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NGUYEN VAN PHUNG

CONTRIBUTION TO RESEARCH INTO USING LPG ON THE COMPRESSION IGNITION ENGINE

Major Field: **HEAT ENGINE ENGINEERING**
Code: **62. 52. 34. 01**

DOCTORAL THESIS ABSTRACT

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This thesis has been completed at the University of Danang.

First Advisor: **Assoc. Prof. Dr. Tran Van Nam**

Second Advisor: **Assoc. Prof. Dr. Tran Thanh Hai Tung**

Approved by:

First Reader: : **Assoc. Prof. Dr. Nguyen Hoang Vu**

Second Reader: : **Assoc. Prof. Dr. Le Anh Tuan**

Third Reader: **Dr. Nhan Hong Quang**

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INTRODUCTION

I/ MAIN REASONS FOR CHOOSING THE RESEARCH TOPIC

1.1 Importance of the research topic

Currently, in the underdeveloped countries and especially in Vietnam, the traditional diesel engines (called compression ignition engines) are quite common in transportation field. The level of pollution emissions has far exceeded their permitted limits. Thus, in order to improve efficiency and reduce environmental pollution, researchers have applied the common rail fuel injection system solutions in reducing pollution emissions on exhaust manifold; but engine price is higher, it’s difficult to compete with gasoline engines. So we need to find another solution to using LPG in this diesel engine. One of the interesting measures is research into converting diesel engines to using LPG in the transportation. This is an effective and indispensable solution to reduce environmental pollution in urban and densely populated areas. In addition to the environmentally friendly advantages, LPG fuel is safe, cheap and convenient in the fuel conversion systems for automobiles; however, due to the occurence of knock phenomena, LPG has not been widely used in diesel engines. Vietnam is developing with the goal of becoming an industrialized country in 2020. During the period of socio-economic development, transportation is an important industry in which automotive branch plays a major role in the development of the industry.

Therefore, the research of applying LPG into the compression combustion engine is not only important for the development of automotive industry but also urgent and necessary for social life in our modern country and in the world.

1.2 The scientific and practical meanings of the topic

- The automotive industry of Vietnam is developing rapidly; it thus requires more specialized applied studies to support this process. The investigation into the combustion model with dual fuel LPG-diesel in the separated combustion chamber by means of the ANSYS Fluent software is capable of providing rapid and accurate calculation saving much time and money for experimental activities.

- There are great reserves of the LPG fuel source in Vietnam and over the world using of LPG fuel will diversify the fuel for more cars and it can easily meet the strict standards of the Environmental Laws.

- In many countries all over the world, cars utilizing diesel engine are still more common. It is necessary to study how to use LPG-diesel fuel and to find the solution to overcome the knocking of LPG-diesel engines.

- The WL-Turbo engine has been tested on a dynamometer APA 204/8 and the AVL instrumentations. The system providing LPG-diesel and limiting knocks has been controlled by the ATmega32 microcontroller, sensors (LPG flow sensor, coil controlling injected LPG, inlet air flow, knock, location accelerator pedal, LPG concentration sensor) and the actuators. It is necessary to control LPG injecting flow and to regulate the air throughout the intake manifold, the diesel fuel and to adjust EGR valve.

According to the Ministry of Education and Training of Vietnam, no previous study on the model of mixed combustion of LPG-air on diesel engines has been assessed. Therefore, the investigation into using LPG on compression combustion engine has scientific and practical significance.

II/ RESEARCH PURPOSES

Research into utilizing LPG in traditional diesel engines in order to minimize environmental pollution as well as restriction of engine knocking when working in frequent load modes (low load, average load) contributing to the diversification of fuel sources for automotive engines.

III/ RESEARCH OBJECTIVES AND LIMITATION

The engines have been selected for experimental studies in this work were the WL-Turbo engine installed on Mazda 2500 truck, Ford Ranger pickup and 1KZ-TE engine installed on Toyota Hilux cars.

IV/ RESEARCH METHODOLOGY AND EQUIPMENT

Research methodology combines theoretical research, simulating methods and experimental study.

V/ THESIS STRUCTURE

Structure of the thesis consists of an introduction, conclusion and five chapters, namely:

Chapter 1: Overview Research

Chapter 2: Theoretical Research

Chapter 3: Simulation Research

Chapter 4: Experimental design and arrangement

Chapter 5: Experimental results and discussions

In summary, the research into the compression ignition engines using LPG-diesel can contribute to reducing environmental pollution, diversify energy resources, and facilitate exploiting oil-gas technology development.

Chapter 1

OVERVIEW RESEARCH

1.1. Overview

1.1.1. Environment and transportation

1.1.2. Alternative fuels used in means of transportation

1.1.3. The compression ignition engine using LPG-diesel

High compression ratio diesel engines have been in use since 1892. The structure of dual fuel engine is the same as a compression combustion one, but using two kinds of co-combustion fuel. Power is created thanks to the main fuel. But the pilot flame of diesel spraying burnt LPG instead of the spark plug flame.

In combustion process the chemical reaction of blending fuel-air mixture and the part of pilot fuel can occur. The phenomenon of rapid release of the chemical energy of gasous fuel in the engine combustion chamber spreads considerably the fire membrane. Resonance between this wave and the pressuring wave speeding on the surface of the combustion chamber will damage to the engine structure and cause a metal knock, known as knocking phenomena.

The advantages of the dual fuel engine are increasingly engine productivity and make combustion mixture before mixing occur faster than an engine run fully by diesel. However, the disadvantages of the dual fuel engine are that the knocking phenomena often occur when the engine operates in the load or high engine speed.

There are two methods converting diesel engines using LPG-diesel:

① Using a spark plug to burn LPG-air mixture provided on the intake manifold; compression ratio needed to diminish and fit to ignition system to replace the high pressure pump and diesel injector.

② Using a pilot diesel fuel pray ignites the LPG-air mixture entered the intake manifold of the engine.

1.2. Status of research into dual fuel LPG-diesel engines in the world and in Vietnam

1.2.1. Studies on engine used LPG-diesel inthe world

1.2.2. Studies on engine used LPG-diesel in Vietnam

1.2.3. The issues need further study

In general, the work of dual fuel engines has been studied in many different directions: research into fabricated fuel supply system using Venturi throat, study on providing LPG-diesel with electronic control, applied research into exhaust gas recirculation, and investigate into model combustion. However, research LPG-diesel mixture combustion on the engine with high compression ratio and experimental models to date is new. The focus of this thesis is the investigation into engine using LPG-diesel on separated combustion chamber of tourism cars by models and experimental research.

1.3. Conclusions

The higher socio-economic development is, the higher diversified transportation is; the more environmental pollution automobile exhaust causes; while the purity requirements of the growing environment are higher; therefore, investigation into the use of LPG combustion engine compression is topical, practical and contributes to reducing environmental pollution. When the compression ignition engine is using LPG, the biggest difficulty now is to limit the knock. So, in order to limit the knock, add an inert gas into the combustion chamber or to recirculate dirty gas mixture or to increase the rate of energy diesel/LPG.

Chapter 2

THE THEORETICAL BASIS OF COMPUTATION OF LPG-AIR MIXTURE COMBUSTION IN SEPERATED COMBUSTION CHAMBER

2.1. The theoretical basis of the combustion process in LPG-diesel dual fuel engine

2.1.1. Energy equation of the mixture of LPG-diesel

In Fluent, the energy equation of the mixture of LPG-diesel is converted from the transport equation:

$$\rho \times S_c = A \times G \times \rho_u \times I^{3/4}\left[U_L \times (\lambda_{lp})\right]^{1/2} \times \left[\alpha \times \left(\lambda_{lp}\right)\right] l_t^{3/4} \left|\nabla c\right|$$

Source of S_c determined by:

$$S_c = \frac{A \times G \times \rho_u}{\rho} \times I\left[\frac{\tau_t}{\tau_c \times \left(\lambda_{lp}\right)}\right]^{1/2} \left|\nabla c\right|$$

2.1.2. Determining the concentration of oxygen, the concentration of the fuel mixture in the separated combustion chamber

Combustion of LPG-diesel-air mixture is process occurring on physical and chemical reactions in the thin mobile membrane. They are influenced by both motion so the spread rate of the fire is determined by laminar flame speed and turbulence intensity. The turbulence increases the surface area of the fire membrane. It will increase the rate of fire consuming the fuel. Burning diesel fuel is characterized as diffused, troubled and unstable. Burning LPG fuel-air mixture in cylinder is characterized as homogeneous, troubled and unstable.

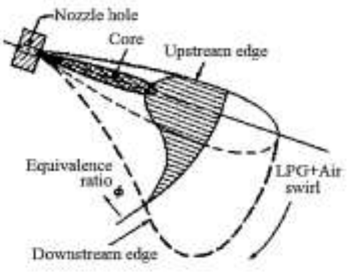

Figure 2.3: *Diagram mixed diesel pilot with LPG and air*

2.1.3. The fire membrane spreading in the LPG-diesel dual fuel combustion process

According to TRAN VAN NAM, The average speed of the combustion reaction in the engine cylinder is modeled by the following equation:

$$\frac{\partial}{\partial t}(\rho \times c) + \nabla(\rho \times \vec{v} \times c) = \nabla\left(\frac{\mu_t}{Sc_t} \times \nabla c\right) + \rho S_c$$

2.1.4. Turbulent speed of laminar flames

+ According to BUI VAN GA, laminar burning speed fuel depends on the fuel concentration, temperature and diffusion properties:

$$S_L = \frac{dm_b / dt}{A_f \times \rho_u}$$

Among them: dm_b/dt: rate of pressure increased in the combustion chamber; A_f: surface fire.

+ The mixture mixed by dirty fired gas, turbulent speed of laminar flames is proposed by TRAN VAN NAM as follows:

$$S_L = S_{L,0} \times \left(a_0 + a_1\phi + a_2\phi^2\right)\left[1 - \left(b_1 \times D + b_2 \times D^2 + b_3 \times D^3\right)\right]\left(\frac{T_u}{T_0}\right)^{\alpha} \times \left(\frac{P}{P_0}\right)^{\beta}$$

2.1.5. Turbulent burning speed

In Fluent, turbulent burning speed is determined:

$$S_t = A \times (u')^{3/4} \times S_L^{1/2} \times \alpha^{-1/4} \times l_t^{1/4} = A \times u' \times \left(\frac{\tau_t}{\tau_c}\right)^{1/4}$$

Where: S_t: disorder fire membrane speed; A: constant model, u': speedsquared deviation (m/s); $l_t = C_D$x (u ') 3/ε (m): disorder length scale (m); chemical time scale $\tau_c = \alpha/S^2_L$ (s); troubled time scale (s); $\tau_t = l_t/u$ ' ε_t: the disorder kinetic energy dissipation rate.

2.1.6. The burned temperature and the density of LPG

2.1.7. Physical and chemical characteristics and the combustion equation of LPG-diesel fuel

2.1.8. Determining of air/fuel ratio as the WL-Turbo engine using LPG-diesel

2.1.9. Some features of the work indicator of the engine using LPG-diesel fuel

2.2. Knocking when engine used LPG-diesel

2.2.1. Delayed burned time

SHIGA et al. set delay burned time equation:

$$\int_{t_{inj}}^{t_{ign}} \frac{dt}{t(p,T)} = \frac{1}{K_{inj}} \int_{t_{inj}}^{t_{ign}} \frac{dt}{[p(t)]^{-q} \exp[E/RT(t)]} = 1$$

Where: K = 2272; q = - 1,19; E/R = 4650

HEYWOOD J.B., KUBESH J. considered that delay burnt coefficient depends on the chemical energy release of gases, speed thermal energy loss occurring at the point of combustion reactions. Delay burnt coefficient k is set:

$$\tau = 17{,}68 \times \left(\frac{ON}{100}\right)^{3{,}402} \times p^{-1{,}7} \times \exp\left(\frac{3800}{T}\right)$$

With: *ON is the appropriate octane number of the fuel; A, B, n are fitted parameters that depend on the nature of the fuel.*

2.2.2. Factors affecting the limit of knocking in the LPG-diesel engine

- The affect of time and quantity of pilot diesel injection
- The affect of the rate of alternative fuel mixture
- The affect of speed mode of dual fuel engine

2.3. The factors affecting the pollution rate of engines using LPG

2.3.1. In case of a diesel engine using 100% diesel

2.3.2. In case of a dual fuel engine using LPG-diesel

2.4. Conclusion

Combustion of the LPG-diesel-air mixture inside the separated combustion chamber shows two phases: pilot diesel fuel combustion is characterized by diffused, trouble and unstable; LPG-air mixture burning in the separated combustion chamber is characterized as homogeneous, confusion and instability. EGR reduces combustion temperature which reduces NO_x concentration and it will limit knock when engine is using LPG-diesel.

Chapter 3

COMBUSTION MODELING AND DETERMINATION OF POLLUTION LEVELS OF DEVELOPMENT OF THE WL-TURBO ENGINE USED LPG-DIESEL

3.1. Introduction of the ANSYS – Fluent software

3.2. Establishing combustion process model mixed flow LPG-diesel

3.2.1. Geometric structure and mesh of combustion chamber of the WL-Turbo engine

Combustion chamber model, geometric structure and mesh of The WL-Turbo engine is presented in Figure 3.1.

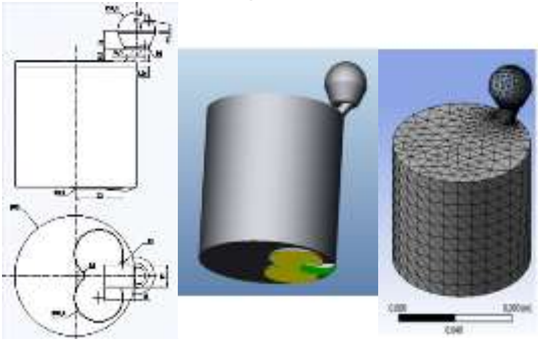

Figure 3.1: *Geometric structure and mesh of combustion chamber of the WL-Turbo engine*

3.2.2. The parameters of the model combustion chamber

3.2.3. The parameters of the fuel

3.3. Combustion evolution of LPG-diesel mixture is simulated by Fluent software

3.3.1. Combustion evolution of diesel fuel

The diesel fuel is injected; the particles of diesel fuel at the margin of injected jet are split and they hence swept by whirling forces and then overflow the main combustion chamber to be mixed with the flow of LPG-air, heated and then evaporated with the fuel mixture.

3.3.2. Combustion evolution of LPG

Figure 3.3 shows that propane and butane burnt intensely and ended at 45 °ATDC earlier combustion of diesel fuel.

3.3.3. Combustion evolution of the soot concentration, NO$_x$

Figure 3.4 shows that the soot and NO$_x$ concentrations began to create at near TDC (about 4 °ATDC) and to prolong the last combustion process. NO$_x$ concentrations increased in 35 °ATDC and then decreased rapidly.

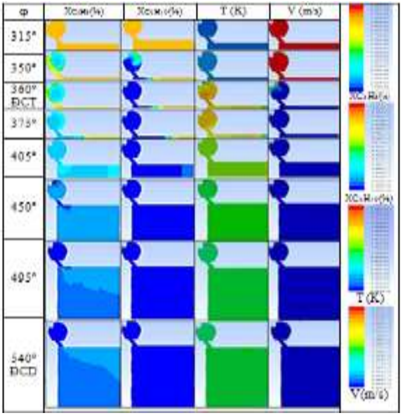

Figure 3.3: Movement of LPG concentration, temperature and air movement rate of flows in combustion chamber of the engine using LPG

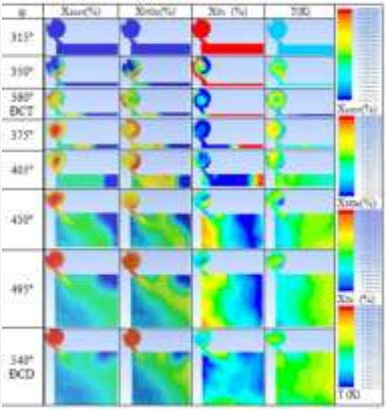

Figure 3.4: Evolution of the concentration of soot, NO$_x$, oxygen concentration and temperature of the engine using LPG

3.4. Factors affecting the technical features of the engine using LPG-diesel

3.4.1. Effect of CO$_2$ component in the mixture

When the CO$_2$ component was increasing in the mixture, the value of indicated pressure decreased. (Figure 3.5 and 3.6).

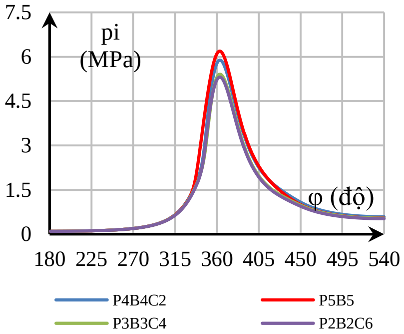

Figure 3.5: Evolution of the indicated pressure and component CO$_2$

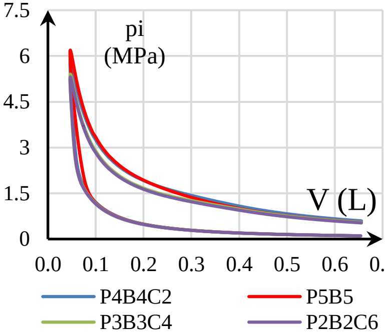

Figure 3.6: Variability of indicator CO$_2$ cycle by ingredient

3.4.2. Effect of residual air coefficient

Figure 3.15 and 3.16 show that when α = 1.2, the maximum value of the average fluid temperature in the combustion chamber is the biggest and the oxidant concentrations is decreased rapidly; therefore, fuel is stoichiometric combustion and power is maximum.

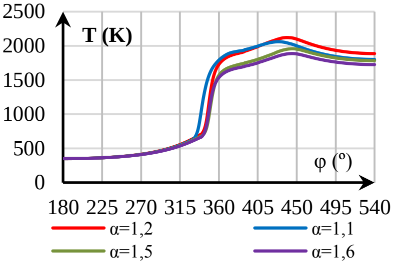

Figure 3.15 *: Influence coefficient α to the average temperature*

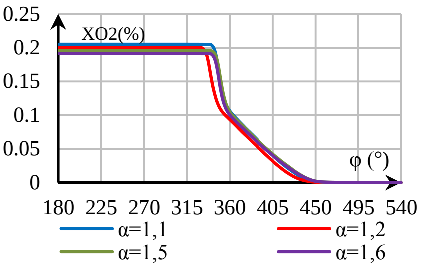

Figure 3.16: *Influence of coefficient α to oxidant concentrations*

3.4.3. Effect of the engine speed

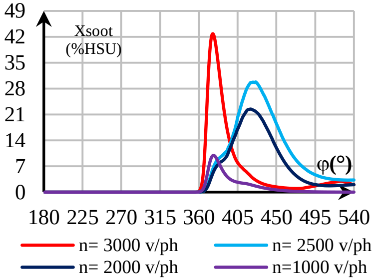

Figure 3.27*: Effect of the speed to the soot concentration*

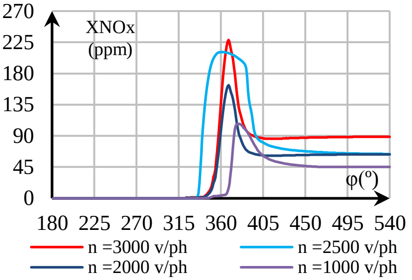

Figure 3.28*: Effect of the speed of the NOx concentration*

3.4.4. Effect of pilot diesel fuel

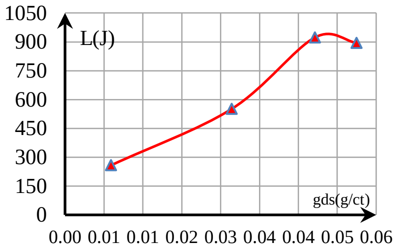

Figure 3.33: *Influence of pilot diesel flow to the indicated cycle*

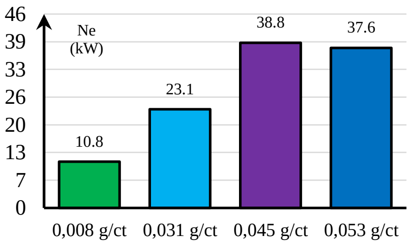

Figure 3.34: *Effect of pilot diesel flow on the engine power*

3.4.5. Influence of knocks

When knocks occur, the average indicated pressure and the average temperature of fluid increase to many times higher compared with normal engine operation. Therefore, need to apply knocking limitation solution (Figure 3.37 and 3.38).

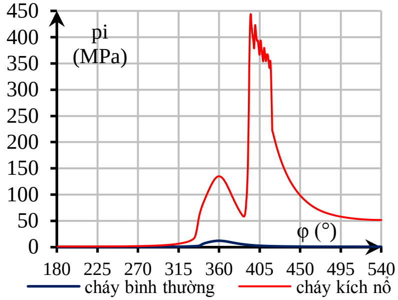

Figure 3.35: *Pressure indicator when the engine knocks*

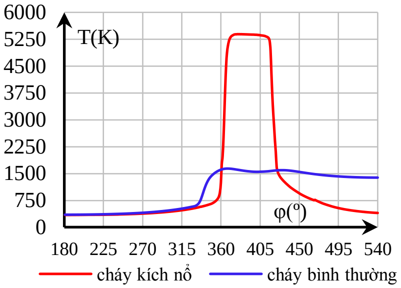

Figure 3.36: *Average temperature when the engine knocks*

3.5.Conclusion

LPG-air mixture combustion model has been established based on FLUENT software gathered reliable results and allowed the experiment orientations the following:

- At engine speed 2000 rpm, when the amount of pilot diesel increased with g_{cyc} = 0.045 g/cycle, the engine power is Ne_{max} = 38.8 kW. Therefore, the amount of diesel fuel is efficiently provided $g_{cyc} \leq$ 0.045 g/cycle.

- When the coefficient α is 1.2, the maximum power is 46.6 kW. Therefore, the coefficient α is (1.2÷1.6).

- When the CO_2 component increased, knock will become more and more limited, but the power of engine will decrease compared to original version.

- When the engine speed increases, engine power will increase and reache a maximum value 43 kW at 2500 rpm. So, the engine works efficiently at speed range n = (1000 ÷ 2500) rpm.

Chapter 4

EXPERIMENTAL DESIGN AND ARRANGEMENT

Experimental research has practical significance to evaluate the correctness of the theoretical research.

4.1. Experimental objectives, conditions, methods and content

4.2. Test Design

4.2.1. Experimental layout for WL-Turbo and 1KZ-TE Engines

The experiments carry out on the WL-Turbo engine using LPG-diesel to compare the performance, energy consumption and pollutant emissions of the engine when applying the test technical solutions, and evaluate the possibility of overcoming the knocking phenomenon as well as the ability to implement these solutions.

4.2.2. Introduction of the experimental engine

The technical specifications of the experimental WL-Turbo and 1KZ-TE engines are shown in Table 4.1

Table 4.1: *The technical specifications of the WL-Turbo and 1KZ-TE engines*

No	Technical specifications	WL-Turbo	1KZ-TE
1	Max power (kW/rpm)	85/3500	96/3600
2	Max torque (Nm/rpm)	280/2000	287/2000
3	Norm speed (rpm)	3500	3600
4	Compression ratio	19,8:1	21,2:1
5	Displacement (cm^3)	2499	2982
6	Bore/Stroke (mm)	93/92	96/103
7	Cylinder	4	4
8	Diesel injection pressure (MN/cm^2)	11,6÷12,4	12,5÷13,4
9	Advanced injection angle (˚ATDC)	10	11

The WL-Turbo experiment engine using LPG-diesel carries out on the dynamometer APA 204/8 in order to assess the ability of the implemented solutions to overcome the phenomenon of engine knock through experimental economic-engineering targets and pollution emissions of the engine. Experimental organizing the 1KZ-TE engine is to determine non-knocking region and relationship with CO_2 flows and LPG flows when this engine uses LPG-diesel.

4.3. AVL measuring instruments used in the experiments

Measuring instruments include power dynamometer APA 204/8, AVL 553 Coolant conditioning system, AVL 554 Oil Conditioning System, AVL 442 blow by meter, AVL DiGas 4000, AVL 439 Opacimeter, and AVL 513 video-scope. Most of the measuring equipments are produced by Austria.

4.4. LPG supply and exhaust gas recirculation equipments used in the experiment

4.4.1. The LPG vaporator

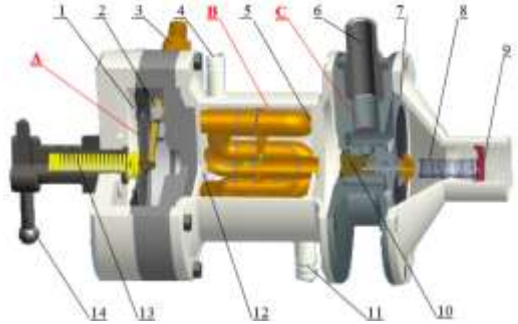

Figure 4.4*: The LPG vapor-reduction*

1. Pressure reduction Rubber membrane ; 2.Liquid LPG valve; 3. LPG liquid connector; 4. Water connecto;r 5. LPG copper tube heat transfer; 6. low pressure LPG gas connector; 7. pressure reduction rubber membrane; 8. LPG gas pressure regulator spring; 9. LPG gas pressure regulator screw; 10. Low pressure LPG gas valve; 11. Water connector; 12. heat water chamber; 13.Adjustable pressure liquid LPG spring; 14. Liquid LPG pressure regulating rod

The two-phase liquid-gas of LPG receives heat transferred from the water of 65°C and becomes vaporization. LPG gas continues through the pressure reduced valve 10 through a low pressure chamber. Low pressure LPG gas before the nozzle can be adjusted by screws 9 and springs 8 ensuring the working mode of the engine as in Figure 4.4. When engine works at high loads, cylinder pressure increases, combustion air temperature increases because specific heat of mixture is high; therefore, it is necessary to be cooled recirculation exhaust gas before circulating to intake manifold.

4.4.2. LPG nozzle

Figure 4.7 shows LPG nozzle injecting into the intake manifold of LPG gas engine, which replaces Venturi throat.

Figure 4 .7: *The parts of a LPG nozzle and injection combination*

4.4.3. Exhaust gas recirculation valve

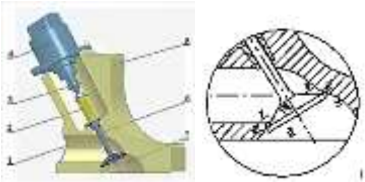

Figure 4.8*: Structure of EGR valve*

1.The emissions from cooling cluster; 2. Position Spring; 3. Stepper motor; 4. Stepper motors; 5. Valve body; 6. Valve fastener; 7. Emissions from the valve.

4.4.4. The exhaust gas recirculation cooler

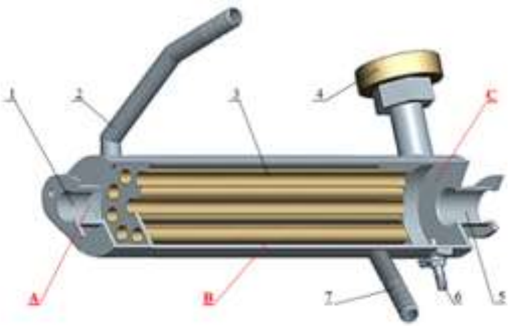

Figure 4.9*: Structure of the exhaust gas recirculation cooler*

1.Exhaust gas inlet cluster; 2. Water outlet pipe; 3. Copper pipes heat transfer between the gas and water; 4. Exhaust gas thermometer; 5. Emissions from cooling cluster; 6. Pressure sensor fittings; 7. Water inlet pipe. A. Gas chamber at high temperature; B. LPG vaporization chamber; C. LPG vaporized chamber at temperatures approximately ambient temperature.

4.5. LPG-diesel injection and exhaust gas recirculation controller

4.5.1. The principle of the regulator's operation

4.5.2. The sensors using in the regulator

4.5.3. The actuators using in the regulator

4.5.4. Electronic circuit control board adjusting LPG-diesel and exhaust gas recirculation

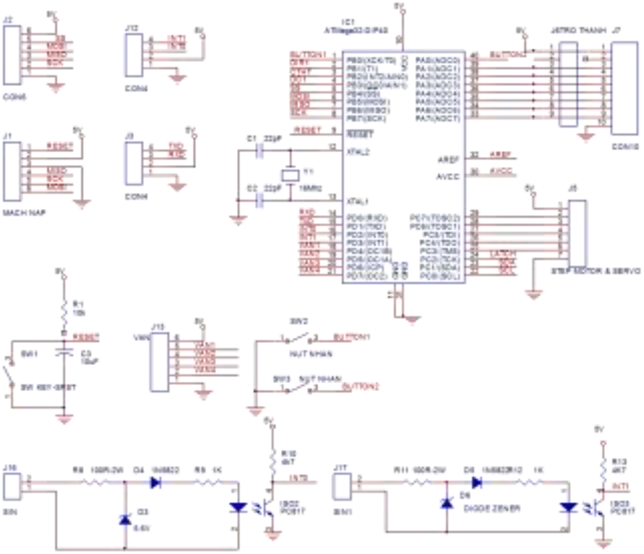

***Figure 4.31**: Electronic circuit control board adjusting LPG-diesel and circulation exhaust gas*

4.6. Conclusion

The equipment made cooling circulated exhaust gas is capable of lowering the temperature from 480 °C down (30 ÷ 45) °C without affecting the operating condition of the engine. LPG vaporizer-reducer has capabilities to supply enough LPG energy (15 ÷ 18) kg/h satisfying all experiment mode of the engine with an power of 100 kW. The ATmega32 processor electronic controller allows automatically adjusting the level of LPG flows, CO_2 flows and overcoming the knock of WL - Turbo engine.

Chapter 5

EXPERIMENTAL RESULTS AND DISCUSSIONS

This chapter presents the results of experiments done on the 1KZ-TE engine, and the WL-Turbo engine using LPG-diesel at idle and low load (Me ≤ 90 Nm) and average load (Me ≤ 150 Nm); simultaneously evaluated by experimental results and compared with the simulation of the WL-Turbo engine used LPG-diesel at an average load mode.

5.1. The experimental results

5.1.1. Scope of regular work of automotive engines using 100% diesel

Figure 5.2 shows that the curves of power and torque varying diesel fuel flow in low load mode with g_{cycle} = (0.043 ÷ 0.098) g/cycle. At that Ne_{max} = 14.7 kW, applying solutions to limit knocking, the rate of LPG alternative energy X_{nal} % = 9.9 %

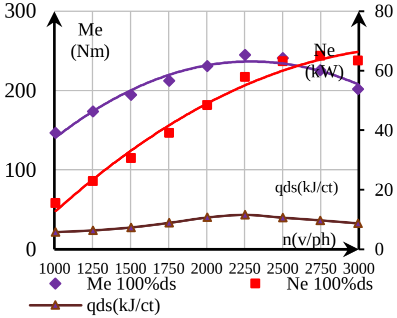

Figure 5.1*: Characteristics of the WL-Turbo engine using 100 % diesel measured on a dynamometer*

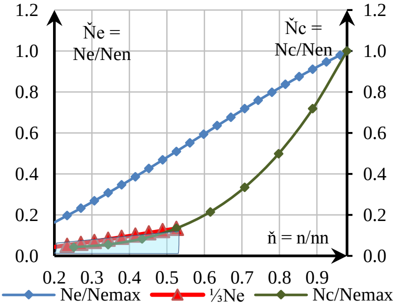

Figure 5.2*: Scope of regular work travel automotive engines using 100 % diesel*

5.1.2. Operation at an idle load mode (The experiment 1KZ-TE engine uses LPG-diesel (CO_2 is added)

The purpose of this experiment is to determine range of non-knocking when increased CO_2 levels according to the amount of LPG into the 1KZ-TE engine. Figure 5.8 shows the upper limit value of LPG and the lower limit of CO_2 measured according to the engine speed that the engine does not knock. Figure 5.9 shows that the engine is not knocked when related equation between the CO_2 flow rate with the LPG is $g_{CO2} = 0.493 x g_{LPG} + 0.0041$.

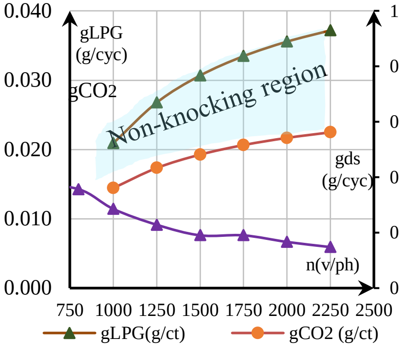

Figure 5.8: Non-knocking region when the 1KZ-TE engine using LPG-diesel, added to CO_2

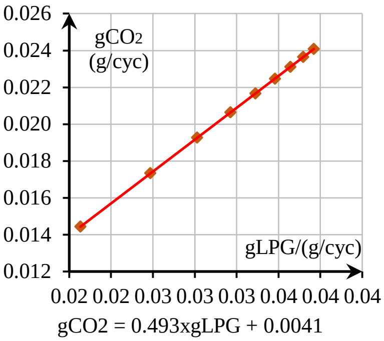

Figure 5.9: Variation of CO_2 flow depend on the LPG fuel

5.1.3. Operation at low load modes (the experiment WL-Turbo engine uses LPG-diesel when applying these solutions reducing knock)

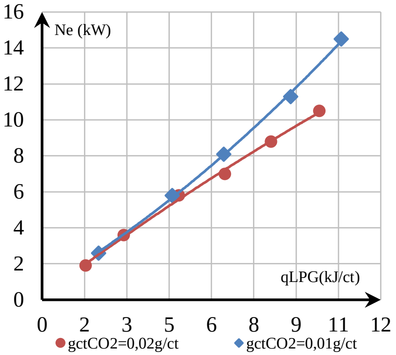

Figure 5.14: Power and torque increases according the amount of CO_2

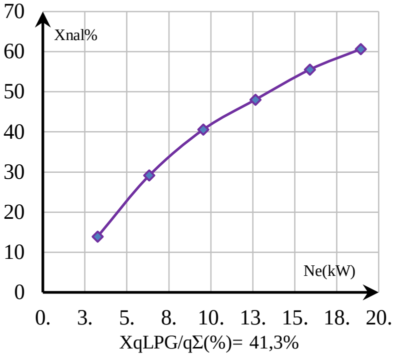

Figure 5.15: Percentage of alternative energy LPG (LPG + diesel) at lower load

Due to the phenomenon of knocking, the engine only works in the range of torque ≤ 75 Nm and n ≤ 1750 rpm; therefore, in order to increase the engine power we can increase pilot diesel fuel. The percentage of LPG fuel energy replacing diesel fuel when supplying more CO_2 at a low load mode (Table 5.2).

Table 5.2: Percentage of LPG fuel energy replacing diesel fuel

Torque (Nm)	15	30	45	60	75	90	ΣX%
X%	13.9	29.1	40.6	48.1	55.5	60.6	41.3

When knock occurs, the energy ratio of LPG flow replaces diesel fuel is very low (X_{CCE}= 10 %). When CO_2 is added, the energy ratio of LPG/diesel will be increased to 41.3 %.

Figure 5.26 and 5.27 show at a lower load, if the LPG energy increases to the value q_{LPG} = 9.83 kJ/cycle, the highest power is 11.9 kW (up 0.8 % compared to engine using 100 % diesel) and the highest power (applying an increasing pilot diesel solution) is 17.7 kW.

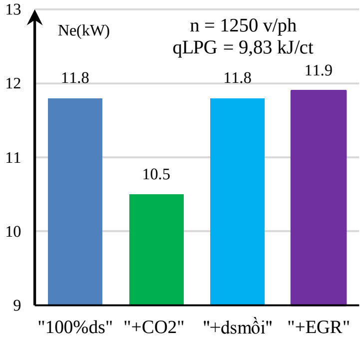

Figure 5.26: *Engine power according solution to limit knockings, at 1250 rpm*

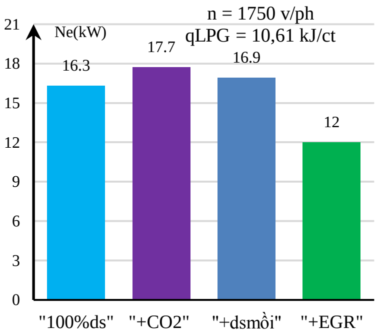

Figure 5.27: *Engine power according solution to limit knockings, at 1750 rpm*

When the engine speed is at 1250 rpm, NO_x concentration is 91.5 % (applying EGR) and NO_x one is 84 % (applying CO_2). When the engine speed is at 1750 rpm, NO_x concentration is 87 % (12 % EGR); NO_x concentration reduces 84 % (applying CO_2) and decreases by 28.7 % (applying to increase pilot diesel fuel).

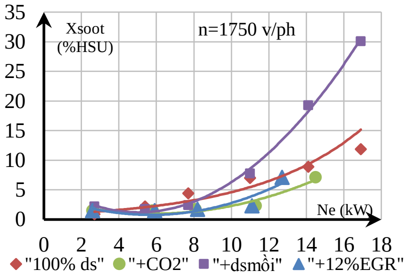

Figure 5.30: *Soot concentrations according to engine power when limited knock at 1750 rpm*

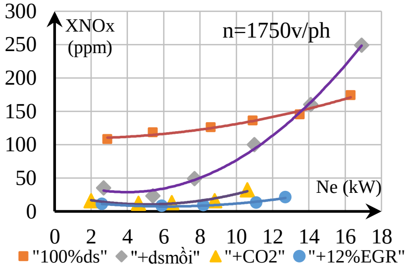

Figure 5.31: *NOx concentration according to engine power when limited knock at 1750 rpm*

By considering both soot and NO_x concentrations, in order to minimize the environmental pollution, the exhaust gas recirculation is the most effective solution for the WL-Turbo engine running LPG-diesel.

5.1.4. Operation at low load modes (The WL-Turbo engine uses LPG-diesel as advance injecting angle is adjusted)

Figure 5.38 and 5.39 show in case of n = 1750 rpm when diesel fuel flow is $g_{cycle} \approx 0.043$ g/cycle; the advance injection angle changes, soot concentration reduces at advance injection angle (6 ÷ 13) °BTDC and increases at advance injection angle (14 ÷ 18) °BTDC. The smallest soot concentration is at 13°30’ BTDC. In this experiment, the power and torque values reach to greatest values; the fuel consumption rate is the lowest, especially the soot concentration is the smallest at the optimal advance injection angle is 13°30'.

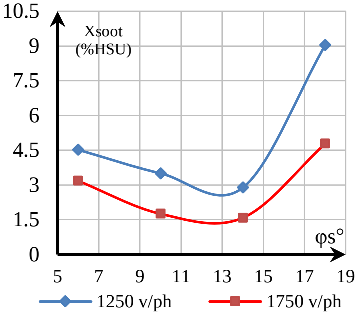

Figure 5.38: Soot concentrations according advance injection angle adjusted in n = 1250 rpm and n = 1750 rpm

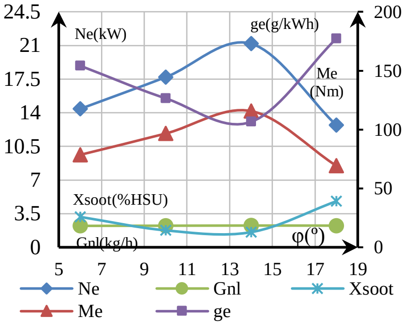

Figure 5.39: *Features adjusted advance injection angle*

5.1.5. Operation at average load modes (the experiment WL-Turbo engine using LPG-diesel CO_2 supplementation)

5.1.6. Co-ordinated experiments with different solutions limiting knock

5.2. Evaluation results for the WL-Turbo engine used LPG-diesel by simulation and experiment

5.2.1. Indicated pressure of the WL-Turbo engine using LPG-diesel at an average load mode

5.2.2. In terms of power and torque of the WL-Turbo engine using LPG-diesel at an average load mode

The graph of indicated pressure inside the cylinder shows that adding the pilot diesel quantity g_{ds} = 0.017 g/cycle and g_{LPG} = 0.036 g/cycle, g_{CO2} = 0.022 g/cycle is consistent with the theory and the error is 0.15 % from experiments (Figure 5.46).

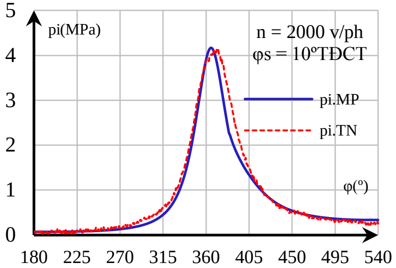

***Figure 5.46**: The Indicated pressure of WL-Turbo engine using LPG-diesel, in simulation and experiment*

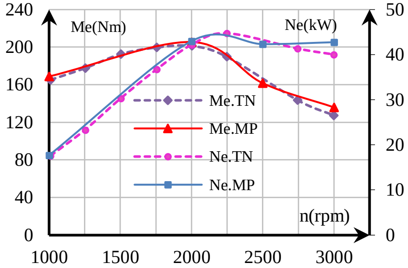

***Figure 5.48**: The power and torque of the WL-turbo engine by simulation and experiment*

5.2.3 . Comparison of soot and NO_x concentrations in the simulation and the WL-Turbo engine using LPG-diesel at average load mode

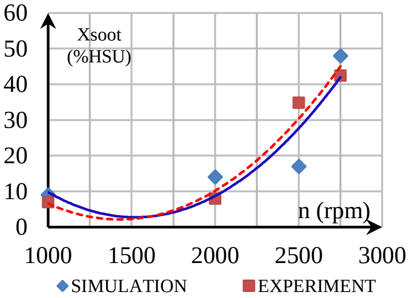

***Figure 5:49:** Soot concentrations of engines, LPG / diesel (addition CO_2) in simulation and experiment*

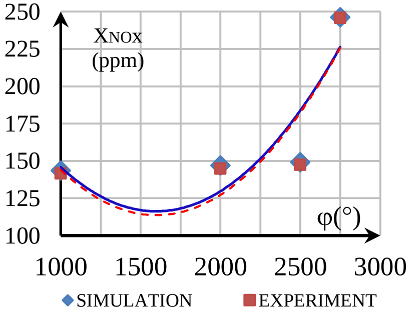

***Figure 5.50:** NOx concentration of engine using LPG-diesel (addition CO_2) in simulation and experiment*

5.3. Conclusion

The results of simulation calculation indicate that the error is less than 8 % in all cases. The simulation method is confirmed effectively and the ANSYS Fluent soltware provided has reliable results.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The study on applying the engine on cars using dual fuel LPG-diesel is to serve two urgent problems in Vietnam and all over the world: pollution restrictions, and energy security. Solutions to convert the traditional diesel engine into the one using LPG-diesel allow taking the advantage of high efficiency, ability to create large power. Furthermore, this application can reduce environmental pollution. Because the engine structure is not changed, it is convenient to use orginal diesel fuel system.

The methodology which combines the simulation of combustion process of the compression-ignition engine with Ricardo pre-chamber (swirling flow) bases on Fluent soltware and the WL-Turbo engine carried out on power dynamometer APA 204/8 is the optimal resolution in technical field. When the model is correct, we can predict the working features and pollution levels of exhaust emission of engine in different working conditions without experiments. This model can be used to establish numerical model of combustion process of a similar dual fuel engine.

In this thesis, we successfully designed and fabricated the automatic control system which is used to provide LPG and level of exhaust emission recirculation. This system used the micro-controller chip ATmega32 and sensors integrated on engine to control the LPG-air mixture with ideal ratio as well as to control the volume of diesel spraying into the WL-Turbo engine. During process of implementing experiment, operators such as LPG vaporizer-reducer with allowable pressure (0.1÷0.5) MPa, LPG nozzle, EGR cooler and adjusting valve of exhaust gas recirculation level were designed and fabricated. Thanks to modern measurement devices, the experimental results are reliable.

From results in this thesis, we can take out some conclusions:

1. The WL-Turbo engine and the 1KZ-TE engine using LPG-diesel are fully capable of performing the limited knock application solutions and components of harmful emissions are improved. Specifically:

a. At average load mode, when the WL-Turbo engine begins to knock, LPG energy ratio in the combustion chamber is provided X_{nal} % = 40.9 %. Soot concentration levels decreased by 16.4 % and NO_x is by 48% and 11 % power reduction is compared to engines using 100 % diesel in the same operation mode.

b. At lower load mode, the emissions and engine powers increase compared with using 100 % diesel engines, while increasing the amount of pilot diesel fuel. Concentrations of soot, NOx and power are reduced when applied to other solutions.

+ When CO_2 added to the combustion chamber, the burnt rate reduces and knock limitation is 5.3%; the LPG-diesel engine power falls 9.8%, torque reduced compared with using 100% diesel engines, with the rate energy of LPG replaced diesel fuel is Xnal% = 41.3%.

+ When exhaust gas circulated at the intake manifold with 3 rates 5% EGR, 12% EGR and 20 % EGR, the concentration of soot of engines using LPG-diesel decreases by 13.9 % and NOx concentration decreased by 51 %. The temperature of solvent reduced at the time of ignition. The non knocking range of the WL-Turbo engine using LPG-diesel is extended from 1750 rpm to 2250 rpm; but power decreased to 13.7 %.

+ The optimal adjust spray angle is 13°30’ BTDC (increased 3°30' compared with the original spray angle) because of this position of spray angle the soot concentration is the lowest, the fuel consumption is the smallest and the engine power is the biggest when the WL-Turbo engine used LPG-diesel.

c. At the idle mode, the experiment determines the relation function of LPG and CO_2 flow, non-knocking in the combustion chamber of the 1KZ-TE engine are:

$$G_{CO_2} = 0{,}49 \times G_{LPG} + 0{,}004$$

At the same time, the range of operating speed extends of the 1KZ - TE engine is from 1500 rpm to 1750 rpm (added CO_2 solution) and from 1750 rpm to 3000 rpm (when combining two provided solutions: supplying CO_2 and increasing pilot diesel fuel)

2. The evaluation of the results the engine operated by simulation and experiment:

a. For the computational simulation result, the indicated pressure approximates to the combustion chamber pressure of the WL -Turbo engine using LPG-diesel in the same experimental conditions and deviations of 0.15 % in comparison with experiments.

b. Power and torque features of the engine in the simulation are consistent with theory. Deviations of power and torque approximate to 3 % when changing the composition of CO_2 or the engine speed compared with experiments.

c. The deviation of soot emission by simulation is 8 % and NOx deviation is 4% when engine speed is changed in compared with experiments.

3. In this thesis, the results of calculated simulation are relevant to the experimental and the theoretical datum. The simulation calculated deviation is less than 8 % in comparison with experiments in all cases; the research hence has confirmed the combustion mixture of LPG-diesel in the WL - Turbo engine with a separated combustion chamber based on Fluent software model is effective and capable of reliable provided data.

Recommendations for further research

A study on using the LPG spray-controlling system combining with exhaust gas circulation and changing pilot diesel fuel flow on another compression-ignition engine to evaluate economic-technical property and exhaust pollution levels of cars on the road.

THE AUTHOR'S WORKS HAVE BEEN PUBLISHED:

[1]. Nguyen Van Phung, Tran Thanh Hai Tung (2009), A study on the manufacture of an automatic adjustment for LPG supply by Venturi throat, Scientific research Theme of Danang University, code SĐH 09-01-04-NCS, Official Acceptance agreement Nov. 15th 2009.

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