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Converting a Diesel Engine to Dual-Fuel Engine Using Natural Gas

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Abstract

Over the past many years, large numbers of car buyers have been opting for a petrol car with a compressed natural gas (CNG) kit fitted by the company. The most important thing is that the petrol engines cause global warming by having a large amount of toxic gases exhausted by the petrol cars. However, by the introduction of catalytic converters (a catalytic converter is a vehicle emissions control device that converts toxic pollutants in exhaust gas to less toxic pollutants by catalysing a redox reaction) we have been able to reduce the toxic emissions. Use of Catalytic converters in internal combustion engines fuelled by either petrol or diesel, which reduces pollutants such as CO to a much less harmful gas, such as CO_2. Because of this, a catalyst car also consumes slightly more fuel, thus reducing its performance. However, by having these improvements, petrol engine cars with catalysts still exhaust more CO and HC than cars with diesel engine, and by using a CNG kit there is are other problem such as starting problems and jerks. Therefore, CNG kit is not as useful as it is expected to be. An alternative to this is a diesel engine (dual fuel engine). However, a question arises that, Why Should one Choose a Diesel Powered dual fuel Engine over other. So the answer is Diesel fuel contains more energy per litre than petrol. Thus, making more efficient than petrol engine car. Diesel fuel contains no emissions of the regulated pollutants like (carbon monoxide, hydrocarbons and nitrogen oxides) which are quite less than those from petrol cars without a catalyst. Therefore, diesel engines are attracting greater attention due to higher efficiency and cost effectiveness. Now, the main objective of this paper is to convert a diesel engine into duel fuel engine with compressed natural gas, which will overcome the problem of cost and global warming. This paper presents a dual fuel system for diesel-natural gas operation for a diesel engine, and analysis of the operating characteristics of the engine.

Keywords

CNG-compressed Natural Gas, CO-carbon Oxide, HC-hydro Carbon, NO-nitrogen Oxide, DNG-diesel Natural Gas Engine

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1. Introduction

This paper gives operation of dual-fuel natural gas/diesel engine. The main advantages of dual-fuel engine include diesel-like efficiency and brake mean effective pressure (Brake Mean Effective Pressure is another very effective method for comparing the performance of an engine of a given type to another of the same type, and for evaluating the reasonableness of performance claims or requirements.) with much lower emissions of oxides of nitrogen (NOx). New methods provide solutions to the problems of poor efficiency and emissions at very low load. Dual-fuel engines are designed to operate interchangeably on natural gas with a diesel pilot, or on 100% diesel fuel. Therefore, economic analyses shows that such conversions could be justified from the fuel cost savings alone in applications such as railroad locomotives, mine trucks, and diesel engine powered generation systems.

Diesel displacement by introducing natural gas as a concurrently combusted fuel source is known as “dual fuel”

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or "bi-fuel" technology. Both of these terms have been used to describe this approach, both can be identified as "mixed fuel". In general, both names used to designate the use of natural gas with diesel combustion. For the purposes of this paper, the term "dual fuel" has been used to designate compression-ignition reciprocating engines that have the capability to co-combust diesel fuel with CNG. Dual fuel diesel engines can operate by on diesel also, offering the flexibility to continue operations even if gas fuel is unavailable. The term "bi-fuel" taken to mean any engine that can utilize either gas or diesel, separately, but not both in combined form. Now, example of this will be turbines that can used multiple type of fuels, such as diesel or CNG, individually but not together in co-combustion.

Back Ground Theory

Dual Fuel Reciprocating Engine

In most dual fuel systems used in the oilfield, natural gas fuel in the form of vapour phase at low pressure is introduced into the air intake system of the engine, whereas Diesel engine fuel introduce directly into the combustion chamber near the end of the compression stroke part. The two fuels are mixed to form a lean mixture and are ignited by compression (on spark plug) in the cylinder. Dual fuel engine in this configuration provide many of the operational advantages of conventional diesel power. In particular, dual fuel diesels offer similar high transient load response, which is so important in hydraulic fracturing operation and had been proven to function well in this application. Dual fuel diesel engine can also run individually on diesel should gas fuel be unavailable.

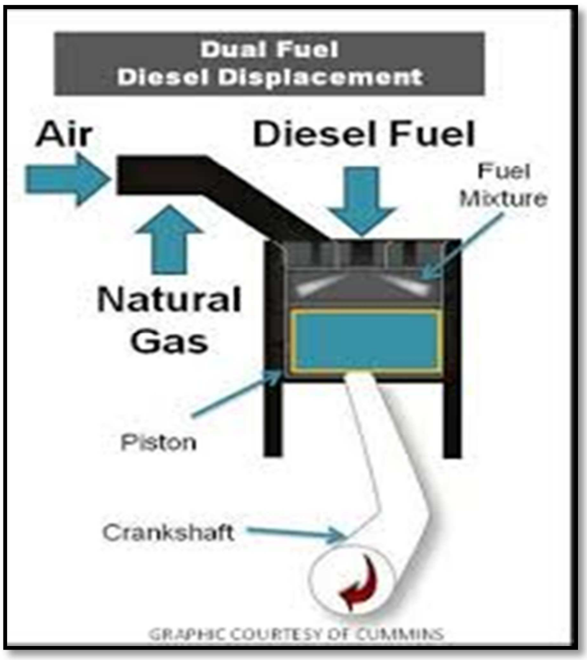

Fig. 1. Shows - the duel fuel diesel displacement.

Natural gas fuel could be substituted for diesel fuel in varying proportion according to working conditions. Dual fuel engine substitution rate is controlled with a system of sensor and ECU fitted with the engine equipment. Many factors that affect actual diesel substitution rates of 50%-70% of gas on energy basis have been reported.

2. Literature Survey

In new and developing automobile sector, the research is being carried out day by day. In this field, the most popular research is going on the conversion of diesel engine car into duel fuel engine car.

Scott Jensen (2006) has worked on the conversion of the diesel engines into duel fuel engine. In his research, he has come up with a number of pros and cons of conversion. A Dual Fuel diesel engine (traditionally) is a diesel engine that has been fitted with additional devices allowing it to utilize natural gas as a supplemental fuel. This engine type is a true diesel and requires some level of diesel for operation, for ignition of the gas fuel. This engine type has been available to industry since the 1930 the duel fuel engine type has a number of quality attributes. A primary benefit that of fuel flexibility, operating with cleaner and cheaper natural gas. Many hundreds of these engines were operated in USA during the rural electrification period. But after grid depression of 1928 economical many of these engines were discarded.

Semin (2008) has worked on the compressed natural gas as an alternate fuel for an internal combustion engine. In our research, of his work we found that, how a CNG is used as an alternate fuel with spark ignition engine and compression ignition engine. In this, we found, during the CNG engine development, that CNG could also be efficiently used in a diesel engine Furthermore, the research is still going on to achieve the desired objective of producing a diesel engine capable of operating on CNG fuel thus making the vehicle more eco-friendly and less harmful to the nature.

3. Methodology

3.1. Significance of Natural Gas in Diesel Engines

Natural gas can be used as a dual-fuel in diesel engines. It is not very toxic as compare to petrol and it is much safer to use, exhausting minimal amount of CO_2, as compared to a normal petrol or diesel engine. As when governments worldwide seek methods of reducing their CO_2 emissions from vehicles, DNG engine can provide a positive and welcome alternative. Purified CNG (methane) has a chemical composition of 4 hydrogen atoms, and only 1 carbon atom. Therefore, during combustion in an engine it emits less CO_2 than gasoline or diesel oil. The CNG can be compressed and stored in the automobile or truck where it is a much safer and environment friendly option in comparison to diesel oil or gasoline fuels.

An overview of the chemical composition-differences between gasoline, diesel, and natural gas.

3.2. Comparing Diesel, Gasoline and Natural Gas

The three fuels used to propel our vehicles are all hydrocarbons or elements of them. They all have various numbers of carbon atoms in hydrocarbon chains that when combusted generate CO_2. It is these CO_2 tailpipe emissions (The so-called Tier 3 standards aim to reduce the existing sulphur in gasoline while setting tailpipe standards to limit smog-forming emissions from new passenger vehicles. The proposal will cut on-road mobile source emissions of nitrogen oxides, carbon monoxide, and volatile organic compounds from vehicles) that should be reduced from the vehicles.

Here are some of the components that make up the composition of hydrocarbons used to fuel our transport;

1. Diesel Oil

Carbon Atoms - Diesel oil contains between 8-18 carbon atoms per molecule, depending on the grade of crude it is refined form.

Chemical Formula - $C_{12}H_{23}$

Density – 7lb/US gallon

Energy Content – 128,700 BTU/US Gallon

CO_2 Tail-pipe Emissions - 73.5 gms/MJ

2. Gasoline

Carbon Atoms - 6

Density **-** 6.217 lb/US gallon

Chemical formula- C6H14

Energy Content – 115,500 BTU/US Gallon

CO_2 Tail-pipe Emissions - 73.4 gms/MJ

3. Natural Gas

Carbon Atoms - 1

Chemical Formula – CH4

Energy Content – 1,000 BTU/cu. ft

Density – 8 kg/m^3 (0.07lbs/US Gallon)

Emission of CO_2 – 15g/MJ

Table 1. CNG properties [9].

Density (kg/m3) 0.72
Flammability limits (volume % in air) 4.3-15
Flammability limits (Ø) 0.4-1.6
Auto ignition temperature in air (0C) 723
Minimum ignition energy (mJ)b 0.28
Flame velocity (ms-1)b 0.38
Adiabatic flame temperature (K)b 2214
Quenching distance (mm)b 2.1
Stoichiometric fuel/air mass ratio 0.069
Stoichiometric volume fraction % 9.48
Lower heating value (MJ/kg) 45.8
Heat of combustion (MJ/kg air)b 2.9

3.3. Method for Converting a Diesel Engine to a Dual-Fuel Using Natural Gas

The use of natural gas in a diesel engine as a dual fuel engine requires the engine to be modified, although natural gas can be compressed, it will not ignite without a spark plug or addition of diesel to the gas. The cylindrical gas tank was designed to withstand the 3000lbs/square inch pressure of the CNG and is usually located in the boot/trunk of the vehicle, with the diesel fuel oil tank being kept in its original location. Dual fuel conversion then consists of the installation of a cylindrical pressure tank and high-pressure piping from there to the engine (diesel/gas) control unit.

In addition to solenoid valves, diesel modulator, high/low pressure gas filters and other small components are also required.

Converting a diesel engine to run on natural gas will reduce the amount of tailpipe emissions of CO_2; since, the CNG is not like diesel in nature, which burns under compression ignition. It is necessary therefore to provide a means of ignition to the gas within the cylinder, and there are two methods of achieving this-

- Converting to spark-ignition
- Converting to dual-fuel compression combustion ignition

The following components to be modified/replaced-

- Modification on cylinder head
- Spark ignition system to add
- Modification to cooling system
- Airs throttle need in the intake system
- Compression ratio requires to be allowed usually by fitting low compression pistons
- Using CNG there is no fall back to alternative fuel as in dual fuelled engines.

Major parts, to be replaced for the conversion of diesel *engine into duel fuel engine-*

3.3.1. Dual-Fuel Electronic Control Unit

The ECU sends high-speed pulse modulated signals to the natural gas and diesel fuel injectors. The component bases this on constant measurements of the air manifold pressure and temperature along with gas pressure and temperature. The unit controls the supply of dual fuel to the engine ensuring optimum fuel control, which is usually 8% diesel, combined with 92% natural gas. This ensures maximum fuel efficiency along with lowest possible emissions of CO_2.

Most modern ECUs can also control the “knock” from dual fuel engines by automatically altering the combustion air/gas ratio. In the event of CNG supply malfunction, the ECU will shut the CNG system down and switch to 100% diesel fuel supply.

3.3.2. Turbo-Charger Air Bypass (TAB)

The TAB unit is required to control the amount of air provided by the turbo-charger. Bypass valve provides this, usually of a butterfly design.

3.3.3. Structural Conversion of Diesel Engine to DNG

The technology of engine conversion is well established and suitable conversion equipment is possible. For Diesel engines to be converted or designed to run on natural gas, there are two available options. The first is a dual-fuel engine. This refers to diesel engines operating on a mixture of natural gas and diesel fuel. Natural gas has a low cetane rating (a quantity indicating the ignition properties of diesel fuel relative to cetane as a standard.) and is not therefore suited to compression ignition, but if a pilot injection of diesel fuel occurs within the gas/air mixture, normal ignition can be initiated. Between 50-75% of usual diesel, consumption can be replaced by gas when operating in this mode [9]. The engine can also revert to 100% diesel operations. The second is dedicated natural gas engine. Dedicated natural gas engines are optimized for the natural gas fuel. They can be originated from petrol engines or may be designed for the purpose. Until manufactured OEM engines are available, the practice of converting diesel engines to spark ignition will continue, which involves the replacement of diesel fuelling equipment by a gas carburettor and the addition of an ignition system and spark plugs. For compression ignition engines convert to spark ignition, the pistons must be redesigned to reduce the original compression ratio and a high-energy ignition system must be fitted along. The system is suitable for CNG and is ideally suited to time(sequential) port injection system but can also be used for single point and low pressure in-cylinder injection. Gas production provides greater precision to the timing and quantity of fuel provided, and to be further developed and to become better in fuel emissions performance. An approximate measure of the equivalent petrol or diesel fuel capacity of a cylinder filled with gas at 20Map has to be obtained by dividing the cylinder volume by 3.5 - thus a 60-litre cylinder will provide the energy equivalent of 17 litres of conventional fuel. The design and installation of appropriate high-pressure on board storage cylinders, plays an important part of the efficient and safe operation of CNG-fuelled vehicle. The cost constitutes a good proportion of total vehicle installation cost. Most widely used are chrome molybdenum steel gas cylinders, which are the cheapest, but also one of the heaviest forms of storage containers. It is possible that the space required and weight of CNG fuel storage systems will fall in the future result of improved engine efficiencies (as with dedicated designs) and lightweight storage tanks. For example fibre reinforced aluminium alloy or even all composite.

CNG pressure tanks Table demonstrate significant weight saving over steel - up to 57%. It is even possible to increase the stored fuel's energy density by, for example, increasing the storage pressure of the gas. Future dedicated CNG-fuelled vehicles will benefit by the fuel storage system being integrated into the vehicle structure, taking up less of the storage space currently lost in conversions. One proposal for a future vehicle, CNG storage system is the so-called "fortress frame". A modified vehicle frame structure, of significant cross-section, would be used to store the gas inside it at low pressure. Additionally, the frame would provide greater crash protection to the occupants. Although the design is likely to be as "safe" as conventional CNG vehicles, product liability issues, especially in the US, make the future development of this concept uncertain. Research is in progress to use adsorbent materials in a tank to store natural gas which reduces the required pressure (from 200 bar for CNG currently, to around 30bar) and thereby avoids the need for high-pressure compressors and provides more design flexibility for the tank. Many types of adsorbent materials have been considered, including activated carbon, zeolites, clay sand phosphates. With activated carbon at pressures of 300-400 psi (2-2,75MPa or 20-27 bar) [9], the percentage of natural gas adsorbed can be 10 to 15 per cent of the weight of carbon.

3.4. Operation Limits

3.4.1. Maximum Gas and Minimum Pilot Diesel

The performance of the dual fuel engines is determined by affected by the amount of natural gas and diesel. To obtain high mass alternative rate, the amount of pilot diesel should be as little as possible. Too little pilot diesel, however should result in unstable operation of engine. Under such conditions, the engine almost renders unstable operation. The testing has confirmed that the dual fuel engine would exhibit obvious detonation if higher mass alternative rate were used [12].

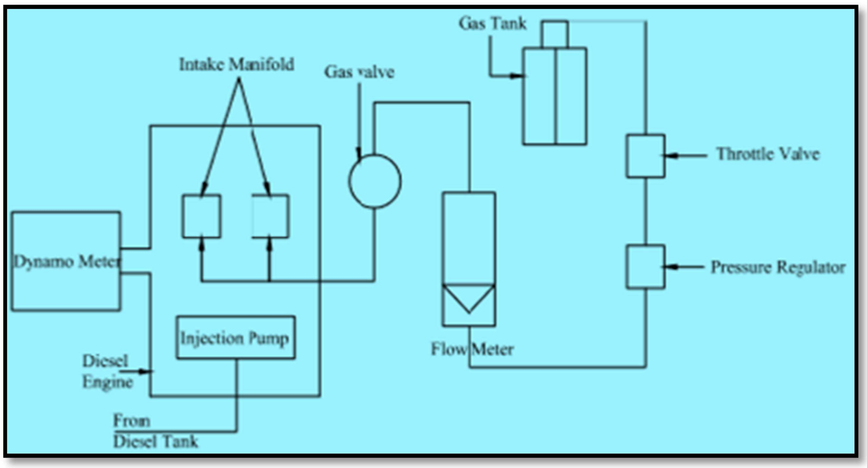

Fig. 2. Shows, the overall arrangements of the engine fuelled with diesel-natural gas.

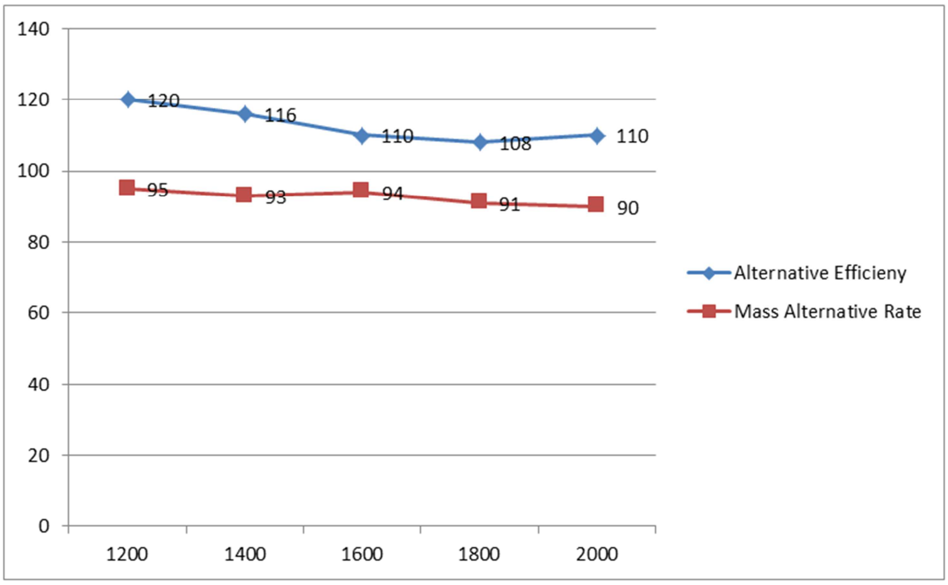

Fig. 3. Shows-the mass alternative rate and alternative efficiency at full loads at speed of range from 1200 to 2000 r/min.

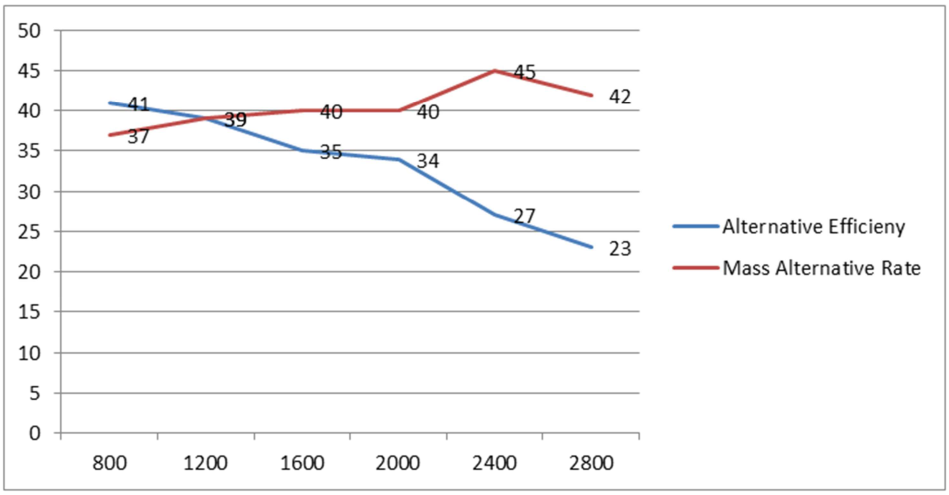

Fig. 4. Shows the mass alternative rate and alternative efficiency at light loads at which the dual fuel engine stably operates with min. gas at speed of the range from 1200 to 2650 r/min. [12].

3.4.2. Maximum Gas and Adequate Pilot Diesel

As described above, too low of an amount of diesel would result in irregular burning or detonation. On the other hand, too little amount of natural gas will cause the misfire of the gas.

4. Operation of a Diesel/CNG Dual Fuel Engine

When a diesel engine is converted into a dual fuel engine to run on CNG, it operates in much the same manner as the original diesel engine, changing over to gas/diesel mix when optimum engine operating temperatures are reached.

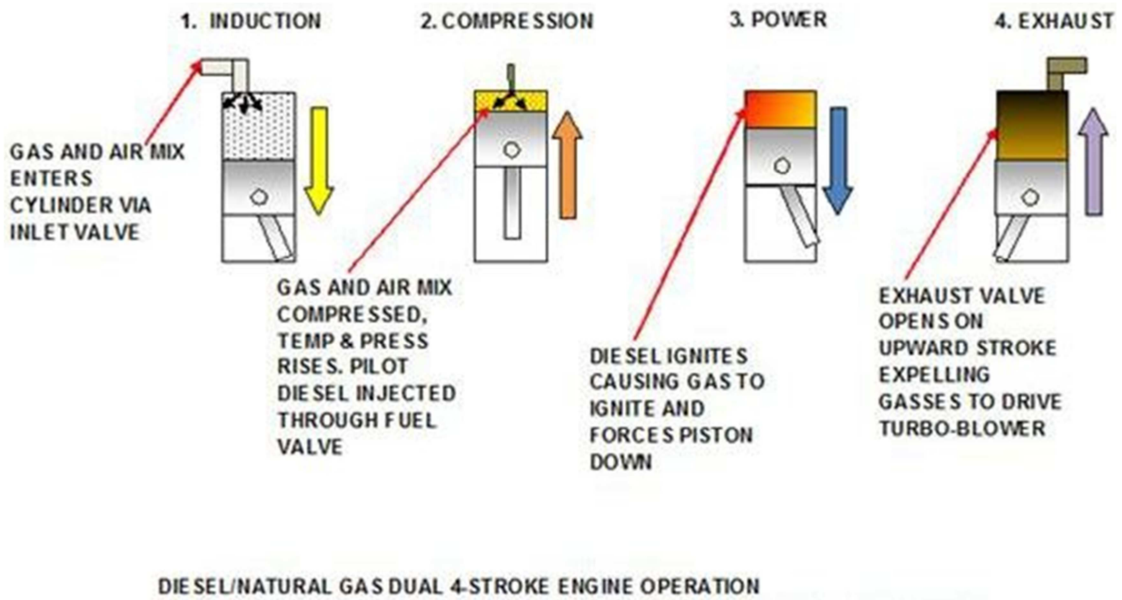

Fig. 5. Shows - the operation of a typical dual fuel 4-stroke diesel/natural gas engine is examined below.

1. Intake Stroke.

As the piston descends into the cylinder, a measured amount of gas in injected into the air inlet manifold and is sucked into the cylinder as a gas/air mixture.

2. Compression Stroke.

The piston continues down until it reaches BDC; it then rises back up the cylinder, compressing the air/gas and increasing its temperature. Before the TDC, a measured quantity of diesel oil (pilot diesel) is injected into the combustion chamber.

3. Power Stroke.

The small amount of diesel ignites into hundreds of little sparks due to compression combustion. This in turn sets off the combustion of natural gas that powers the piston back down the cylinder.

4. Exhaust Stroke

The piston returns to BDC and, as it begins to rise up the cylinder, the exhaust valve opens expelling the exhaust gasses into the turbo-charged inlet turbine, thus completing the 4-stroke cycle.

5. Conclusion

Some conclusions could be drawn from this brief review: Use of compressed Natural gas is not practical applicable unless a high quality ignition source provided. Emission of pollutants from CNG-fuelled vehicles seems to be more benign on both global and local environment than currently used vehicles because of less CO and "active" HC emissions. Combustion chamber design is a very important factor in natural gas utilization. Fumigation is the simplest approach to use CNG in an engine. However, the emission characteristics are relatively low compared to other technologies. Air/fuel ratio control in CNG-fuelled engines is more critical and difficult than that of gasoline engines. Therefore, special fuel metering and mixing systems must be used. Since higher ignition energy is required for natural gas, more powerful ignition systems should be used in CNG-fuelled SI engine than in gasoline-fuelled engine. Converted CNG-fuelled SI engine can perform well if the combustion chamber is modified for natural gas utilization. Natural gas / diesel dual fuel CI engine can perform well if it operates with suitable ECU (electronic control) system.

Based on the analysis of combustion characteristics of gaseous engines, some measures for reducing emissions and improving engine performance at light engine loads are suggested in this paper, such as gaseous fuel cost, conversion benefits, safety and gas storage facility, are reviewed [15].

Now, in this paper, there is a proper and a suitable method mentioned with physical and chemical analysis of both CNG and Diesel fuel for the conversion of diesel engine to duel fuel engine.

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