SUDAN UNIVERSITY OF SCIENCE & TECHNOLOGY

COLLEGE OF GRADUATE STUDIES

The Applied System of Bi-Fuel (Diesel + Natural Gas) at South Annajma Power Station

تطبيق نظام ثنائي الوقود (الديزل + الغاز الطبيعي) في محطة النجمة جنوب لتوليد القدرة

A Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (Power)

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الآيــة

قال تعالى :

(وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا

نَ الْعِلْمِ إِلَّا قَلِيلًا)

صدق الله العظيم

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I am thankful also for STAROIL CO. Production Department for Cooperation and facilitate to my supervisor visited to field ... May Allah bless them all.

Dedication

To my parents, who are the reasons of my existence in life -after Allah the Almighty-, and who I will not ever be able to satisfy in return what they have done for me.

To all teachers who have taught me even a letter, through all my education years everywhere.

To everyone I knew in my whole life.

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Abstract

Bi-Fuel can be defined as the simultaneous combustion of two fuels. In the case of the Bi-Fuel System, natural gas (methane as based fuels) is utilized in conjunction with diesel fuel to operate the engine.

In this research LPG air mixes have been used in the air intake manifold at different concentration level while the diesel injection through injector at the end of compression stroke.

Results of experimental test indicated that using diesel fuel and diesel fuel with LPG, decreases the diesel fuel consumption relative to single diesel fuel by the following percentages 75% at 1600 rpm and torque 100 N.m, 42% at 1800 rpm and torque 105 N.m , 39% at 2100 rpm and torque 110N.m. This percentage produced the optimum power and power efficiencies same as single diesel fuel as follow: 16.75 KW and 39.38% at 1600 rpm, 19.8 KW and 37.1% at 1800 rpm, 24.19 KW and 36.5% at 2100 rpm.

Analysis of the exhaust emission characteristics for the fumigate and diesel fuel, shows that the pollutants (CO, NO_x , SO_2) as follow: CO 1024 ppm and SO_2 21 ppm.

Finally when we used the LPG with Diesel fuel will reduce the diesel consumption and at the same time we get the same result of power and efficiency when we used the diesel alone without any effect in engine performance.

المستخلص

الوقود الثنائي هو احتراق لوقودين مع بعضهما في وقت واحد كاحتراق الغاز الطبيعي (الميثانCH_4 كوقود أساس) بالتعاون مع وقود الديزل لتشغيل المحرك.

حيث يكون مزج غاز البترول المسال مع الهواء في مشعب السحب بمستوى تركيز مختلفة ويتم حقن وقود الديزل من خلال حاقن في نهاية شوط الضغط

وأشارت نتائج الاختبار التجريبي أن استخدام وقود الديزل مع LPG يقلل من استهلاك الديزل بالنسب التالية:

تقليل استهلاك الديزل بنسبة 75٪ في 1600 دورة في الدقيقة وعزم 100 N.m

تقليل استهلاك الديزل بنسبة 42 ٪ في 1800دورة في الدقيقة وعزم 105N.m

تقليل استهلاك الديزل بنسبة 39٪ في 2100دورة في الدقيقة وعزم N.m110

وهذه النسب تنتج نفس القدرة والكفاءة التي يمكن الحصول عليها عند استخدام وقود الديزل لوحده كالتالي:

16.75 KW –39.38% في 1600 دورة في الدقيقة

19.8 KW - 37.1% في 1800دورة في الدقيقة

24.19 KW- 36.5% في 2100دورة في الدقيقة

ومن تحليل خصائص انبعاث غاذات العادم لوقود الديزل تبين أن (CO , NO_x, SO_2) كالتالي CO : 1024ppm جزء في المليون و SO_2 21ppm .

وأخيرا عند استخدام الغاز الطبيعي المسال مع وقود الديزل سوف يقلل من استهلاك وقود الديزل، ونحصل على نفس القدرة والكفاءة عند استخدم الديزل لوحده من غير اي تغير في اداء الماكينة.

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Abbreviations

Abbreviation	Nomenclature
E39%	39 percent LPG and 61 percent diesel by volume
E42%	42 percent LPG and 58 percent diesel by volume
E75%	75 percent LPG and 25 percent diesel by volume
LPG	Liquefied Petroleum Gas
BTU	British Thermal Unit
HCCI	Homogeneous Charge Compression Ignition
CN	Cetane Number
ASTM	American Society for Testing and Materials
API	American Petroleum Institute
CI	Compression Ignition
SI	Spark Ignition
ICE	Internal Combustion Engine
MSCFD	Million standard cubic feet per day
PM	particulate matters
kW	kilowatt
BTDC	Before Top Dead Center
SOI	start of injection
CAI	Controlled Auto Ignition
cuft	Cubic Feet

ECM	Electronic Control Module
DGCS	Dynamic Gas Control System
BPE	Break Power Efficiency

Chapter One

The theoretical conceptual frame work

1.1 Introduction:

A challenge exists today in the competitive energy markets for the need to provide an efficient and low cost method of producing power at an end-users location.

As end users search for ways to improve the reliability of their standby power systems, increased interest has been directed toward the issue of on-site diesel fuel storage. How much fuel is enough? How much is too much?

A bi-fuel engine is a compression-ignited diesel engine that runs on the simultaneous combustion of diesel fuel and natural gas.

Under normal operating conditions, bi-fuel generators operate on 70% natural gas and 30% diesel fuel. This greatly extends run times and limits the amount of diesel fuel that must be stored on site. [1]

Bi-fuel which is used in the diesel engines is object to reduce the fuel consumption and to conserve the environment by released good burned exhaust to an atmosphere, especially in the gas and petroleum industry where the gases is released after the complexity oil processing, this bi-fuel application is used to re-use the resultant gases again and injected it with zero pressure to raise the efficiency of combustion and reduce the consumption of the fuel.

In this application the gas and air are mixing in the air manifold (before entering the combustion chambers), this could able to allow the fire inside the combustion chambers ignite with minimum require of the diesel, due to the saturated air with gases, there is air –gas mixer is used to combine engine intake combustion air with an appropriate quantity of natural gas. Bi-fuel operation will typically reduce production of nitrogen oxides, sulfur oxides reactive hydrocarbons, carbon dioxide, and particulates and also reduce exhaust opacity levels. This system has been designed for constant speed application such as engine driven, electric power generation, and compressors, variable speed application may also be converted to bi-fuel depending on the governing system used and the methods of engine operation, has been designed as scalable technology that can be adapted to various engine size and high speed 1200 rpm diesel engines ranging in size from 75 kW (100 horsepower) to over 3000 kW (4000 horsepower) as explained briefly in the above paragraph, bi-fuel is economically and environmentally is achieved good practical results.

1.2 Problem statement:

The South Annajma Oil Field produces 10000 barrels of oil associated with 2,568 million standards cubic feet per day of natural gas, the natural gas usually burnt to atmosphere in Flare Stack.

This project seeks for experimenting to use the natural gas with diesel fuel in the diesel engine to produce 600 kWh and 13.88 µWh/d.

1.3 Significance of research:

Natural gas in combustion engines is a clean fuel relative to other fuels. It is free of particulate matters PM and produces less CO_2 than petrol fuel. The emissions of dual fuel engines therefore show less PM and CO_2. Diesel and natural gas fueled generators have been common solutions for Industrial standby power applications for decades.

The natural gas generators offer numerous advantages compared to diesel fuel. The most noticeable is the extended run time offered by an endless supply of natural gas. This is a huge advantage given that refueling conventional diesel generators can be quite challenging during long-term outages.

1.4 Objectives:

1.4.1 General objectives:

1) Reduced diesel fuel storage requirements.
2) Lower capital cost per kilo Watt (kW) compared diesel fuel only.
3) Improved reliability with redundant fuel supply.
4) Extended run time capabilities.
5) Reduced maintenance costs.
6) Potential for less fuel costs.
7) Lower exhaust emissions than diesel engines.

1.4.2 Specific objectives:

Scientific experiments task of the use of natural gas as secondary fuel (additional) for diesel and study the impact on:

1) To investigate the Capability of diesel engine to operate with bi-fuel.
2) To investigate the physical properties of natural gas-diesel in comparison to diesel.
3) To investigate the environmental impact by analysis the exhaust gas emission.
4) Impact of the bi-fuel on power and efficiency comparison to diesel.

1.5 Theoretical methodology:

1) Lab analysis for produce gas component.
2) Pilot test in diesel engine for diesel fuel and Bi-fuel and calculate the Power and efficiency and comparing between them.
3) Specify the characteristics of the Bi-fuel and effective at the diesel Engine.
4) Fabricate and Install suitable gas carrier flow line.
5) Install filtration system at gas line with drain.
6) Install gas train (Bi-fuel system) with high secure system.

Chapter Two

Literature Review

2.1 Previous Studies:

-Mohamed Mustafa Ali, have developed control of combustion diesel Engine using gasoline fumigation**.** [2]

This study was made to identify the most favorable conditions for dual fuel mode (diesel + gasoline) of operation using diesel as main fuel and gasoline as a combustion improver. The selected approach is to improve the brake thermal efficiency through improving the combustion efficiency. This will help in both aspects of improving thermal efficiency and on the other hand reducing incomplete combustion products and thus improving emission level. The experiments are conducted in two stages, first by running a pilot test in a variable speed multi cylinder diesel engine. Air has been fumigated by gasoline and the effect on part and full load have been defined. The point of higher engine loads was found in need for more development. The second stage is the main test running where a single cylinder constant speed direct injection diesel engine has been modified to run in gasoline fumigated mode.

These modes of operations are namely (D+GI) and (D+GII).

The obtained effect with (D+GII) showed an increase of thermal efficiency by 10% and a significant decrease in CO and NO_X emissions. In order to reduce HC to a level below that of diesel fuel mode, the fuel injection timing was found need to be retarded by 2 degree (D+GIII). This produced the optimum performance with the same increase in thermal efficiency and a significant decrease in CO (by 73%) and HC by 25% and NO_X decreased as well by 7.5%.

See table (2.1) and figure (2.1).

Table 2.1 list of Test modes for dual fuel (diesel + gasoline) [2]

Test	Description
D	Baseline performance with diesel fuel alone
D+GI	Dual fueling with gasoline using 0.25mm jet
D+GII	Dual fueling with gasoline using 0.50mm jet
D+GIII	Dual fueling with gasoline using 0.50mm jet and retarded start of diesel injection timing

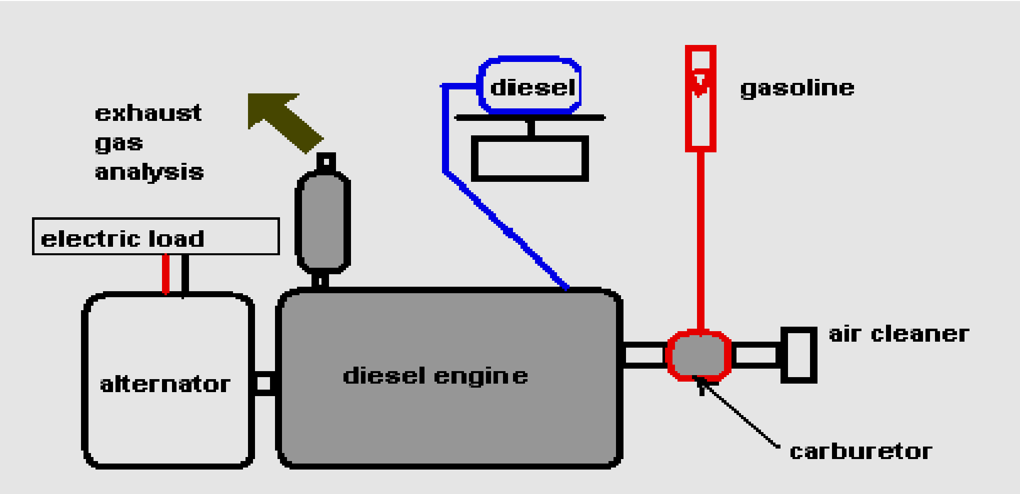

Figure 2.1 Test Rig Setup for diesel and gasoline [2]

-Deo Raj Tiwari, [3], have developed Performance and Emission Study of LPG and Diesel Dual Fuel Engine.

This paper was observed, results and their analysis with respect to the experiments conduced on fuel mix used in a set up on CI engine. LPG air mixes have been used in the air intake manifold at different concentration level while the diesel injection through injector at the end of compression stroke has remained undisturbed at the original level.

The experiments were conducted at different loads. The objective of the study has been to minimize the pollutant emission, observations were also taken for the impact on thermal efficiency and the power developed.

There are two ways for controlling emissions. The first method is to control the emission after the combustion, at the exit point using various equipment such as catalytic converter, thermal converter etc. The second method is to control the emissions during combustion. This can be done either by the changing the fuel injection timing or by injecting some additive from outside which may react inside combustion chamber and produces clean exhaust. This can be done by injecting LPG, hydrogen, or steam in combustion chamber.

The following inferences can be drawn from the experimental observations:

(A) Impact on pollutant emission:

(*i*) The emission level goes up with the increasing load.

(*ii*) With LPG injection, however, there is a significant reduction (almost 30%) in smoke level at all loads.

(B) Impact on fuel consumption:

Fuel Consumption reduces progressively at all loads as LPG injection is stepped up. This substitution of the usual fuel diesel is cost effective.

(C) Impact on exhaust temperature and NO_x in exhaust:

For the minimum exhaust temperature, LPG injection has to be less than 0.5 l/min for this engine. Thus reduction in temperature of exhaust is likely to decrease the formation of NO_x an undesirable constituent of emission. In more effective utilization of the engine.

(D) Impact on Brake Thermal Efficiency (%):

Thermal efficiency increases with LPG injection till 2.5%.

(E) Impact on specific fuel/consumptions (kg/kWh):

Specific fuel consumption shows an all-round drop in fuel consumption till 10% when added about 1.9 L/min LPG.

2.2 Description of the bi-fuel technology: [4]

2.2.1 The basics:

To understand the technology that is a quick overview is need on the basic technology of natural gas and diesel engines.

While the obvious difference between the two engine types is the fuel input, the basic technology of a diesel and natural gas reciprocating engine is also different. Natural gas engines are similar to gasoline driven engines utilized in vehicles, by the requirement of a spark ignited method. This means that a spark is required to start combustion.

The spark plugs are necessary because natural gas like gasoline has a heat content that cannot create combustion by itself.

However diesel engines utilize a fuel that does not require spark plugs because the heat content of the fuel is enough to combust with a compression cycle. This method allows for a piston to compress the fuel/air mixture, whereby combustion occurs due to the compression.

To allow diesel engines to use natural gas would require a Change to the technology. This would mean installing spark ignition systems and various other changes. Such conversions are not cost efficient and also do not maintain the original power output that the engine was designed to provide.

2.2.2 The bi-fuel technology:

The Bi-fuel technology allows diesel reciprocating engines to use natural gas (a mixture of natural gas and diesel). The Bi-fuel system can replace up to 70% of the diesel fuel requirements of the engine.

The Bi-fuel system is comprised of four main components. An air fuel mixer, gas power valve, gas train and an engine control system. The gas flow initially enters the gas train, which will reduce the inlet gas pressure to atmospheric pressure. The negative outlet pressure allows the system to pull natural gas depending on the intake airflow of the engine. Thus, as engine load will change, the intake air volume will draw additional fuel into the mixer.

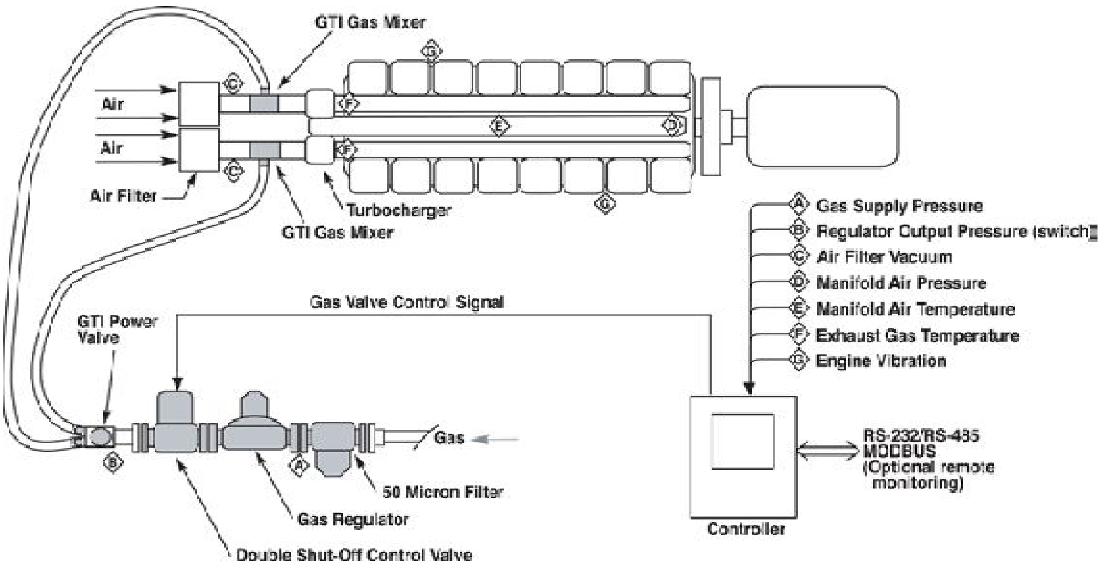

Figure 2.2 Bi-fuel system diagram [5]

Once the natural gas leaves the gas train, the gas power valve is used to provide the engine the required gas flow rate for a given engine load. After leaving the gas power valve, the natural gas is mixed with air in the air-fuel mixer. This device allows for the correct mixture of air and natural gas.

The air-natural gas mixture is then compressed in the turbocharger and distributed to each cylinder, where it is compressed and ignited when diesel is injected into the cycle. The whole process is monitored by

The electronic control system and pressures temperature, exhaust gas temperature, gas pressure, engine vibration, and manifold air pressure. The electronic control uses this information to ensure that the engine will not operate in bi-fuel mode if any of these measurements go beyond their expected parameters.

It is important to note that the Bi-fuel technology does not replace the diesel fuel 100%. This is self explanatory because the diesel generator operates on a compression cycle it is necessary to maintain a level of diesel fuel to operate the system. The diesel fuel is also needed for providing lubrication of the diesel engine system.

The performance of the engine does not change with the bi-fuel system. There is no de-rating of the engine and the total BTU input is the same for the natural gas/diesel mixture as it would be for 100% diesel. In addition, if natural gas is lost during the bi-fuel operation mode, then the diesel generator will revert back to using 100% diesel fuel with no Interruption.

Finally, the bi-fuel system does not require a substantial natural gas pressure. The range of pressure required for the bi-fuel system ranges from 6.9 to 34.5 kPa (1 to 5 *psi*). Thus it is not necessary to install any sort of compressor to provide high pressure natural gas. The pressure requirements provides an added logistical for application of this technology, especially in areas of natural gas service where natural gas pressure is low due to age of the system.

With this explanation of how the bi-fuel system works, an overview will be given to show the various benefits of utilizing the dual fuel technology**.**

2.3 Benefits of the Bi-Fuel Technology: [4]

2.3.1 Overview

The dual fuel technology has the capability to convert a diesel engine to use natural gas. The primary reason to convert their existing diesel engine to natural gas must create some sort of economic incentive. in addition the dual fuel technology provides environmental benefits and fuel supply benefits**.**

2.3.2 Economic benefits:

With the cost of diesel fuel rising, and dual-fuel engines considerably reducing diesel fuel usage, converting an engine to operate primarily on a cheaper gaseous fuel is economically attractive. In addition, spark plugs and an ignition system are not required, eliminating the costly spark plug maintenance associated with traditional natural gas engines, which helps to further reduce overall cost of operation. depending on the expected number of running hours and the cost of diesel and gaseous fuels, the up-front installation cost of retrofitting an existing diesel engine to dual-fuel operation can be recovered quickly**.**

2.3.3 Environmental benefits:

Gaseous fuels and natural gas in particular are much cleaner than diesel. Diesel engines that have been converted to Bi-fuel operation have exhibited significant reduction in NO_X and CO_2 over their original diesel operation see the equation below.

$$70\%CH_4 + 30\%\ C_{14.6}H_{24.8} + (O_2 + 3.76N_2) \rightarrow CO_2 + H_2O + N_2$$

This is even more important in areas with increasingly tough emissions regulations. In addition, on-site diesel storage capacity can be reduced**.**

2.3.4 Technical benefits:

Retrofit systems can be installed in the field quickly, minimizing engine downtime. No modifications are required to the core engine or to the factory fuel management system. With the engine's main fuel becoming gaseous fuel rather than diesel and the electronic control system maximizing fuel efficiency, installing an alternative fuel system enables the on-site diesel supply to last much longer, extending engine uptime without compromising performance.

Replacing diesel fuel with natural gas typically extends engine maintenance intervals and overall engine life. For example, life expectancy of cylinder-head valve seats is improved due to the cleaner combustion that gaseous fuel exhibits over diesel. Benefits of the factory diesel engine, including hardware ruggedness and operational efficiency, are maintained. Returning to operation on 100% diesel fuel is possible at any time.

2.3.5 Safety:

Diesel fuel is less volatile; it presents the same storage and handling problems. Comparatively, natural gas exhibits many different characteristics. It is buoyant at temperatures above -71°C (-160 °F), does not pool on the ground, and dissipates rapidly in the atmosphere. It is nontoxic, noncorrosive, and environmentally safe.

2.4 Compression Ignition Engines: [1]

In a compression ignition engine there is no spark to create the flame but rather high temperatures and pressures in the combustion chamber cause a flame to initiate at different sites of the combustion chamber. Combustion increases with increasing pressure and temperature. Compression ignition engines are divided into direct and indirect ignition engines. Diesel engines require fuel injection systems to inject fuel into the combustion chamber.

Fuel injection systems are either linear or rotary, rotary fuel injectors are used in indirect ignition engines because of low pressures.

Direct injection engines use pressures of up to 1000 bars to inject fuel into the combustion chamber. High pressure is needed because the heat addition process takes place at a compressed state, so in order for the fuel to inject well the pressure has to be greater than the one that has been accumulated through compression. There are several engineered direct injection combustion chambers. This goes to show that the actual design of compression ignition engines is not as critical as the design considered for spark ignition engines. Swirl is the most important air motion in the Diesel engine. The importance of swirl is that it mixes the air and fuel so that combustion can increase. The direction of swirl is at a downward angle so that proper mixing can take place. The compression ratio for direct ignition engines is usually between 12 : 1 and 16 : 1.

Indirect ignition engines have a pre-combustion chamber where the air to fuel mixture is first stored. The purpose of the separate chamber is to speed up the combustion process in order to increase the engine output by increasing the engine speed. The two basic combustion systems are the swirl and pre-combustion chambers. Pre-combustion chambers depend on turbulence to increase the combustion speed and swirl chambers depend on the fluid motion to raise combustion speed. In divided chambers the pressure required is not as high as the pressure required for direct ignition engines. The pressure required for both type of divided chambers is only about 300 bars.

With all diesel engines there is some type of aid to help combustion, electrical components aid in the initiation of the combustion process by using an electrical source, such as a car battery, to heat themselves and transfer the energy to the mixture for combustion. Cold starting a diesel engine is very difficult without the use of these tabs that conduct an electric current. When electrical elements heat up and the air to fuel mixture comes in close contact with the tab then combustion occurs.

The diesel engine has high thermal efficiencies, and therefore low fuel consumption. The disadvantage of diesel engines is their low power output, relative to their weight, as compared with spark ignition engines.

2.5 Hydrocarbon Fuels: [1]

Crude oil is composed mainly of 85% carbon and 13% hydrogen. the carbon and hydrogen molecules combine to form thousands of hydrocarbon mixtures.

Crude oil is separated into components by cracking and or distillation using thermal or catalytic methods at oil refineries. the process of cracking involves the breaking up of large molecular components into smaller molecular components, which are then used for processing. It is important to break up the large strands because the smaller the molecular weight of the component the lower the boiling temperature will be. Fuels need to have components with low boiling points so that they can be readily vaporized.

More than 50% of world's primary energy comes nowadays from petroleum, i.e. all vehicle fuels, and small and medium stationary applications fuels are petroleum derivatives, obtained by fractional distillation and reforming.

2.5.1 Diesel fuel: [6]

Diesel fuel, also called diesel oil, combustible liquid used as fuel for diesel engines, ordinarily obtained from fractions of crude oil that are less volatile than the fractions used in gasoline. In diesel engines the fuel is ignited not by a spark, as in gasoline engines, but by the heat of air compressed in the cylinder, with the fuel injected in a spray into the hot compressed air. Diesel fuel releases more energy on combustion than equal volumes of gasoline, so diesel engines generally produce better fuel economy than gasoline engines. In addition, the production of diesel fuel requires fewer refining steps than gasoline, so retail prices of diesel fuel traditionally have been lower than those of gasoline (depending on the location, season, and taxes and regulations). On the other hand, diesel fuel, at least as traditionally formulated, produces greater quantities of certain air pollutants such as sulfur and solid carbon particulates, and the extra refining steps and emission-control mechanisms put into place to reduce those emissions can act to reduce the price advantages of diesel over gasoline.

2.5.2 Associated Gas: [7]

Associated gas is the term typically used for natural gas produced as a by-product of the production of crude oil. Industry publications typically refer to associated gas as gas that is co-produced with crude oil while the well is in the production phase and is vented directly to the atmosphere or is flared. One published definition for associated gas is "gaseous hydrocarbons occurring as a free-gas phase under original oil-reservoir conditions of temperature and pressure (also known as gas-cap gas)." Therefore, associated gas can include gas that is produced during flow back associated with completion activities and gas that is emitted from equipment as part of normal operations, such as natural gas driven pneumatic controllers and storage vessels.

2.6 Cetane Number: [1]

Diesel fuels are usually characterized by their molecular weight. there are low and high molecular weight fuels, each with different characteristics. Usually the greater the refining done on the fuel the less viscous, lower molecular weight, and higher cost of the fuel. The less refining done on the diesel fuel the more viscous, higher molecular weight, and lower cost of the fuel.

Numerical scales exist that denote whether a diesel fuel is high or low in molecular weight. The scale ranges from one (1) to five (5) or six

(6),with subcategories using alphabetical letters (e.g. 3B, 2D). The lower number the lower the molecular weight of the diesel fuel. Fuels with low numbers are typically used in CI engines, while the high numbered diesel fuels are used in large, massive heating units. Diesel fuels can be divided into two extreme categories; light and heavy diesel fuel. Light diesel fuel has a molecular weight of about 170 and is approximated by the chemical formula $C_{12.3}H_{22.2}$. Heavy diesel fuel has a molecular weight of about 200 with approximately a chemical formula of $C_{14.6}H_{24.8}$.

In CI engines combustion starts with the self ignition of the air and fuel mixture. There are different fuels which have different ignition characteristics. Ignition delay is a property of CI engines that is dependent on the fuel used. The cetane number CN is a quantifiable number that gives a fuel the property of whether it will self ignite early or late. The higher the CN the shorter the ignition delay. On the other hand the lower the CN the longer the ignition delay. The CN ratings are established through testing.

2.7 Fuel Comparison: [8]

Table 2.2 compares fuels and their energy densities. [8]

Fuel	Chemical formula	Description	Energy density (compared to diesel) by volume
Diesel	$C_{10}H_{20}$ to $C_{14.6}H_{24.8}$	Combustible hydrocarbon mixture that ignites when compressed in an internal combustion engine.	100%
Gasoline	C_8H_{18}	Combustible mixture of hydrocarbons and additives. Hydrocarbon composition is modified to obtain different octane ratings.	90%
Liquefied petroleum gas (LPG)	C_3H_8	Combustible hydrocarbon mixture obtained by refining fossil fuels.	65%

Natural gas	CH_4	Mixture of combustible gases, primarily consisting of methane found beneath the Earth's surface	18%
Compressed natural gas (CNG)		Obtained by compressing natural gas, typically between 200 and 248 bar (2,900 and 3,600 psi).	25%
Liquefied natural gas (LNG)		Obtained by super cooling natural gas to approximately -260 F.	60%

2.8 Combustion in Diesel Engines: [2]

2.8.1 Conventional CI Diesel Combustion:

Known also as Compression Ignition Engines, diesel engines are using compressed hot air at the end of compression stroke to ignite the injected liquid atomized fuel by self-ignition conditions. The fuel need to be injected at an advanced timing BTDC. From start of injection SOI to start of ignition, fuel passes through what is known as the physical delay, during which liquid fuel is transferring into gaseous phase and mixing with air inside combustion chamber. The prevailing conditions of temperature and pressure will determine the start of ignition, and spontaneous combustion will occur, next to this phase, and due to increase in pressure and temperature caused by the spontaneous ignition, other parts of the fuel/air charge will start to ignite. This is described as premixed combustion phase due to premixing of the charge. As diesel will continue to be injected, the next phase called diffusion combustion is mainly driven by the spray continuation. Even after the fuel injection is completed, there is a final phase of combustion will still take place, and this is due to subsequent burning of the thermally cracked but not completely combusted fuel products, like higher HC, and soot.

The above conceptual drawing show the different phases of conventional diesel combustion. It consists of liquid fuel zone near the injector nozzle, then rich zone premixed combustion, and at the end the diffusion combustion zone at the peripheries.

2.8.2 Unconventional Compression Ignition Combustion:

Controlled Auto Ignition CAI, is the name used to describe under-development combustion strategies which are aimed towards more control over the wild combustion initiated by auto ignition. The investigation is covering both gasoline and diesel engines. All combustion control parameters like fuel types, fuel reactivity, compression ratios, means of fuel induction, and mode of ignition, injection timing, valve timing, mixture strength, inlet temperature, and other parameters affecting combustion are all over the table for investigation and study.

2.8.3 Homogeneous Charge Compression Ignition: [9]

HCCI is the most commonly used name for the auto ignition of various fuels and is one of the most promising alternatives to SI combustion and CI combustion. In an IC engine, HCCI combustion can the achieved by premixing the air-fuel mixture and compressing it until the temperature is high enough for auto ignition to occur.

HCCI combustion can be described by the oxidation of the fuel driven solely by chemical reactions governed by chain-branching mechanisms and two temperature regimes exist for these reactions – one below 850K (low temperature oxidation or cool flame combustion) and one around 1050K (high temperature oxidation or main combustion). This auto ignition phenomenon has been the focus of various Researchers since the early 20th century.

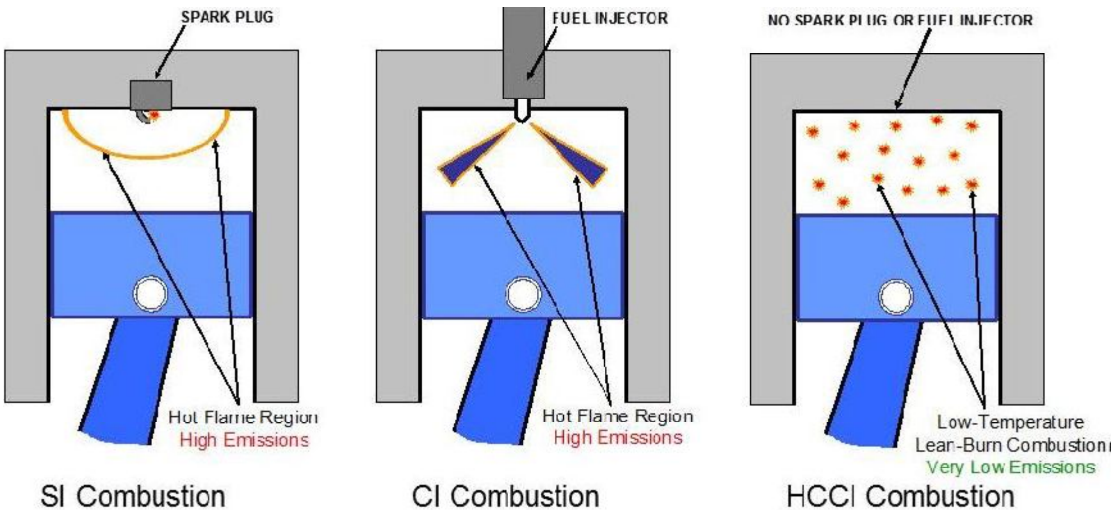

Figure 2.3 Combustion differences between the three modes of IC operation.

Chapter Three

Materials and Methods

Performance test and analysis of exhaust gas emissions were carried out at Sudan University of Science and Technology (Faculty of Engineering, Thermo Laboratory).

3.1 Materials:

3.1.1 Diesel fuel property:

Tables 3.1 ASTM D975 Diesel Fuel Specification.

Property	**Diesel Fuel Standard**
Flash Point, min	52°C
Cetane Number, min	40
Cetane Index, min	40
Kinematic viscosity Cst,40 °C, min	1.9
Sulphur, % weight, max	0.05
API Gravity @ 60°F , min	34
API Gravity @ 60°F , max	38

3.1.2 Liquefied petroleum gas:

Liquefied petroleum gases are products of the refining of crude oil, and are therefore closely related to petrol, diesel. They consist of hydrocarbons, which are compounds containing only carbon and hydrogen.

The simplest form of LPG is methane (CH_4) but as this can only be liquefied at low temperatures and is therefore difficult to handle commercially, the most commonly used varieties of LPG are propane (C_3H_8) and butane (C_4H_{10}). These are gases at normal temperatures and pressures, but can be liquefied by the application of a relatively low pressure. Because a small volume of liquid equals a very large volume of gas (l to 274 for propane, l to 233 for butane) a small pressurized cylinder can contain a significant amount of 'energy' for home appliances.

Butane and propane have slightly different properties, the most important to the home being the boiling point at atmospheric pressure. In other words, the temperature at which it changes from being a liquid to a gas. Butane will only readily change to a gas above 0 °C, so is generally suitable for the spring to autumn season. Propane, on the other hand, will become a gas down to - 40 °C and therefore can be used in winter, or all year round if desired.

Table 3.2 Properties of Propane and Butane.

Properties of	**Unit**	**Propane**	**Butane**
Chemical formula	--	C_3H_8	C4H10
Boiling point of liquid at atmospheric pressure	°F	- 44	32
Specific Gravity of vapor (Air = 1)	--	1.53	2.00
Specific Gravity of liquid (water= 1)		0.51	0.58
Latent heat of vaporization	BTU/gal	785	808
Liquid weight	lbs/gal	4.24	4.81
Vapor volume from 1 gallon of liquid at 60 °F	cft	36.39	31.26
Combustible limits	% of gas in air	2.4-9.6	1.9-8.6
Amount of air required to burn 1 cuft. of gas	cft	23.86	31.02
Ignition temperature in air	°F	920-1020	900- 1000
Maximum flame temperature in air	°F	3595	3615
Octane Number	--	Over 100	92

LPG Cylinder, gas hose pipe and gas regulator

It is a simple cylinder of capacity 5 liters made up of steel to store LPG gas. The weight of the cylinder is 4.5 kg. The pressure inside the cylinder is a little above the atmospheric pressure. Gas hose pipe of PVC is used to supply LPG from cylinder to intake manifold of engine through regulator. LPG valve gas regulator is used to control the supply of LPG from cylinder to inlet manifold. It is made of copper and capacity of supplying gas at the rate of 0.5m3/hr at atmospheric pressure when it is fully open.

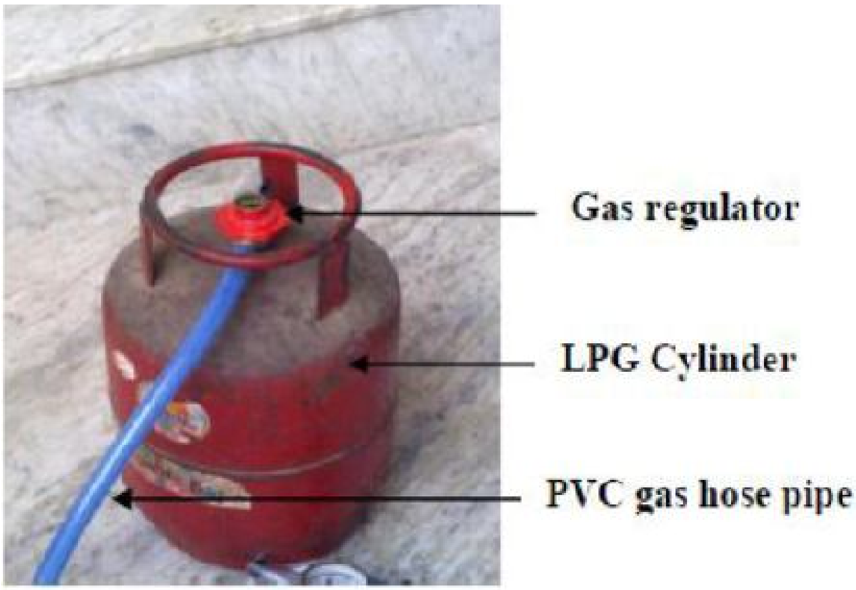

Figure 3.1 LPG Cylinder

3.2 Engine Experimental Specifications

Table 3.3 Test engine specifications.

Engine name	**Mitsubishi cyclone motor Intercooled Turbo (TD04 water cooled Turbo)**
Model	4D56, JG3553
Displacement	2.5 L (2,476 cc)
Bore	91.1 mm
Stroke	95.0 mm
Fuel type	Diesel
Power	78 kW (104 hp) at 4,300 rpm
Torque	240 N·m (177 lb·ft) at 2,000 rpm
Engine type	Inline 4-cylinder
Rocker arm	Roller Follower type
Fuel system	Distribution type jet pump (indirect injection)
Combustion chamber	Swirl type
Bore x Stroke	91.1 x 95mm
Compression ratio	21:1
Lubrication System	Pressure feed, full flow filtration
Intercooler Type	Aluminum Air to Air, Top-mounted
Turbocharger	Mitsubishi TD04-09B

3.3 Equipments

3.3.1 Gas analyzer Unit (EcoLine Device)

EcoLine 6000 emission analyzer was used to measure the concentration of NO, NO_x ,SO_2, CO and the smoke opacity was measured using Smoke meter. The exhaust temperature was measured with a thermo couple.

Figure 3.2 EcoLine Device

[(A) gas sampling probe, (B) Remote control unit

(C) Gas analysis unit, (D) Data transfer cable]

EcoLine 6000 consists of two functional parts: the gas analysis unit and the remote control unit (RCU). Communication between the two devices is via standard RS232. All data collected by the analysis unit can be sent to the RCU as to be viewed, stored and printed.

Gas analysis unit is a portable, flue gas laboratory. It includes: aspiration pump, filters, condensate drain with peristaltic pump, cells and electronics. Gas analysis unit (GAU) can be positioned beside of the stack of the sampling point and can work, after programming, as a standalone unit (black-box). The operator can survey the overall read out at a distance by using the Remote Control Unit. RCU is used to send operative instructions to the unit, to display and memory store the analysis data, to printout data, and to transfer data to a Personal Computer.

3.3.2 Electronic Display Board Device

An electronic display device includes a housing having a sliding slot and engine speed recorder unit, load and discharge load engine recorder unit.

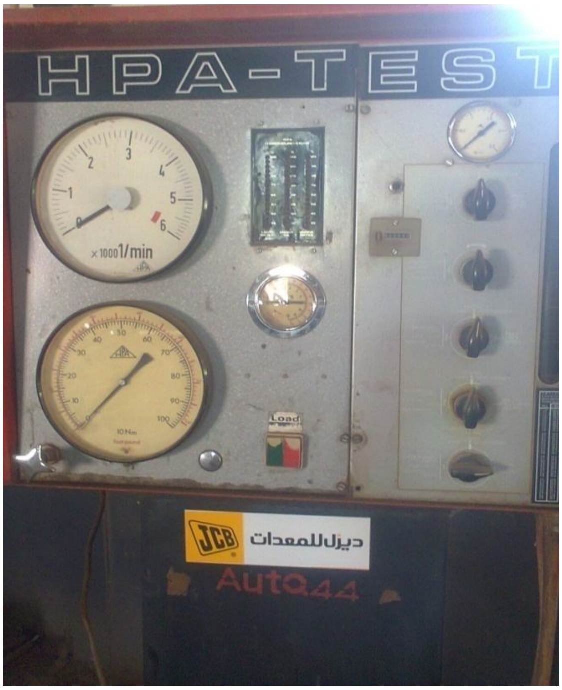

Figure 3.3 Electronic Display Board.

3.3.3 Electronic Digital Balance

A digital balance is a non-automatic weighing instrument in which a load cell converts the gravitational force on a mass into an electrical signal to show the weight digitally on the display panel.

Model	YZ-328
Capable	ROHS, OMIL
Region	Jinhua Zhejiang
Brief Description	50 kg Price computing, can change to bigger platter. Bigger size and stronger body.
Capacity	50 kg

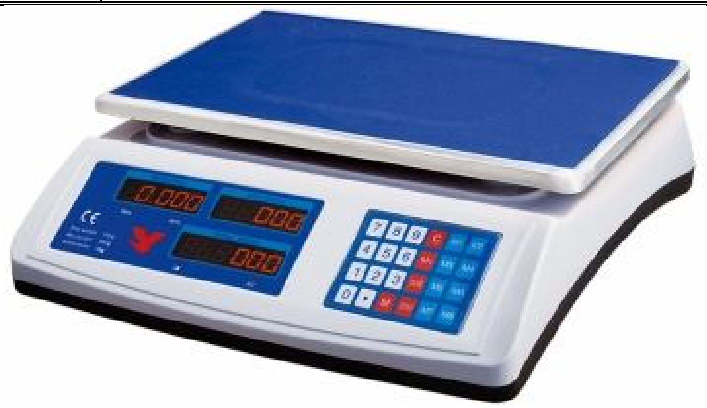

Figure 3.4 Electronic Digital Balance.

3.3.4 Engine Experimental Test

Diesel engine type Mitsubishi, model 4D56 JG3553,Turbocharger TD 04,Compression ratio 21:1, it was coupled with dynamometer.

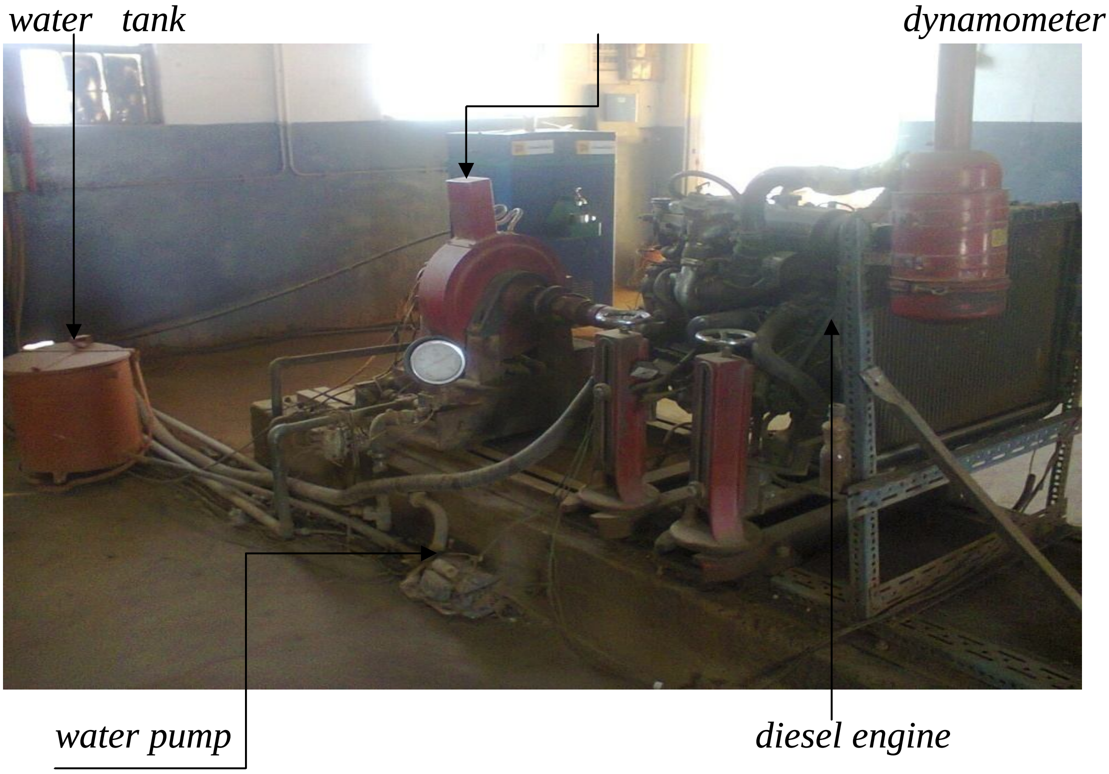

Figure 3.5 Engine Experimental Test

3.4 Experimental procedure

This test will be carried out just to sense and analyze the variation in engine performance parameters when we compared between Diesel and Bi-fuel in a multi-cylinder Diesel Engine, and define the direction on which the investigation needs to be deepened further. The cost of modification will be kept minimal. In this pilot experiment, liquefied Petroleum gas LPG, I have connected to my engine via the air inlet.

The experiments were conducted as follows:

1. Firstly the amount of fuel level in diesel tank, engine cooling water, engine lubrication and the dynamometer water level were checked.

2. Reset the data stored in the RCU.

3. The engine was operated without load. The speed was gradually increased to 1600 rpm where the weight of fuel was recorded in kg to 60 second. Another weight for the fuel was recorded 60 seconds later at 1800 rpm and 2100 rpm for purpose of knowing the fuel consumption in 60 seconds.

4. The engine was operated without load by dual fuel (LPG + diesel) the speed was gradually increased to 1600 rpm the weight of fuel and LPG was recorded individually in Kg to observe to observe the diesel fuel saving and LPG added.

5. The engine was operated with torque 100N.m added gradually at the speed of 1600 rpm, dual fuel consumption during 60 seconds was recorded together with the data of the components of the exhaust fumes in the 60 seconds.

6. Step (5) was repeated with speeds 1800rpm and torque 105N.m and 2100 rpm with torque 110N.m, in each case was recorded the dual fuel consumption and engine status.

Chapter Four

Result and Discussion

Due to of non availability of natural gas and hard to get it the experiment executed by LPG because it's one of the components of natural gas.

4.1 Fuel Properties diesel + LPG

Table 4.1 the table provides data about various properties of diesel and LPG.

Properties	Diesel	LPG
Normal State	Liquid	Gaseous
Formulae	$C_{12}H_{26}$	C_3H_8
Calorific Value (kJ/kg)	44,800	50,350
Specific gravity	0.8	0.587(Liquid)
Auto Ignition Temperature (°C)	225	540
Flash Point (°C)	62	-104
Cetane no.	5 -10	40 - 60
Stoichiometric A/F(mass)	14.5	15.7
Peak Flame Temperature (°C)	2054	1990

-Experimental results (Brake power and fuel consumption and brake thermal efficiency with engine loads) shown in the table 4.2.

Table 4.2 result of brake power and fuel consumption and brake Power efficiency

Fuel	Speed (rpm)	Brake Power (kW)	Diesel Fuel Consumption (kg/s)	BPE
Pure diesel	1600	16.761	0.00095	0.39
	1800	19.799	0.00119	0.37
	22100100	24.178	0.00147	0.36
E75%	1600	16.75	0.00017	0.3938
E42%	1800	19.8	0.00043	0.371
E39%	2100	24.19	0.00048	0.365

4.2 Experimental Result

The results is tabulated and presented in graphical form as follows:

Table 4.3 Diesel fuel consumption without torque

Speed(rpm)	Torque (N.m)	Consumption(g/s)	Time (s)
1600	0	0.57	60
1800	0	0.64	60
2100	0	0.92	60

Table 4.4 Diesel fuel consumption with torque

Speed(rpm)	Torque (N.m)	Consumption(g/s)	Time(s)	Break Power (kW)	Efficiency %
1600	100	0.95	60	16.761	39
1800	105	1.19	60	19.799	37
2100	110	1.14	60	24.178	36

Table 4.5 Consumption of Bi-fuel (LPG + Diesel) with torque

Speed (rpm)	Torque (N.m)	Diesel Consumption (g/s)	Gas Consumption(g/s)	Time(S)	Break Power (kW)	Efficiency%
1600	100	0.17	0.23	60	16.75	39.38%
1800	105	0.43	0.69	60	19.8	37.1%
2100	110	0.48	0.89	60	24.19	36.5%

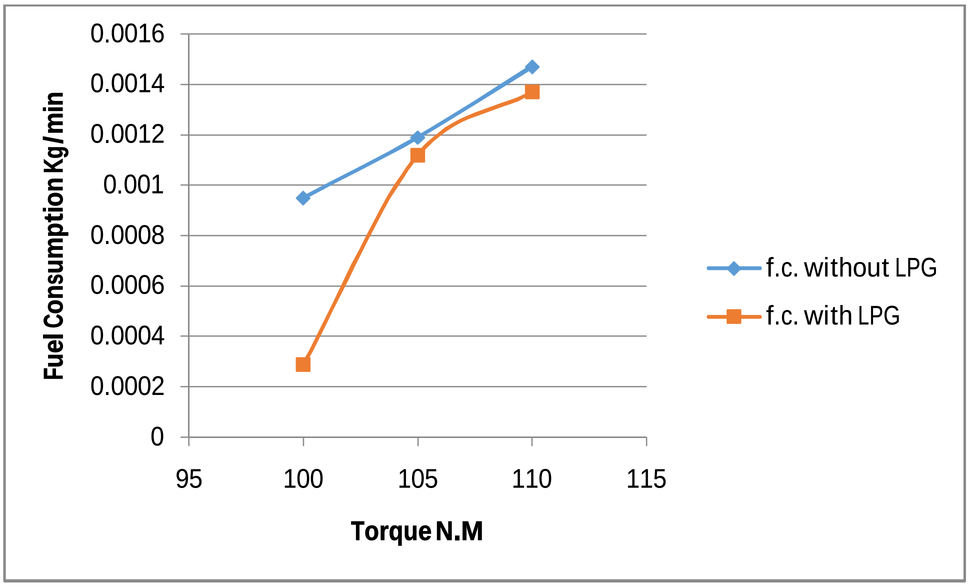

Figure 4.1 Fuels Consumption vs. Torque

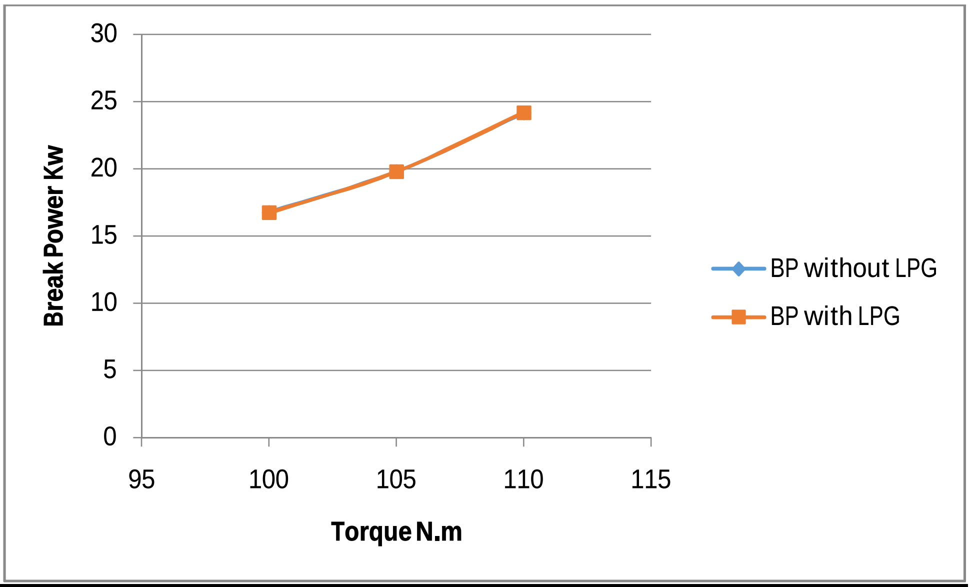

Figure 4.2 Break Power vs. Torque

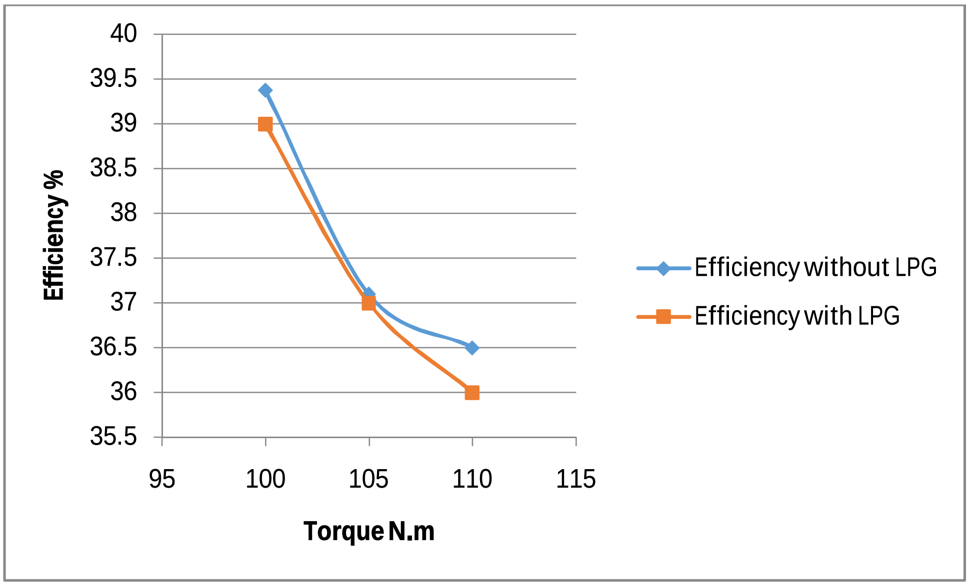

Figure 4.3 Efficiency vs. Torque

4.2.1 Experimental Discussion:

From above tables getting same Break powers and efficiency from different Test case of single diesel fuel and Bi-fuel LPG + Diesel.

From this table can see that with increase in Torque, fuel consumption increases but when we supply LPG with diesel then fuel consumption at every Torque decreases because LPG in itself is a fuel.

From this table can see that with increase in Torque the break power increase, but increase in Torque decrease the Break efficiency.

4.2.2 Conclusion of Experimental:

Baseline performance with normal diesel fuel running was compared with Bi-fuel mode of gas/diesel running. When a homogeneous mixture of gas and air is established in the air intake manifold, the engine performance has shown improvement. The engine was running without any modification to its diesel fuel settings.

From this experiment, the following conclusions are obtained:

- The first and most important change in soot. When LPG is added through inlet manifold soot level is reduced at higher loads, although at lower loads there is almost no change soot level is observed.
- The running cost of an engine is also decreased from the single fuel.
- Fuel consumption is also reduced.
- Efficiency of engine is improved.
- The noise level is also reduced at higher load when LPG is added.

4.3 Experimental Recommendation:

- An electronic injector can be used to inject the LPG in a properly measured quantity and directly into the cylinder in spite of through intake manifold in suction stroke.
- Various digital flow measuring instruments can be used to measure the accurate amount of LPG and the experiments may be conduct with different proportions of LPG and diesel fuel.
- Gas Analyzer to be provided in the combustion chamber to study its impact on pollution.

Chapter Five

Conclusion and Recommendation

5.1 Conclusions:

Owners or operators of existing diesel engines interested in cost savings should evaluate the benefits of Bi-fuel conversion. While the Bi-fuel engine concept is not new, rising diesel fuel costs, more emphasis on emission regulations, desire to increase engine maintenance intervals, and controlling overall costs of operation are increasing interest in this technology.

Offering ease of installation and relatively low capital investment, Bi-fuel conversions provide the ability to realize this cost savings and adhere to regulations through the use of gaseous fuel in both low- and high-speed industrial engine applications.

5-2 Recommendations:

When we installed this system, carefully assembly is required to prevent cross threading which can cause damage to the gas train component.

Failure to follow the above instruction may result in fire, explosion, or improper engine operation causing property damage, injury or loss of life.

Personal who lack appropriate training should not attempt to install the system.

It's better to do not modification air-gas mixer and this could result in improper operation of the engine or damage to the converted engine.

Ensure that the quality of the gas and composition it has appropriate percent, because it's critical factors for bi-fuel operation. Ideally pipe line supplied gas will have high concentration of methane and low overall concentration of heavier hydrocarbon gasses, for the lower quality gasses (pipeline supplied or other), reduction in engine performance and\or gas substitution rate may be required.

Ambient temperature have effect of gas density, drop in ambient temp leads to an increase in density of the gas therefore increase in substitution rate, and hence gas rate to be kept lower during the day as it will automatically increase at night.

Due to service hour for the engine no changes are required for lube oil when we use bi-fuel ,natural gas burns with minimum particulate residues so that the engine may kept cleaner during bi-fuel operation this can possibly lead to longer average intervals between lube oil and oil filter changes and extended periods between engine over haul.

As mentioned before to increase the load compensation will done by diesel and that happen because the valves are used it has constant adjusted, and this could not allow the gas to participate with diesel, because the governing system of diesel is variable.

It’s possible to allow bi-fuel system working with combination but the system may need some modification in the governing and this could be happen by:

1) Extend the zero governor range and make it flexible with high good control to allow suitable quantity of gas enter when the load increased.
2) Combine the bi-fuel governing system and diesel governing or (ECM) in one control unit.
3) The gas coming in high pressure and high temperature, recommend install fin fan cooler before gas scrubber to increase the gas density.
4) With continuous change in load during the day we are recommended to install Dynamic Gas Control System (DGCS) utilizes a generator kW sensor as an indicator of engine load which independently adjusts the flow of natural gas to achieve an optimum gas substitution percentage based upon load.
5) Total gas produced per day in South Annamja oil field is approximately is 2,568 MSCFD and the total consumption less than 10%. that means more than 90% is released to an atmosphere after burned, our recommendation to:

i. Create project to use this gas in any other field like house consumption and that by installed gas plant to treat it again, this project may need studies but can be apply.

ii. Gas Engine project recommend it for improvement and forthcoming project to maximize flared gas utilization.

6) Finally for operation wise more carefully should be take for bi-fuel engine due to availability of gas, so before starting engine should be use the Gas Tester to be sure no Gas leakage.

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