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Effect of Induction Length and Flow rate on Performance and Emission of Diesel-LPG Dual Fuel Engine – A Review Study

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ABSTRACT: The conventional petroleum fuels for internal combustion engines will be available only for few years, due to tremendous increase in the vehicular population with time. In addition to this, these fuels cause serious environmental problems by emitting harmful gases into the atmosphere at increased rates. Generally, pollutants released by engines are CO, NOx, Unburnt hydrocarbons, smoke and some amount of particulate matter. At present, alternative fuels like methyl esters of vegetable oil (commonly known as biodiesels), alcohols etc. which are in the form of liquid and hydrogen, acetylene, CNG, LPG etc. in gaseous fuels are in the line to replace the petroleum fuels for IC engines. This research paper reviews about the research work done by the researchers in order to improve the performance, combustion and emission parameters of a LPG–diesel dual fuel engines. From the studies it is shown that the use of LPG in diesel engine is one of the capable methods to reduce the PM and NOx emissions but at same time at part load condition there is a drop in efficiency and power output with respect to diesel operation.

Keywords: Dual fuel engine, Emission, Induction technique, LPG, Performance

1. Introduction

1.1. Dual Fuel Mode

Dual-fuel operation combines the possibility of operating diesel engine on liquid fuels such as diesel oil or gas oil and on gaseous fuels such as natural gas, sewage gas and cook oven gas. It works on diesel cycle. Gaseous fuel (primary fuel) is added to air inducted into the engine or supplied by supercharger. The mixture of air and gaseous fuel gets compressed in the cylinder. Liquid fuel called pilot fuel injected near the TDC acts as a source of ignition. Gas-air mixture ignites establishing a number of flame-fronts. In a dual-fuel engine combustion starts similar to CI engine, but it is propagated by flame-fronts as in SI engine [1]. The mass fraction of the LPG used in dual fuel mode is calculated by using the following expression, 'Z':

$$Z = \frac{m_{LPG}}{m_{Diesel} + m_{LPG}} * 100\,\%$$

where m_{Diesel} is mass flow rate of diesel and m_{LPG} is mass flow rate of LPG. And Z = 0% represents diesel operation, Z=10%, 20%, 30%, 40% represent the LPG mass fraction used in dual fuel mode [2].

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1.2. Ccombustion process of LPG–diesel dual fuel engine

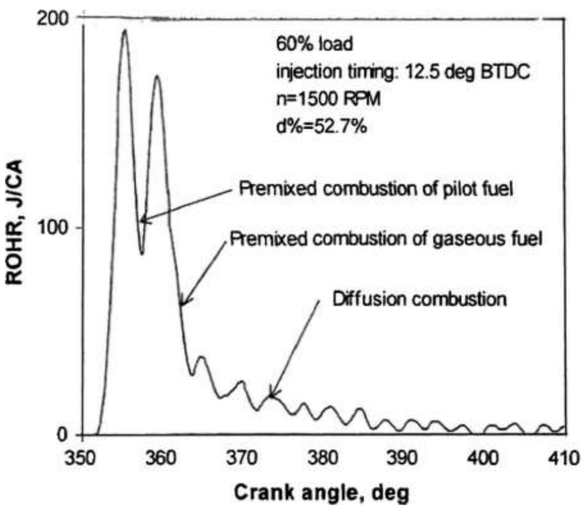
The combustion process of pure diesel engine takes place in four stages, termed as Ignition delay, rapid combustion, controlled combustion and period after burning. Whereas the combustion process of the LPG dual fuel engine shares the characteristics of both SI and CI engine combustion characteristic and consists of five stages throughout the combustion process of Ricardo E6 single cylinder as shown in Fig. 1 The stages are pilot ignition delay (AB), pilot premixed combustion(BC), primary fuel (LPG) ignition delay (CD), rapid combustion of LPG fuel (DE), period after burning (EF).

Pilot ignition delay period (AB) is longer than the pure diesel fuel operation due to the reduction in concentration of intake oxygen, resulting from LPG inducted along with intake air and partly due to the change in the specific heat of the compressed mixture that resulted in lowering the compression temperature. The pilot premixed combustion (BC) leads to produce the small flame, which is first initiated by the small quantity of diesel and combustion increases the pressure smoothly. Primary fuel (LPG) occupying in compression process undergoes chemical pre-ignition reactions leading to primary ignition delay (CD) where the pressure starts to decrease in this period and its rate is very low. The phase of rapid combustion (DE) is very unstable, because it started with flame propagation that has been initiated by the spontaneous ignition of pilot diesel fuel. At first in this stage pressure is increased mainly due to the premixed burning of part or whole of the pilot diesel in addition to combustion of a small part of the LPG gas entrained. Then again the pressure is increased to its maximum level because of combustion of the major part of the LPG gaseous fuel and small amount of the remaining pilot diesel inside the cylinder. Period after burning stage (EF) starts at the end of rapid pressure raise and continues well into the expansion stroke. This is due to the slower burning rate of LPG fuel and the presence of diluents from the pilot fuel. The success of this phase primarily depends on the length of ignition delay.

However, the combustion process also generally has problems of knocking and misfiring when the percentage of inducted LPG fuel is increased [9,10]. So the mass of LPG used at higher loads has to be considered in order to overcome the knock and misfiring. Increasing the amount of diesel pilot fuel quantity reduces the engine knock at high output conditions. For LPG dual fuel engine, the maximum pressure is always higher than diesel fuel case, due to the combustion and extra heat released from gaseous fuel [11].The higher LPG ratio in dual fuel modes leads to two effects. First, the premixed combustion and the speed of flame propagation increases but the mixing-controlled combustion for the liquid fuel reduces. Second, the reduced amount of pilot injection causes the smaller size of the ignition sources, therefore increases the path that the flame needs to propagate to consume all the premixed mixture in the chamber.

The Rate of Heat Released (ROHR) of LPG diesel dual fuel shown in Fig. 2 for a single cylinder constant speed engine shows that there are three important burning phases of the combustion process, and they are premixed combustion of the pilot diesel fuel, premixed combustion of the primary LPG fuel and diffusion combustion of LPG fuel and the left over pilot diesel fuel. The first phase is mainly due to the pilot diesel fuel and small part of the LPG entrained by the spray of diesel is burning along with diesel. Heat energy released in this phase is mainly due to the diesel fuel burned. The second phase is due to the burning of a maximum part of the LPG fuel and a part of the rest of the pilot diesel fuel. The heat energy released during the premixed combustion phase of the LPG fuel depends on the increasing quantity of pilot diesel substitution. It means that the amount of heat energy released by the LPG is more when its quantity is increased. Hence, the gaseous fuel burns mostly during the second phase of the combustion.

Finally, the third phase is due to the combustion of the rest of the two fuels which are not burned in the last phase. The diffusion combustion phase is due to the diesel droplets that did not burn during the premixed combustion or that are injected after the start of the premixed combustion. These droplets are burning slowly and gradually in a liquid phase inside the cylinder[9,12].



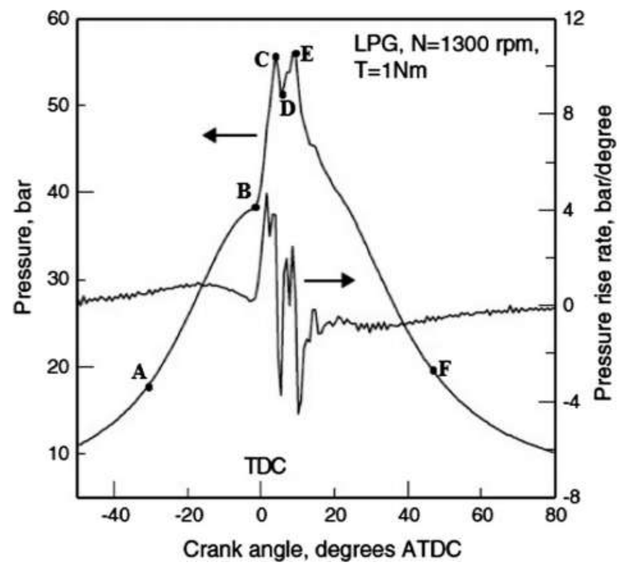


Fig. 1 Combustion pressure & pressure raise rate vs crank angle of LPG diesel fuel engine [11].

Fig. 2 Rate of heat release rate vs crank angle of a dual fuel diesel engine combustion [12].

2. Literature Review

In this section review of various literatures has been presented on effects of various parameters on performance and emission characteristics of diesel engine.

B. Ashok et al. [2] studied various research papers and concluded that use of LPG in the diesel engine as dual fuel operation is one of the noticeable and effective measures to overcome the fossil fuel scarcity and exhaust emissions. Also the study reviewed that the part load characteristic can be improved by optimizing the engine operating parameters and design elements such as engine speed, load, pilot fuel quantity, injection timing, intake manifold condition and intake gaseous fuel compositions.

Kanit Wattanavichien et al. [3] investigated and to identified the effect of biodiesel as the pilot injection in dual fuelled engine. At first, images of spray and spray combustion characteristics of diesel fuelled engine and palm bio-diesel were investigated. Next, images of spray and combustion characteristics of liquefied petroleum gas (LPG) premixed charge-diesel dual fuelled engine was studied. At last, the investigation continued with the pilot injection changed to palm biodiesel (PME). Test bench experiments (steady state) were conducted with a 4-cylinder IDI CI engine, at selected fixed load, high probability operating points corresponding to the ECE15+EUDC cycle. The engine ran as LPG-air premixed mixture was maintained at four fixed values by an electronic controlling system. The acquired data included basic parameters and accessed combustion chamber visualization.

The comparative analysis deals with the energy efficiencies, liquid fuel substitution, combustion chamber phenomena including spray, combustion, flame probability distribution, flame temperature, and soot concentration (two colour method).

With LPG-PME, the flame probability distribution and the area of high flame temperature was smaller, due to the PME properties like lower heating value, lower adiabatic flame temperature, and heavier. This was also thought due to the limit of the two colour method when applied for gaseous and oxygenated fuel combustion. Concentration of soot in flame was observed to be lower with higher LPG and was much lower in LPG-PME cases.

Mohamed Y.E. Selim et al. [4] analysed cycle-to-cycle combustion variation as reflected in the combustion pressure data of a single cylinder, naturally aspirated, four stroke, Ricardo E6 engine converted to run as dual fuel engine on diesel and gaseous fuel of LPG or methane. A measuring set-up consisting of a piezo-electric pressure transducer with charge amplifier and fast data acquisition card installed on an IBM microcomputer was used to gather the data of up to 1200 consecutive combustion cycles of the cylinder under various combination of engine operating and design parameters. These parameters included type of gaseous fuel, engine load, compression ratio, pilot fuel injection timing, pilot fuel mass, and engine speed. The data for each operating conditions were analysed for the maximum pressure, the maximum rate of pressure rise—representing the combustion noise, and indicated mean effective pressure. The cycle-to-cycle variation is expressed as the mean value, standard deviation, and coefficient of variation of these three parameters. It was found that the type of gaseous fuel and engine operating and design parameters affected the combustion noise and its cyclic variation.

H.E. Saleh et al. [5] investigated the effect of variation in LPG composition on emissions and performance characteristics in a dual fuel engine run on diesel fuel and five gaseous fuel of LPG with different composition. To quantify the best LPG composition for dual fuel operation especially in order to improve the exhaust emissions quality while maintaining high thermal efficiency comparable to a conventional diesel engine, a two-cylinder, naturally aspirated, four-stroke, DI diesel engine converted to run as pilot-injected dual fuel engine. The tests and data collection were performed under various conditions of load at constant engine speed. From the results, it is observed that the exhaust emissions and fuel conversion efficiency of the dual fuel engine are found to be affected when different LPG composition is used as higher butane content lead to lower NOx levels while higher propane content reduces CO levels. Fuel #3 (70% propane, 30% butane) with mass fraction 40% substitution of the diesel fuel was the best LPG composition in the dual fuel operation except that at part loads. Also, tests were made for fuel #3-diesel blend in the dual fuel operation at part loads to improve the engine performances and exhaust emissions by using the Exhaust Gas Recirculation (EGR) method.

G.H. Abd Alla et al. [6] conducted test on a special single cylinder compression ignition research engine (Ricardo E6) to investigate the effect of pilot fuel quantity on the performance of an indirect injection diesel engine fuelled with gaseous fuel. Diesel fuel was used as the pilot fuel and methane or propane was used as the main fuel which was inducted into the intake manifold to mix with the intake air. Through experimental investigations, it is shown that, the low efficiency and excess emissions at light loads can be improved significantly by increasing the amount of pilot fuel, while increasing the amount of pilot fuel at high loads led to early knocking.

Antonio P. Carlucci et al. [7] conducted experiment on A diesel common rail research engine was converted to operate in dual fuel mode and, by activating/ deactivating the two different inlet valves of the engine (i.e. swirl and tumble), three different bulk flow structures of the charge were induced inside the cylinder. A methane port injection method was proposed, in which the gaseous fuel was injected into the inlet duct very close to the intake valves, in order to obtain a stratified-like air–fuel mixture up to the end of the compression stroke. For comparison purposes, a homogeneous-like air–fuel mixture was obtained injecting methane more upstream the intake line. Combining the different positions of the methane injector and the three possible bulk flow structures, seven different engine inlet setup were tested. In this way, it was possible to evaluate the effects on dual fuel combustion due to the interaction between methane injector position and charge bulk motion. In addition, methane injection pressure and diesel pilot injection parameters were varied setting the engine at two operating conditions

L. M. Das et al. [8] discusses four modes of induction techniques 1. Continuous carburation, 2. Continuous manifold injection, 3. Timed manifold injection, 4. Low pressure direct cylinder injection. It concludes that a mixture formation method plays a decisive role in the practical emergence of a future hydrogen specific engine. Future developments of such engines depend a lot also on the mode of storage and supply system. Using cryogenic hydrogen supplied from a liquid hydrogen tank has the prospects of increase in volumetric efficiency and thus the power output. It also reduces the specific fuel consumption as well as the level of NOx emissions. The limits of backfire are further lowered. Late fuel injection, on the other hand, is a very promising fuel induction technique as it does preclude the possibility of backfire, the century-old problem which has been bothering the hydrogen researchers. This technique could also be adopted to both two-stroke as well as four stroke engines.

An appropriate TMI system designed specifically on the basis of hydrogen's combustion characteristics for a particular engine configuration ensures smooth engine operational characteristics without any undesirable combustion phenomena. However, all those characteristics have been evaluated in converted engines. So, an integrated fuel induction and storage method must be designed for a hydrogen-specific engine which can embrace the benefits of good performance, least exhaust emission and controlled combustion characteristics of an ideal engine system.

Conclusion

From the literatures studied it was observed that the use of LPG in diesel engine is one of the capable methods to reduce the PM and NOx emissions but at same time at part load condition there is a drop in efficiency and power output with respect to diesel operation.

It is also observed that LPG was inducted in different ways i.e., manifold induction, port induction, direct injection in dual fuel mode. Some researchers induct hydrogen and varied according to load and compared with diesel and some other vegetable oils. But there was a lack of literature about where they inducted gaseous fuel along with air away from the engine manifold. The present work is to contribute some past data and experience for the future investigations.

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