel economy is tested using the two drive cycles, and corresponding fuel economies are reported as urban and extra urban, in 100 kilometer per liter. The urban economy is measured using the test cycle known as ECE-15 introduced in 1970 by EC Directive 70/220/EWG and finalized by EEC Directive 90/C81/01 in 1999 [11]. It simulates a 4,052 meter urban trip at an average speed of 18.7 km/h and at a maximum speed of 50 km/h [11]. The extra urban driving test or EUDC lasts up to 400 seconds at an average speed of 62.6 km/h and a top speed of 120 km/h [11].

Another largest part of automobile manufacture is the United States of America. The United States imposes a much stricter regulation on fuel economy. The energy tax act of 1978 established a gas guzzler tax on the sale of the new vehicles whose fuel economy fails to meet certain statutory levels [11]. The tax applies only to cars and is collected by the IRS. Its purpose is to discourage the production and the purchase of fuel-inefficient vehicles. The tax was phased in over ten years with rates increasing over time. It applies only to manufactures and importers of vehicles, although presumably some or all of the tax is passed along to impose on used car sales. The tax is graduated to apply a higher tax rate for less fuel efficient vehicles. To determine the tax rate, manufacturers test all the vehicles at their laboratories for fuel economy. The US environmental protection agency would then confirm a portion of those tests at an environmental protection agency (EPA) lab [11].

From the past up to 2007, two separate fuel economy tests simulate city driving and highway driving were used to identify fuel economy of automobile in the US [11]. The city driving program or urban dynamometer driving schedule or UDDS that defined in 40 C.F.R. 86 Application I consists of starting with a cold engine and making 23 stops over a period of 31 minutes for an average speed of 32 km/h and with a top speed of 90 km/h [11]. The highway program or highway fuel economy driving schedule is also implemented in the fuel economy test. It defined in 40 C.F.R. 600

Application I and uses a warmed-up engine and makes no stops, averaging 77 km/h with a top speed of 97 kilometer per hour over a 16 kilometer distance [11]. The measurements are then adjusted downward by 10% in the city and 22% in the highway to more accurately reflect real-world results [11]. A weight average of city (55%) and highway (45%) fuel economies is used to determine the guzzler tax [11]. Furthermore, the procedure has been updated to FTP-75, adding a hot start cycle which repeats the cold start cycle after a 10 minute pause [11].

From 2008 until present, US EPA added three new supplemental federal test procedure tests (SFTP) to include the influence of higher driving speed, harder acceleration, colder temperature and air conditioning use [11]. SFTP is a high speed and quick acceleration loop that lasts 10 minutes, covers 13 km, averages 77 kilometer per hour and reaches a top speed of 130 kilometer per hour [11]. Four stops are included during this test, and brisk acceleration maximizes at a rate of 13.62 km/h per second. The engine begins warm and air conditioning is not used. Ambient temperature varies between 20 °C to 30 °C [11].

SFTO SC03 is the air conditioning test, which raises ambient temperatures to 35 °C, and puts the vehicle's climate control system to use [11]. Lasting 9.9 minutes, the 5.8 km loop averages 35 kilometer per hour and maximizes at a rate of 88.2 kilometer per hour [11]. Five stops are included, idling occurs 19 percent of the time. Engine temperatures begin warm. Lastly, a cold temperature cycle uses the same parameters as the current city loop, except that ambient temperature is set to −7 °C [11]. EPA tests for fuel economy do not include electrical load tests beyond climate control, which may account for some of the discrepancy between EPA and real world fuel-efficiency [11].

Performance calculation

Performance calculation of diesel and diesel dual fuel engine has been conducted within many research studies. Most of the performance calculation aimed at calculating performance parameters in fuel power, fuel consumptions, energy consumptions and thermal efficiency of the engine.

For example, Leelanoi, et al. [12] studied the performance of diesel engine using buthanol base diesohol fuel with diesel. They had presented diesel engine performance calculations for their experimental study which are useful for the calculation of performance parameters in diesel dual fuel as described below.

1. To find out brake specific fuel consumption of both diesel and dual fuel engines, it can be calculated according to the equation (1) below,

$$Bsfc = \frac{\dot{m}_f \times 3600}{\text{BP}} \quad (1)$$

where Bsfc = brake specific fuel consumption in kg per kW per hour

$\dot{m}_f$ = mass flow rate in kg per hour, which can be calculated according to the equation (2) below,

$$\dot{m}_f = \frac{W_f \times 3600}{\text{t}} \quad (2)$$

where W_f = actual mass of fuel in kg

t = time consumed to burn the actual mass in second

2. To find out brake specific energy consumption of both diesel engine and dual fuel engine, it can be calculated according to the equation (3) below,

$$\text{Bsec} = Q_{HV} \times \text{Bsfc} \quad (3)$$

where Bsec = brake specific energy consumption in kJ per kW per hour

Q_{HV} = Lower heating value in kJ per kg

3. To find out brake fuel power of both diesel engine and dual fuel engine, it can be calculated according to the equation (4) below,

$$\mathrm{FP} = \dot{m}_f \times Q_{HV} \tag{4}$$

where FP = Fuel power in kW

Q_{HV} = Lower heating value in kJ per kg

4. To calculate brake thermal efficiency of both diesel engine and dual fuel engine, thermal efficiency can be calculated according to the equation (5) below,

$$\eta_{BTH} = \frac{\mathrm{BP}}{FP} \times 100 \tag{5}$$

Where η_{BTH} = brake specific thermal efficiency in percentage (%)

BP = brake power in kW

FP = fuel power in kW

5. To calculate air-fuel Ratio of both diesel engine and dual fuel engine, it can be calculated from the equation (6) below,

$$\mathrm{A/F} = \dot{m}_a / \dot{m}_f \tag{6}$$

where A/F = air fuel ratio per unit of mass fuel

$\dot{m}_a$ = volume of air intake into the cylinder in kg/s

$\dot{m}_f$ = mass flow rate in kg per hour

Another important performance parameter for dual fuel is the original diesel substitution. According to the research study in Das, et al. [13], they have presented calculation of diesel substitution with diesel dual fuel engine using producer gas and diesel. To be more specific, they had presented calculations of the engine thermal efficiency, specific diesel consumption and percentage of diesel substitution in their experimental study. Their performance calculation of a diesel engine operated on dual-fuel mode was generally measured in terms of specific diesel consumption, engine thermal efficiency and percentage of diesel substitution. These parameters were determined in the following steps,

1. To calculate specific diesel consumption (SDC), it can be calculated from equation (1)

$$\text{SDC} = \frac{3600 v_d P_d}{1000t\, p} = 3.6\ \frac{V_d P_d}{t\, p} \qquad (1)$$

where SDC = specific diesel consumption in gram per kilowatt per hour

V_d = Volume of diesel consumed in cubic meter, cm^3

P_d = specific weight of diesel in kg/l

t = time required to consume diesel in second

p = engine power in kw

2. Thermal efficiency of diesel engine is calculated according to equation (2)

$$n_t = \frac{Brake\ Power}{Power\ input\ from\ fuel} \qquad (2)$$

The Power input from fuel in equation (2) is given in equation (3) in below,

$$P_f = \frac{CV_d \times P_d \times f_c}{3600} \qquad (3)$$

where P_f = Power input from fuel in kW

CV_d = Calorific value of diesel = 39 MJ/kg

P_d = density of diesel = 640 kg/m^3

f_c = fuel consumed in cm^3/h

Substituting the values of CV_d and P_d, the equation (3) yields equation (4),

$$P_f = \frac{39 \times 840 \times f_c}{3600} = 9.1\, f_c \quad (4)$$

Using equation (4), equation (2) gives thermal efficiency of pure diesel operation as,

$$n_t = \frac{Brake\ Power}{9.1\, f_c} \quad (5)$$

3. Thermal efficiency of diesel dual fuel is then equal to (6),

$$n_t = \frac{Brake\ Power}{Power\ input\ from\ pilot\ diesel + power\ input\ from\ gas} \quad (6)$$

Power input from gas is given by

$$P_g = \frac{CV_d \times g_c}{3.6} \quad (7)$$

where P_g = power from gas in kW

CV_g = calorific value of gas in KJ/Nm^3

g_c = gas consumption in Nm^3 per hour

Substituting equation (5) and (7) in equation (6), thermal efficiency of a diesel dual fuel engine equal to,

$$n_t = \frac{Brake\ Power}{9.1\, f_c + \frac{CV_d \times g_c}{3.6}} \quad (8)$$

4. Diesel substitution: The percentage of diesel substitution in dual fuel engine is given in equation (9)

$$ds = \frac{D_d \times D_{dg}}{D_d} \times 100 \quad (9)$$

For dual fuel which uses diesel as pilot source of fuel and blending of alternative fuels and used as a secondary source of fuel in diesel engine, Lata, et al. [14] has presented calculation of thermal efficiency for the dual fuel engine in below equation. Their experimental study blended pilot diesel with hydrogen and LPG as a secondary source of fuel. They presented an equation of calculating thermal efficiency for diesel dual fuel with varies LPG blended and hydrogen addition as a secondary source, which uses the following steps below.

1. The indicated power output is calculated as

$$w_i = \sum_{i=1}^{720} \rho_i (V_i - V_{i-1}) \quad (1)$$

where W_i is work output and P_i is pressure and P_i = W_i(N/2x60) where P_i indicated power, N is RPM.

2. Brake thermal efficiency of their calculation is given in equation (2) as

$$n_b = \frac{BP}{(m_d Q_d + m_{H_2} Q_{H_2} + m_{LPG} Q_{LPG}) \times 1000} \quad (2)$$

where m_d, m_{H_2}, m_{LPG} are the mass flow rate of diesel, hydrogen and LPG respectively, and Q_d, Q_{H_2}, Q_{LPG} are the lowest heat of combustion of diesel, hydrogen and LPG, respectively.

Emission calculation

Calculating automobile emission is meant for the purpose of calculating major harmful emission from an automobile. Lim [10] conducted a study of exhaust emissions from diesel trucks and presented emission calculation for important pollutants to determine the tons of emissions from these trucks. A sample calculation of mass CO_2 is shown in the below equation (1),

$$\text{Mass of } CO_2 = [ß \cdot \forall \cdot C \cdot dt] / F \qquad (1)$$

where:

ß = Density of CO_2 in gram per ft^3

$\forall$ = Volume flow rate in ft^3 per minute

C = CO_2 concentration in %

F = water condensation in the sample line factor

dt = delta time = 1 second

Related Literatures

There are many research studies of using alternative fuels in internal combustion engine. Lessons and technical details can be found in many of the literatures over the past years. However, as for the purpose of this research study is on potential development of using HCNG for the diesel engine. Thus, the majority of the literatures are dedicated to reviews in part and components of hydrogen, natural gas, and diesel dual fuel engine.

Early development of experimental study on replacing traditional petroleum fuel can be seen in many business trajectories depending on local circumstances and local resources of the given area. Replacing normal petroleum products such as normal diesel driven vehicle with compressed natural gas (CNG) can be seen in Fontaras, et al. [15]. They conducted an investigation of on road emission tests of EURO V diesel vehicle comparing to pure CNG vehicles. Their experimental results showed advantage of reducing NO_x and PM emissions. But when they had compared to the original diesel operation, pure CNG vehicles had shown decreased in performance efficiency of higher CO, HC and other greenhouse gas emissions. Therefore, with running on pure CNG vehicles may not likely to improve emission levels.

Another interesting area of today's future fuel for the internal combustion engine is the feasibility of bringing hydrogen into the replacement of today's renewable energy. Hydrogen addition to the internal combustion engine is another area of interest among new renewable energies that have been conducted in many laboratories and many major institutions around the world. It is believed that by beginning to implement hydrogen into internal combustion engine, major automobile manufactures will consider building a bridging technology to early trail out blending hydrogen with many other alternative fuels or traditional petroleum fuels in both gasoline and diesel engine [16]. Even new developing country such as Algeria, the research has sought out for combination of hydrogen and compressed natural gas altogether at once without trials in using other alternatives first [17]. India is another example of considering replacing traditional compressed natural gas program with an upgrade version which includes hydrogen addition at the filling station and to ensure an early entry of hydrogen fuel into local infrastructure [18, 19, 20, 21].

In the past years, many research studies have been using LPG as an alternative fuel to blend with petroleum diesel or bio-diesel depending on the given area and the availability of diesel on the given experiments. Results have shown better performance and lower emission level in various applications. However, there are still many problems with inconsistency of fuel economy and emission of NO_x level [14, 22].

Acharya and Jens [23] conducted experimental study of using Karanja oil methyl ester with LPG to improve higher performance of diesel engine. Their results showed positive sign of reducing NO_x and smoke emission while performance of the engine has been increased positively. However, their experimental results suffered from higher HC and higher CO emissions; particularly at lower load level because of the poor ignition.

Poonia, et al. [24] suggested using EGR and larger amount of pilot diesel quantity in low load to improve poor exhaust emissions during low loads in their experimental study of using LPG with diesel in an LPG diesel dual fuel engine.

Saleh [25] investigated LPG diesel dual fuel system by using various LPG compositions with diesel to examine emissions and performance characteristics of the engine. The results had shown that higher LPG composition and lesser diesel injection leads to lower NO_x content levels while it had also reduced CO levels but it happened only in part loads, not in all loads.

There are also many research studies previously chose compressed natural gas over LPG because natural gas is another promising alternative fuel for many reasons. First, it has already been successfully utilized in ground transportation sector in many internal combustion engines such as gasoline and diesel engine. However, for the diesel engine; natural gas cannot be used as the sole fuel because of its high compression ratio and engine knock limitation. Therefore, for diesel engine; natural gas must be used as dual fuel.

Furthermore, many researchers have been trying to find an optimization of the use of natural gas and diesel as it promotes improvement in performance and promise to lower emission levels. But in the past researches, using CNG diesel dual fuel may provide positive results in improving performance to certain levels but emission levels of NO_x and other emission results are still poor as comparing to original diesel engine alone.

Egusquiza, et al. [26] conducted an experimental study of using natural gas and diesel in a diesel dual fuel turbocharged to investigate the performance and emission characteristics of the dual fuel system, and then compared with the original diesel operation. Their results show that diesel dual fuel system improved emission level of NO_x. However, under the low load measurements; the results had indicated poor results on higher CO and HC emissions as well as higher brake specific fuel consumption when compared to the original diesel engine.

Liu, et al. [27] conducted various emission tests on using CNG with diesel in a diesel dual fuel engine. Their results presented interesting improvement in reducing NO_x to 30% as comparing to the original diesel engine. However, hydrocarbon level results of their experiment had been increased at low to medium load level. Moreover, particulate matter (PM) decreased with using natural gas with diesel in a diesel dual fuel engine with less diesel pilot injection but when they tried to increase the amount of pilot diesel injection; PM results also increased when comparing to the original diesel engine.

Ryu [28, 29] studied combustion and emissions characteristics of using biodiesel and compressed natural gas as dual fuel in the diesel engine. Biodiesel was used as a pilot fuel to ignite the engine followed with compressed natural gas to operate in diesel dual fuel mode. The results showed that the combustion of biodiesel-

CNG mode starts later compared to diesel mode but begins and ends earlier if there were more pressures in the pilot injection stage. Also, in the biodiesel-CNG mode; BSFC (brake specific fuel consumption) was higher than those of diesel single combustion. Furthermore, the results showed lower smoke but higher NO_x with more pilot injection pressure in the biodiesel-CNG mode.

Paul, et al. [30] investigated using CNG with diesel and combination of diesel with ethanol blends with CNG. The investigation examines performance characteristics and emission characteristics of using both CNG with diesel and combination of diesel with ethanol blends with CNG.

Their experimental study showed that at excess full load, diesel and ethanol with CNG enrichment increases brake thermal efficiency by 6.32%, brake specific energy consumption increases by 80.18% with the inclusion of more CNG. And on the emission, CO emission increases by 41.37% at 40% load, 70% at 80% load, and 94.21% at 120% load with increasing CNG content. NO_x emission decreased with diesel and CNG combination. With their strategies in the experiment, NO_x emission reduced by 91.29% with using diesel mixed with ethanol and CNG enrichment. Their study has also presented method of calculating calorific value on the basis of base fuels, diesel, ethanol and CNG with using the equation 1 and method of calculating brake specific energy consumption in all base fuels in equation 2.

Below equation is a method of calculating calorific values of a blend between diesel and ethanol in equation (1).

$$\text{Qcal, mix} = \frac{\sum x_i \times \rho_i \times \text{Qcal.i}}{\sum x_i \times \rho_i} = \frac{(x_d \times \rho_d \times Q_{cal.d}) + (x_{eth} \times \rho_{eth} \times Q_{cal.eth})}{(x_d \times \rho_d) + (x_{eth} \times \rho_{eth})} \quad (1)$$

Where,

x_i = Volume percentage of a base fuel in the blend

x_d , x_{eth} = Volume percentage of a base fuel in the blend

ρ_d , ρ_{eth} = Density of diesel and ethanol respectively

$Q_{cal.d}$, $Q_{cal.eth}$ = Calorific value of diesel and ethanol respectively

Below is a method of calculating BSEC (Brake Specific Fuel Consumption) in equation 2 which indicates the efficiency of the engine with which the input energy content of the fuel is utilized by the engine during combustion.

$$\text{BSFC (kJ/kg)} = \frac{M_D \times LHV_D + M_{Eth} \times LHV_{Eth} + M_{CNG} \times LHV_{CNG}}{BP} \quad (2)$$

Where,

M_D , M_{Eth} , M_{CNG} = Mass flow rate of diesel, ethanol and CNG respectively

LHV_D , LHV_{Eth} , LHV_{CNG} = Lower Calorific value of diesel, ethanol and CNG respectively

Carlucci, et al. [31] investigates using natural gas with diesel common rail mono-cylinder to operate in dual fuel mode with new technique of using electronic control to control the whole system of diesel and natural gas operation. The experiment was conducted with defining combustion development and engine exhaust emission in low load and high load with varies amount of CNG injected into the engine. The result shows that comparing low load and high load emission results, the dual fuel is a very effective strategy to reduce unburned hydrocarbons and NO_x.

Similar to other researchers in the field of CNG diesel dual fuel system, Ehsan and Bhuiyan [32] investigated using natural gas with light duty diesel engine, their performance results had shown nearly the same with the original diesel performance nearly 90% close to the original diesel with an impressive 88% replacement of diesel.

On the other hand, Papagiannakis, et al. [33] conducted a study on a direct injection single cylinder CNG diesel dual fuel engine and found that the brake thermal efficiency of this system was lower comparing to normal pure diesel operation. Moreover, their results had also shown that NO_x decreased as compared to normal diesel operation. At the same time, their CNG diesel dual fuel operation provided significant decreases in smoke.

Venkatesan [34] examined diesel dual fuel engine with the use of Jatropa oil methyl ester biodiesel and CNG. The findings from his study provide positive results in both performance improvement and emission level improvement. Similar results were obtained in another CNG diesel dual fuel experiment. This means that faster combustion process and lower exhaust temperature are the reaction of using proper blended and proper amount of pilot and secondary fuel [35].

Many institutions, organizations and private companies are working to develop engines that might efficiently exploit the potential of hydrogen. Researches in using hydrogen with diesel engine have also grown in number previously. The aim is to find energy systems that will be renewable and sustainable, efficient and cost effective, convenient and safe and hydrogen is one of the possible solutions to that.

In addition to single traditional fuel operation, dual fuel operation is also of interest to the automobile manufacturer. The major advantage is the opportunity to refill with a traditional fuel when the hydrogen is not available. But the disadvantage part of this system is the hydrogen storage on board and their management.

Plenty of literature provided positive results in implementing hydrogen addition in diesel engine such as higher brake thermal efficiency when the engine is compared against pure diesel operation [36].

Kumar Bose and Maji [37] investigated using hydrogen as inducted fuel and diesel as injected fuel with exhaust gas recirculation technique to see the performance and emission of the hydrogen diesel dual fuel mode with a single cylinder diesel engine. The results showed that brake thermal efficiency increased by 12.9% with the supply of 0.15 kg/h of hydrogen. And the brake specific fuel consumption is less than operating in pure diesel because higher calorific value of hydrogen and operation of hydrogen fuelled engine under lean burn conditions. Furthermore, the results showed higher engine temperature under hydrogen diesel dual fuel mode. But smoke decreased tremendously 42% comparing to pure diesel operation. CO_2 also decreased by 40.5% and HC emission decreased by 57.69% with hydrogen diesel dual fuel mode. Beyond that, CO emission decreased by 45.8% compared to pure diesel operation under 80% engine load. This investigation reported that low EGR percentage was preferred to lower NO_x concentration as NO_x increased with higher engine temperature.

Boretti [38] reported that hydrogen diesel dual fuel engine has increased engine thermal efficiency close to 40% comparing to the original diesel engine.

Many research studies have found significant enhancement in engine power and decreased in emission levels under hydrogen and diesel dual fuel engine [39][40]. However, some research had pointed out that high percentage of hydrogen addition may cause higher emission levels. In Chaisermtawan, et al. [41], their research study stated that as hydrogen addition to the engine increases, the amount of H_2, CO and CH_4 in the exhaust gas also increased depending on the air and fuel ratios given to the engine.

Other problems are also found in other experimental research studies. Santoso, et al. [42] conducted a study on dual fuel engine with diesel and hydrogen and found that at the low load, hydrogen enhancement reduced the cylinder pressure and also reduced engine efficiency. Higher emission level of NO_x comparing to original diesel operation is another major problem for hydrogen addition [43].

Many research studies have found low percentage of hydrogen to provide better results in mixing with diesel when it comes to operate a diesel dual fuel engine. Szwaja, et al. [44] found that 5% hydrogen addition to the diesel engine shorten ignition time and at the same time decreased temperature of the engine which will enhance engine durability when comparing to only pure diesel operation.

Various results were inconsistent depending on how the research experiment had been conducted, techniques and technologies. SinghYadav, et al. [45] pointed out that using EGR (exhaust gas recirculation) technique will provide better results in lowing emission level and improved performance level when compared to the pure diesel operation. Escalante and Fernandez [46] claimed that higher volume of injection is needed to achieve better results because a low hydrogen density makes larger volume of fuel. Christodoulou and Megaritis [47] reported that hydrogen addition can actually decrease smoke and CO at the expense of higher NO_x emission levels.

An advance experiment has also been conducted with using hydrogen and compressed natural gas or LPG in diesel engine. However, there are still many problems with using this technique. Arat, et al. [48] conducted an experiment using HCNG in diesel engine and found three problems, namely; minor reduction in power output, higher brake specific fuel consumption and storage problem. In Lata and Misra

[49] experimental study, blending both hydrogen and LPG and used them altogether as a secondary source provided better results in performance and emission.

Indeed, HCNG has already been experimented with many spark ignition engines previously. The results of using HCNG in spark ignition engines are still providing unsatisfied results but certainly the results are much better comparing to the normal natural gas engine.

Ma, et al. [50] investigated engine performance and emission of a turbocharged CNG engine fueled by hydrogen and natural gas with 55% hydrogen ratio. The results of this experiment are highly suggested that introducing additional hydrogen can improve combustion, reduce flame propagation duration, increase torque output comparing to using pure CNG in such an engine. Furthermore, the results have shown that high hydrogen ratio can significantly extend the lean burn limit and increases thermal efficiency [51]. Their study has confirmed that high hydrogen ratio increased burning speed of the fuel [52]. The reason for faster burning speed is because the additional hydrogen provides a pool of H and OH radicals which makes the combustion reaction much easier and faster, thus leading to shorter burn duration. Thermal efficiency of high hydrogen ratio obtained in this experiment also improved by 33.7% under the operating conditions of a lambda of 2.4. Beyond that, emission such CO and CH_4 are remarkable reduced with this methodology of high hydrogen ratio but NO_x increased at the same time [53].

Mohammed, et al. [54, 55] investigated engine characteristics and emissions with using hydrogen in CNG spark ignition engine. They were expected that small amount of hydrogen addition into the CNG supply can increase the burning velocity and the combustion will be faster even when the mixing is poor in the low engine speed. Their results have demonstrated that engine torque increased in low speed but decreased in high speed of 4000 rpm. The brake thermal efficiency was also increased with additional hydrogen in the CNG supply to the engine. As well as improvements in performance of the engine, their results also show that emissions were also improved as well.

Suryawanshi and Nitnaware [21] investigated HCNG in the spark ignited engine and summarized many benefits of using HCNG as a better choice of alternative fuel. Their arguments pointed out that using CNG alone will result in engine wear out, damage inlet valve and engine parts as compared to conventional fuel gasoline. Because using CNG alone in gasoline engine will slow down burning velocity, thus leading to poorer combustion stability. Furthermore, using CNG alone in gasoline engine will reduce torque and power of the engine comparing to using gasoline. Therefore, based on their findings; using HCNG will be a better choice for gasoline engine comparing to the original fuel supply from using CNG. Their report further examines properties of adding hydrogen to natural gas. Many benefits of using blending hydrogen with natural gas were investigated thoroughly in their report. These results are hydrogen mass specific lower heating value, LHV of 120 MJ/kg is nearly three times that of methane and gasoline, an approximate seven fold of increasing burning speed over pure methane and gasoline, less heat transfer from a hydrogen flame compared to either methane and gasoline flames and quenching distance of 0.064cm is approximately $1/3^{rd}$ of pure methane and gasoline.

For HCNG, technical adaptation to the actual engine is the most significant in getting better performance and emission results. Many researchers have found difficulties in balancing expected performance results and satisfied decreasing results of emission levels. Ceper, et al. [56] evaluated a blended of varies percentage of hydrogen from 0% to 30% and found that at the rich mixtures of hydrogen content went up to 30%, CO2 emission level also increased as the percentage of hydrogen content had increased at the same time. Ma, et al. [57] also found the same problem with increasing percentage of hydrogen in the spark-ignition engine but in different results of emission concerns. Ma, et al. found that nitrogen oxides (NO_x) increased as the percentage of hydrogen has increased during the experiment. On the other hand, Ortenzi, et al. [58] conducted experimental study of using 10% and 15% hydrogen addition to the CNG spark-ignition engine and found HC emissions increased at the low load when applying hydrogen addition. Huang, et al. [59] found similar characteristic of hydrogen addition when comparing to pure CNG operation alone. They found that at the normal operation, running the engine with CNG gave higher values of peak cylinder pressure and better heat release rate. Only in the case of stoichiometric mixture combustion, then hydrogen addition gave the highest values of peak cylinder pressure and maximum heat release rate. Park, et al. [60] conducted an experimental study of using HCNG in spark-ignition engine and found greater performance but also found that CH_4 emission was higher than normal CNG and did not meet the standard of EURO VI requirement.

In summary from reviewing all of the literatures, there are still many problems of using alternative fuels with internal combustion engine either in finding optimization point to balance in between gaining better performance and better emission levels or finding effective and reliable technology to maximize the use of alternative fuels. Thus, it is rational to explore the potential of using reliable, affordable and emission friendly technology to achieve greater performance and lower emission levels from the advantages and disadvantages of many alternative fuels for diesel dual fuel engines. In addition to that, HCNG has the highest feasibility to the normal CNG supply to the diesel dual fuel engines. Therefore, this experiment will be choosing HCNG as the main source of normal diesel substitution.