STUDY THE EFFECT OF LPG INJECTION PARAMETERS ON THE PERFORMANCE AND EMISSION FOR DUAL FUEL (DIESEL-LPG) DIESEL ENGINE

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Received 07/12/2015, Peer reviewed 30/12/2015, Accepted for publication 05/01/2016.

ABSTRACT

This paper presents the effect of LPG injection control parameters on performance and emission for dual fuel diesel. The engine has been modified to determine the best LPG composition (ratio) for dual fuels to improve the emission quality while maintaining high thermal efficiency in comparison with the conventional diesel engine. A LPG electronic injection system controls the flow of liquefied petroleum gas (LPG) to manifold has been designed and manufactured for the above mentioned purpose.

The experimental results have been obtained on various Diesel-LPG modes at different loads at constant speed (1500 rpm). Compared to 100% Diesel at full load, the optimum value of Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC) were observed to improve by 31% with (68%-32%) Diesel-LPG mode. Exhaust gas emissions; namely NOX, CO2 and Smoke reduced by 30%, 48% and 29% at full load respectively with the use of (68%-32%) Diesel-LPG mode. After scrutinizing the results, a Dual fuel Diesel - LPG controller was developed for optimizing the performance on different operating conditions. With Diesel - LPG controller, it was possible to maximize fuel economy along with minimizing emission pollutants.

***Keyword**: dual fuel, fuel consumption, engine, LPG.*

TÓM TẮT

Bài báo trình bày kết quả nghiên cứu ảnh hưởng của thông số điều khiển phun khí hoá lỏng (LPG) trên đường ống nạp của động cơ Diesel đến hiệu suất và khí thải. Động cơ được cải tạo chuyển đổi để xác định thành phần LPG tốt nhất cho hoạt động với nhiên liệu kép, để cải thiện chất lượng khí thải trong khi duy trì hiệu suất nhiệt cao so với một động cơ diesel thông thường. Hệ thống phun LPG điều khiển bằng điện tử kiểm soát lưu lượng khí hóa lỏng (LPG) cung cấp cho động cơ được nghiên cứu, chế tạo phục vụ cho mục đích trên.

Kết quả thử nghiệm trên động cơ khi thay đổi tỷ lệ hỗn hợp của Diesel và LPG ở các chế độ tải khác nhau ở tốc độ 1500 v/p. Kết quả giá trị tối ưu của hiệu suất nhiệt (BTE) và hiệu suất tiêu thụ nhiên liệu (BSFC) cải thiện khoảng 31% ở mức tỉ lệ Diesel-LPG (68% - 32%) so với động cơ khi chạy 100% Diesel khi đầy tải và lượng khí thải ở chế độ này giảm cụ thể là NOx, CO2, Độ mờ khói giảm (30%, 48% và 29%). Sau thực nghiệm có kết quả thực nghiệm một bộ điều khiển Diesel-LPG đã được chế tạo để điều khiển hiệu suất tốt nhất nhằm tiết kiệm nhiên liệu và giảm ô nhiễm do khí thải sinh ra.

***Từ khóa:** Nhiên liệu kép, tiêu thụ nhiên liệu, động cơ, khí hoá lỏng, LPG.*

1. INTRODUCTION

In recent years, the studies using liquefied petroleum gas (LPG) for the transport in the world as well as in Vietnam have had positive results. LPG fuel has several advantages such as: reduce emission pollutants for gasoline engines while the performance of engine still maintains, low cost and easy to use [1] ... With dual fuel engine (LPG – Diesel) it was possible to improve emission pollutants, performance of diesel engines, the cost to change fuel system was low without making any modifications in the engine design…[3].

The dual fuel engines, the mixture of LPG and air is formed on the intake manifold and put into the cylinders of the engine, combustion of Diesel fuel leads to flame propagation and thus it burns LPG and air mixture. More Diesel in dual fuel at low loads is better for the improvement of Brake Thermal Efficiency (BTE). Other than performance enhancement, emissions as NOx and smoke are reduced significantly with the use of Dual fuel (Diesel-LPG) [3][8].

At low loads, BTE of a Dual fuel Diesel - LPG engine can be improved with the help of a heating element like a glow plug in combustion chamber but it requires a complicated process to make modifications in the existing design of the engine. Addition of LPG in diesel engine helps to improve the performance along with decreasing the cost but there is an increase in NOX emissions [4] and causes the detonation in engine. Detonation is caused by problem of rapid combustion with severe engine knock, It may damage the engine parts at higher loads; thus, it affects to the engine performance [12].

The purpose of the present study is thus, to experimentally analyze the emission and performance analysis of a small diesel engine operated on diesel and Dual (Diesel-LPG) modes. Different set of experiments were conducted to optimize the Diesel–LPG mode with a Dual fuel controller and a retrofitted LPG on the air inlet manifold but without any modifications to the engine foe Dual fuel.

2. THE SYSTEM PROVIDES LIQUEFIED PETROLEUM GAS AND DUAL FUEL DIESEL-LPG ELECTRONIC CONTROLLER

2.1 Modeling of engine using dual fue LPG - Diesel

The engine 3C - TE used pump VE - EDC (Electronic Diesel Control) axial piston type with electronic controller (ECU) control the operation two actuator solenoid valves (SPV: Spill control Value and TCV: Timing control Value). Therefore, ECU controlled exactly the fuel flow and injection timing into each cylinder of engine [2].

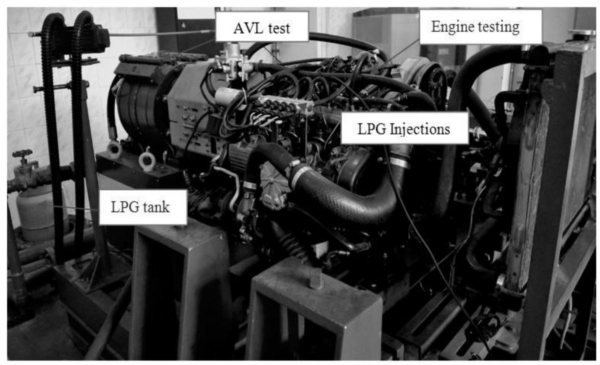


Fig. 1.*The schematic diagram of Dual fuel LPG - Diesel engine fuel system*

When LPG spray into the combustion chamber that the combustion process of diesel engine is completed by reduce ignition delay. LPG fuel, itself is not flammable because combustion temperature (over 400^0C) is higher than diesel fuel (250^0C) [9]. Therefore, diesel fuel burning before at end of compression stroke then flame propagation to ignite LPG and air mixture. At the time, LPG fuel as flame propagation cause reduce ignition delay.

The system provides LPG, with electronic injections is installed on the air inlet manifold on Diesel engine [7]. In addition, pilot diesel fuel is injected which is considered as appropriate techniques and easy to convert the engine using conventional diesel fuel to dual fuel engine without change the structure of the engine diesel.

LPG is supplied to engine diesel from tank through pressure relief valve. The controller is calculated injection timing by signal of crankshaft position sensor, timing injection LPG by signal of acceleration sensor *el engine fuel system*

The injector is installed on the manifold at the intake valve. While intake valve opened, LPG injected into the intake manifold which will be mixed with air then input combustion chamber of engine.

LPG is liquid state in tank with pressure 6-8 bar, when the valve open, liquid LPG to the pressure relief and vapor, at the time liquid LPG converted vapor with pressure 1.3 - 1.5 kg/cm^2 through pipelines leads to the injectors LPG.

The fuel flow supplied to the engine operating which is decided by SPV on injection pump VE – EDC.

2.2 Model of the engine control system using dual fuel LPG - Diesel

Mass flow of LPG is determined by the time picked injectors. ECU engine control SPV valve to change flow of fuel diesel by method control timing close open of SPV. So, system is limited by calculate the flow of fuel LPG supply to the engine based on engine speed and angle of the throttle (corresponding to the load of the engine) [6].

Mass flow of LPG m_{LPG} supply proportional timing injection t_{inj} and square root of pressure difference Δp between fuel distribution pipe and man- ifold in case of spraying on the manifold, density of fuel ρ_{LPG} and open area of injectors A_{eff} is considered constant formula as follows [7]:

$$\dot{m}_{LPG} = \rho_{LPG}.A_{eff}.\sqrt{2\frac{\Delta p}{\rho_{LPG}}}.dt_{inj}$$

$$m_{LPG} = \int_0^{t_{inj}} \dot{m}_{LPG} dt_{inj} = \rho_{LPG}.A_{eff}.\sqrt{2\frac{\Delta p}{\rho_{LPG}}}.t_{inj}$$

Therefore, timing is calculated:

$$t_{inj} = \frac{m_{LPG}}{\rho_{LPG}.A_{eff}.\sqrt{2\frac{\Delta p}{\rho_{LPG}}}}$$

Where:

+ m_{LPG}: Mass flow of LPG;

+ t_{inj}: Timing injection;

+ A_{eff}:Open area of injectors;

+ Δp : Pressure difference between fuel distri- bution pipe and manifold;

+ ρ_{LPG} : density of LPG;

From basis of the theory, the researchers has designed made dual fuel Diesel-LPG electronic controller as shown Figure 2:

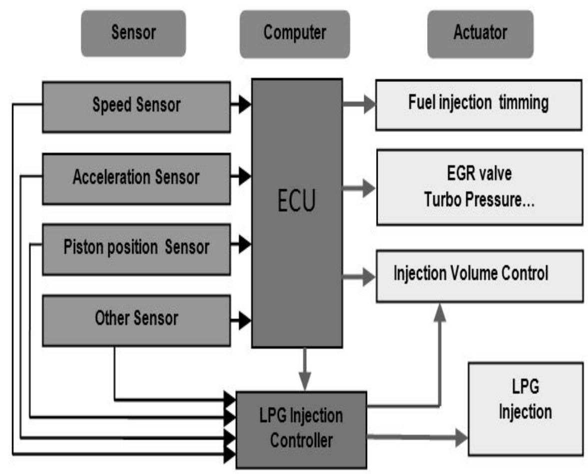
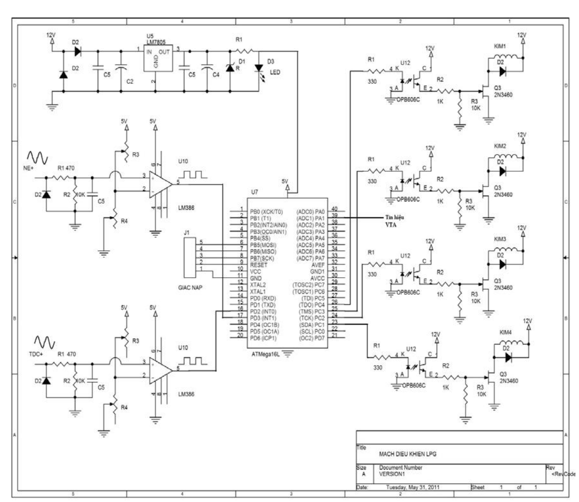


Fig. 2.*The schematic diagram of Dual fuel LPG - Diesel engine control sysyem*

Circuit of dual fuel LPG - Diesel controller with microcontrollers Atmega 16 [5] and using C to program for controller (Figure 3).



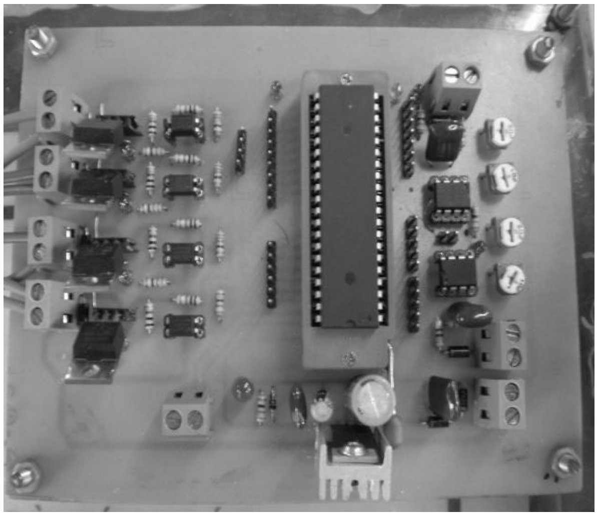


Fig. 3. *The diagram of ircuit principle and dual fuel controller*

2.3. Experimental for dual fuel LPG - Diesel system

The engine used for experimental is diesel engine Toyota 3C-TE with the basic technical parameter of the engine show as (table 1).

Table 1. *The technical parameters of the engine Toyota 3C - TE*

Engine type	Diesel 3C–TE, EDC-Diesel, Auxiliary combustion chamber, turbocharger
Idle speed	800 ± 50 rpm
Maximum speed	5000 rpm
Maximum power	99 kw / 5000 rpm
Maximum torque	206 Nm / 4000 rpm
Compression ratio	18:1
Cylinder	4
Stroke	4
Bore	86 mm
Cylinder capacity	2438 cm^3

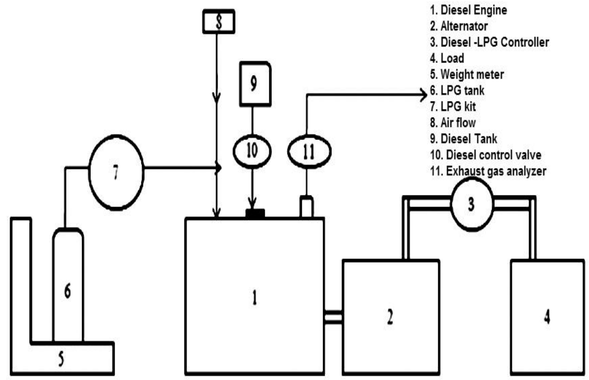


Fig. 4. *The schematic diagram of experimental set up*

The system of experimental include: LPG tank, vapor valve, system supply LPG to the injectors. LPG controller (12V) and load equipment. The exhaust gas analyzer of Maha and Korea to determine characteristics of emissions from the engine.

The fuel system is installed to engine run completely by Diesel fuel and dual fuel LPG - Diesel. The engine runs on diesel fuel (100%) at idle speed. Dual fuel mode, LPG is injected into manifold by the LPG controller [8].

Initially, the engine was tested using diesel at loads 0%, 20%, 40%, 60%, 80% and 100%, to measure the engine operating characteristics and pollutant emissions. The test was conducted on five different Diesel-LPG modes i.e., (84%-16%), (76%-24%), (68%-32%), (60%-40%), and (52%-48%) to find the optimize Diesel-LPG mode. The Diesel-LPG ratio (%) which is defined by equation below:

$$Z = \frac{(\text{Mass of LPG})}{(\text{Mass of LPG} + \text{Mass of diesel})} \times 100\%$$

Where Z = 0% means Diesel operation

Z= 16%, 24%, 32%, 40% means the LPG mass fraction in the Dual fuel mode.

3. RESULT AND DISCUSSION

3.1 Characteristics of the fuel system without LPG - Diesel controller:

- Brake specific fuel consumption (BSC)

Figure 5 shows that variation of BSFC with load is almost similar for all the Diesel-LPG modes. A maximum BSFC was observed at (52%-48%) diesel-LPG mode. Average BSFC was more by 10.8% than on100% Diesel. At all other Diesel–LPG modes i.e., (84%-16%), (76%-24%), (68%-32%) and (60%-40%), the BSFC improved by 11%, 8.3%, 11% and 6% respectively. The best results were observed at (68%-32%) diesel-LPG mode

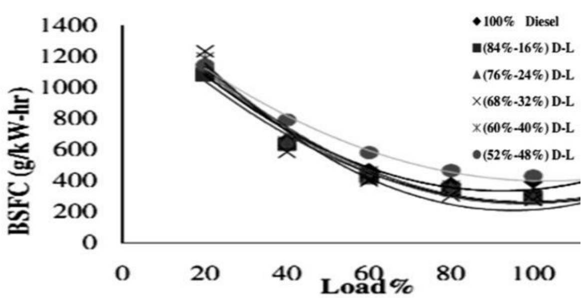


Fig. 5. *BSFC against load at different Diesel-LPG modes*

- Brake Thermal Efficient (BTE):

Figure 6 shows that the pattern followed by the entire Diesel-LPG modes is almost similar. At all the other Diesel–LPG modes i.e., (84%-16%), (76%-24%), (68%-32%) and (60%-40%), the BTE improved by 16%, 15.4%, 20% and 8.5% respectively. The best results were observed at (68%-32%) diesel-LPG mode on higher loads.

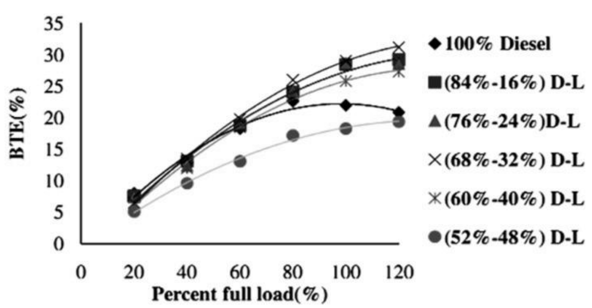


Fig.6. *BTE against load at different Diesel-LPG modes*

The Lowest BTE was on (52%-48%) diesel LPG mode. Brake thermal efficiency of engine running on 100% Diesel gradually increased from 8% to 23% from 20% load to 80% load.

- Smoke emission

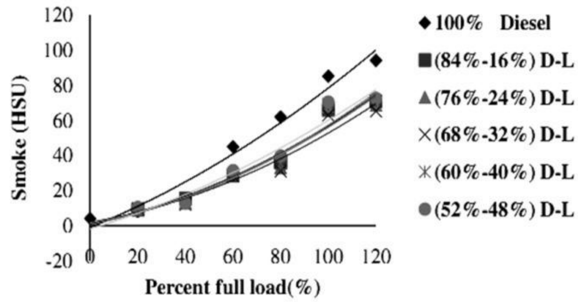


Fig .7. *Smoke emissions against load at different Diesel-LPG modes*

Smoke emissions for Diesel-LPG modes compared to 100% Diesel modes shows as figure 7. At all the other Diesel–LPG modes i.e., (84%-16%), (76%-24%), (68%-32%), (60%-40%), and (52%-48%) the average smoke emissions was lower by 27%, 28%, 32% and 27% respectively. The highest smoke was observed on 100% Diesel nearly 95 HSU. Reason for reduction in smoke emission could be because LPG has a lower carbon/ hydrogen ratio.

- NOx emissions

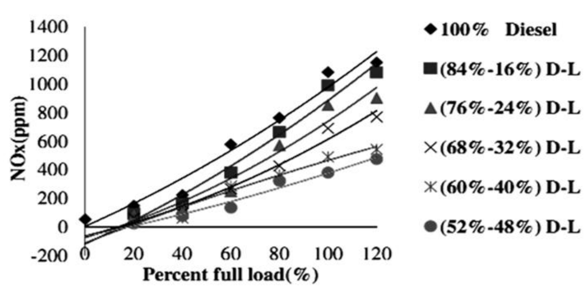


Fig.8. *NOx emissions against load at different Diesel-LPG modes*

NOx emissions for Diesel-LPG modes compared to 100% Diesel modes shows as figure 8. At all the other Diesel–LPG modes i.e. (84%-16%), (76%-24%), (68%-32%), (60%-40%), and (52%-48%) the average NOx emissions were lower by 14.4%, 29%, 41%, 54% and 64% respectively. Reason for reduction in NOx emissions could be the cooling effect produced by LPG in the combustionchamber.

3.2 Characteristics of the fuel system with LPG-Diesel controller (LPG – Diesel):

- Brake specific fuel consumption (BSFC)

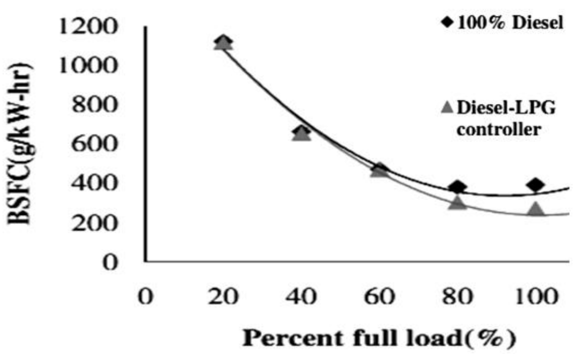


Fig. 9. *Fuel consumption against load*

Variation of BSFC against load is shown in Figure 9. Using Dual fuel controller Diesel-LPG, BSFC varied from 1119 gm/kW-hr to 258 (gm/kW-hr) from no load to overload condition. And BSFC reduced from 20% to 37% for100% Diesel against above 60% load.

- Brake thermal efficiency (BTE)

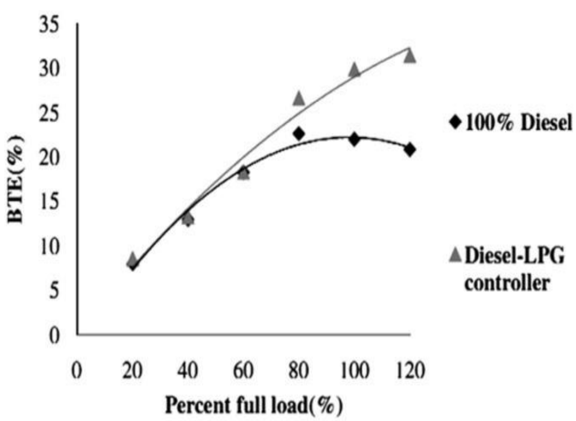


Fig. 10. *Brake thermal efficiency against load*

The variation of brake thermal efficiency against load is shown in Fig.10. The Dual fuel controller Diesel-LPG, assisted operation improved the efficiency by 31% on full load. Brake thermal efficiency ranges from 8% to 23% maximum on 80% load but in case of 100% diesel, it ranged from 8% to 32%.

- Nitrogen oxide emissions

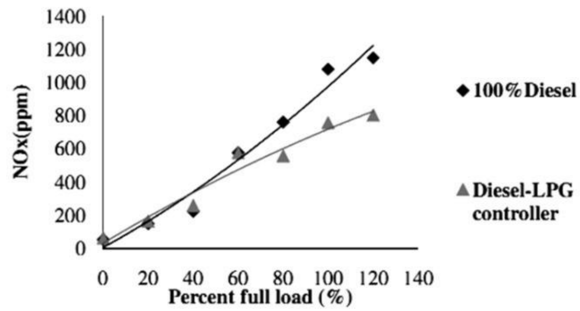


Fig. 11. *NO_x emissions*

Figure 11 illustrates the variation of NOx emission with load. With Dual fuel Diesel-LPG controller there was a reduction in NOx emissions at higher load. Compared to 100% Diesel, the reduction in NOx emission observed on 60% to 100% load was 26% to 30%.

- Smoke Emissions

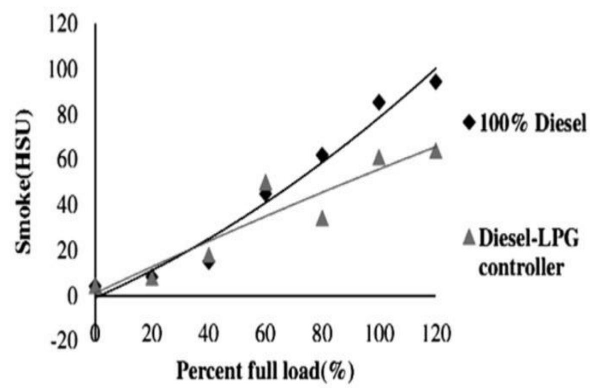


Fig. 12. *Smoke Emissions*

Variation of the smoke emission against load is shown in figure.13. Smoke emissions on 100% Diesel were high and were found nearly 95 HSU but when the engine was made to run using Dual fuel Diesel - LPG controller emissions dropped o 60 HSU on full load.

4. CONCLUSION

The article "Study the effect of LPG injection control parameters on the performance and emission of Diesel engine run with dual fuel (Diesel - LPG)" has obtained the results:

The article tested, evaluated parameters such as: brake specific fuel consumption, brake thermal efficient and emissions (smoke emissions, NOx…) with all the other Diesel–LPG modes i.e. (84%-16%), (76%-24%), (68%-32%), (60%-40%), (52%-48%).

Succeeded in converting a Diesel 3C-TE which can be made to run on Dual fuel with LPG and Diesel without any modifications ine design.

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