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Spark ignition engine performance analysis of liquefied petroleum gas

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Abstract. Liquefied petroleum gas (LPG) consists of propane, propylene, butane and butylene. Currently propane is used as an alternative fuel to gasoline gas for internal combustion engine in vehicles. This is because the targets to achieve near zero emissions from ICE. But, there are the biggest challenges about the reduction of emissions of refining performance and fuel consumption. Thus, the analysis of engine performance of LPG in SI engine has been done. The purpose of this research paper is to analyse the engine performance of SI engine using LPG fuel instead of gasoline fuel by doing a simulation. This paper is based on the zero dimensional models with the single zone model approach. In order to develop a mathematical model, multiple heat transfer equations have been researched. In calculation performed at different engine speeds have been selected for each fuel to make comparisons from engine performance view. The simulation results will show the difference between the engine performance between gasoline and LPG such as brake power, brake torque and indicated specific fuel consumption. In conclusion, by doing a simulation analysis other parameters can be analysed and cut the costs.

Keywords. Liquefied Petroleum Gas (LPG); Spark Ignition (S1) engine; Alternative fuel; Engine performance

1. Introduction

The increase in energy usage has been the main catalyst for enhancing the quality of life and societies, from developing to well-developed countries. Currently the dependence for the non-renewable energy increase with the growth of demand globally. This includes the fossil fuel that has been used to generate industries and also for vehicle usage. The depletion of fossil fuel leads to the seeking of alternatives in order to sustain this energy from running out in the future. One of the alternatives taken is by changing the application of gasoline and diesel for internal combustion engine in a vehicle with other alternative fuel such as Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), and hydrogen.

LPG or Propane is one of the most widely used fuels for vehicle in the world, which make it the most popular alternative fuel globally. Since LPG contain lower carbon compared to gasoline, it produces almost zero emissions of particulate matter (PM) and lowered the amount of NOX emission [1]. The idea of near zero emissions from internal combustion engine likely becomes a realistically achievable target [2]. The countries that commonly use LPG are mostly in the European Union such as

Germany, Italy, Netherland and Poland and also some Asian Countries like Australia, Turkey, South Korea, Philippines and Hong Kong.

Currently vehicles move from different places by the energy generated in Internal Combustion Engine (ICE) mostly implied using the conventional four-stroke engine. This power generator transforms fuel mixture into energy by combustion process, which will be used for moving the vehicle. However, the internal process of energy changing will produce emissions that are harmful for the environment. Many studies have been made to minimize the emission as well as to maintain the performance and fuel consumption.

In this paper, spark ignition (SI) four-stroke single cylinder is used to analyse the performance of LPG as compared to Gasoline. A single-zone engine model is developed using MATLAB to study the engine performance. In advance, formulas and equations related to the study have been listed in order to develop the mathematical model. The output of the model will be generated by MATLAB, such as cylinder temperature, pressure, volume, heat transfer. The engine performance results also will be shown from MATLAB. These include power, torque, specific fuel consumption and heat transfer. The researcher can easily modify and enhance the routines for analysis by having the fundamental routines that available in MATLAB [3].

2. Methodology

2.1. Single zone thermodynamic model

The single zone model assumes that the engine is in a thermodynamic system. The energy conversion and heat transfer during the combustion process is obtained by applying the first law of thermodynamics to the system. The compositions and thermodynamic properties including temperature and pressure are spatial uniform and vary with time only in the whole cylinder [4]. The ideal gas law form for the single zone model is expressed as:

$$PV = mRT \tag{1}$$

The first law of thermodynamics is defined as:

$$\Delta U = Q - W \tag{2}$$

The conservation of energy equation is used for single zone modelling. Applying the thermodynamics expression, the detailed equation which consists of temperature, volume and pressure is stated as below:

$$\frac{dP}{d\theta} = \left(\frac{P}{T}\right)\frac{dT}{d\theta} - \left(\frac{P}{V}\right)\frac{dV}{d\theta} \tag{3}$$

2.2. Heat transfer

During the engine combustion, the heat transfer from the air fuel mixture to combustion chamber affect the production of emission and temperature change inside the cylinder. Surface area of the combustion chamber is analysed using the equation given below:

$$A = A_{ch} + A_p + \pi B(l_r + a - s) \tag{4}$$

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$$A = A_{ch} + A_p + \frac{\pi BL}{2}\left(R + 1 - \cos\theta - \left(R^2 - \sin^2\theta\right)^{\frac{1}{2}}\right) \quad (5)$$

In addition, to calculate the cylinder volume, V, at any crank angle is as given [5].

$$V = V_c + \left(\frac{\pi B^2}{4}\right)\left(l_r + a - s\right) \quad (6)$$

Overall, the heat transfer model is based on the Newton`s law of cooling and Woschni (1967) found the correlation between the convection heat transfer along with thermodynamics properties and certain geometry. The equations are as expressed [6].

$$\dot{Q}_{conv} = h_c A\Delta T = h_c A_s\left(T_s - T_w\right) \quad (7)$$

2.3. Combustion modelling

In this study, the analysis of combustion process was done by applying the Weibe`s equation in order to calculate the burned mass fraction. The burned mass of air fuel mixture is assumed to be proportional to the amount of energy released. When calculating the mass burned fraction, the heat release during the combustion process can be estimated. The Weibe's equation can be expressed as in Equation 8 [7].

$$x_b(\theta) = 1 - \exp\left[-a\left(\frac{\theta - \theta_s}{\theta_d}\right)^{m+1}\right] \quad (8)$$

2.4. Chemical equilibrium

In order to evaluate the ratio of air-fuel and equivalence ratio, the balance stoichiometric combustion for LPG and gasoline reacts with air need to be carried out first [5].

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \quad (9)$$

The stoichiometric reaction of gasoline and air:

$$C_8H_{18} + 12.5O_2 + 47N_2 \rightarrow 8CO_2 + 9H_2O + 47N_2 \quad (10)$$

2.5. Friction of engine model

The engine performance was measured based on few indicators such as engine torque, power, specific fuel consumption, thermal efficiency, mean effective pressure and power output. In this study, the engine performance was analyzed for both LPG and Gasoline at the same engine speed.

Engine torque, which is defined as the force acting at the certain distance was expressed as below:

$$2\pi\tau = W_b = (bmep)V_d/n \quad (11)$$

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Meanwhile, the power is defined as the rate of work on the engine and commonly measured by horse power. The equation for calculating the power as given:

$$bp = bmep V_d \left(\frac{N}{2} \right) \tag{12}$$

The indicated mean effective pressure (imep) described as the uniform pressure that would be required throughout the power stroke of an engine to do some amount of work. It is done by varying pressures that are in fact obtained during the stroke. For computing imep, the equation as given in equation (13).

$$imep = \frac{ip\ n}{V_d N} \tag{13}$$

Specific fuel consumption is to measure the efficiency of fuel provided to the engine to generate power. A high sfc indicates that the fuel consumption is high. The indicated specific fuel consumption is calculated by the equation below:

$$isfc = \frac{\dot{m}_{fuel}}{ip} \tag{14}$$

3. Results and discussions

3.1. Cylinder pressure

Text The peak cylinder pressure of gasoline was recorded higher than LPG as shown in figure 1. The motion of the piston towards TDC causes the air fuel mixture to become compressed. When the spark ignition phase start and the combustion occur, the energy released generate pressure to the cylinder. Then, the pressure of cylinder drastically decreases as the product leaving the combustion cylinder through the exhaust pipe.

The higher pressure obtains by gasoline fuels compared to LPG is due to more air fuel mixture burnt and energy release causing the burnt mixture to expand. The slowly decrement of LPG at the end of the process is because of the residual particle remain inside the combustion cylinder.

3.2. Heat transfer

Based on the figure 2 shown above, LPG has a higher heat transfer compared to gasoline. At the beginning, the heat transfer was considered as non-exist since the combustion process is yet to occur.

During the pre-combustion, the more air fuel mixture was filled inside the combustion chamber. When the combustion occurs, the mixture burnt and more heat was released. After reaching the maximum limit of combustion, the heat slowly decreases. The heat transfer of LPG higher compared to gasoline since LPG needed more air fuel mixture during the combustion.

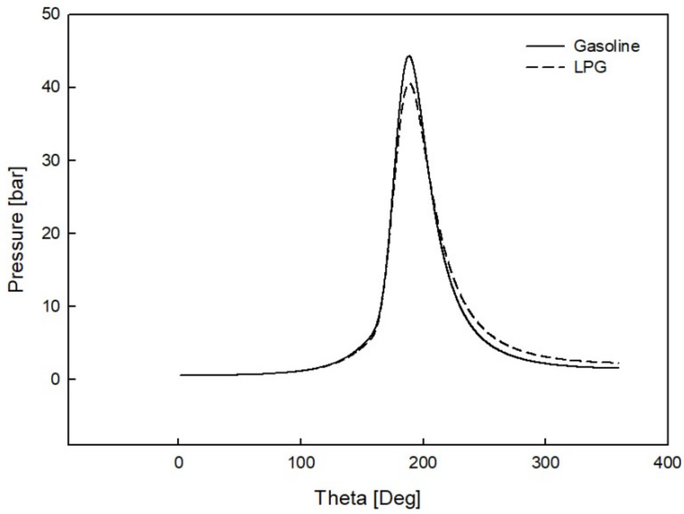

Figure 1. Cylinder pressure for gasoline and LPG fuels inside combustion cylinder.

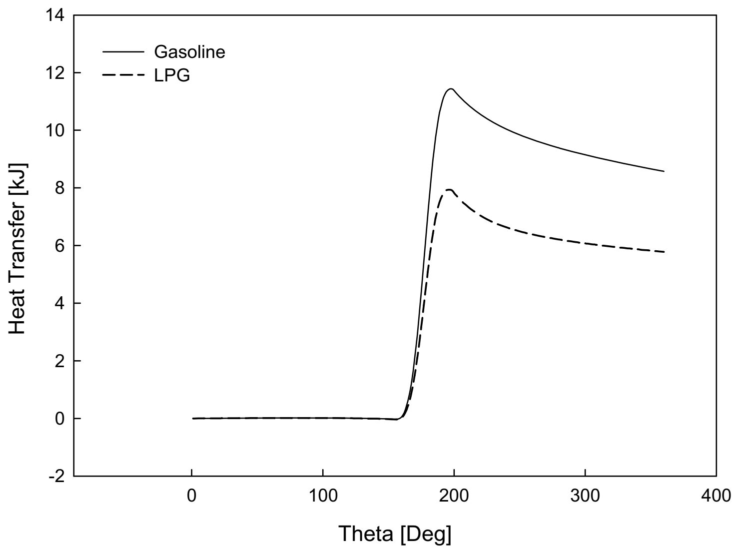

Figure 2. Heat transfer for gasoline and LPG fuels.

3.3. Mass fraction burned

Figure 3 shows the indicated mass fraction burned for gasoline and LPG fuels throughout the engine cycle. When using the LPG fuels for gasoline fuel engine, the combustion of LPG will occur earlier at 10 degrees crank angle different than gasoline. This is due to the higher flame speed of LPG.

For overall cycle, the mass burned fraction of both fuels was at similar percentage and the mixture for both fuels was completely burnt at the end of the combustion.

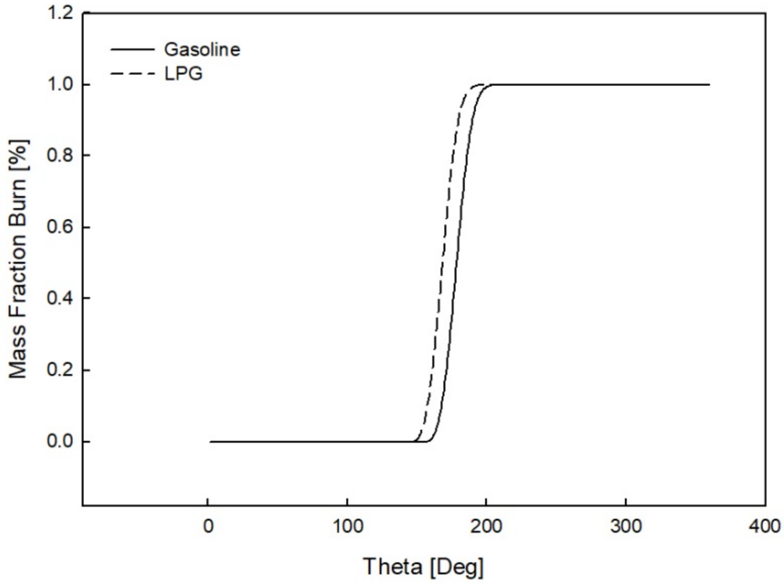

Figure 3. Mass burned fraction.

3.4. Power, torque and indicated specific fuel consumption (ISFC) at different engine speed for gasoline and LPG fuels

The effect of the brake power, torque and indicated specific fuel consumption at different speed of an engine for both gasoline and LPG fuel illustrated in Figure 4.

The brake power of the engine increase as the speed of the engine increase as well. Higher speed will have higher efficiencies of combustion, thus resulting higher energy release. Gasoline has higher energy released due to complete combustion than LPG. The engine used in this study is designed for gasoline. Hence, the gasoline has more advantage on the engine power compared to LPG fuels. Besides, the compression ratio of LPG is lower when using the gasoline designated engine.

Apart from that, brake torque also rises as the engine speed increase. As engine speed higher, the produced energy increase and more torque will be produced until reaching its maximum. Since gasoline produces more energy release from the combustion, the torque will be higher than LPG.

As the engine speed increase, the more air fuel mixture is needed to burn in the cylinder combustion. Because of more air fuel mixture needed to run the engine at higher speed, the indicated specific fuel consumption is diminished. A lean mixture of gasoline is having advantage of fuel consumption efficiency compared to a rich mixture of LPG.

4. Conclusions

The single zone model create using MATLAB was able to analyses the parameter of the engine cylinder as well as calculate the performance of the engine. In addition, the results obtained from the model were desirable and meets the exact condition and properties of both LPG and gasoline fuels. Besides, by doing simulation, a lot amount of time had been saved and also cut the cost.

From the data obtained, the difference of engine performance using these two fuels can be demonstrated using graphical approach. Overall, the gasoline has higher engine performance than LPG.

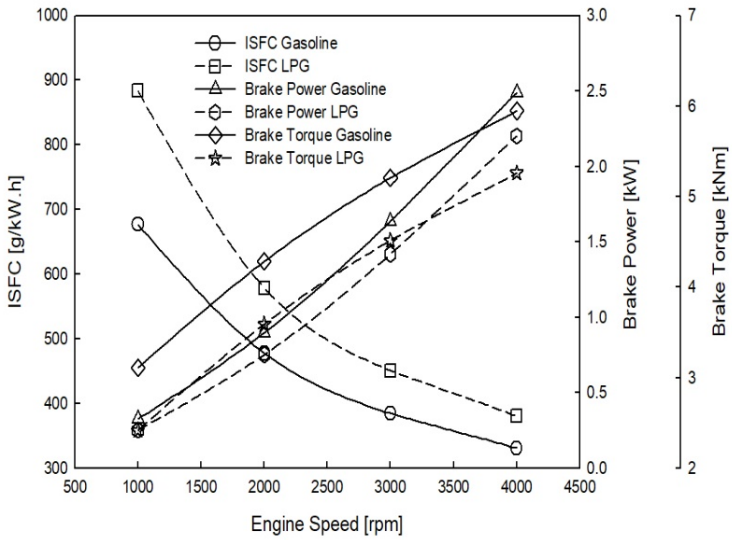

Figure 4. Power, torque and ISFC for gasoline and LPG fuels at different speed.

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