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Experimental investigations on LPG - diesel dual fuel engine

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ABSTRACT

In this experimental study, the performance, combustion and emission parameters of single cylinder, four-stroke, air-cooled, naturally aspirated, compression ignition (CI) engine with a compression ratio of 17.5 was modified to operate in the liquefied petroleum gas (LPG)-diesel dual fuel mode of operations. Diesel being injected into the cylinder and LPG being inducted in the intake manifold of an engine in the dual fuel mode at a constant BMEP of 4 bar with a fixed engine speed of 1500 rpm. It was seen from the experimental data that the maximum possible operating range of energy ratio (LPG to diesel) was limited by misfire and the corresponding values of the energy ratio ranges from 0% to 89.5% at this operating condition. The concentration of nitric oxide (NO) emission was significantly decreased from 550 ppm to 50 ppm with introduction of LPG as the contribution of diesel that was injected reduced in order to maintain the same energy ratio. It was noticed that the lower peak in-cylinder pressure at higher energy ratios signifying the low in-cylinder gas temperature. As the energy ratio increases, the level of hydrocarbons (HC) emissions raises from 23 ppm to 824 ppm. Brake thermal efficiency reduces with increase in energy ratio because of poor ignition quality of air-fuel mixture that was used with lesser amounts of diesel.

KEY WORDS: Liquefied petroleum gas (LPG), energy ratio, Dual fuel mode, Engine emissions.

1. INTRODUCTION

Diesel engines since its invention in late 19th century proven to be most reliable, durable than other engines. It is simple in design. Higher oxides of nitrogen (NOx) and Particular matter (PM) emission are main drawback of diesel engines. With engine design modification, by implementing EGR emissions can be reduced. With current engine design modifications and EGR, NOx and PM limit proposed in EURO-VI norms cannot be satisfied (Premkartikkumar and Annamalai, 2015; Sangeetha Krishnamoorthi and Ravi Yadav, 2016). Further increase in EGR induction results in decrease in thermal efficiency, rise in PM emission and BSFC. Gaseous fuels have great potential to tackle these problems. On combustion these fuels produces little NOx and CO_2. Diesel engines have positive response to these fuels, it requires slight modification to operate on gaseous fuels. LPG, natural gas, H_2 and biogas are widely available gaseous fuels. Each having its own advantages(Rao, 2015).

Liquefied petroleum gas (LPG) having higher Octane number (105) so it is having good knock resistance ability. Calorific value for LPG is 47.7 MJ/kg which represents it has high energy density. LPG lowers the in-cylinder temperature and peak pressure this results in comparatively lesser NOx emission. LPG cannot burn all alone as it's auto ignition temperature is high (410-580 ◦C), it requires little amount of liquid fuel to initiate combustion. Hence, it is economical and ecofriendly to use LPG in diesel engine in dual fuel mode(Vijayabalan & Nagarajan, 2009; Zhang, Bian, Si, Liao, & Odbileg, 2005).

Literature Survey: Earliest experiments in dual fuel mode were carried out in 1930 by Sokes and Helmore. They used hydrogen in diesel engine. Experimental performance of dual fuel (diesel+ LPG) was studied by varying composition of LPG. They also reported that due to use of LPG, resulting peak pressure is lower, so engine runs more quitter (Poonia and Ramesh, 1998).In 1999, Poonia used LPG in diesel engine and analyzed combustion and emission characteristics in the dual fuel mode. He reported that due to LPG significant reduction results in NOx and CO2 emissions(Poonia and Ramesh, 1999). Dual fuel technology by using diesel and CNG is promising technique. It reduces toxic emissions like NO_x, CO, CO_2 by approximately 54%, 59%, 31% respectively than those conventional diesel engines. With diesel and CNG dual fuel engine it is possible to control both PM and NOx simultaneously with slight modifications in engine which is considered to be a remarkable advantage of dual fuel technology over conventional engines (Yusaf and Al-Atabi, 2001). Due to lower calorific value of CNG, dual fuel engines have penalty in specific fuel consumption but it can be partially compensated by lower fuel prices of CNG. With modifications in engine tuning like injection timing of pilot diesel fuel at part load conditions this fuel consumption can be further improved. With more electronics in engine sophisticated and close control over various engine operating parameters is possible. It includes electronic control unit, sensors and diagnostic unit. By adopting multi-point electronic control injection for dual fuel system one can get as high as 92% of CNG substitution at rated power and reduce NOx and PM emissions greatly (Zhang and Liu, 2001). In dual fuel engines intake temperature and pilot quantity of fuel are important factors which controls combustion. Brake thermal efficiency gets improved and lower HC and CO emissions are observed at increased intake temperature of LPG (Mohanan and Suresh Kumar, 2001). Dimethyl ether and LPG dual fuel engine is also a good option to control combustion phase and improve power output of engine due to use of high cetane and high octane rating fuel simultaneously (Jang and Yang, 2009).

In this paper, the effect of LPG energy ratio on performance, combustion and emission characteristic were studied. An experimental result indicates significant reduction in NOx and CO_2 with increase in LPG energy ratio.

Peak in-cylinder pressure also lower at higher LPG energy ratios. On the other hand HC emissions increased with LPG energy ratios, but it can be reduce by after treatment devices.

2. EXPERIMENTAL

A single cylinder, stationary, four-stroke, air-cooled, naturally aspirated, diesel engine coupled to an eddy current dynamometer was used for this experimental investigations on dual fuel mode with LPG and pilot quantity of diesel. The engine specifications were listed in Table 1. The mass flow rate of air was measured using an orifice meter which was connected to the upstream of the intake manifold. The mass flow rate of diesel was measured on volume basis. Exhaust gas temperature was measured using a K-type thermocouple. The volume flow meter was used to measure the flow rate of LPG that was inducted along with incoming air. In order to avoid the possibility of backfiring, flame arrestor and water trap were incorporated with the intake system. The flow rate of LPG was adjusted using a fine control needle valve. The concentration of emissions such as nitric oxide (NO), hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2) were detected using a Horiba analyzer. In-cylinder pressure data was recorded through an oscilloscope using a piezo-electric pressure transducer (Make: Kistler, Switzerland).

Table.1.Engine specifications

Make	Kirloskar
Model	TAF
Cycle	4-Stroke
Rated Power	4.4 kw (6BHP)
Speed	1500 rpm
Cooling System	Air cooling
Ignition System	Compression Ignition
Capacity	661 cc
Compression Ratio	17.5
Stroke	110 mm
Bore	87.5mm

Table.2.Dynamometer specification

Make	Power Mag
Max Torque	7.5 Hp @ 1500 rpm
Max Power	10 kw

The conventional engine was modified to run in dual fuel mode. LPG induction provision was made in intake manifold. Following table shows various parameters and instruments used to measure them.

Table.3. List of instruments used

Parameter	Instrument/purpose of measurement
Loading	Eddy current dynamometer (governor controlled)
Air flow rate	U tube manometer
Diesel consumption measurement	Burette and stopwatch
LPG consumption measurement	Flow meter(volume basis)
Emission measurement	Horiba gas analyzer
In cylinder pressure measurement	Piezoelectric pressure transducer

Experimental Setup: LPG is being inducted along with incoming air from the cylinder at a pressure of about 150 bar. LPG cylinder connects to intake manifold via flame arrester. Precise control of a needle valve was used to regulate flow rate of LPG entering into the intake manifold of an engine. Flow meter (Make: STARK, Model No: HPC400) was installed after needle valve to measure flow rate of LPG on volume basis. The quantity of air that enters into the engine was measured using a orifice meter. Exhaust emissions such as NOX, HC and CO are detected using NDIR based analyzer (Make: Horiba, Model No: sv-5q, Japan).

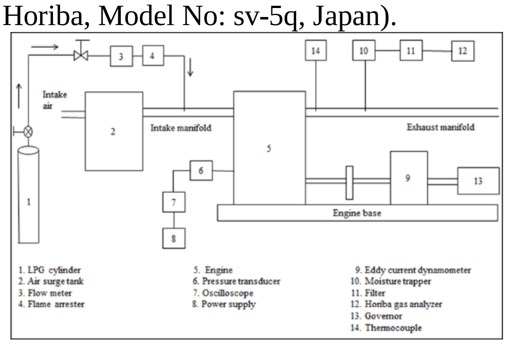

Figure.1. Schematic diagram of the experimental setup

Experimental procedure: Initially the engine was started in compression ignition (CI) mode using neat diesel as a fuel with conventional injection system. The engine was maintained at a constant speed of 1500 rpm throughout the experiment and the loading of the engine was done by making use of an eddy current dynamometer. The best static injection timing of diesel was set at 23°BTDC. The engine was operated at a fixed load of 50% and its corresponding brake mean effective pressure (BMEP) of 4bar. The quantity of LPG was increased by adjusting the fine control needle valve. Subsequently the quantity of diesel that was injected reduces with help of governor control. The LPG energy ratio was varied from 0% to maximum possible operating range. The range of operation in the LPG-diesel dual fuel mode at 50% load was ranges from 0% to 89.5% and above which the engine was started to misfire.

$$\text{LPG Energy Ratio} = \frac{E_{LPG}}{E_{LPG}+E_{diesel}}$$

Where, E_{LPG}=Energy input from LPG; E_{diesel}=Energy input from diesel

3. RESULTS AND DISCUSSIONS

In this experimental study at 50% load, 1500 rpm engine was run in dual fuel mode. After this LPG energy ratio was varied and all readings were taken.

Nitric oxide (NO) emissions: Figure.2, depicts the effects of LPG energy ratio over NO emissions. Basically there are two types of NO emissions namely thermal and chemical NO. NO emissions are because of oxygen in air and high in-cylinder temperature. Being combustion promoter fuel diesel leads to higher in- cylinder temperature in neat diesel engine. With rise in LPG energy ratio, volume percentage of diesel in combustion decreases which finally reduces in-cylinder temperature. Hence thermal NO gets reduces significantly whereas chemical NO remains same so overall reduction in NO observed at higher LPG energy ratio.

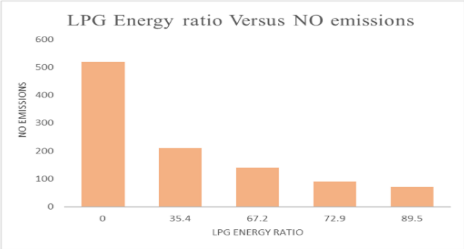

Figure.2. LPG Energy ratio versus NO emissions

Unburnt hydrocarbons (HC) emissions: LPG is basically mixture of hydrocarbons (Butane and Propane) having lower carbon content than diesel. This reduces energy density of LPG. Hence at higher energy ratios LPG retards the combustion which leads to misfire and lack of energy to complete combustion of these hydrocarbons. This results into more amount of hydrocarbons are emitted as unburnt hydrocarbons (UHC). Hence in graph higher HC emission were observed at higher LPG energy ratio. By installing three way catalytic converter one can reduce these excessive UHC. Figure.3, depicts variation of HC with LPG energy ratio.

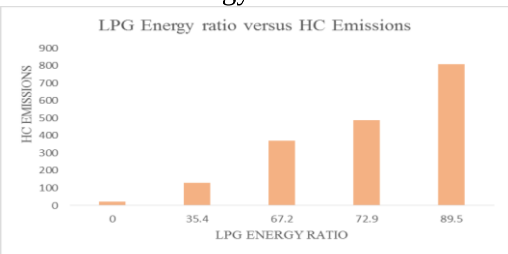

Figure.3. LPG Energy ratio versus HC emissions

Variation of in-cylinder peak pressure: Relatively higher in-cylinder temperature and pressure were observed during neat diesel operation. With rise in LPG energy ratio (contribution of diesel decreased) temperature and pressure starts reducing due reduction in C/H ratio in final mixture. After particular value of LPG energy ratio, due to deficiency of required amount of diesel for combustion engine leads to misfire. Figure 4 showing that peak pressure gets reduced with increasing LPG energy ratio. At 89.5% LPG energy ratio engine leads to misfire.

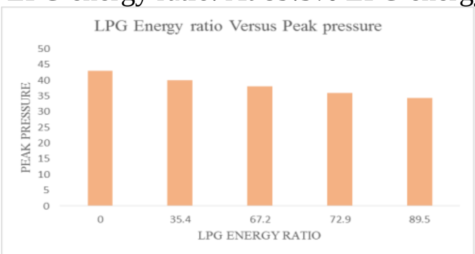

Figure.4. LPG Energy Ratio versus In-cylinder peak pressure

Carbon monoxide (CO) emission: Mixture temperature and unburnt gas content are factors responsible for production of CO emissions. These two factors control the rate of oxidation and decomposition of fuel. At higher LPG energy ratio content of unburnt gases (unburnt HC) increases. Also at higher LPG energy ratio oxygen availability in combustion chamber goes on reducing, so it is difficult for CO to convert into CO_2. Hence, at higher LPG energy ratio CO emissions are more as compared to lower energy ratio.

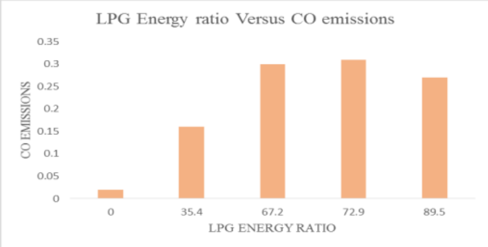

Figure.6. LPG Energy ratio versus CO emissions

4. CONCLUSIONS

In this experimental study, performance and emission characteristics of single cylinder diesel engine operating in dual fuel mode using LPG as primary fuel are observed. By keeping constant engine speed 1500 rpm and 50% of the engine load following conclusions were drawn

- At higher LPG energy ratio as in cylinder temperature and pressure decreases so it leads to reduction in NO emissions. (at 0% LPG energy ratio=526 ppm and at 89.5% LPG energy ratio=68 ppm)
- With increase in LPG energy ratio HC emissions increases (at 0%LPG energy ratio=23ppm and at 89.5% LPG energy ratio=824 ppm) this can be reduced by installing three way catalytic converter
- With increase in LPG energy ratio peak in-cylinder pressure and heat release rate decreases.

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