# INVESTIGATION ON THE PERFORMANCE GASOLINE BLENDED WITH HYDROGEN PEROXIDE AS FUEL FOR PETROL ENGINE

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**This report is submitted**
**In fulfillment of the requirement for the degree of**
**Bachelor of Mechanical Engineering (Automotive)**
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## DECLARATION

I declare that this project report entitled "Investigation On The Performance Gasoline Blended With Hydrogen Peroxide As Fuel For Petrol Engine" is the result of my own work except as cited in the references.

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**APPROVAL**

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive) with Honours.

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| Date | : | .................................... |

# DEDICATION

To my beloved mother, Puan Siti Hawa Binti Abdul Aziz

## ABSTRACT

This report represents an experimental investigation on the performance gasoline blended with hydrogen peroxide as fuel for petrol engine. The main objective of this investigation was to identify the effects of hydrogen peroxide on engine performance when blended with gasoline. Literature reviews showed that previous studies had demonstrated better engine performance parameters with hydrogen peroxide blend. Test fuels was set with 5% and 10% of hydrogen peroxide in the fuel blends. An experiment was done to identify those fuel blend's chemical properties. For engine performance testing, each test fuel was tested at various engine speeds and loads. Data from those experiments were analysed into engine performance parameters. Then, the results of hydrogen peroxide-gasoline blend was compared with gasoline alone in terms of combustion analysis and engine performance analysis. The results showed blending off hydrogen peroxide with gasoline did improved performance of the engine when compared to gasoline alone.

**ABSTRAK**

*Laporan ini mewakili peyiasatan ke atas prestasi petrol yang dicampur dengan hidrogen peroksida sebagai bahan bakar untuk enjin petrol. Objektif utama penyiasatan ini adalah untuk mengenal pasti kesan-kesan hidrogen peroksida pada prestasi enjin apabila dicampur dengan petrol. Kajian kesusasteraan menunjukkan bahawa kajian sebelum ini telah menunjukkan prestasi enjin yang lebih baik dengan campuran hidrogen peroksida. Bahan api ujikaji telah ditetapkan dengan 5% dan 10% kandungan hidrogen peroksida dalam campuran bahan api. Eksperimen dilakukan untuk mengenal pasti sifat-sifat kimia campuran bahan api tersebut. Untuk ujian prestasi enjin, setiap bahan api ujikaji diuji pada pelbagai kelajuan dan beban. Data-data dari eksperimen tersebut dianalisis ke dalam bentuk prestasi enjin. Kemudian, hasil analisis pembakaran dan analisis prestasi enjin untuk gabungan campuran hidrogen peroksida-petrol dibandingkan dengan petrol sahaja. Hasil dari pembandingan tersebut menunjukkan campuran hidrogen peroksida dengan petrol meningkatkan prestasi enjin berbanding dengan petrol sahaja.*

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I would like to thank my Faculty of Mechanical Engineering course mates for giving me their support, patience and encouragement. Finally, I would like to thank my family for their support.

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| | |
|---|---|
| TDC | Top Dead Centre |
| BDC | Bottom Dead Centre |
| DAQ | Data Acquisition System |
| MEP | Mean Effective Pressure |
| IMEP | Indicated Mean Effective Pressure |
| BMEP | Brake Mean Effective Pressure |
| ITE | Indicated Thermal Efficiency |
| SFC | Specific Fuel Consumption |
| ISFC | Indicated Specific Fuel Consumption |
| BSFC | Brake Specific Fuel Consumption |
| SOC | Start Of Combustion |
| $H_2O_2$ | Hydrogen Peroxide |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $\tau$ | = | Torque |
| $n$ | = | Number of revolution per cycle |
| $N$ | = | Engine speed |
| $m_a$ | = | Mass of air |
| $m_f$ | = | Mass of fuel |
| $Q_{in}$ | = | Heat energy input |
| $W_i$ | = | Indicated work per revolution cycle |
| $W_b$ | = | Brake work per revolution cycle |
| $\dot{W}_i$ | = | Indicated power |
| $\dot{W}_b$ | = | Brake power |
| $\eta_m$ | = | Mechanical efficiency |
| $\eta_{th}$ | = | Thermal efficiency |
| $\eta_{b.th}$ | = | Brake thermal efficiency |
| $\phi$ | = | Equivalence air-fuel ratio |
| $\eta_v$ | | Volumetric efficiency |
| $V_d$ | = | Displacement volume |
| $\rho_a$ | = | Air density |
| $A_p$ | = | Area of piston face |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Project

Decreasing supplies of fossil fuels and steadily rising concentrations of atmospheric carbon dioxide concentrations and levels of atmospheric pollutants are some of major challenges to the modern society (Kumar & Rao, 2013). An attempt to replace fossil fuels with cleaner and renewable sources of energy is proposed to overcome these problem. The biomass-based fuels were indicated to be the best option according to the conducted research because they do not require changes in the existing technologies in use. Probably then, the best alcohol that can be an alternative to petroleum is ethanol.



A study was done by Melo, et al (2012) and the main propose is to study combustion effects on existing internal combustion engines with no modifications to existing injection and ignition systems, when the engine is applied with various fuel mixtures including gasoline, ethanol, and oxy-hydrogen gas, stabilized hydrogen peroxide, and offer the optimal fuel mixture (Kumar & Rao, 2013).

Hydrogen peroxide-gasoline blended is now considered as the alternative fuel for internal combustion engine. Unfortunately, not many investigation has been carried out yet. Hydrogen peroxide is a strong oxidizing agent and a weak acid in water solution. Since it is an oxidizing agent, it oxygenates hence adds oxygen to the reaction when it burns (Brain, 2002). Although it does not boost the octane number of gasoline like MTBE did in the past, ideally hydrogen peroxide reduces the amount of unburned hydrocarbons and carbons monoxide in the exhaust. In case of performance, addition of oxygen will cause a leaner combustion and reduce the unburned hydrocarbon. This will affect the performance of engine.

Hydrogen peroxide is known as the simplest form of peroxide compound which consists of an oxygen-oxygen single bond. It is a colourless liquid with a sharp odour also a weak acid and strong oxidizing agent. The specific gravity of hydrogen peroxide is 1.135. Hydrogen peroxide is soluble in water and it is a polar solution. So it is slightly unstable and will decompose at a reasonably slow rate.

$$\mathbf{2\ H_2O_2 \longrightarrow 2\ H_2O + O_2}$$

During the decomposition of hydrogen peroxide, one volume of hydrogen peroxide is able to release 10 volumes of oxygen. Due to this characteristic, hydrogen peroxide is currently utilized as rocket propellant fuel.

A research was conducted and found that brake thermal efficiency, $\boldsymbol{\eta_{b.th}}$ of diesel engine increased when hydrogen peroxide is blended with the fuel. This lead to the finding that additional oxygen molecule released by hydrogen peroxide has led to better combustion (Nagaprasad & Madhu, 2012).

Before that, effects of alcohol-gasoline blends such as ethanol-gasoline blends on the performance engine have been investigated by many researchers. Palmer (1986) showed when 10% of ethanol with constant concentration is added to gasoline, the engine power improved by 5%. Next, Cowart et al. (1995) proved that the engine torque and power increased by 4% respectively when blended fuels were used. Al-Hasan (2003) found that by using ethanol as fuel additive to unleaded gasoline, engine performance can be boost. Also, increment by about 8.3%, 9.0%, 7% and 5.7% mean average values in brake power, brake thermal efficiency, volumetric efficiency and fuel consumption respectively was noticed. Then, he concluded that the best results of the engine performance is when 20% ethanol fuel blend was used.

Engine performance is evaluated by some parameters. The parameters are work done, torque, power, fuel consumption and engine efficiencies. Engine torque measured with dynamometer is known as brake torque, $\boldsymbol{\tau_b}$ while power delivered by the engine and absorbed by the dynamometer is known as brake power, $\dot{\mathbf{W}}_\mathbf{b}$. Brake mean effective pressure (BMEP) can be determine from dynamometer or water pump pressure. Fuel consumption is defined as the flow rate or mass flow of fuel per unit time while specific fuel consumption is the rate of fuel flow per unit power output. There are indicated specific fuel consumption (ISFC) and brake specific fuel consumption (BSFC). Then, the thermal efficiency, $\boldsymbol{\eta_{th}}$ of engine is the conversion of the heat energy stored in the liquid fuel into mechanical energy. While mechanical efficiency, $\boldsymbol{\eta_m}$ is the ratio of brake power, $\dot{\mathbf{W}}_\mathbf{b}$ delivered by the engine to the indicated power, $\dot{\mathbf{W}}_\mathbf{i}$ produced in cylinders (Pulkrabek, 2004).

Based on early literatures, the use of hydrogen peroxide-gasoline blended fuels is not very clearly whether it improved or unimproved the engine performance compared to gasoline alone. In this project, the performance of petrol engine using the hydrogen peroxide-gasoline blend will be investigated and the results will be compared when using gasoline alone.



## 1.2 Problem Statement

Everyday amount of gasoline is consumed in cars, light trucks, motorcycles, small aircraft, boats, watercraft, also in landscaping and construction equipment. Major problem with gasoline when it is burned, it produces substances like carbon monoxide, nitrogen oxides, unburned hydrocarbons and some particular matter. These substances contribute to air pollution.

On performance matters, usage of gasoline alone does not improve the engine performance. Alternative fuels beside are needed petroleum, so blending of gasoline with some additives like ethanol and methanol was discovered. These blend give a leaner combustion thus better performance and lesser fuel consumption. However currently, the new alternative fuel is begin to arise. It is hydrogen peroxide-gasoline blend.

Lately, consumers began to question if the hydrogen peroxide is the best blending with gasoline which could boost engine performance. Besides the price of hydrogen peroxide in the market is considerably expensive.

Hence, for this project, blending off hydrogen peroxide with gasoline as fuel for petrol engine with different percentage of hydrogen peroxide should be boosting the engine performance in order to overcome those problem.

## 1.3 Objective

The objectives of this project are as follows:

1. To study the effects of hydrogen peroxide on engine performance parameter.
2. To compare the results between hydrogen peroxide-gasoline blends with gasoline alone.
3. To study which blend percentage that give best performance to the engine.
4. To study the percentage of hydrogen peroxide for optimum performance.



## 1.4 Scope of Project

The scopes of this project are experimental data and analysed results such as calculations, table, graph and effects of different composition of blends on engine performance are presented in this report. The emission of engine at different blends is not covered.

## 1.5 General Methodology

Throughout this project, several of methodologies will be carried out in order to achieve those objectives. The first methodology will be literature review. Journals, articles, technical papers or any materials regarding this project need to be gathered as much as possible and then be reviewed. Outcomes from literature reviews will be a help regarding this project. As example, with the literature reviews, outcome of this project can be predicted before carrying out the experiment.

Experiments are the next methodology that will be carried out in this project. Several experiments like chemical properties determination and engine performance testing experiment will be carried out at the respective laboratories. For engine performance testing, the setup is shown in **Figure 1**. In order to study the effect of blending off hydrogen peroxide with gasoline to engine performance, the percentage of hydrogen peroxide in the fuel blend will be varied. Other parameters like engine specification, gasoline properties, air and fuel temperature will be constant in this project. Generator will be used to supply load. Experimental data will be collected through data acquisition system.

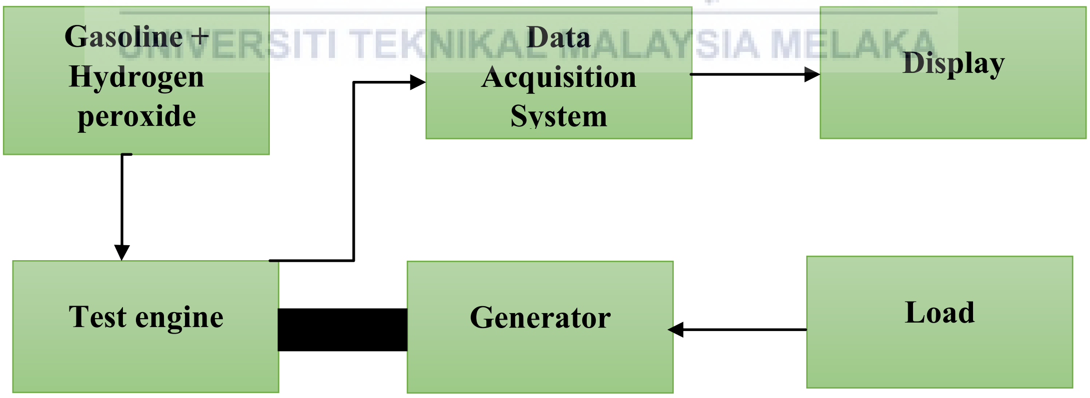


**Figure 1:** Schematic diagram of engine testing

Data analysis are the methodology that will be presented up after conducting the experiments. Based on each fuel blends tested on the engine, the raw data will be calculated, tabulated and analysed based on various performance parameters. Result at the end of the analysis will be concluded according to the objectives of this project.

Last but not least, the last methodology that will be report writing. A thesis, progress reports and draft reports on this project will be produced and submitted along the project's duration. Report writing is important such as progress report means to show and update project's progress while draft report is to ensure that the mistakes are corrected before submitting the thesis.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Theoretical Background

Conversion of chemical energy of a fuel into mechanical energy that took place in a heat engine is called internal combustion engine. The mechanical energy is then used to rotate a shaft. Combustion of air-fuel mixture within the engine which later converted chemical energy into thermal energy. Because of this thermal energy, the temperature and pressure of the gases are raise within the engine, and the high pressure gas expands against the mechanical mechanism of the engine. This expansion later is transmitted into the mechanical linkages of the engine to the rotating crankshaft, which is the output of the engine. Transmission or power train which is connected to the crankshaft used to transmit the rotating mechanical energy to the desire final use. Most of the internal combustion engines are reciprocating engines having pistons that reciprocate back and forth in cylinder internally within the engine.

a) First stroke: Intake stroke

The piston moves downward that draws a combustible mixture of fuel and air past the throttle and intake valve into the cylinder. At this stroke, thus intake valve open and the exhaust valve closed.

b) Second stroke: Compression stroke

During this cycle, the piston moves upward, compressing the fuel-air mixture. Both valves closed, and it will raise the temperature of the mixture as pressure in the cylinder increased. A spark ignites the mixture toward the end of this stroke.

c) Third stroke: Power stroke

At this stroke, ignition of spark plug, ignites the compressed fuel. As the fuel combust it expands, driving the piston downward. The expansion or power stroke resulting from combustion of the fuel-air mixture. At this stroke, both intake and exhaust valve still closed.

d) Fourth stroke: Exhaust stroke

At the end of power stroke, the exhaust valve is opened by the cam mechanism. The upward stroke of the piston drives the combustion product out of the cylinder. At this stroke, the intake valve is still closed.



## 2.2 Engine Performance Parameter

### 2.2.1 Work

Indicated work, $\mathbf{W_i}$ is the work inside the combustion chamber while actual work available at crankshaft is called brake work, $\mathbf{W_b}$. SI unit of work is Joule (J).

$$W_b = W_i - W_f$$

$$W_b = 2\pi\tau = \frac{BMEP.V_d}{n}$$

### 2.2.2 Torque

The engine torque, $\boldsymbol{\tau}$ is a measure of the work done per unit rotation (radians) of the crank. It is a good indicator of an engine's ability to do work. SI unit of torque is Nm.

$$\tau = BMEP.V_d/2\pi n$$

### 2.2.3 Power

Power, $\dot{\mathbf{W}}$ is defined as the rate of work of the engine. Depending on which definition of work and mean effective pressure (MEP), power can be categorized into indicated power, $\dot{\mathbf{W}}_{\mathbf{i}}$ brake power, $\dot{\mathbf{W}}_{\mathbf{b}}$ and friction power, $\dot{\mathbf{W}}_{\mathbf{f}}$. SI unit for power is Watt (W).

$$\dot{W} = \frac{WN}{n}$$

$$\dot{W} = \frac{(MEP)(A_p)(\bar{U}_{p)}}{2n}$$

$$\dot{W}_b = \eta_m \dot{W}_i$$



### 2.2.4 Air-Fuel Ratio

Air-fuel ratio is the ratio of mixture presented during combustion process.

$$AF = \frac{m_a}{m_f} = \frac{\dot{m}_a}{\dot{m}_f}$$

### 2.2.5 Specific Fuel Consumption

It is the fuel flow rate per unit power output. It is a measure of engine efficiency. In fact . specific fuel cocnsumption and engine efficiency are inversely related, so that the lower the sfc the greater engine's efficiency. Brake power gives brake specific fuel consumption (BSFC) and incated power gives indicated power fuel consumption (ISFC).

$$BSFC = \frac{\dot{m}_f}{\dot{W}_b}$$

$$ISFC = \frac{\dot{m}_f}{\dot{W}_b}$$

### 2.2.6 Thermal Efficiency

It is the amount of useful work an engine can produce based on the amount of heat input.

$$\eta_{th} = \frac{W}{Q_{in}} = \frac{\dot{W}}{\dot{Q}_{in}}$$

### 2.2.7 Volumetric Efficiency



Briefly, volumetric efficiency is the ratio or percentage of quantity of fuel and air that actually entered the cylinder during intake stroke to the actual capacity of the cylinder under static condition.

$$\eta_v = \frac{m_a}{\rho_a V_d} = \frac{n\dot{m}_a}{\rho_a V_d N}$$

## 2.3 Effects of hydrogen peroxide-Diesel blend on engine performance

Hydrogen peroxide is blended with diesel and then injected into the engine. Effects on the engine performance were studied. First of all, hydrogen peroxide with various percentage with diesel are tested at injection timing of 10˚ BTDC and injection pressure of 150 bar. It was noticed at half load, 15.48% of thermal efficiency is achieved which is the highest when the engine used 5% of hydrogen peroxide-diesel blend. So it was concluded as the concentration of hydrogen peroxide increased, the brake thermal efficiency of the engine will increased too. Next, different percentage of hydrogen peroxide with diesel at injection timing of 10˚ BTDC and 15˚ BTDC for 40% of full load. Highest brake thermal efficiency achieved when using pure diesel and 10% hydrogen peroxide-diesel blend. Both are injected at 15˚ BTDC. It was stated that the efficiency of engine increases by advancing the injection timing by 5˚ (Nagaprasad & Madhu, 2012).

Next, an experiment discovered that effect of additive hydrogen peroxide on the performance of a diesel engine on brake thermal efficiency is higher for 0% hydrogen peroxide at low loads but start to decrease as the loads go higher. Next, for 2.5 and 10% of hydrogen peroxide content, brake thermal efficiency is lower at low loads but start to take effect and goes higher once the load is increased, where 10% of hydrogen peroxide exhibits the highest thermal efficiency at maximum load. They concluded that there were no significant improvements in the brake power over different level of hydrogen peroxide and is mostly dependent on the load, exhibiting a linear increase over increase of load. For specific fuel consumption, they found that it has a peak at low loads and tends to constantly decrease for higher load levels. It is highest for 2% of hydrogen peroxide and is higher than 0% for all loads (Sandeep & Vinay, 2014).



## 2.4 Effects of various alcohol-gasoline blend on engine performance

A study about the effects of ethanol-gasoline blends on performance of spark ignition engine was carried out. The fuel blends were 3%, 5% and 10% of ethanol. The results were compared along with the result of gasoline alone. Maximum brake power was obtained at 10% ethanol-gasoline blend. The study concluded that increment of ethanol content in the blended fuel increase the brake power at all engine speed.

Next, specific fuel consumption of all fuel blend were compared. At low range engine speed, 10% ethanol-gasoline blend showed the lowest specific fuel consumption (SFC) value but then went maximum at medium range engine speed. This upward in SFC with the use of 10% ethanol-gasoline blend is normal and it is due to the lower energy content of the ethanol. In term of brake torque, gasoline alone produced the lowest brake torque at all engine speed. The results indicated an improving brake torque with increasing ethanol ratio in the blends. This improvement in the brake torque can be attributed to better anti-knock behaviour. Lastly, volumetric efficiency increased with the increasing brake power and torque. When volumetric efficiency increased, combustion efficiency will increased too and in turn specific fuel consumption will decreased (Elfasakhany, 2014).

Another experiment on effect of ethanol-unleaded gasoline was carried out. Firstly, it was noted that brake thermal efficiency, $\eta_{b.th}$ increases as the percentage of ethanol increases. Maximum brake thermal efficiency was with 20% of ethanol in fuel blend at all engine speeds. Next, it was noted that a drop of brake thermal efficiency, $\eta_{b.th}$ for ethanol content more that 20% at all engine speeds. This is due to decreasing in the latent heat of the fuel blend used. Then, it was concluded that at minimum value of equivalence air-fuel ratio, $\phi$, the brake thermal efficiency, $\eta_{b.th}$ is maximum.

Furthermore, at all engine speeds, brake torque, $\tau$ and brake power, $\dot{W}_b$ increase with the increase of ethanol in fuel blend. Both torque and power increased up to 20% of ethanol content, and then started to decrease. This is also due to what happened in brake thermal efficiency, $\eta_{b.th}$ which is the latent heat of the fuel used being decreased. It was suggested that power, $\dot{W}_b$ is dependent on the engine speed while brake torque, $\tau$ is not.



Lastly, brake specific fuel consumption (BSFC) decreased with the increase of ethanol up to 20% in fuel blend. Increase of BSFC at engine speed more than 3000 rpm was due decrease of brake thermal efficiency, $\eta_{b.th}$ and increase of equivalence air-fuel ratio, $\phi$ (Al-Hasan, 2003).

In general, as the alcohol concentration increases so does the blend's specific gravity. The higher the oxygen content in the blend, the lower its energy mass-density value. Blends with higher alcohols have larger energy-volume densities, when compared to those with lower alcohols. For the same operating condition, engines burning a stoichiometric mixture need to consume more alcohol-gasoline blend that neat gasoline (Yacoub, Bata, Gautam, & Martin, nd).

## 2.5 Effects of hydrogen-gasoline blend on engine performance

A study about hydrogen operated on internal combustion engine was conducted. Firstly, it was discovered that a lean hydrogen mixture is less likely to knock than conventional gasoline. This can lead to higher compression ratios of engine. Because of simpler molecular structure, hydrogen has higher specific heat ratio than conventional gasoline. At constant speed and load, the thermal efficiency, $\eta_{th}$ of engine increased as the percentage of hydrogen blending increased. Hydrogen improved the mixing process of fuel and air hence improved the combustion process. The thermal efficiency, $\eta_{th}$ dropped at higher loads due to incomplete combustion of richer mixture (Prasath, et al., 2012).

Another experiment on effect of hydrogen addition on performance characteristics of gasoline engine was carried out. From the results analysed, brake mean effective pressure (BMEP) increased as well the hydrogen content increased. This because hydrogen has larger flammable range, faster flame propagation speed and higher adiabatic flame temperature than gasoline which accelerated the combustion of gasoline-hydrogen-air mixtures. Then, it was noticed that BMEP dropped at 25% of hydrogen content. It was due to reduction of intake of air as the hydrogen content increased in the total intake gas. This means volumetric efficiency decreases as the percentage of hydrogen increases which led to improper combustion. So, maximum BMEP and higher torque were obtained at engine speed of 3000 rpm for all blends (Shivaprasad, Raviteja, Chitragar, & Kumar, 2014).

Furthermore, research about using hydrogen, $H_2$ as fuel, addition hydrogen to gasoline and their effects to engine performance is quite wide too. An experimental study was performed to explore the effect of hydrogen addition to gasoline fuel in a stationary spark ignition engine to bring out the optimum conditions for a better performance under different load conditions. The addition of hydrogen improves the brake thermal efficiency, $\eta_{b.th}$ with the increase of hydrogen percentage up to percentage 31% for all tested loads (Elsemary, Attia, Elnagar, & Elaraqy, 2016). After that, they found that increase in hydrogen percentage, decreases the thermal efficiency, $\eta_{th}$ more than 31% due to reduction in amount of air inside the cylinder. The results trend for both experiments are consistent when they compared it with using gasoline alone.

## 2.6 Effects of various hydrogen-alcohol blend on engine performance

A study was conducted on effect of ignition and compression ratio on the performance of a hydrogen-ethanol fuelled engine. For specific ignition timing, the brake mean effective pressure (BMEP) and the brake thermal efficiency increased with the increase of hydrogen fraction in ethanol at all compression ratios. Moreover, all fuel blends showed the maximum increase in brake thermal efficiency and reduction in brake specific fuel consumption (BSFC) value at around 25 ˚BTDC ignition timing at all compression ratios too. It was recommended that the best operating conditions could be at compression ratio of 11:1 and the optimum fuel combination could be 60 to 80% hydrogen substitution to ethanol. Hence, crucial improvement of hydrogen addition is to reduce the SFC of ethanol fuelled engines. As detailed in this study hydrogen fuel is a very strong candidate for use in dual fuel applications with ethanol due to a main reason of its ease of availability. The predictions from the present study rely on the idea of lower specific fuel consumption and high efficiency advantages of hydrogen that would lead to hydrogen blended ethanol engines in the near future (Yousufuddin & Masood, 2009).

An investigation on the effect of spark timing on the performance of a hydrogen-blended methanol engine was conducted experimentally. The test was conducted at a speed of 1400 rpm and a manifolds absolute pressure of 61.5 kPa. Three hydrogen volume fractions in the intake of 0, 1.5% and 3% were tested with an excess air ratio of 1.20. Firstly, the results showed a raise in indicated thermal efficiency for methanol engines as hydrogen is added up. This is due to the enhanced fuel-air mixture homogeneity and enhanced combustion. Increase of hydrogen blending fraction, reduces both flame development and propagation periods due to the low ignition energy and high flame speed of hydrogen. The flame development period is prolonged whereas the flame propagation period is shortened with the increase of spark advance. Cylinder temperature at the exhaust valve opening could be reduced by either hydrogen addition or advancing the spark timing, indicating that both advancing the spark timing and increasing the hydrogen addition fraction could help reduce the engine exhaust loss (Zhang, Ji, & Wang, 2015).

An investigation on the effect of hydrogen enrichment on butanol blended gasoline engine operating at a stoichiometric conditions was performed. From the results obtained, fuel blend with 30% of butanol content was observed to be a better replacement to pure gasoline in a natural aspirated engine. Next, it was found that fuel consumption is reduced due to hydrogen enrichment, which is rather high for butanol blends compared to pure gasoline. Due to the enrichment of both hydrogen and oxygen the combustion is more complete which came from butanol in the mixture. As a result, thermal efficiency, $\eta_{th}$ increased. The cylinder's temperature raised when the air is enriched with hydrogen and then increased furtherly with oxygen content from butanol. As a result, NOx emissions increased from the engine. The delay period and combustion duration have reduced upon hydrogen enrichment (Raviteja & Kumar, 2015).

## CHAPTER 3

## METHODOLOGY

### 3.1 Introduction

Briefly, this project is to determine which percentage of hydrogen peroxide in fuel blend gives the better performance compare with gasoline alone. So, several experiments need to be carried out in this project. The experiments are chemical properties determination and engine performance testing. In engine performance testing, percentage of hydrogen peroxide in the fuel blend will be the only manipulating variable. Another input like fuel and air temperature, fuel-air ratio and engine specification will be the fixed variable. Then, the responding variable which is the result will be the performance analysis of the engine testing data. The combustion and engine performance analysis are like in-line cylinder pressure, peak pressure, work per cycle, power, thermal efficiency, specific fuel consumption, heat release rate and peak heat release rate. Emission will not be covered in this project.

### 3.2 Test Engine Specification

SHV6000EXE is the model of the test engine that will be used during all tests throughout this project. Moreover, this 4-stroke engine with single cylinder is equipped with overhead valve, carburetion system and air cooling system. More on specifications of this engine are shown as in **Table 1** and its respective figure is shown in **Figure 2**.

**Figure 2:** Test engine with electric generator.

| Engine model | SHV6000EXE |
|---|---|
| Engine type | 4-stroke, air-cooled, overhead valve |
| No of cylinder | 1 |
| Bore (mm) | 90 |
| Stroke (mm) | 66 |
| Displacement volume ($cm^3$) | 420 |
| Compression ratio | 9.4 : 1 |
| Maximum power output (hp) | 15 |

**Table 1:** Specifications of test engine.



### 3.3 Electric generator

Practically, electric generator is mounted directly to the engine to become an engine generator. Theoretically, engine generator operates on principle producing electrical power using a gasoline engine and electromagnet. Basically, electric generator is built from rotor, stator, voltage regulator and brushes which can generate up to 120 volts of alternating current.

Rotor is essentially a magnet that rotates inside of a conductor like copper coil creating a magnetic field that induces current. While stator has 3 main copper coil windings which are the excitation winding and 2 voltage output windings. The excitation winding sends voltage to the rotor through the voltage regulator and brushes. By increasing and decreasing the voltage applied to the rotor, the generator controls the voltage of the output windings. Voltage regulator converts the voltage sent to the rotor for alternating current to direct current and monitor the output winding voltage as well.

**Figure 4:** 500 W and 1 kW spotlight


**Figure 3:** Alternating current output socket

In this engine testing, mechanical energy come from the rotating crankshaft from the test engine. When mounted to the test engine, generator can be used as load to the test engine just like what dynamometer and transmission system did. In this case, generator acts like passive dynamometer which is driven by the engine only. . In these engine testing, there are 500 W, 1 kW, 1.5 kW and 2 kW halogen bulb of spotlight as shown in **Figure 3** that will act as load to the engine. **Figure 4** shows the some part of engine generator.



### 3.4 Data Acquisition System

DEWESoft SIRIUS is the data acquisition system that will be used in the whole engine testing. This hardware acts as the interface between computer and the test engine. It primarily functions as a device that digitalizes incoming analogue signal from engine sensors so that the computer can interpret them.

There is two type of sensors used in this engine testing which are pressure transducer and optical angle encoder. **Figure 5** and **Figure 6** show the pressure transducer and optical angle encoder used in this engine testing. Pressure transducer used to measure in-line pressure cylinder is mounted to the engine cylinder through a modified cylinder head. Then, optical angle encoder used to detect position of crank angle is directly attached at the very end of crankshaft. These sensors are then connected to the DAQ. While **Figure 7** and **Figure 8** show the DAQ hardware and its software interface on laptop.

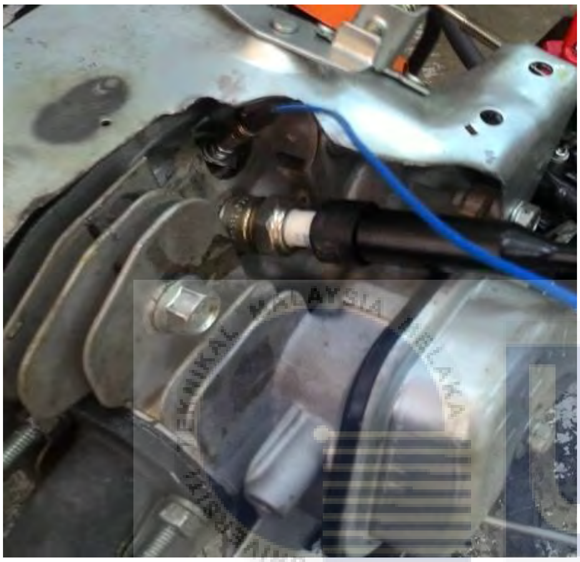

**Figure 5:** Location of pressure transducer mounted on the engine head (blue cable)

**Figure 6:** Location of optical angle encoder



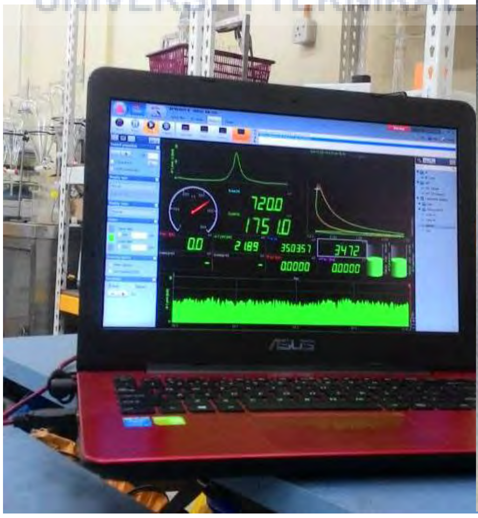

**Figure 8:** DEWESoft software user interface

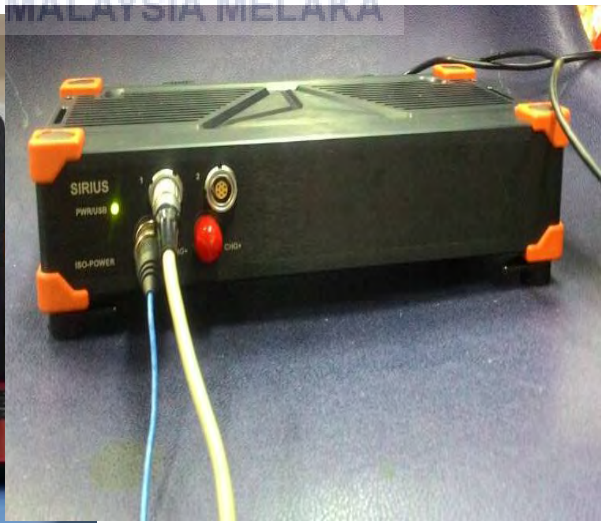


**Figure 7:** DEWESoft DAQ hardware

## 3.5 Fuel Blends Preparation

First of all before starting the engine testing, the properties of fuel blends need to be determined. The properties are like density, viscosity, kinematic viscosity and flash point can be experimentally determined. This experiment was done at the Chemistry Laboratory, Technology Campus.

Next for the experiment, the reference gasoline fuel was obtained from CALTEX fuel station as in **Figure 9** while the poly, hydrogen peroxide with 50% of concentration in **Figure 10** was obtained from the Polyscientific Enteprise Sdn. Bhd. This experiment was started by blending off the gasoline and hydrogen peroxide according to blend compositions stated before which are 5% and 10 % of hydrogen peroxide by volume.



**Figure 9:** CALTEX RON 95 gasoline.

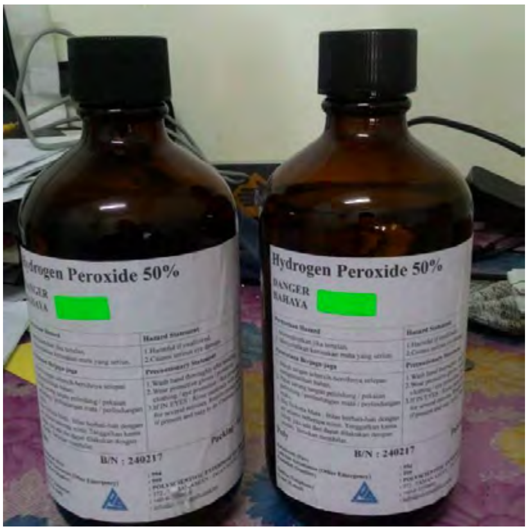


**Figure 10:** Hydrogen peroxide with 50% concentration.

Then, 500 ml each of fuel blends were prepared at least. For 5% fuel blend, 475 ml of gasoline and 25 ml of hydrogen peroxide are used. For 10% fuel blend, 450 ml of gasoline and 50 ml of gasoline are used then. Those materials are measured using measuring cylinder and blended using magnetic stirrer as shown in **Figure 11** without any heat addition to the mixture. However due to the difference in polarity between gasoline and hydrogen peroxide, the mixture has tendency to form two immiscible layers. The separating immiscible layer in the mixture is form by the undissolved hydrogen peroxide. Therefore, emulsification process is required to produce a stable mixture of fuel blend. Polysaccharide as emulsifier was added in order to reduce the surface tension between the gasoline and hydrogen peroxide and stabilizes the blend for longer period.

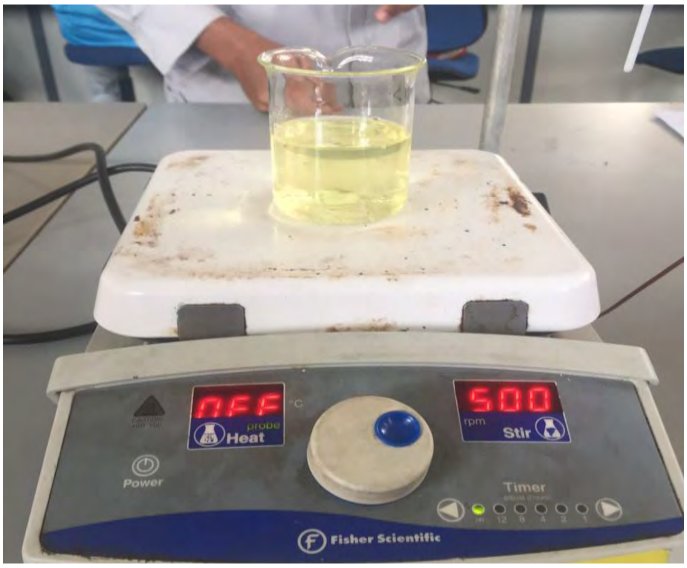


**Figure 11:** Fuel sample being blended using magnetic stirrer at 500 rpm

In literature review, there was limited numbers of journal and technical paper related to this project. Those papers are needed as a reference for this project. It was decided to run the experiment with gasoline alone first as the baseline. The result obtained will act as the reference for the other test fuels in this project.

### 3.6 Chemical Properties Identification of Fuel Blends



Unfortunately, density and calorific value of fuel blends is the only properties that able to be determined during this experiment due to some limitations. An advice was given by the laboratory assistant engineer to refer to the existing standards related to this experiment prior to conducting the experiment. By referring those standards, the experimental errors can be minimized hence better results achieved. List of standards referred are shown in **Table 2**.

| S. No | Name of Standard | ASTM Method |
|---|---|---|
| **1** | Automotive Spark-Ignition Engine Fuel | ASTM D-4814 |
| **2** | Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method) | ASTM D-287 |
| **3** | Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method | ASTM D-1298 |

**Table 2:** List of standard referred

### 3.6.1 Density Identification using Hydrometer Method

All the samples are transferred to the clean, 500ml volumetric flask each without splashing to avoid the formation of air bubbles. If there any air bubbles, it is removed by touching them with a piece of clean filter paper. Water bath is turned on and set to 15°C. Temperature of water bath is ensured equilibrium at 15°C then each volumetric flask is placed into it. The volumetric flask is let in order to achieve the equilibrium temperature as shown in **Figure 12**. Sample temperature is checked regularly using thermometer until equilibrium achieved. Thermometer also can be used to stir the sample.




**Figure 12:** Temperature of sample being checked until it is equilibrium.

Next, the thermometer is removed from the volumetric flask when the equilibrium temperature is achieved. Then, the hydrometer with appropriate range as in **Figure 13** is lowered and released into the samples. The hydrometer is allowed to come to rest for air bubbles to come to the surface. Any air bubbles is removed before taking a reading. The hydrometer scale is read to the nearest one-fifth of a full scale division when it had come to rest floating freely away from the walls of volumetric flask. Reading of hydrometer is recorded. To take another reading, the hydrometer is lifted out the samples carefully. Then, the samples temperature is verified again with thermometer and hydrometer is dropped into samples again. All experiments are repeated three times for consistency and the average reading was used.

**Figure 13:** Glass hydrometer used to identify fuel sample’s density.

### 3.6.2 Calorific Value Identification using Bomb Calorimeter

The main objective of this experiment is to identify the energy content of each test fuels. Firstly, samples which are the fuel blends are prepared and the oxygen combustion vessel is charged. Next, calorimeter bucket is tared and filled with 2000 g of distilled water.

**Figure 14:** Calorimeter bucket that will be filled with 2000 g of distilled water.

Then, the bucket is then set placed the calorimeter. After that, the cover is set on the jacket then the stirrer is started using the motor. A digital thermometer is turned on and in order to reach equilibrium before start the stirrer is ran for 5 minutes first. After 5 minutes, timer on digital thermometer is started and temperature is read at one-minute intervals for 5 minutes again. The bomb is ignited at the start of the $6^{th}$ minute. Next, within 20 seconds after ignition the bucket temperature is raised and time required to reach 60% of the total rise is measured. After the rapid rise, temperatures are recorded at one minute intervals until the difference between successive readings has been constant for five minutes. The motor is stopped after the last temperature reading. Before attempt to remove the cap, knurled knob on the bomb head is opened to release the gas pressure.

**Figure 15:** Head of the bomb need to be knurled to release the pressure inside it.

After done conducting the experiment, the all interior surfaces are washed and all the unburned pieces of fuse wire are removed. Last but not least, the bomb washing is titrated with sodium carbonate solution.

## 3.7 Engine Performance Testing

First, the ventilation system of the laboratory is turned on. Meanwhile, the exhaust system of the combustion product (tail pipe engine exhaust) is connected to the test engine. Next, cable from pressure transducer and optical angle encoder which mounted at the test engine are connected to the data acquisition system (DAQ) hardware. Then, DAQ hardware is turned on and is connected to the computer via USB. After that, DAQ software in computer is opened. Sensor sensitivity and TDC offset are set for the first time running engine testing. Before running the engine testing, fuel tank is first connected to the burette. Then, burette is connected to the engine. Engine is started with free load. Make sure DAQ hardware and software ran properly after engine started.

**Figure 17:** Modified fuel tank

**Figure 16:** Usage of burette to measure fuel consumption

Burette is filled with test fuel from tank and its stopcock is closed. Then, load is applied to the test engine first. Engine speed is set into desired speed and let it stabilized. Before starting the testing, fuel from tank is stopped by closing its valve. Initial reading of burette is recorded. At the same time, burette's stopcock is opened and DAQ data storing is started. Each testing duration is set to 60 seconds using stopwatch. After 60 seconds, burette's stopcock and DAQ data storing are stopped at the same time. Final reading of burette is recorded. Step (f) to (l) are repeated with different engine speeds and load tests. After done with one test fuel, step (f) to (m) are repeated with different test fuels.

## 3.8 Experimental Project Flowchart

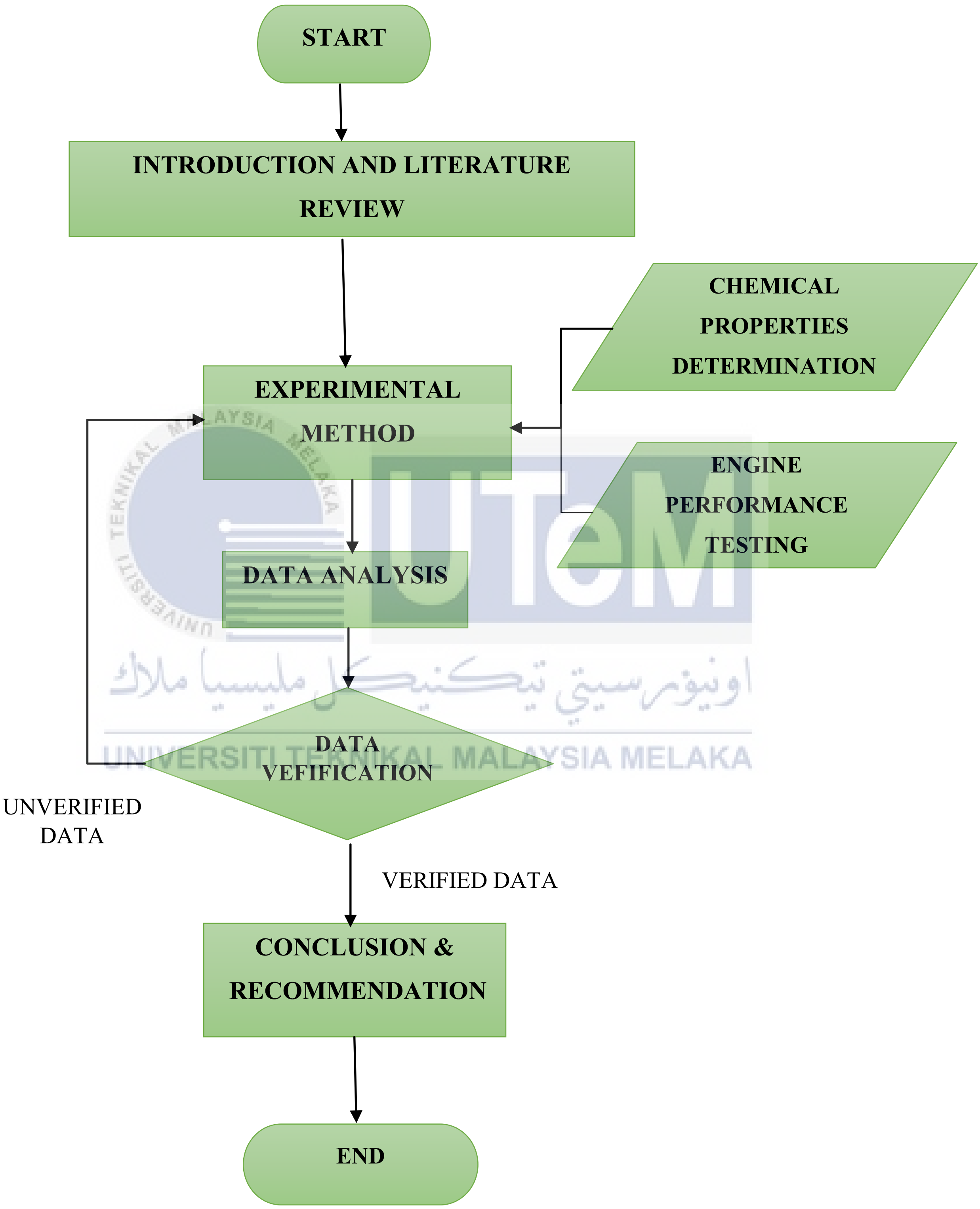


**Figure 18:** Flowchart of engine testing experiment

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Experimental Data

### 4.1.1 Engine Testing Data

Throughout the engine testing experiment, three raw data that can be retrieved from Dewesoft data acquisition system which are cylinder pressure, cylinder displacement volume and crank angle. All these data are first exported into Excel worksheets before being analysed into various performance parameter. **Table 3** shows some of raw data obtained from DAQ for gasoline alone at 2500 rpm and free load.

| Crank angle (deg) | Volume ($dm^3$) | Pressure (bar) |
|---|---|---|
| **5** | 0.0509847 | 5.5072098 |
| **6** | 0.051424 | 5.5730538 |
| **7** | 0.0519426 | 5.6411676 |
| **8** | 0.0525404 | 5.7125959 |
| **9** | 0.053217 | 5.7864923 |
| **10** | 0.0539721 | 5.8668714 |
| **11** | 0.0548054 | 5.9501691 |
| **12** | 0.0557164 | 6.0412917 |
| **13** | 0.0567048 | 6.1391053 |
| **14** | 0.05777 | 6.2431412 |
| **15** | 0.0589116 | 6.3410993 |

**Table 3:** Sample of data exported from the DAQ

Besides those DAQ exported data, fuel consumption data are crucial for some of performance analysis. So for every fuel blends at different engine speed and load, fuel consumption are observed and recorded. **Table 4, Table 5 and Table 6** show the fuel consumption for all test fuel at every engine speed and load.



| Load (W) | Fuel Consumption (ml) | | |
|---|---|---|---|
| | **GA** | **5% $H_2O_2$** | **10% $H_2O_2$** |
| **0** | 14.6 | 15.9 | 20.3 |
| **500** | 21.3 | 21.4 | 22.4 |
| **1000** | 26.7 | 25.7 | 35.2 |
| **1500** | 30.5 | 30.3 | 41 |
| **2000** | 34.2 | 37.6 | 37.5 |

**Table 4:** Fuel consumption at 2500 rpm

| Load (W) | Fuel Consumption (ml) | | |
|---|---|---|---|
| | **GA** | **5% $H_2O_2$** | **10% $H_2O_2$** |
| **0** | 17.4 | 20.5 | 21.8 |
| **500** | 25.4 | 25 | 24.3 |
| **1000** | 29.6 | 31.8 | 32.3 |
| **1500** | 32.6 | 42 | 45.5 |
| **2000** | 31.7 | 42 | 46.2 |

**Table 5:** Fuel consumption at 3000 rpm.

| Load (W) | Fuel Consumption (ml) | | |
|---|---|---|---|
| | **GA** | **5% $H_2O_2$** | **10% $H_2O_2$** |
| **0** | 23.8 | 29.5 | 22.4 |
| **500** | 34.2 | 32.1 | 30.5 |
| **1000** | 33.9 | 35.7 | 49.1 |
| **1500** | 37.2 | 40.5 | 48.1 |
| **2000** | 34.4 | 45.9 | 43.7 |

**Table 6:** Fuel consumption at 3500 rpm



### 4.1.2 Fuel Blends Chemical Properties

Some of chemical properties of fuel like density, and energy content are likely to be known in order to determine some performance parameters. Since the gasoline is blended with different percentage of hydrogen peroxide, so the chemical properties of each fuel blend needs to be determined including gasoline itself. **Table 7** shows chemical properties for gasoline alone, 5% and 10% $H_2O_2$-Gasoline test fuels.

| Test Fuels | Density ($g/cm^3$) | Energy content (kJ/g) |
|---|---|---|
| **Gasoline alone** | 0.735 | 38.102 |
| **5% $H_2O_2$-Gasoline blend** | 0.75 | 33.474 |
| **10% $H_2O_2$-Gasoline blend** | 0.765 | 28.845 |

**Table 7:** Density and calorific value of test fuels.

Fuel blends are observed to be denser as the composition of $H_2O_2$ in fuel blend increased as well. However, the density of the fuel blends does not increase much when hydrogen peroxide exceed more than 15% (Khan, Ahmed, Mutalib, & Bustam, 2013). Surprisingly, there is drop in energy content for $H_2O_2$-Gasoline blends when compared to gasoline alone. The drop is because of exothermic reaction between gasoline, hydrogen peroxide and emulsifier being mixed up. The vigorous reaction of mixture released amount of heat resulted in low amount of energy content.

## 4.2 Performance Analysis

### 4.2.1 In-Cylinder Pressure



In order to generate P-θ diagram, the in-cylinder pressure and crank angle must be captured while running the experiment. This was done by using the pressure transducer and optical angle encoder which were compatible with DEWESoft data acquisition system. **Figure 19** shows the variation of in-cylinder pressure due to crank angle for each test fuels at 2500 rpm and 2kW.

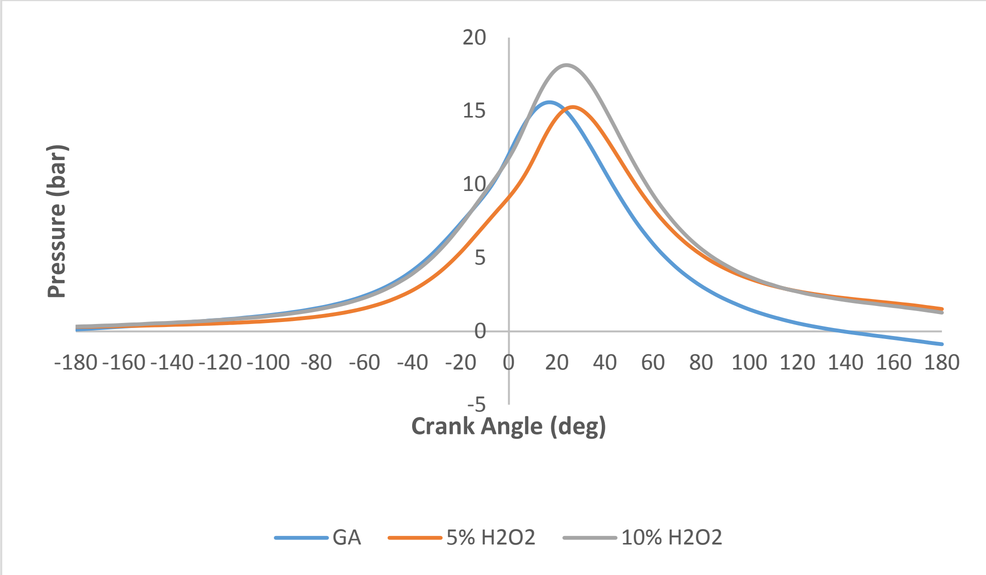


**Figure 19:** In-cylinder pressure for al test fuels at 2500 rpm and 2 kW load.

From above figure, it shows that each test fuels is having a normal combustion without pre ignition or knocking. This is because each fuel test showed a similar pattern of moving upward before top dead center (BTDC) and then reached maximum of in-cylinder pressure after top dead center (ATDC). It was noticed that 10% $H_2O_2$-Gasoline test fuel and gasoline alone had higher cylinder pressure than 5% $H_2O_2$-Gasoline test fuel during compression stroke. Moreover, gasoline alone reached maximum cylinder pressure quicker than $H_2O_2$-Gasoline test fuels. It was 15.59 bar at 17 °ATDC. While maximum in-cylinder pressure for $H_2O_2$-Gasoline test fuels occurred within the range of 24-27 °ATDC. Maximum in-cylinder pressure for 10% H2O2-gasoline test fuel was 18.1 bar at 24 °ATDC which is the highest in this test.

However, 5% $H_2O_2$-Gasoline test fuel has the lowest maximum in-cylinder pressure in this test which is 15.27 bar at 27 °ATDC. Lower in-cylinder pressure for 5% $H_2O_2$-Gasoline test fuel can be attributed to the higher latent heat of evaporation of oxidizing agent (Imtenan, Masjuki, Varman, & Fattah, 2015). It was noticed there is little delay in start of combustion (SOC) for both $H_2O_2$-Gasoline test fuels. This is because of presence of water vapour in both fuel blends which lead to low energy content. In-cylinder pressure for all test fuels at others engine speed and load are included in the **Appendix A**.

### 4.2.2 Heat Release Rate

Analysis of heat release rate can explain the in-cylinder pressure characteristics of the fuel blends in a better way as it permit greater access to the combustion mechanism. Heat release rate of the fuel blends at 2500 rpm and 2 kW load tests is given in **Figure 20**.

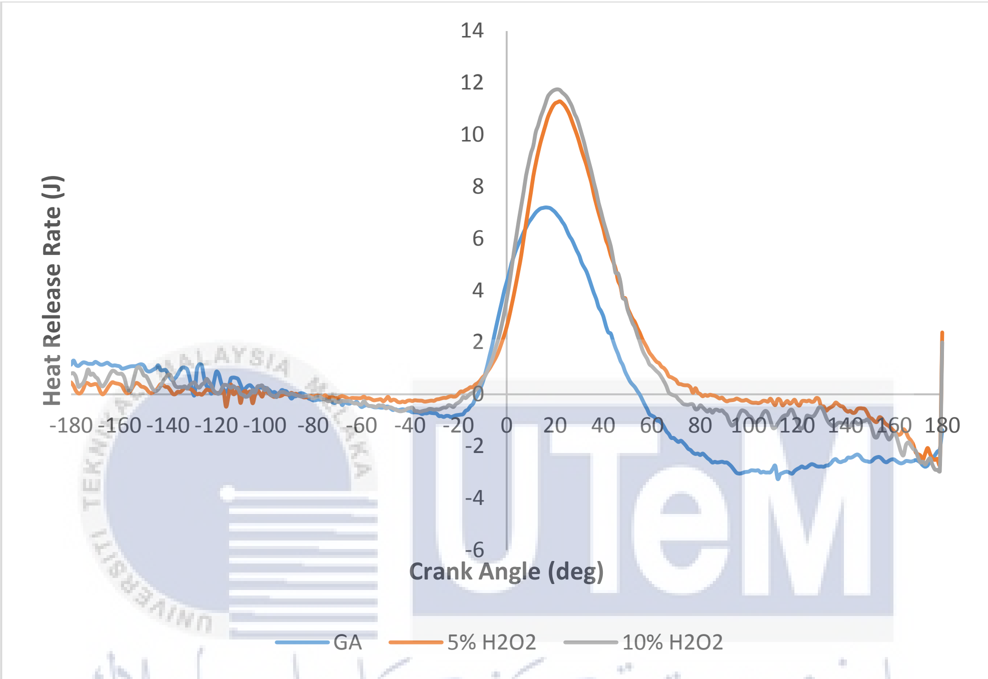


**Figure 20:** Heat release rate for all test fuels at 2500 rpm and 2 kW load.



10% $H_2O_2$-Gasoline test fuel has the highest peak of heat release rate which is 11.75 J. It can be noticed that the peak of heat release rate for gasoline alone is the lowest compared to other test fuels. This is because of the poor atomization and air-fuel mixing rate which in turn reduced the premixed air-fuel mixture (Imtenan, Masjuki, Varman, & Fattah, 2015). Gasoline alone has fastest start of combustion (SOC) followed by 10% and 5% $H_2O_2$-Gasoline test fuels. SOC for all test fuels occurred just before piston reached top dead center which indicates normal combustion of charge. Gasoline alone started to combust around at 10 °BTDC while 10% $H_2O_2$-Gasoline test fuel was at 8 °BTDC.

However SOC for 5% $H_2O_2$-Gasoline test fuel was slightly delayed than others which at 6 °BTDC. Higher latent heat of evaporation reduced the in-cylinder temperature during atomization and it is more likely that combustion occurred in lower temperature environment produces lower heat release rate in correspondence lower peak in-cylinder pressure. Early SOC implies relatively faster evaporation of the fuel to create combustible charge (Imtenan, Masjuki, Varman, & Fattah, 2015). Heat release rate for all test fuel at other engine speeds and loads are included in the **Appendix B**.

### 4.2.3 Peak Pressures

Actually, peak pressures for every engine speed and load can be obtained from P-θ diagrams. Peak pressures are obtained in order to determine the maximum force engine piston and cylinder can exert. This could be help in material selection for engine fabrication. **Figure 21** and **Figure 22** show the variation of in-cylinder peak pressure for all test fuels at every engine speeds with 500 W and 1 kW load tests.



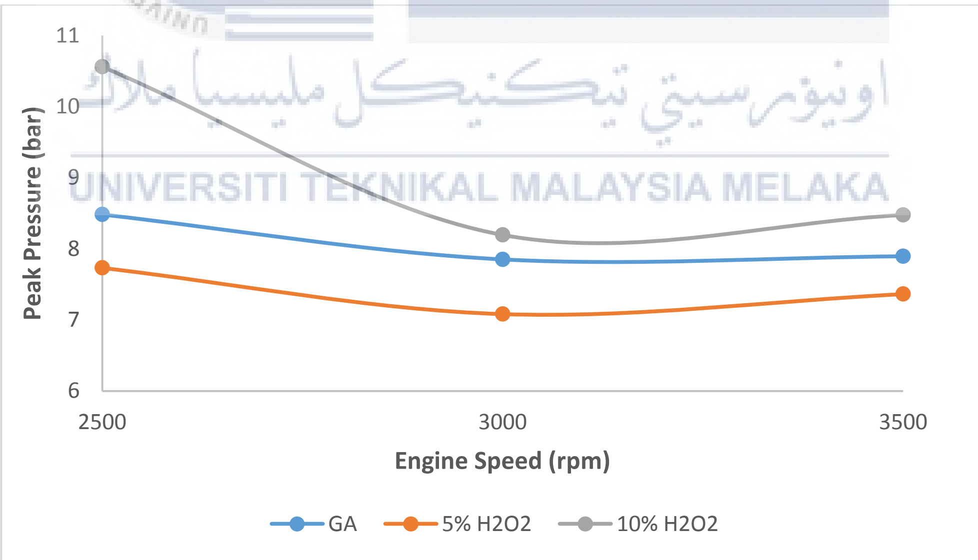


**Figure 21:** Variation of peak pressure at 500 W load for all test fuels.

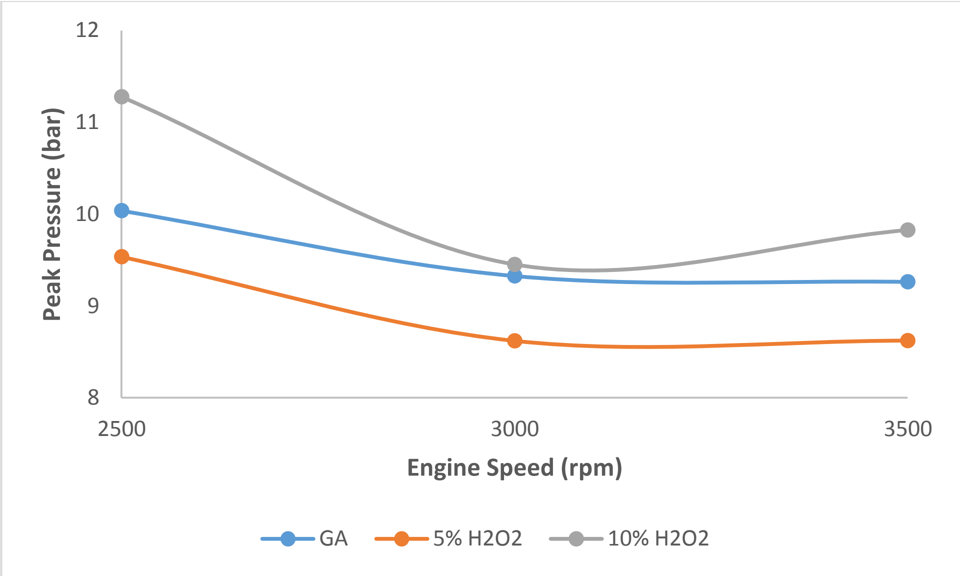


**Figure 22:** Variation of peak pressure at 1 kW load for all test fuels.

For both load tests, 10% $H_2O_2$-Gasoline test fuel showed the highest peak pressures at all engine speed compared to others. Furthermore, at all engine speeds, 5% $H_2O_2$-Gasoline test fuel showed the lowest peak pressures. The pattern for peak pressure at all load tests are almost the same. The highest peak pressures will be at 2500 rpm. Then, the peak pressures will dropped as the engine speed revved up to 3000 rpm. However at 3500 rpm, peak pressures of certain test fuel went up and other went down depend on loads applied. The drop in peak pressure at higher engine speed due to incomplete combustion of richer mixture (Prasath, et al., 2012). Since 10% $H_2O_2$-Gasoline test fuel displayed the highest peak pressure at all engine speed, so the material selection for engine need to be strong and durable as the force that will be exerted on the piston and cylinder wall is greater than other test fuel. Variation of peak pressure at other load tests are attached at the **Appendix C**.

### 4.2.4 Indicated Work per Cycle

When testing the engine for 1 minute, there are number of cycles recorded at different engine speed. In order to get work per cycle, average cycle for each engine speed and load is exported and analyzed. Basically, pressure and volume data are first plotted into a Pressure-Volume diagram. **Figure 23** shows the change in pressure due to volume for 10% $H_2O_2$-Gasoline test fuel at 2500 rpm and zero load.

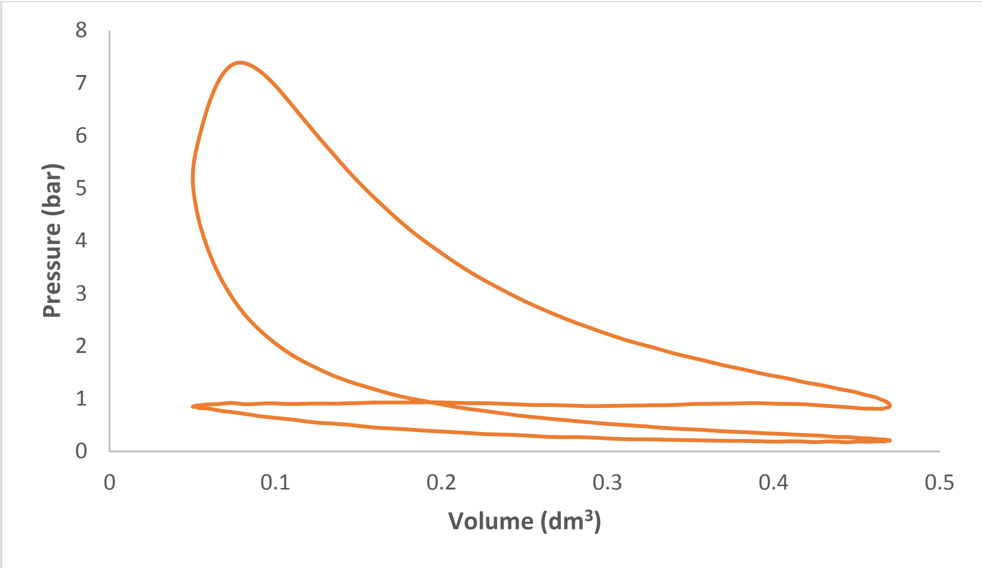


**Figure 23:** Pressure-Volume diagram for 10% $H_2O_2$-Gasoline test fuel at 2500rpm and free load.



By calculating the area enclosed under PV diagram, indicated work per cycle can be obtained. Work per cycle is a crucial parameter in order to determine another performance parameter later. **Figure 24** and **Figure 25** show the variation of indicated work per cycle at zero load, 2 kW load and different engine speed for all test fuels.

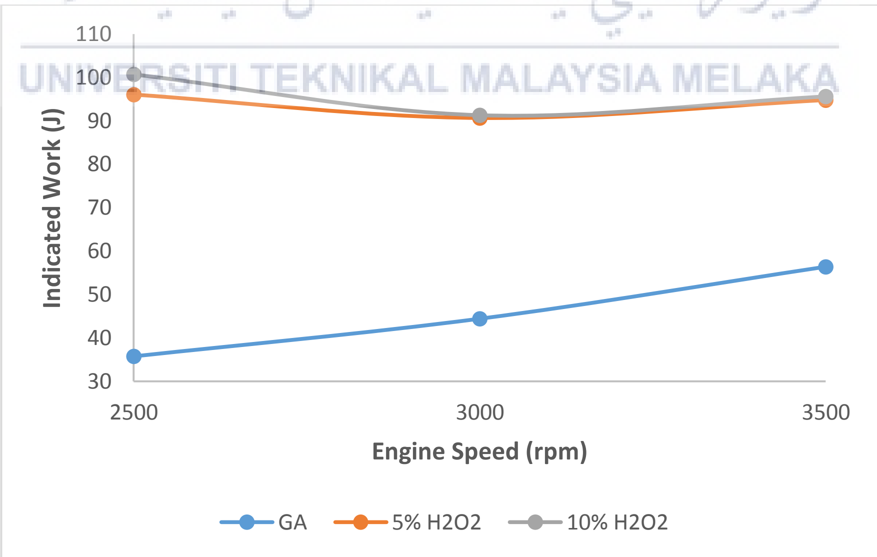


**Figure 24:** Variation of gross indicated work per cycle at free load for all test fuels.

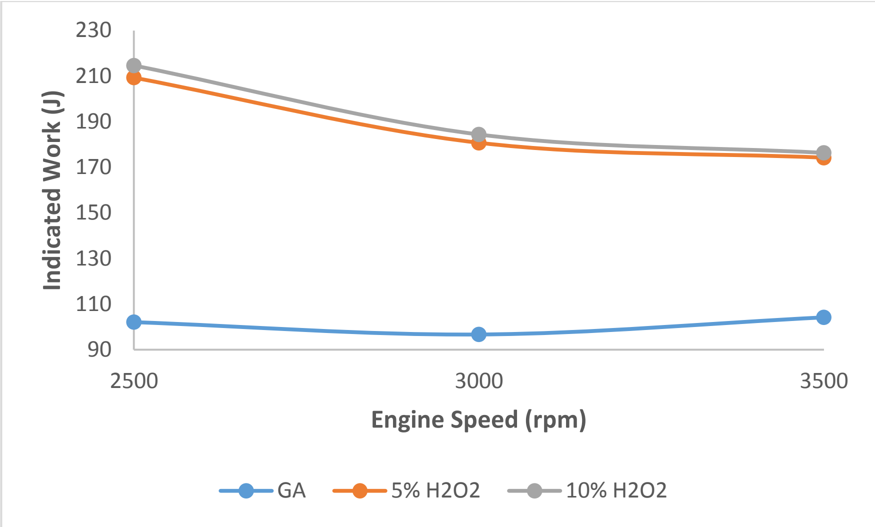


**Figure 25:** Variation of gross indicated work per cycle at 2 kW load for all test fuels

For both load tests, 10% $H_2O_2$-Gasoline test fuel showed the highest gross indicated work per cycle along the engine speeds. Moreover, at all engine speeds, 5% $H_2O_2$-Gasoline test fuel showed the lowest gross indicated work per cycle. There is not much differences in gross work per cycle between 10% and 5% $H_2O_2$-Gasoline test fuels but still 10% $H_2O_2$-Gasoline test fuel is the highest at all engine speed and load tests. As the percentage of hydrogen peroxide in the test fuel increased, the hydrogen content is increased too. Increase in hydrogen content will increase the indicated mean effective pressure which later will increase the indicated work per cycle. This is because hydrogen has larger flammable range, faster flame propagation speed and higher adiabatic flame temperature than gasoline which accelerated the combustion of gasoline-hydrogen-air-mixtures (Shivaprasad, Raviteja, Chitragar, & Kumar, 2014).

It was noticed that for $H_2O_2$-Gasoline test fuels, as the engine speed increased, the gross indicated work will be decreased. This is because as the engine speed increased, the volumetric efficiency decreased due to reduction air intake into the engine cylinder. The highest gross indicated work per cycle was obtained by 10% $H_2O_2$-Gasoline test fuel at 2500 rpm which are 100.68 J and 214.6 J respectively. Hence it can be concluded that indicated work per cycle will increased as the percentage of hydrogen peroxide in fuel blend increased as well. Variation of indicated work per cycle at other load tests are attached in the **Appendix D**.

### 4.2.5 Indicated Power

The effects of $H_2O_2$-Gasoline blends on indicated power at all engine speeds for zero and 2 kW load tests are illustrated in **Figure 26**and **Figure 27** respectively.

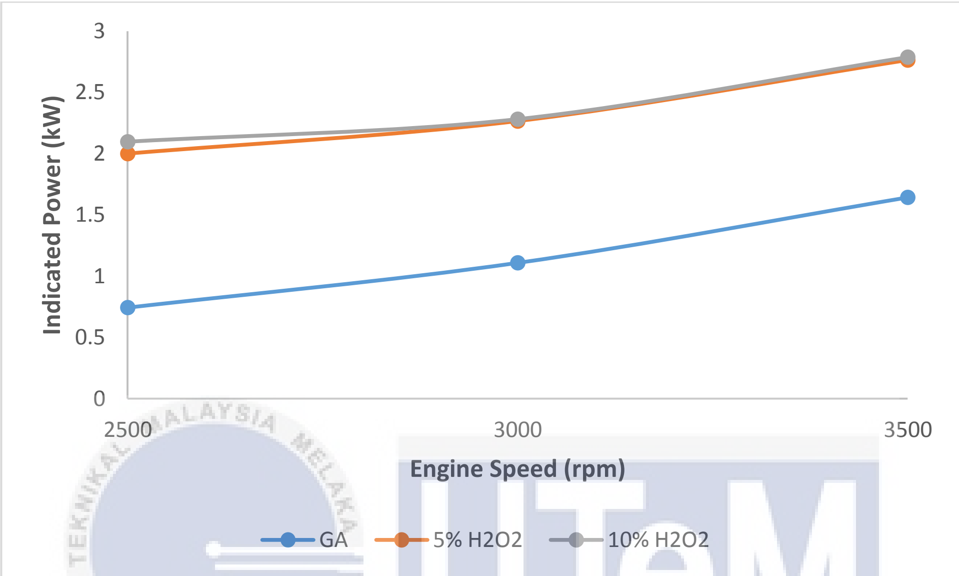


**Figure 26:** Variation of indicated power at free load for all test fuels.

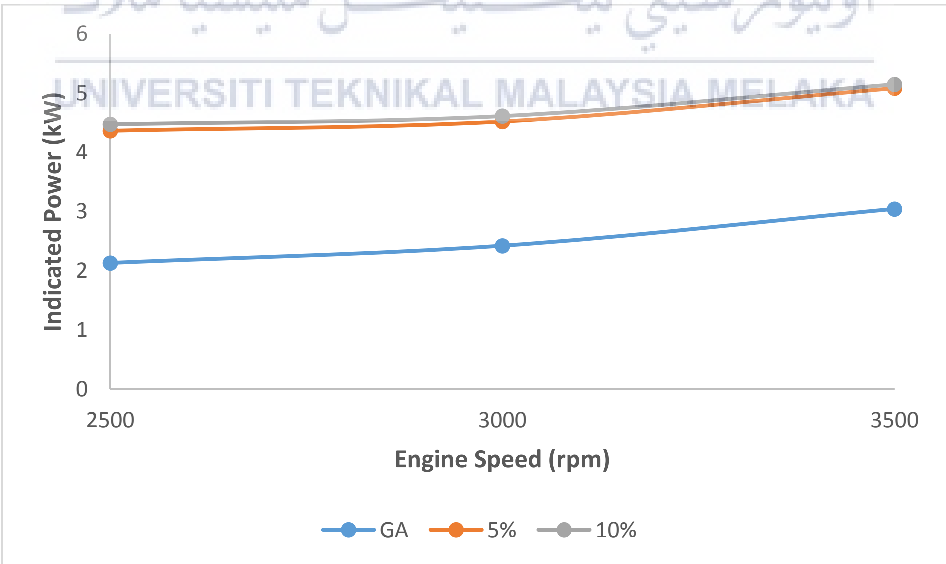


**Figure 27:** Variation of indicated power at 2 kW load for all test fuels.

For both load tests, 10% $H_2O_2$-Gasoline test fuel showed the highest indicated power along the engine speeds. Moreover, at all engine speeds, 5% $H_2O_2$-Gasoline test fuel showed the lowest indicated power. There is not much differences in indicated power between 10% and 5% $H_2O_2$-Gasoline test fuels but still 10% $H_2O_2$-Gasoline test fuel is the highest at all engine speed and load tests. This due to the presence of H2O2 in the fuel, which starts decomposing and releasing a large amount of oxygen which assist to complete the combustion of fuel (Nagaprasad & Madhu, 2012).

It was noticed that indicated power of each fuel test increased as the engine speed revved up. This is because friction losses is not considered so indicated power increases with engine speed while brake power increases to a maximum and then decreases at higher speed. Furthermore, $H_2O_2$-Gasoline fuel test had higher indicated power than gasoline alone is due to higher indicated work per cycle which is then related with higher IMEP. Highest indicated power recorded for zero and 2 kW load test at 3500 rpm are 2.79 kW and 5.14 kW respectively. It was found that as the percentage of $H_2O_2$ in blend increased, the indicated power of the engine increased too. Variation of indicated power at other load tests are attached in the **Appendix E**.



### 4.2.6 Indicated Thermal Efficiency

Indicated thermal efficiency (ITE) is the amount of useful gross indicated work an engine can produce based on the amount of energy or heat input. For thermal efficiency, the input, $\mathbf{Q_{in}}$ to the engine is the heat-content of test fuel that is consumed and combustion efficiency. Heat-content of test fuel is determined from mass of test fuel consumed for one cycle and energy content of test fuel in **Section 4.1.2**. Hence, **Figure 28** and **Figure 29** represent the effect of , $H_2O_2$-Gasoline blends on thermal efficiency at all engine speed for free and 2 kW load tests.

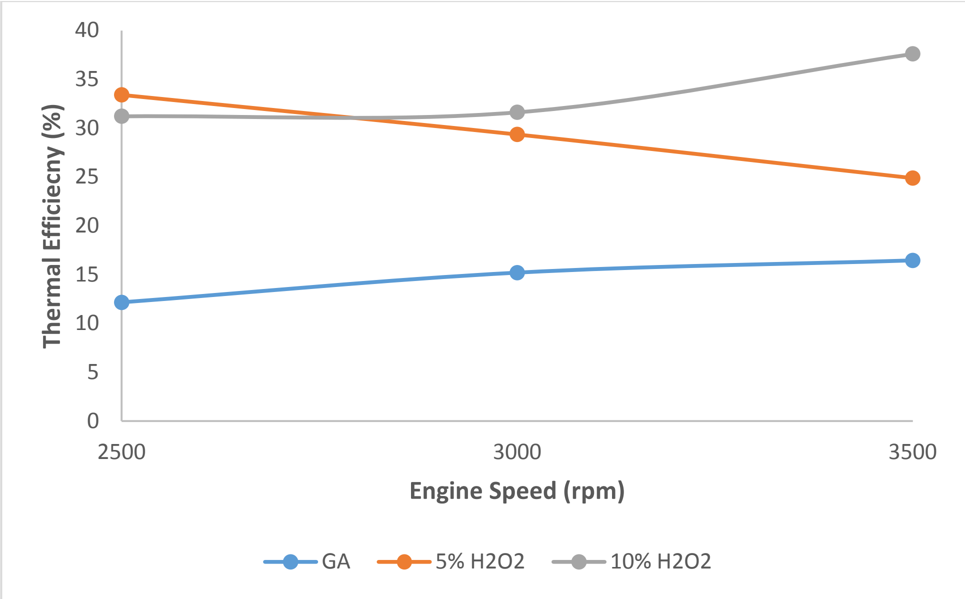


**Figure 28:** Variation of indicated thermal efficiency at free load for all test fuels.

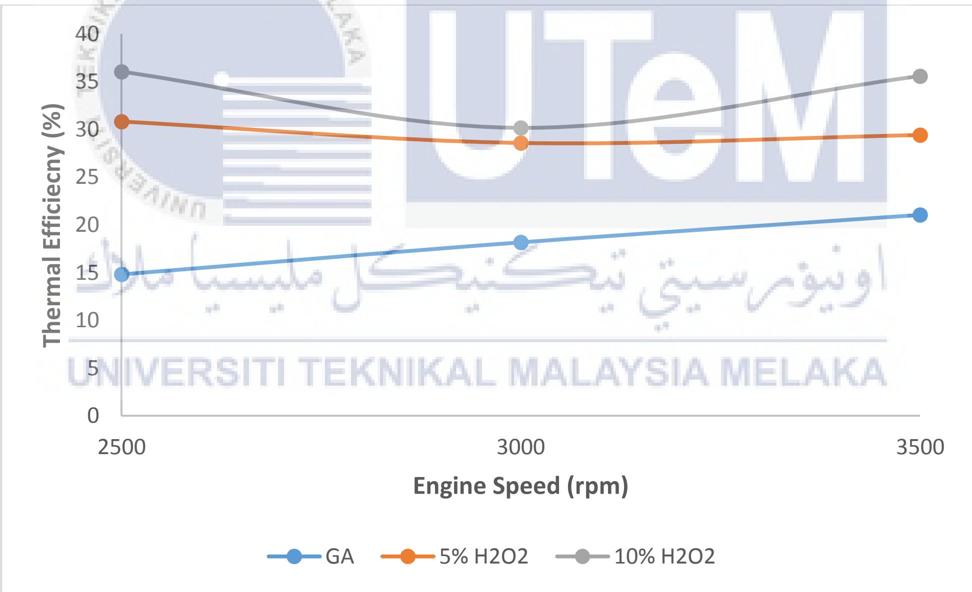


**Figure 29:** Variation of indicated thermal efficiency at 2 kW load for all test fuels.

For all load tests, $H_2O_2$-Gasoline test fuels showed higher indicated thermal efficiency than gasoline alone at all engine speeds. Furthermore, between 5% and 10% of $H_2O_2$-Gasoline test fuels, the indicated thermal efficiencies were varied due to applied load and engine speeds. This is because indicated thermal efficiency is the ratio of indicated work per cycle to the energy or heat input to the engine. It was noticed at free load, 37.61% of thermal efficiency was achieved which is the highest ITE when the engine used 10%

$H_2O_2$-Gasoline test fuel. As the concentration of hydrogen peroxide increased, the thermal efficiency, $\eta_{th}$ of the engine is increased too (Nagaprasad & Madhu, 2012). So, $H_2O_2$-Gasoline blends displayed better thermal efficiency than gasoline alone to the engine.

The variation of 5% and 10% $H_2O_2$-Gasoline test fuels is due to variation of latent heat of the fuel used (Al-Hasan, 2003). At free load test, indicated thermal efficiency for 10% $H_2O_2$-Gasoline blend and gasoline alone went up from 2500 rpm to 3500 rpm. Oppositely for 5% $H_2O_2$-Gasoline blend, thermal efficiency dropped along the engine speed. While at 2 kW load test, the pattern of ITE for each test fuel is different than at free load test. This is because thermal efficiency, $\eta_{th}$ is affected work per cycle, mass of test fuel used per cycle, calorific value of test fuel and combustion efficiency. Variation of indicated thermal efficiency at other load tests are attached in the **Appendix F**.

### 4.2.7 Indicated Specific Fuel Consumption

Specific fuel consumption (SFC) measures how efficiently an engine is using the fuel supplied to produce work (Heywood, 1988). The effects of $H_2O_2$-Gasoline blends on indicated specific fuel consumption (ISFC) at all engine speeds for free and 2 kW load tests are illustrated in **Figure 30** and **Figure 31** respectively.



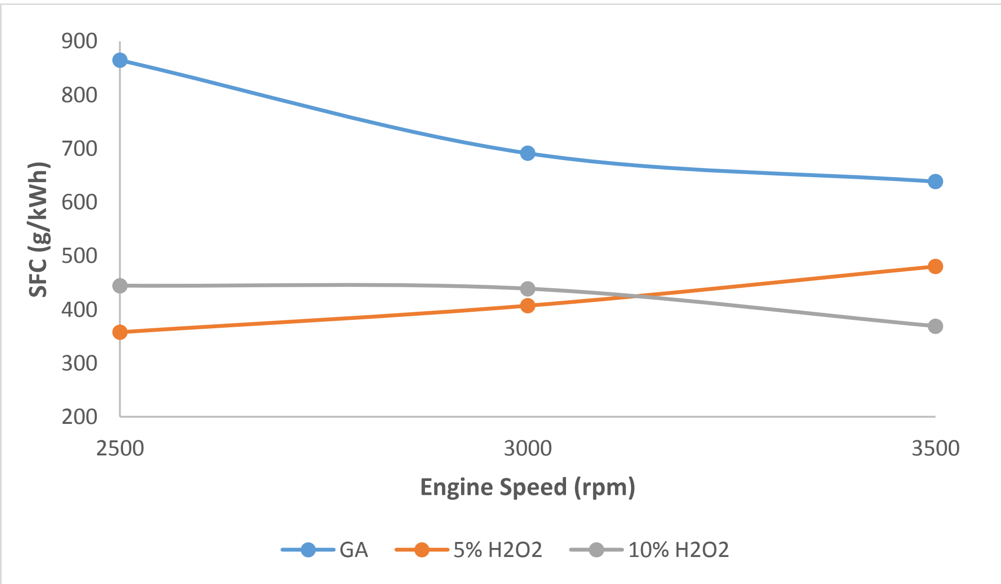


**Figure 30:** Variation of indicated specific fuel consumption at free load for all test fuels.

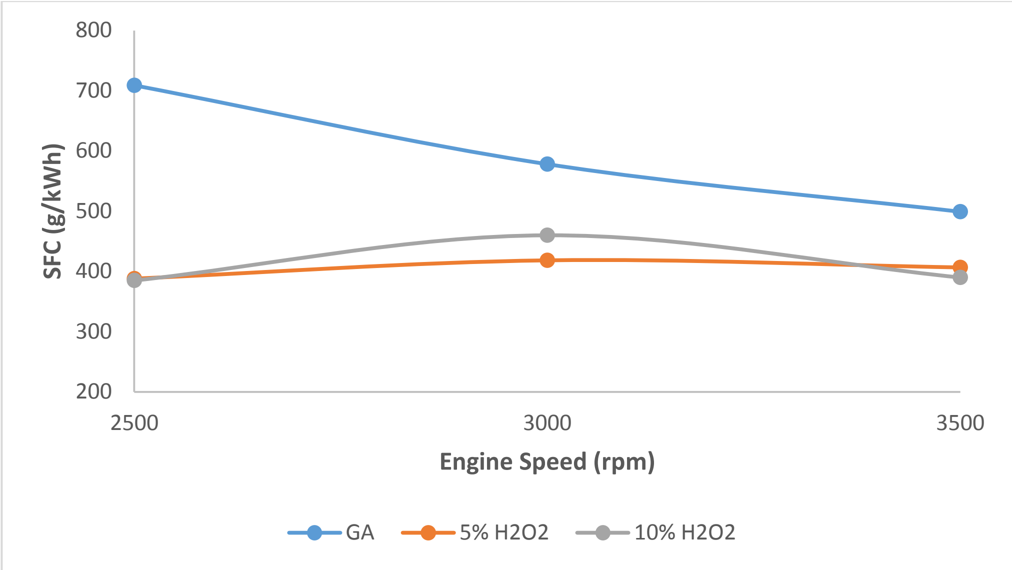


**Figure 31:** Variation of indicated specific fuel consumption at 2 kW load for all test fuels.

Gasoline alone showed the highest SFC especially on high engine speeds and loads. Low value of SFC is desirable. At both load tests, it is discovered that hydrogen peroxide-gasoline fuel blends have lower ISFC than gasoline alone. At 2500 rpm and free load, 5% $H_2O_2$-Gasoline fuel blend showed 58.63% decrease in ISFC than gasoline despite its low calorific value. This is because of higher combustion efficiency owing to higher oxygen atom (Baskar & Senthilkumar, 2016).

10% of $H_2O_2$-Gasoline fuel blend showed the biggest differences in ISFC which is 48.76% when compared to gasoline alone at 2500 rpm. At 3500 rpm, lowest ISFC displayed for 10% $H_2O_2$-Gasoline test fuel which were 368.75 g/kWh for free load and 389.96 g/kWh for 2 kW load tests. This is due to the highest ITE displayed for the 10 10% $H_2O_2$-Gasoline test fuel at given engine speed and load tests.

At free load test, the specific fuel consumption for 5% hydrogen peroxide-gasoline blend is increased as the engine speed increased. This is due to decrease in indicated thermal efficiency of engine. Hence, higher thermal efficiency results in lower specific fuel consumption. Variation of indicated specific fuel consumption at other load tests are attached in the **Appendix G**.

## CHAPTER 5

## CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

In this project, the engine runs successfully up to load of 2 kW at 3500 rpm without any difficulties. However, if the engine speed is increased more than 3500 rpm, halogen bulb of the spotlight most likely will burnt out. Also, the engine runs successfully with 10% of hydrogen peroxide in fuel blend without getting any problems. However, with 20% hydrogen peroxide in fuel blend, most likely test engine will not be able to start up.

The main objective of this project was to study the effects of hydrogen peroxide on engine performance parameters like in-line cylinder pressure, heat release rate, indicated work per cycle, indicated power, indicated thermal efficiency and indicated specific fuel consumption. Then, results from engine performance analysis for $H_2O_2$-Gasoline fuel blends were compared to gasoline alone. All $H_2O_2$-Gasoline blends showed massive improvement in engine performances compared to gasoline under all test conditions.

The study showed that 61.1% increment in indicated thermal efficiency for 10% $H_2O_2$-Gasoline blend at 2500 rpm and free load test when compared to gasoline alone. The study also showed 58.63% drop in indicated specific fuel consumption which was the highest for 5% $H_2O_2$-Gasoline blend at 2500 rpm and free load test when compared to gasoline alone.

There were slightly differences in the performance parameters between 5% and 10% $H_2O_2$-Gasoline fuel blends. The maximum differences were 33.8% and 30.3% in indicated thermal efficiency and indicated specific fuel consumption respectively for 10% $H_2O_2$-Gasoline blend at 3500 rpm and free load test compared to 5% $H_2O_2$-Gasoline blend. The test engine displayed better performance characteristics for $H_2O_2$-Gasoline blends at all engine speeds and load tests.

Third objective of this study was to determine fuel blends that give best performance to the engine. Based on the results and discussion, test engine displayed the best performance characteristic with 10% $H_2O_2$-Gasoline blend for free and full load tests at all engine speeds. Last objective of this study was to determine fuel blend that display optimum engine performance. According to analyzed results, since there was not too much differences in performance characteristics between 5% and 10% of hydrogen peroxide in fuel blend, 5% $H_2O_2$-Gasoline blend is chosen.

On the whole, it can be concluded that the engine performance had improved with blending off hydrogen peroxide with gasoline for petrol engine.



## 5.2 Future Recommendations

Some areas in this study which respect to blending off hydrogen peroxide with gasoline and engine performance testing need further attention as follows.

i. A further study on blending off hydrogen peroxide with gasoline is needed with better methodology such as usage of proper emulsifier and stabilizer so the blend is stabilized and its calorific value is not dropped.

ii. Further study on engine performance testing with a brake unit such as water pump or a dynamometer is really needed as well. So the performance analysis will be more accurate because mechanical efficiency can be identified since there are indicated and brake performance parameters.

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## APPENDIX A

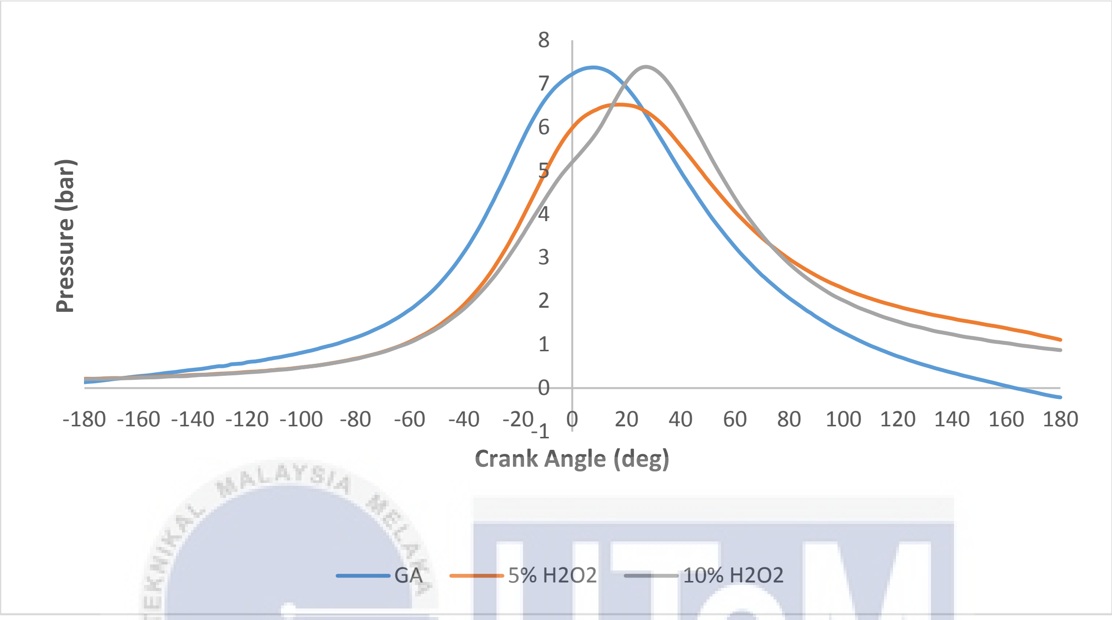


Figure A1: In-cylinder pressure for al test fuels at 2500 rpm and free load



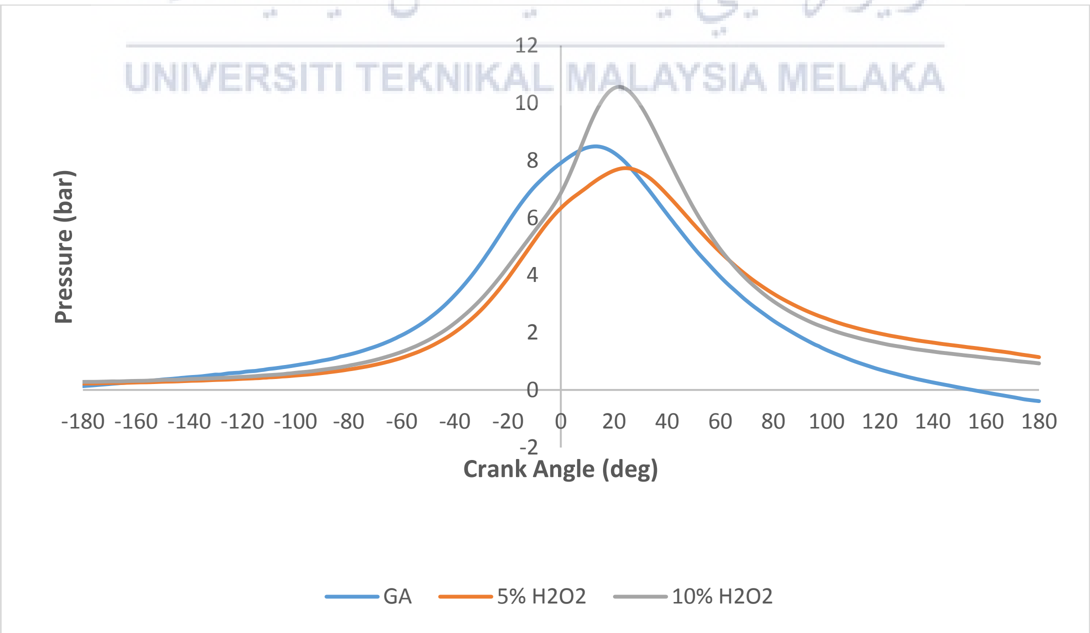


Figure A2: In-cylinder pressure for al test fuels at 2500 rpm and 500 W load

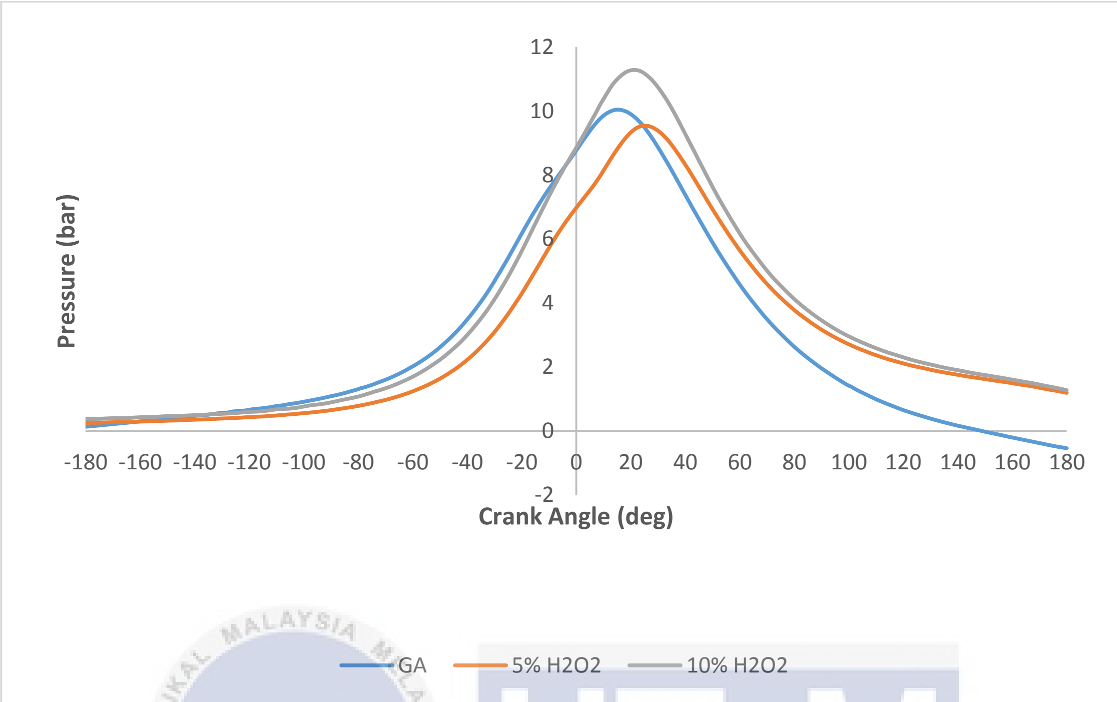


Figure A3: In-cylinder pressure for al test fuels at 2500 rpm and 1 kW load.



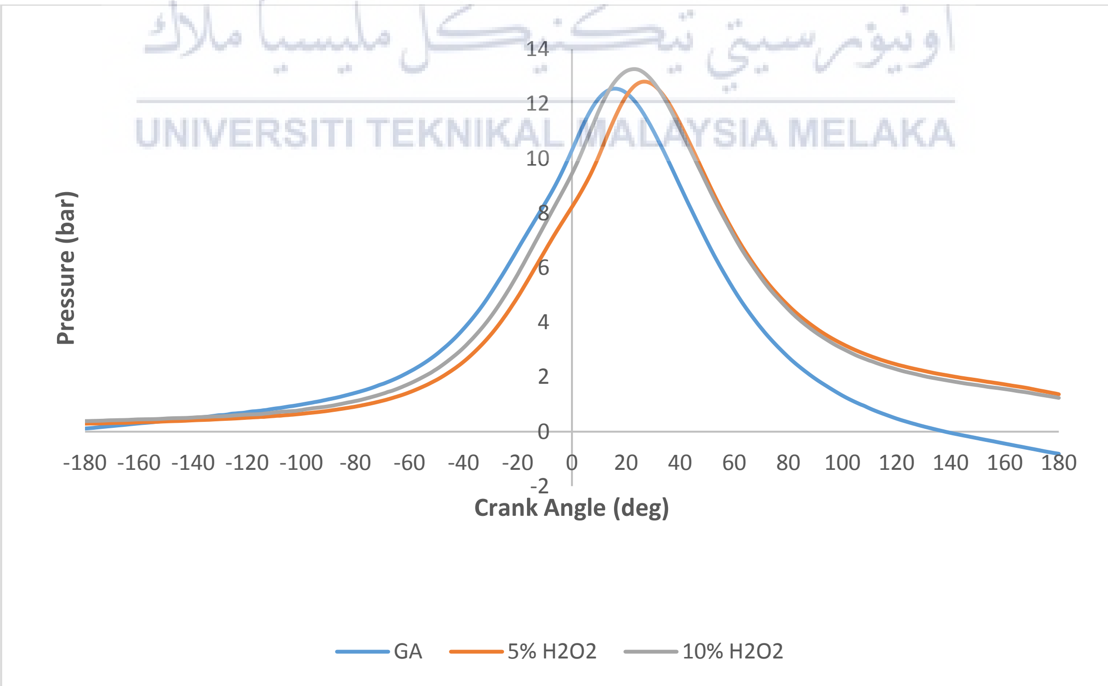


Figure A4: In-cylinder pressure for al test fuels at 2500 rpm and 1.5 kW load.

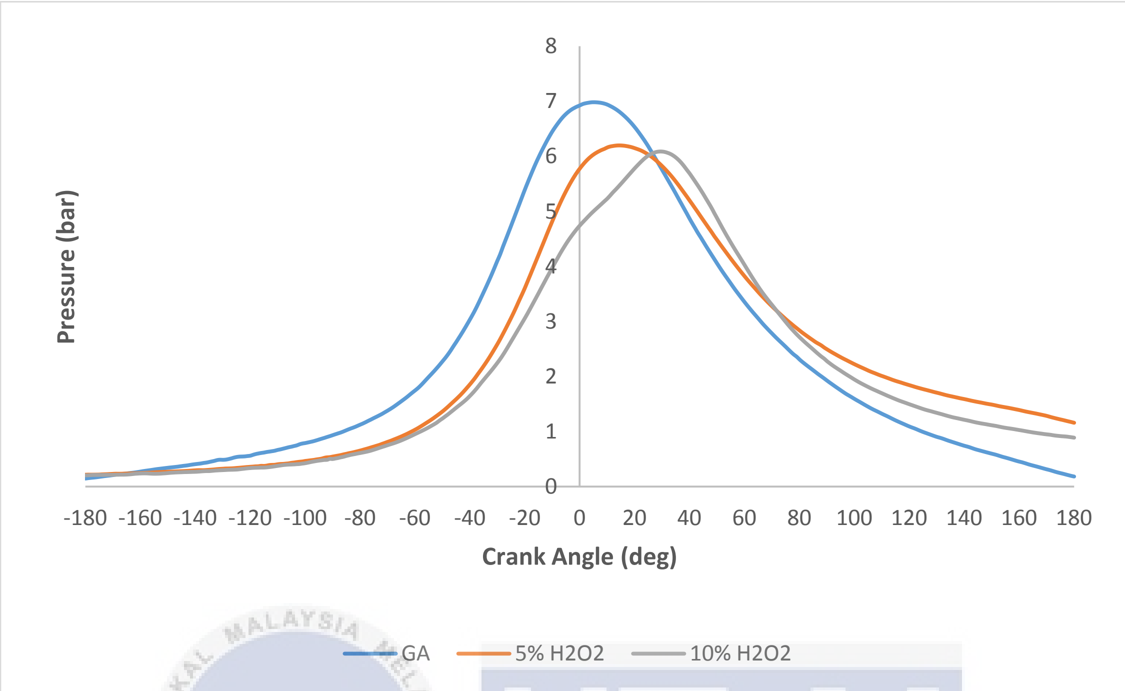


Figure A5: In-cylinder pressure for al test fuels at 3000 rpm and free load.



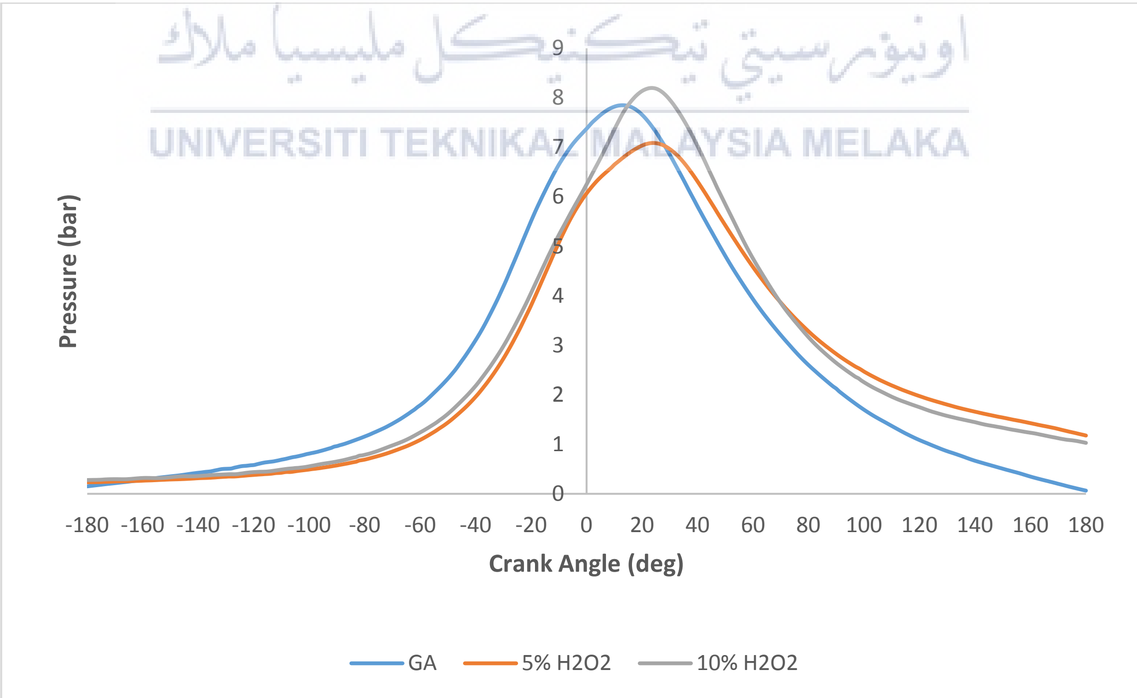


Figure A6: In-cylinder pressure for al test fuels at 3000 rpm and 500 W load

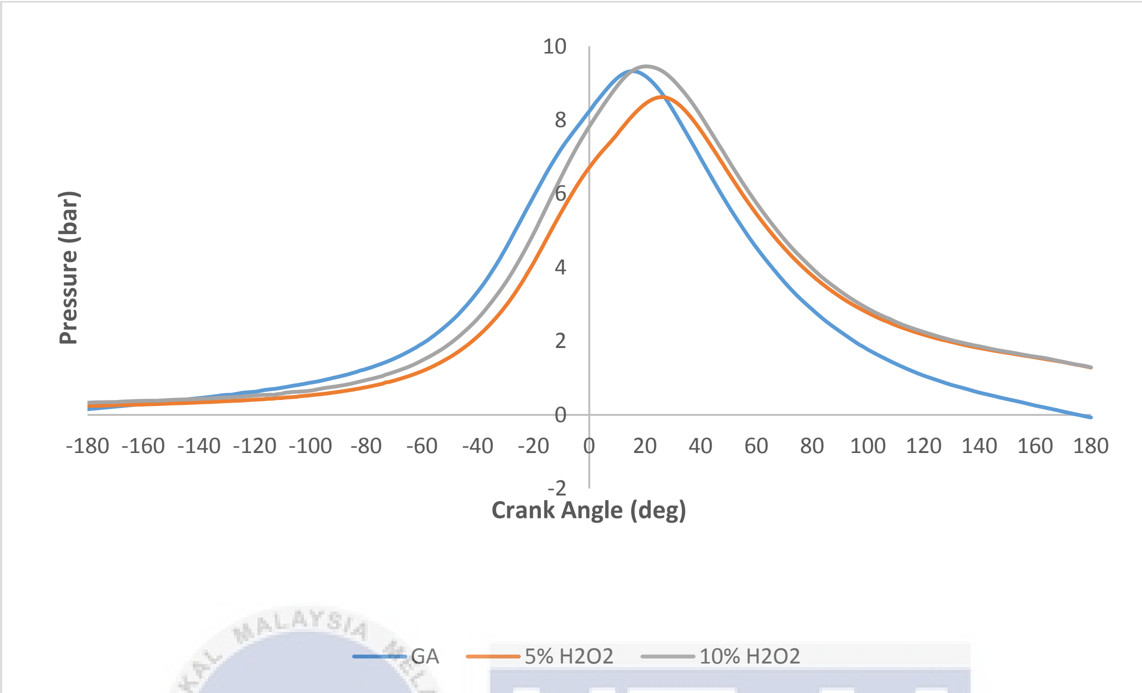


Figure A7: In-cylinder pressure for al test fuels at 3000 rpm and 1 kW load



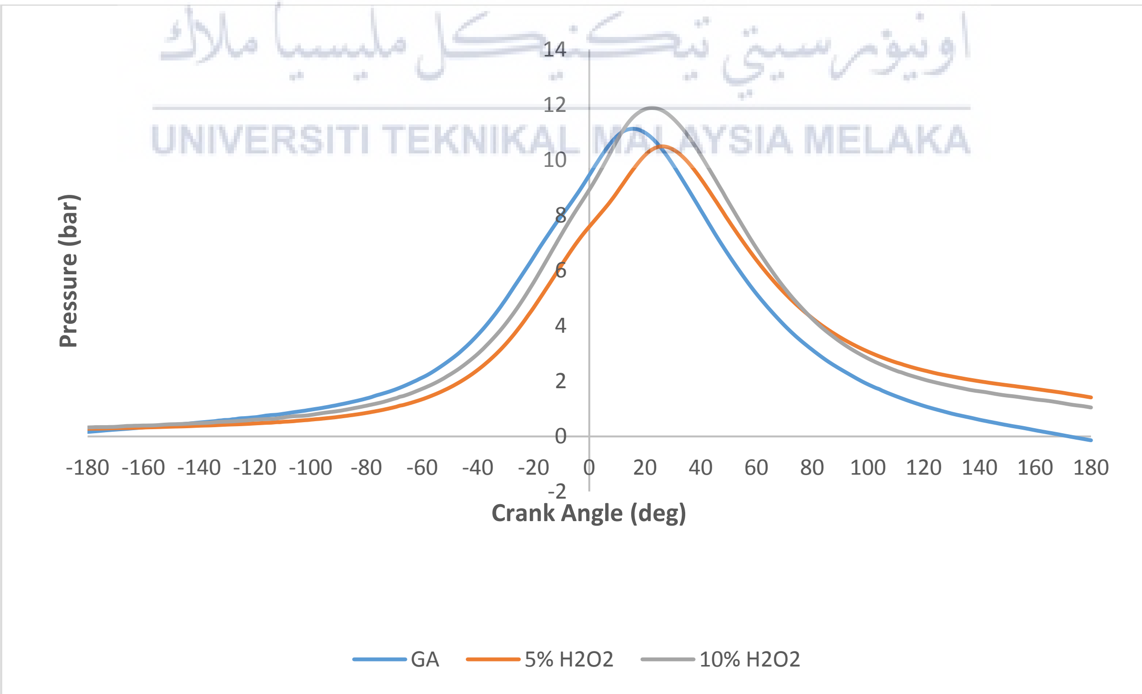


Figure A8: In-cylinder pressure for al test fuels at 3000 rpm and 1.5 kW load

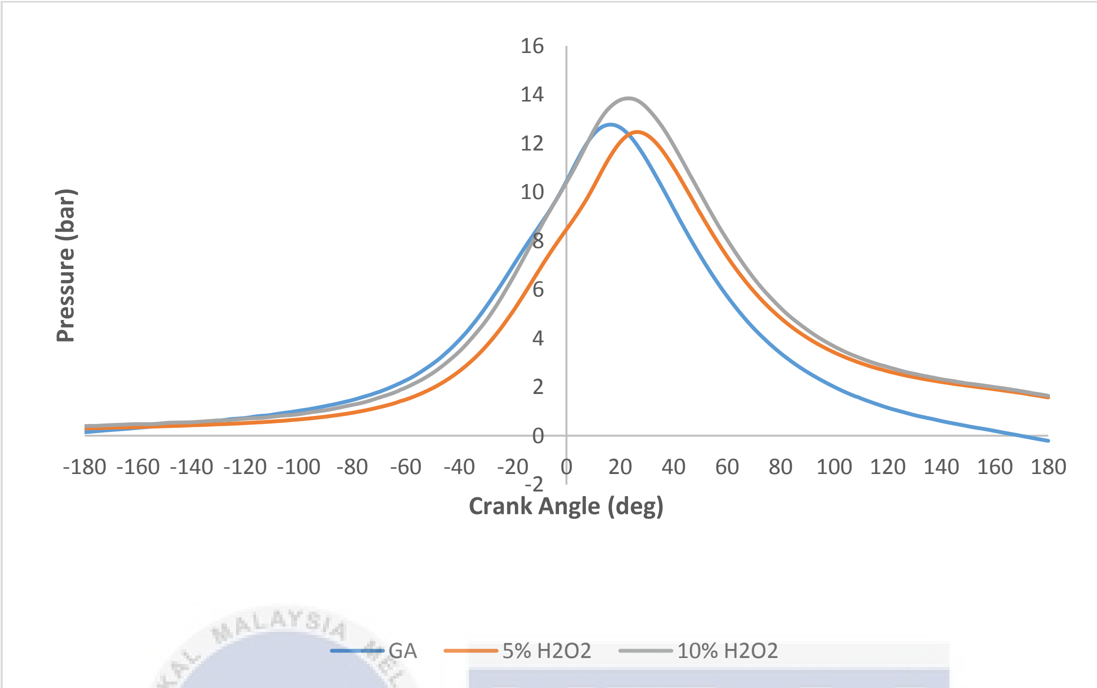


Figure A9: In-cylinder pressure for al test fuels at 3000 rpm and 2 kW load



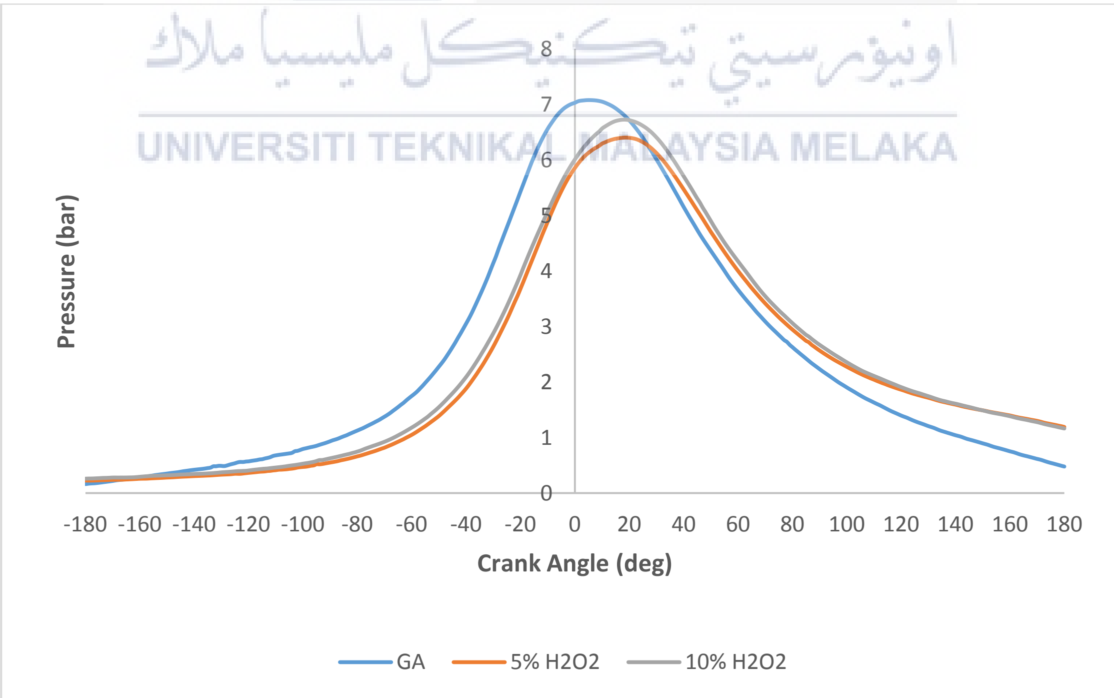


Figure A10: In-cylinder pressure for al test fuels at 3500 rpm and free load

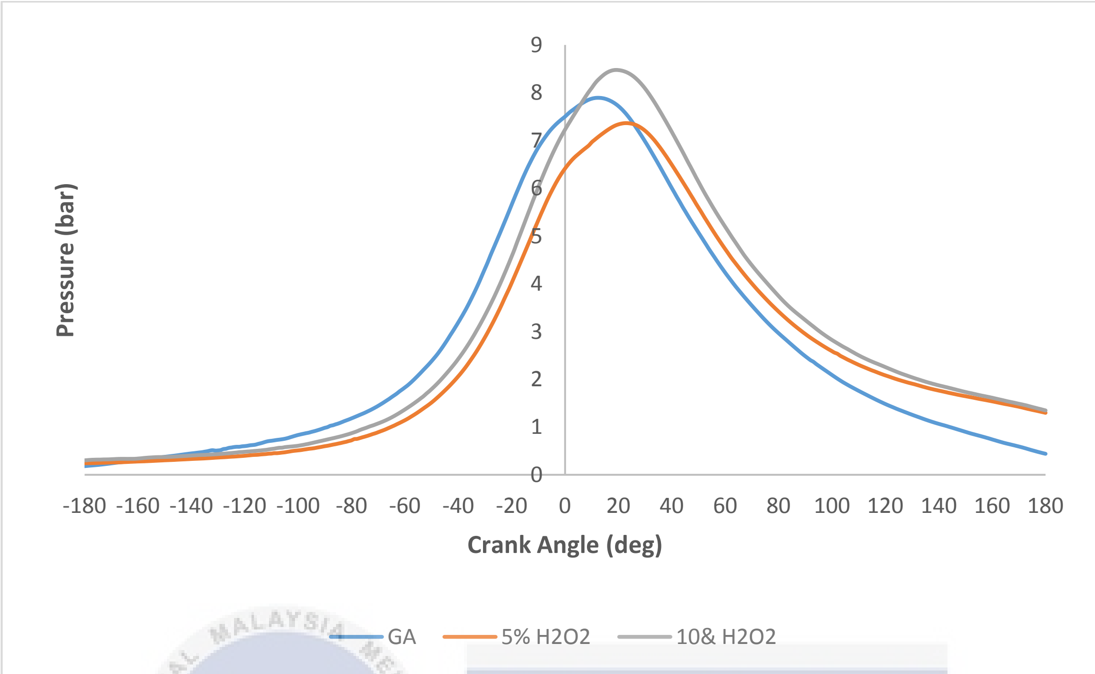


Figure A11: In-cylinder pressure for al test fuels at 3500 rpm and 500 W load



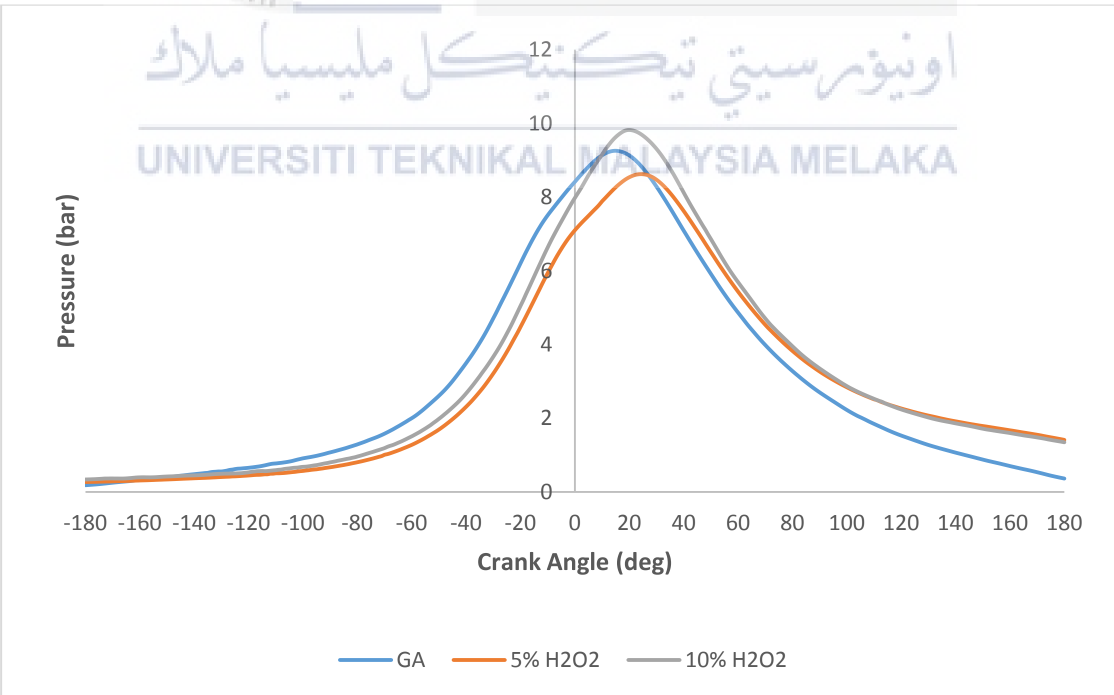


Figure A12: In-cylinder pressure for al test fuels at 3500 rpm and 1 kW load

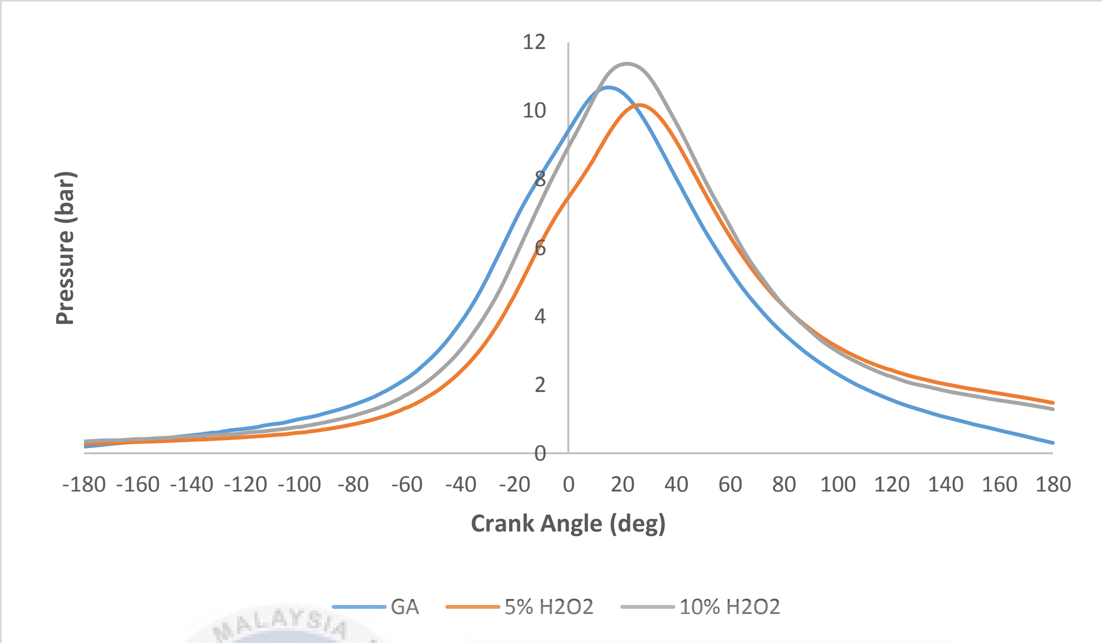


Figure A13: In-cylinder pressure for al test fuels at 3500 rpm and 1.5 kW load



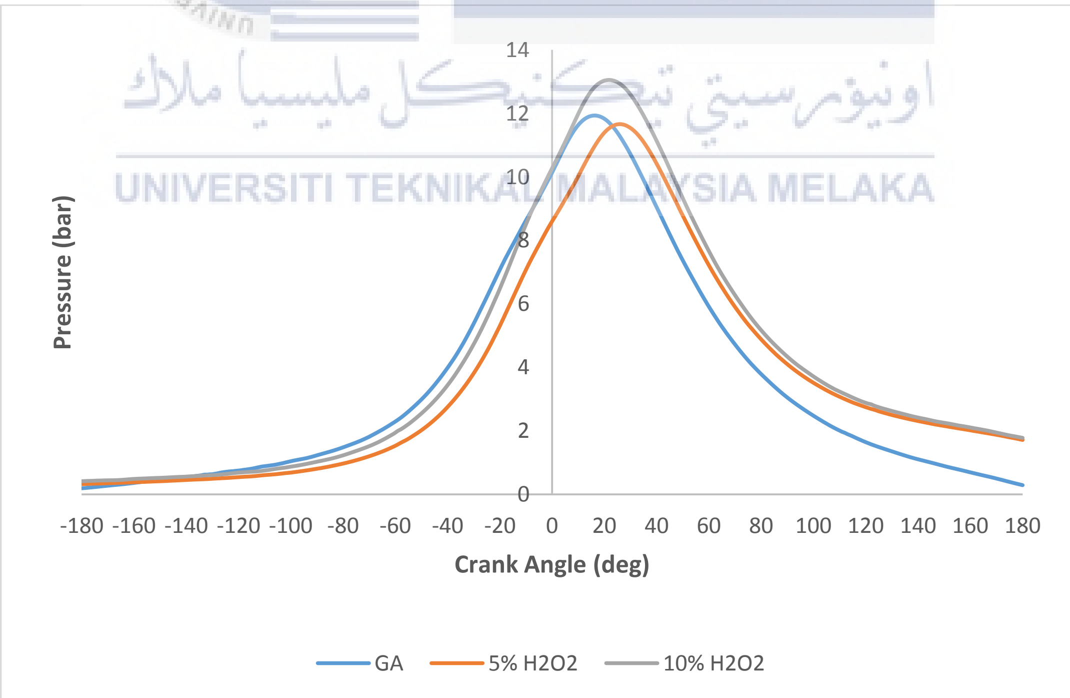


Figure A14: In-cylinder pressure for al test fuels at 3500 rpm and 2 kW load

## APPENDIX B

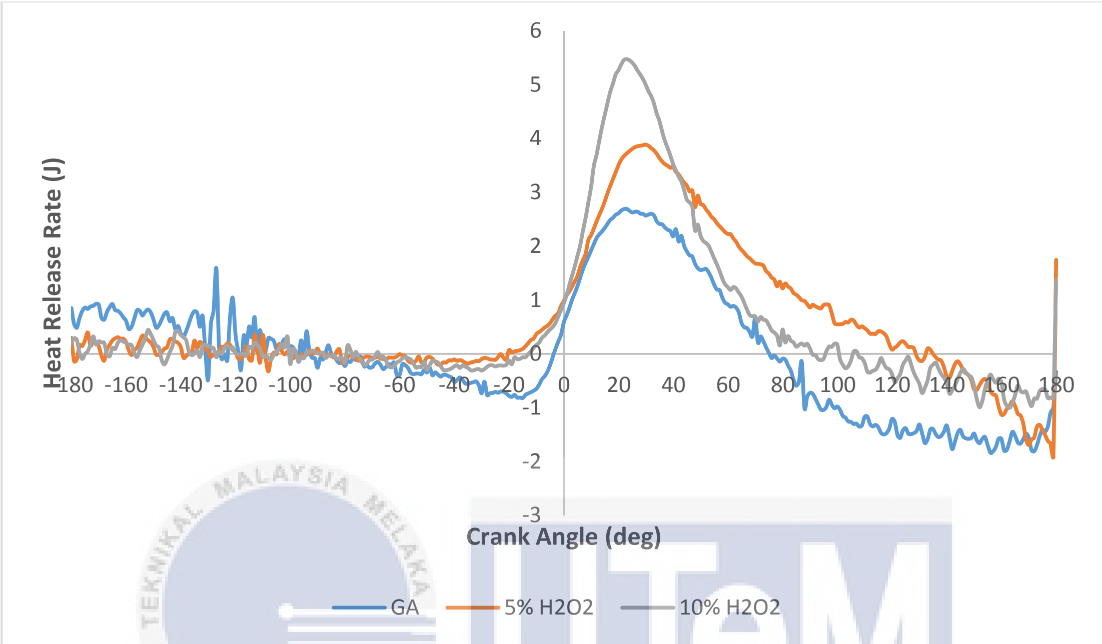


Figure B1: Heat release rate for all test fuels at 2500 rpm and free load



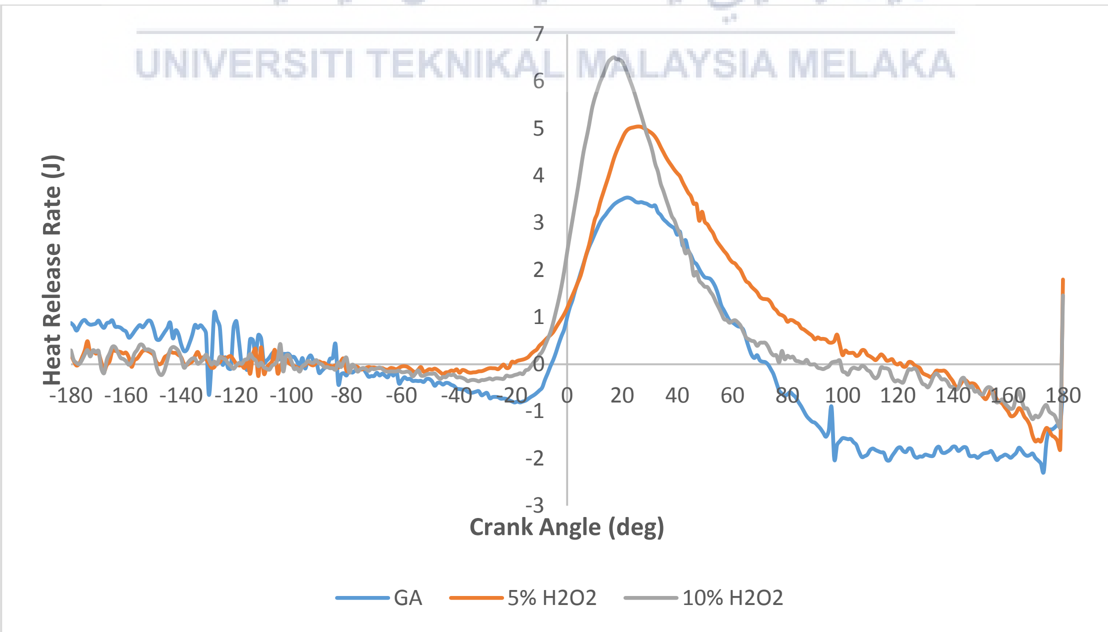


Figure B2: Heat release rate for all test fuels at 2500 rpm and 500 W load

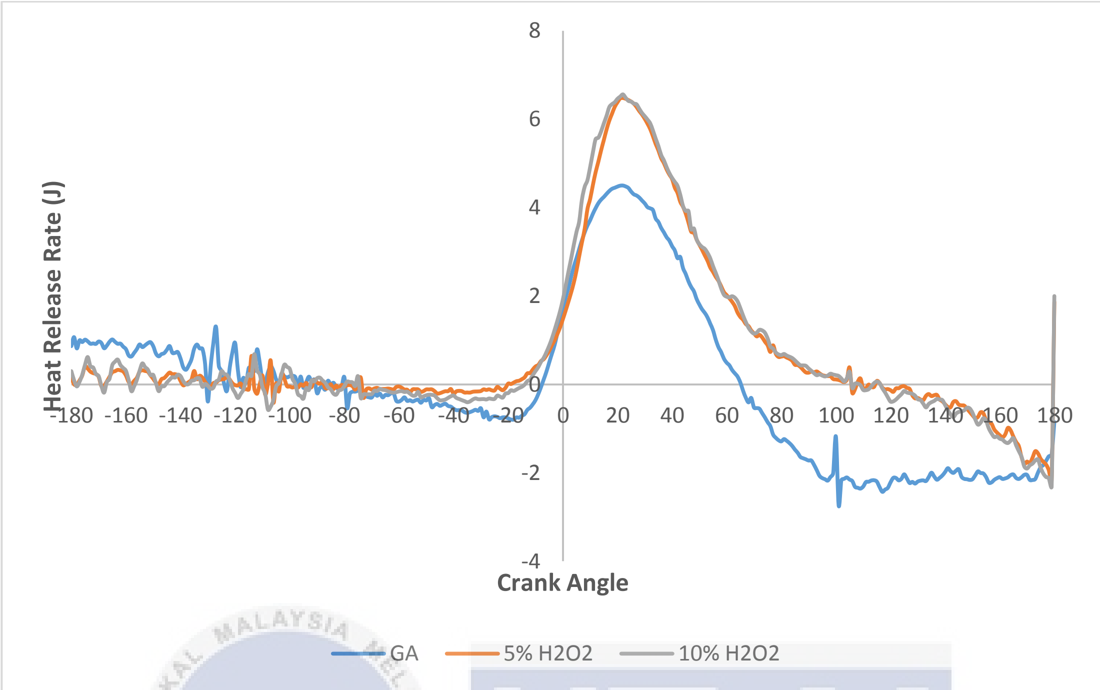


Figure B3: Heat release rate for all test fuels at 2500 rpm and 1 kW load



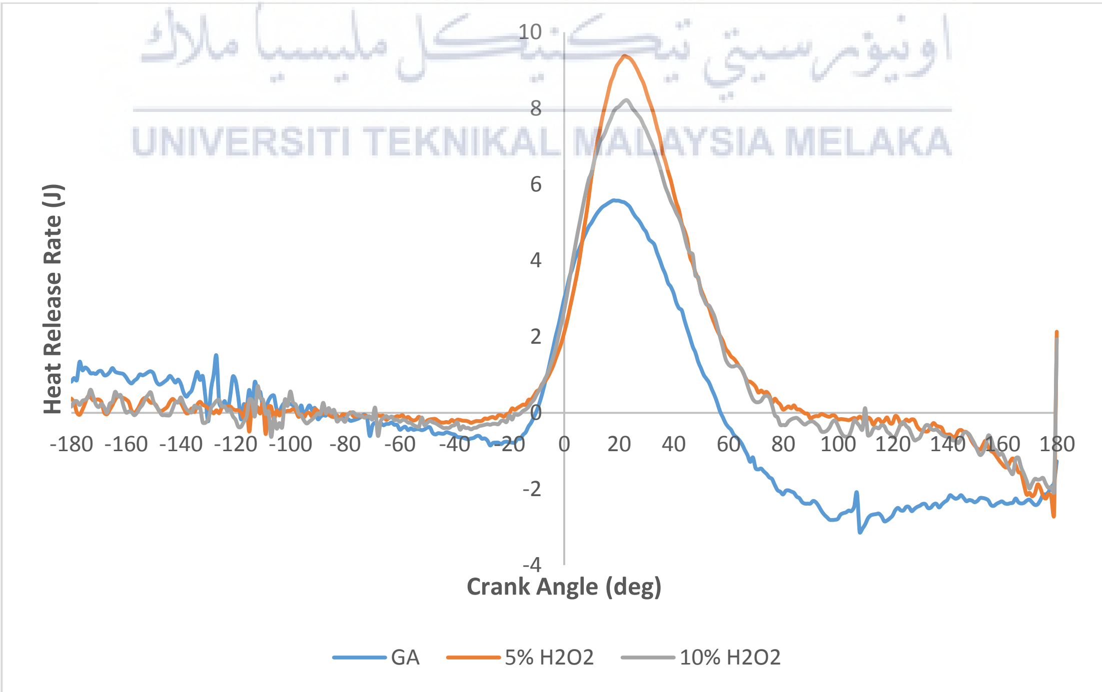


Figure B4: Heat release rate for all test fuels at 2500 rpm and 1.5 kW load

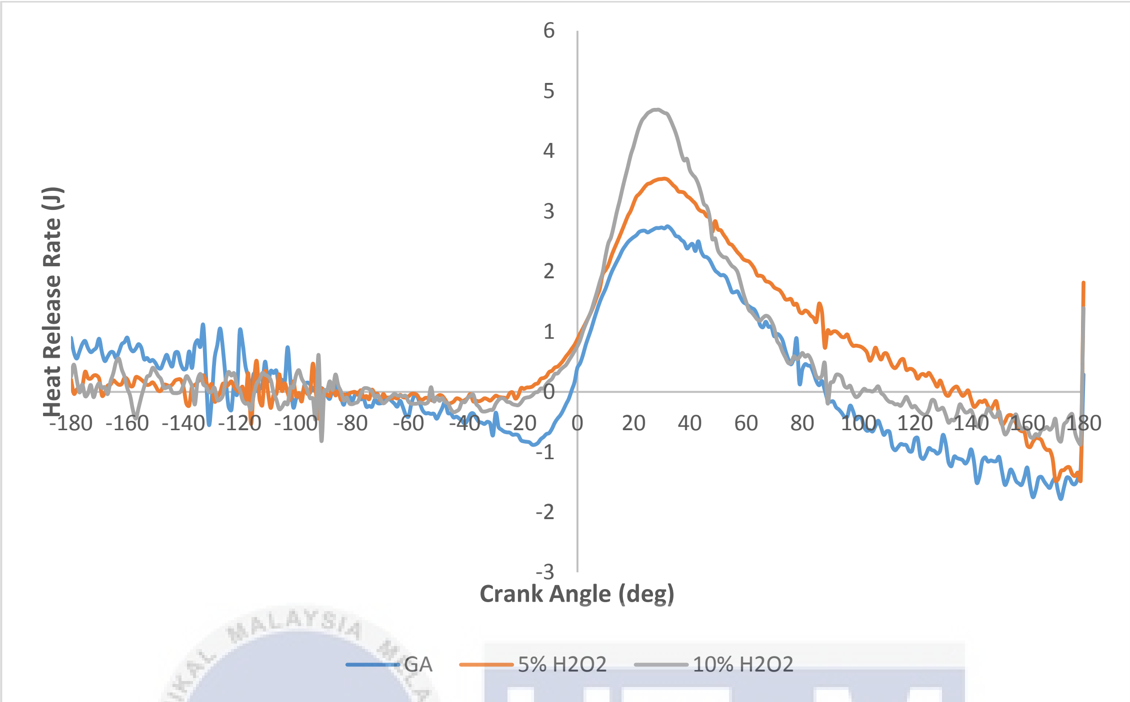


Figure B5: Heat release rate for all test fuels at 3000 rpm and free load



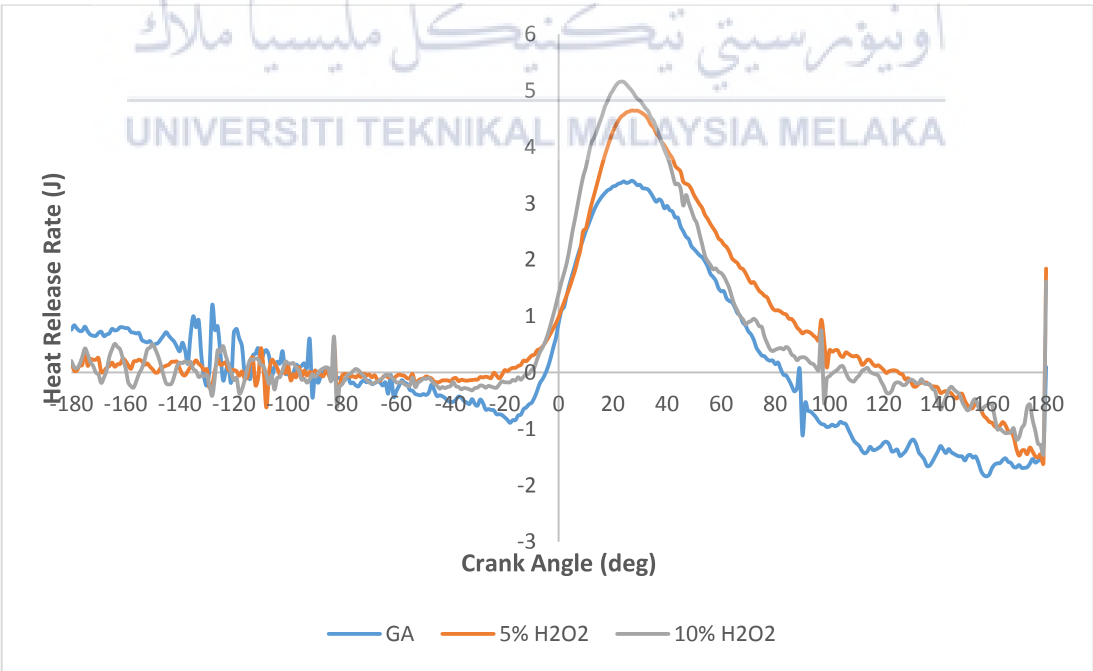


Figure B6: Heat release rate for all test fuels at 3000 rpm and 500 W load

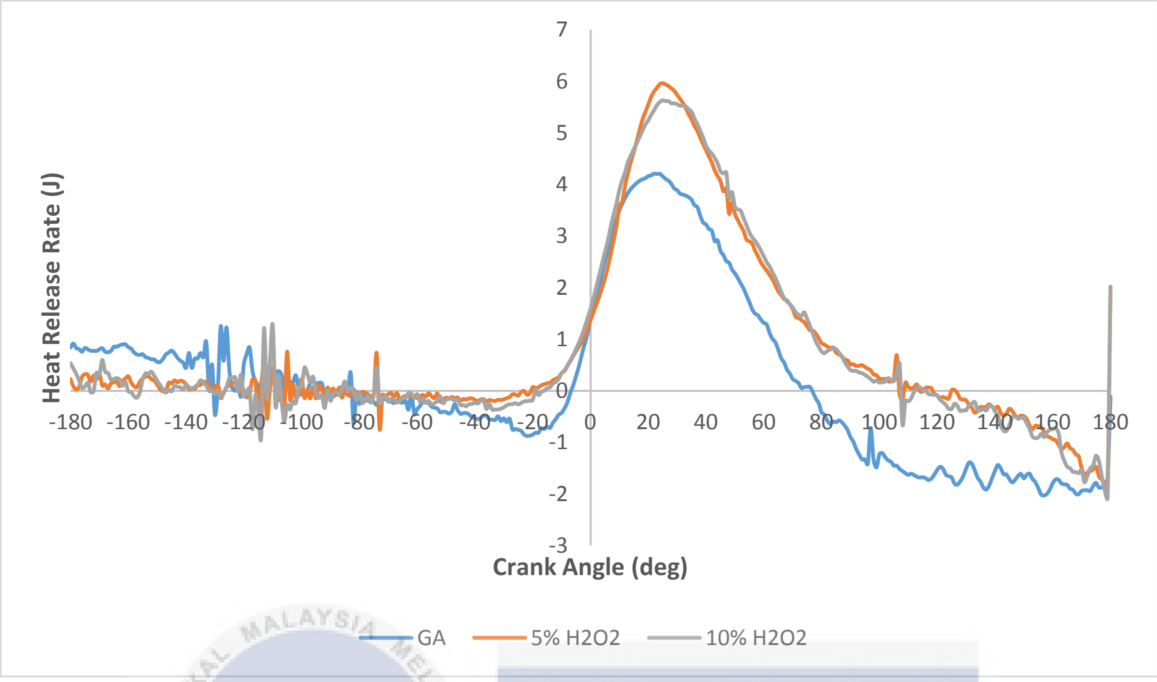


Figure B7: Heat release rate for all test fuels at 3000 rpm and 1 kW load



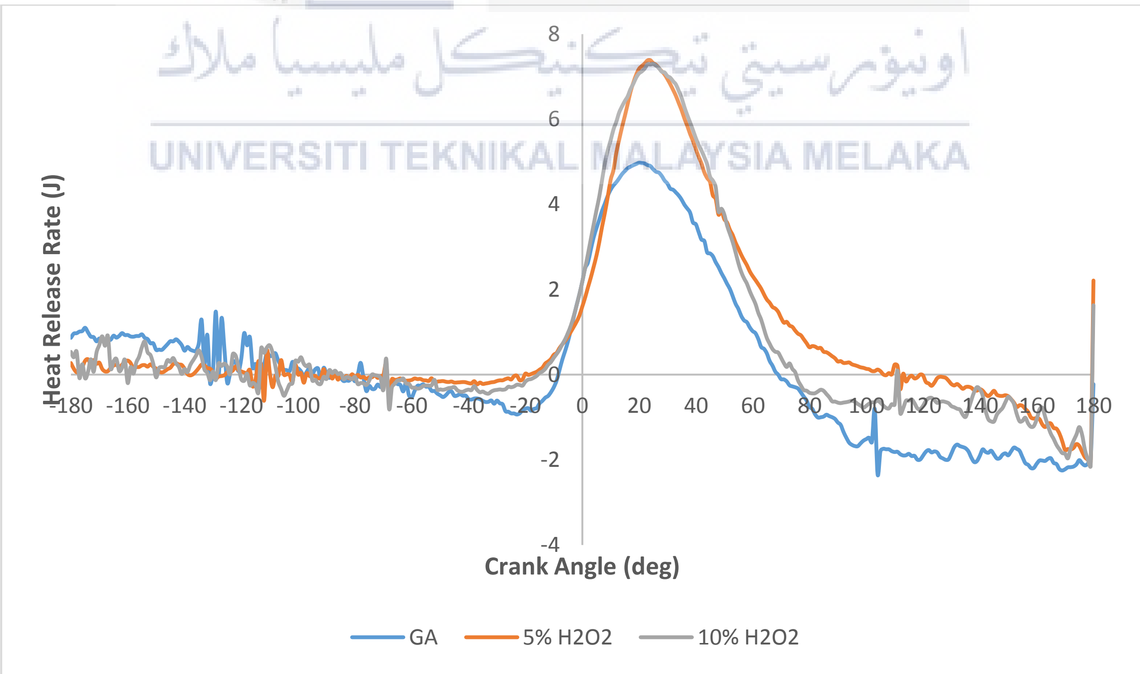


Figure B8: Heat release rate for all test fuels at 3000 rpm and 1.5 kW load

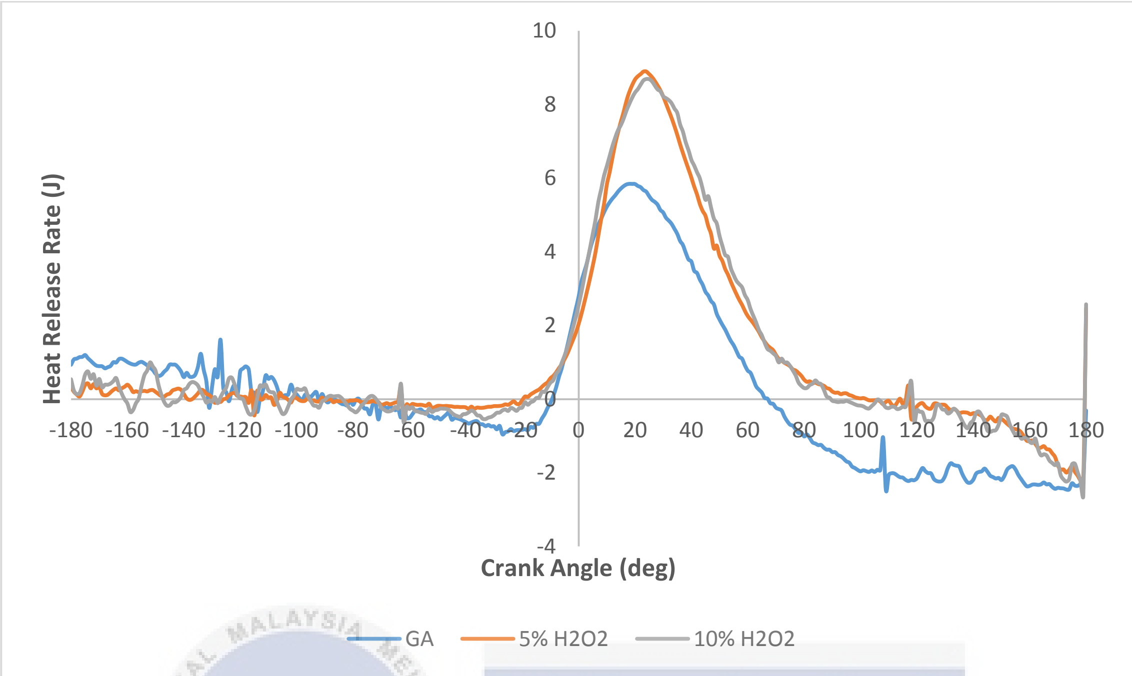


Figure B9: Heat release rate for all test fuels at 3000 rpm and 2 kW load



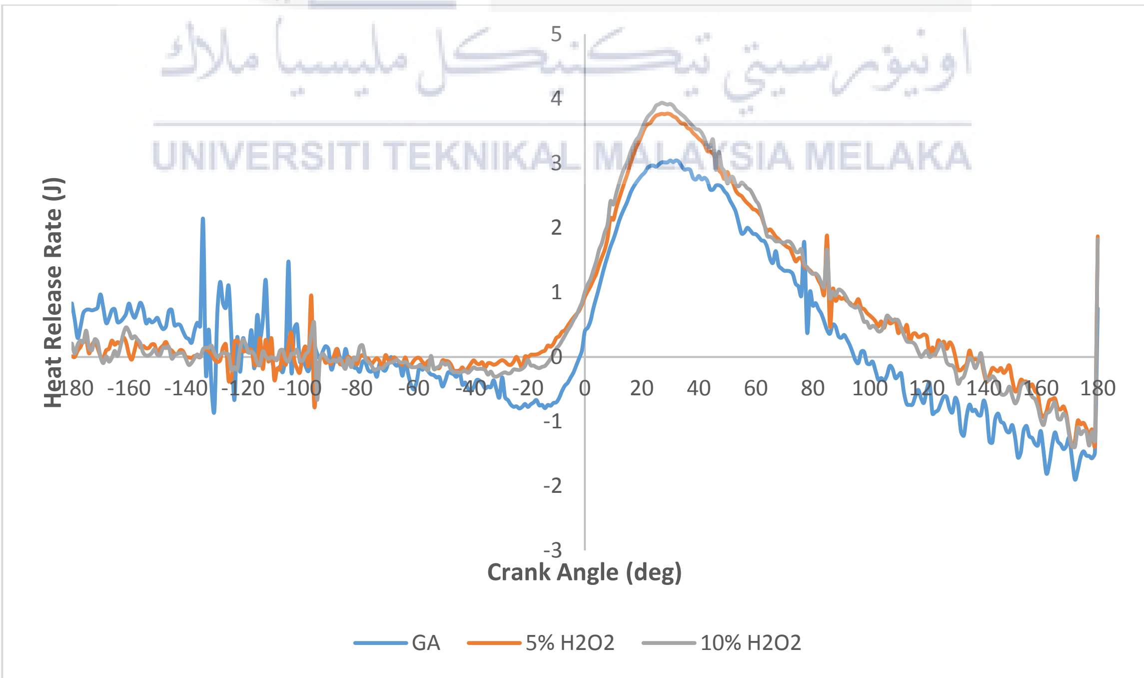


Figure B10: Heat release rate for all test fuels at 3500 rpm and free load

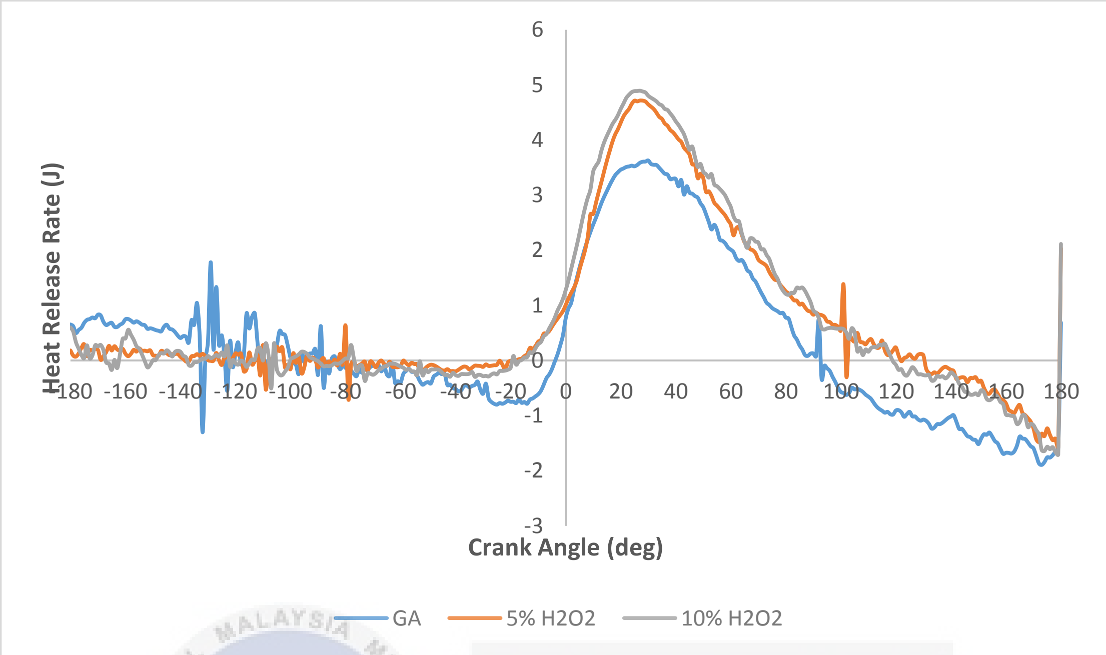


Figure B11: Heat release rate for all test fuels at 3500 rpm and 500 W load



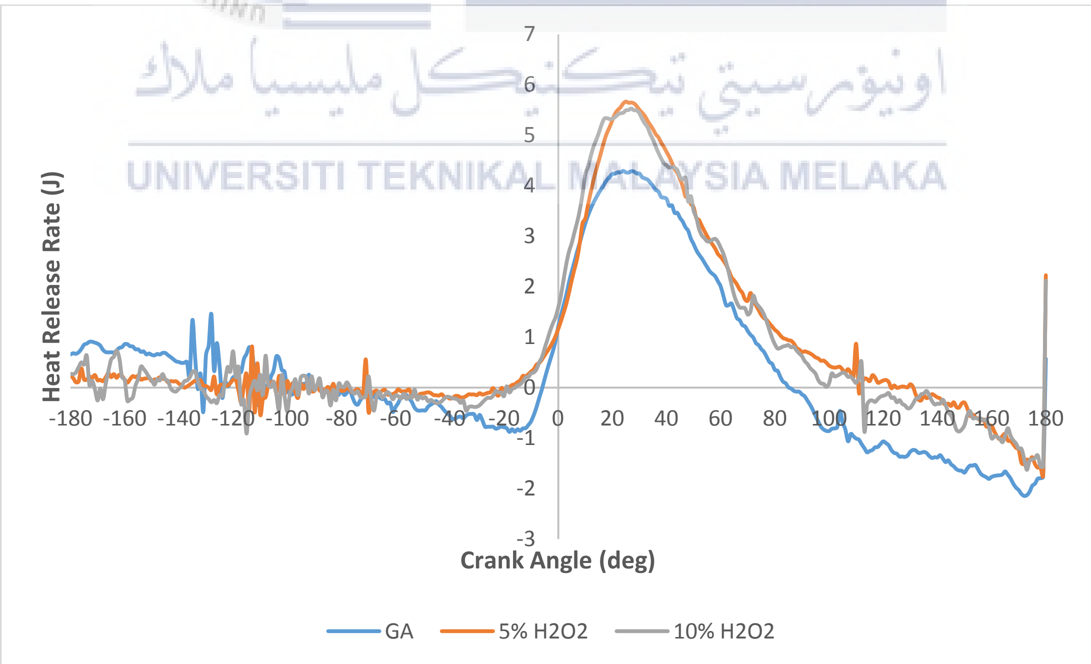


Figure B12: Heat release rate for all test fuels at 3500 rpm and 1 kW load

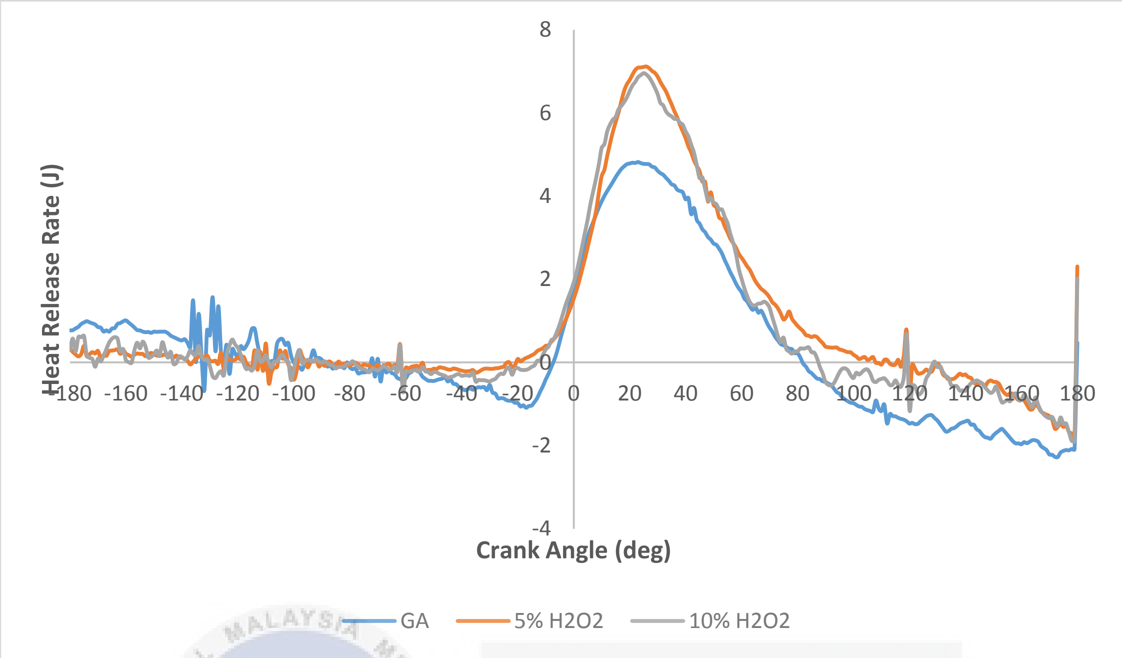


Figure B13: Heat release rate for all test fuels at 3500 rpm and 1.5 kW load



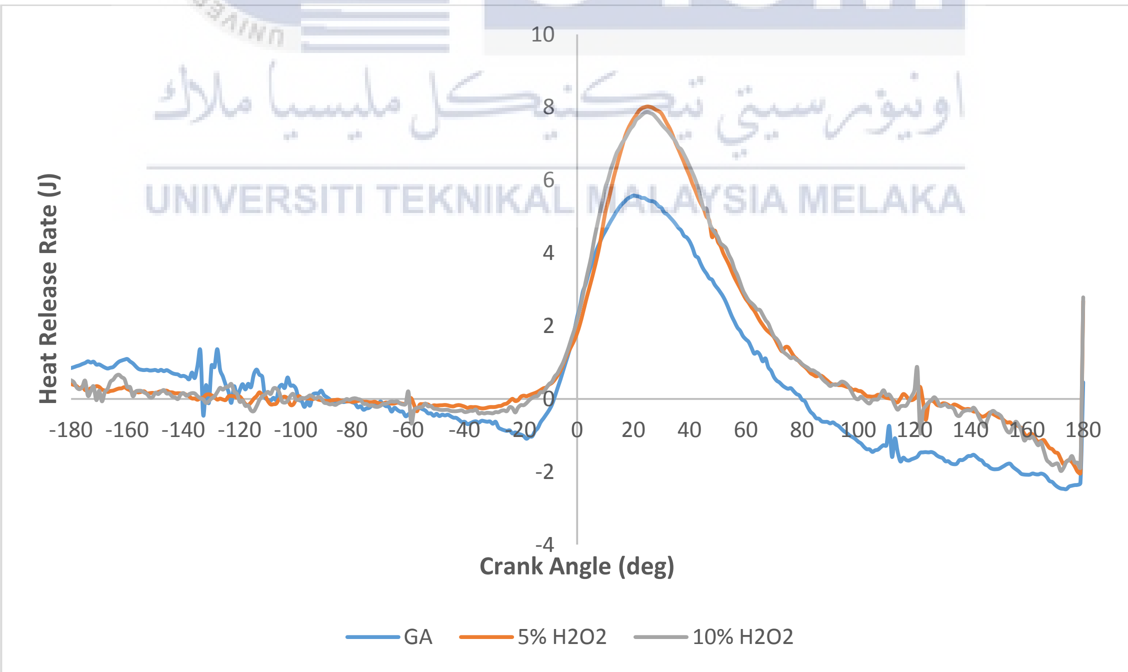


Figure B14: Heat release rate for all test fuels at 3500 rpm and 2 kW load

## APPENDIX C

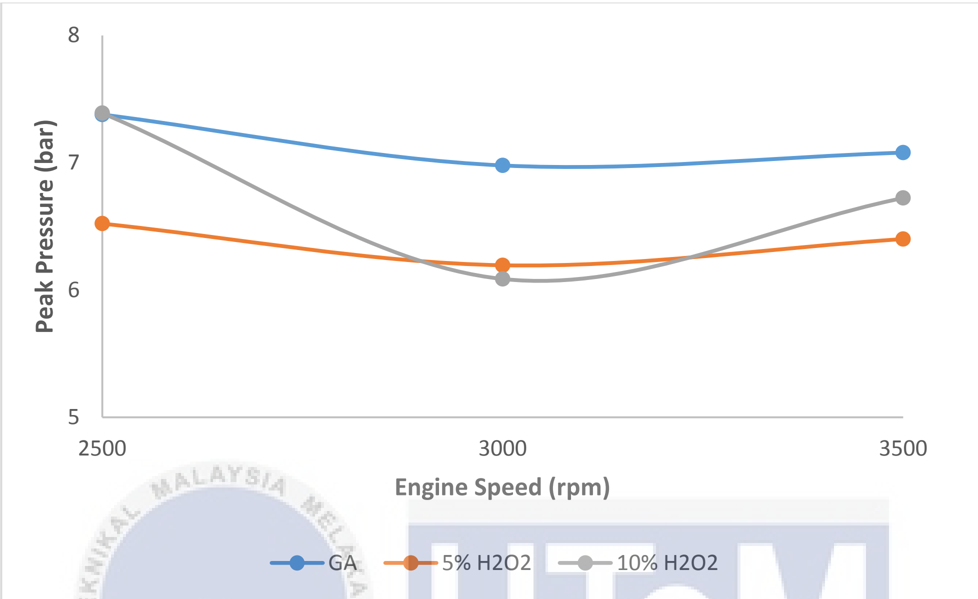


Figure C1: Variation of peak pressure at free load for all test fuels.



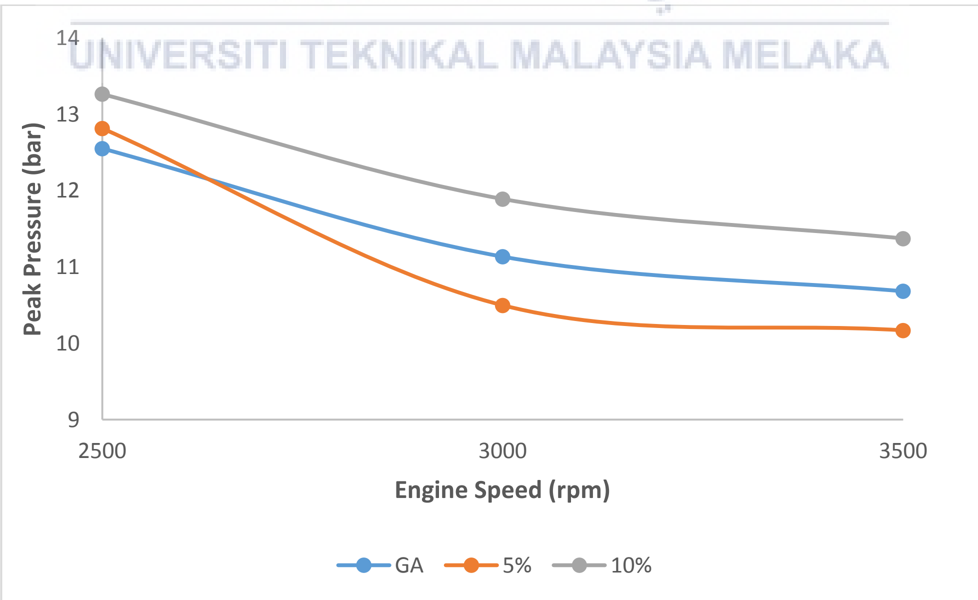


Figure C2: Variation of peak pressure at 1.5 kW load for all test fuels.

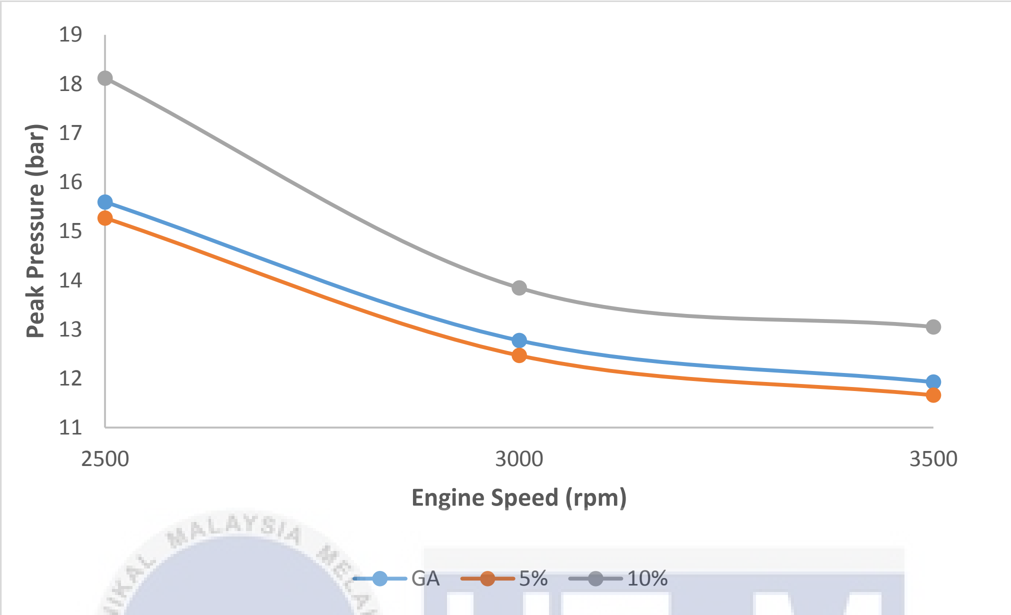


Figure C3: Variation of peak pressure at 2 kW load for all test fuels.

# APPENDIX D

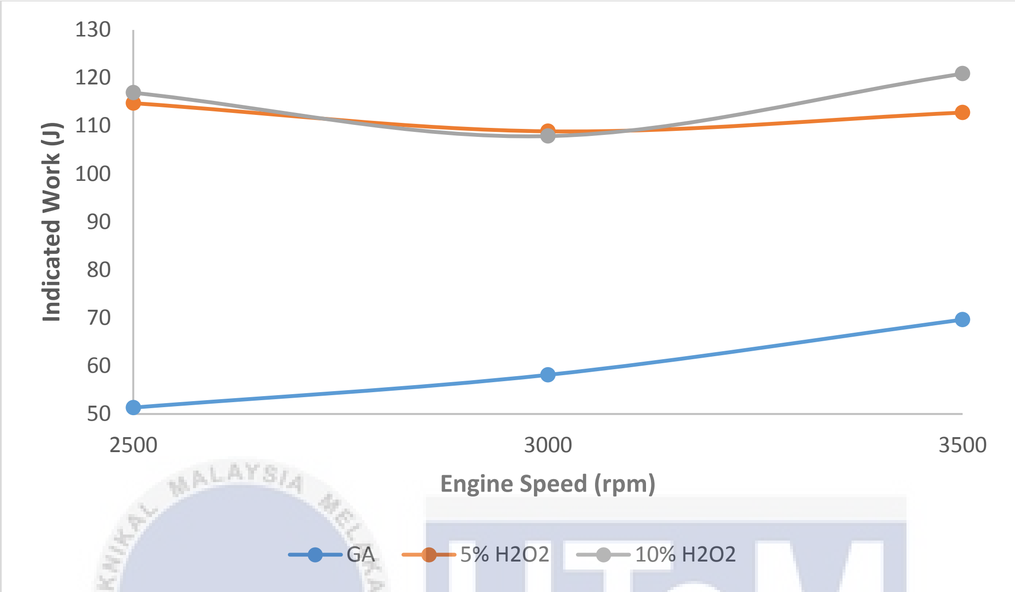


Figure D1: Variation of gross indicated work per cycle at 500 W load for all test fuels



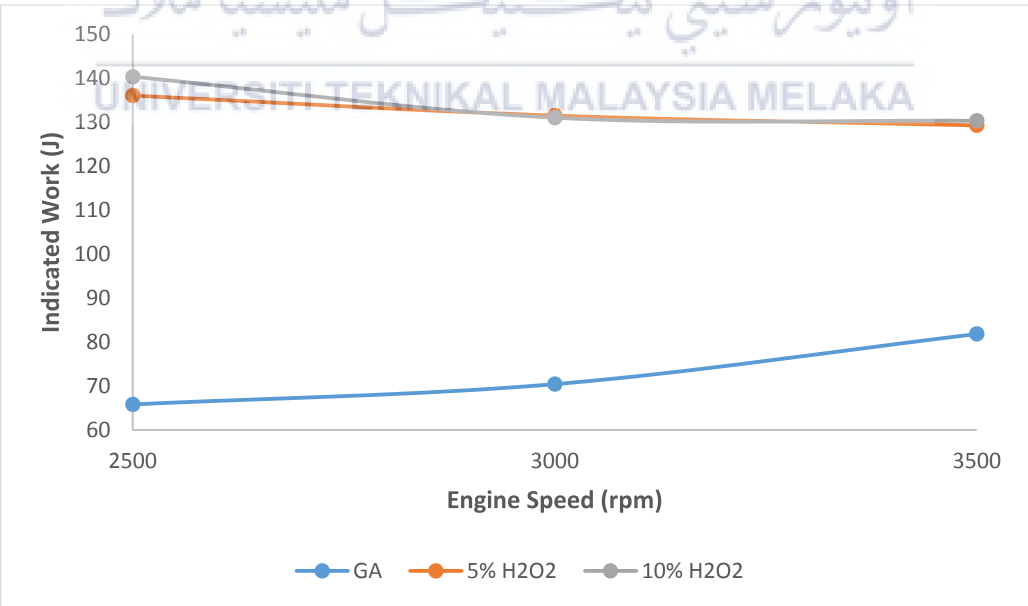


Figure D2: Variation of gross indicated work per cycle at 1 kW load for all test fuels

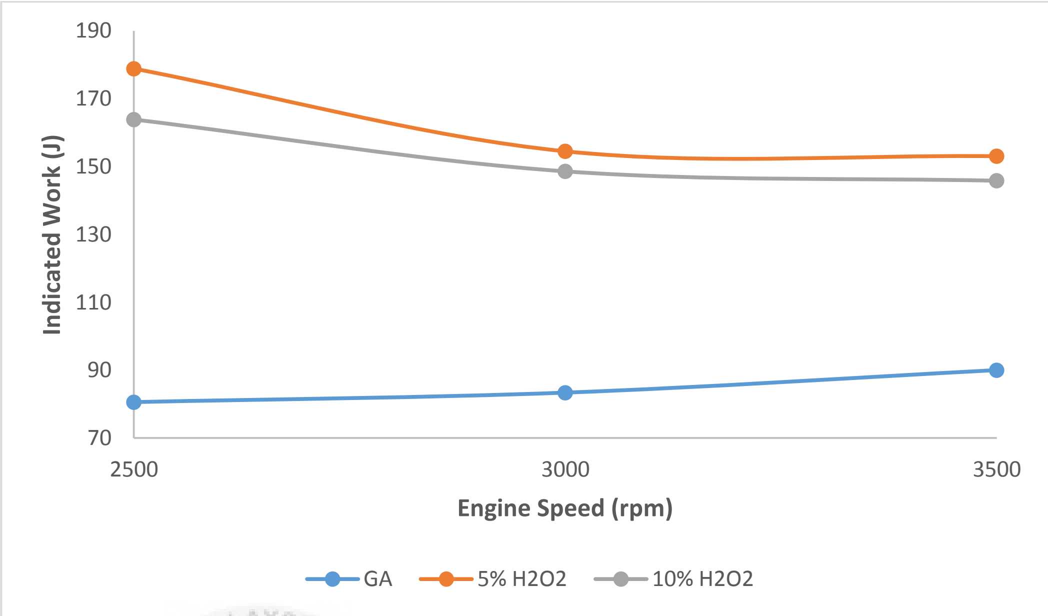


Figure D3: Variation of gross indicated work per cycle at 1.5 kW load for all test fuels

# APPENDIX E

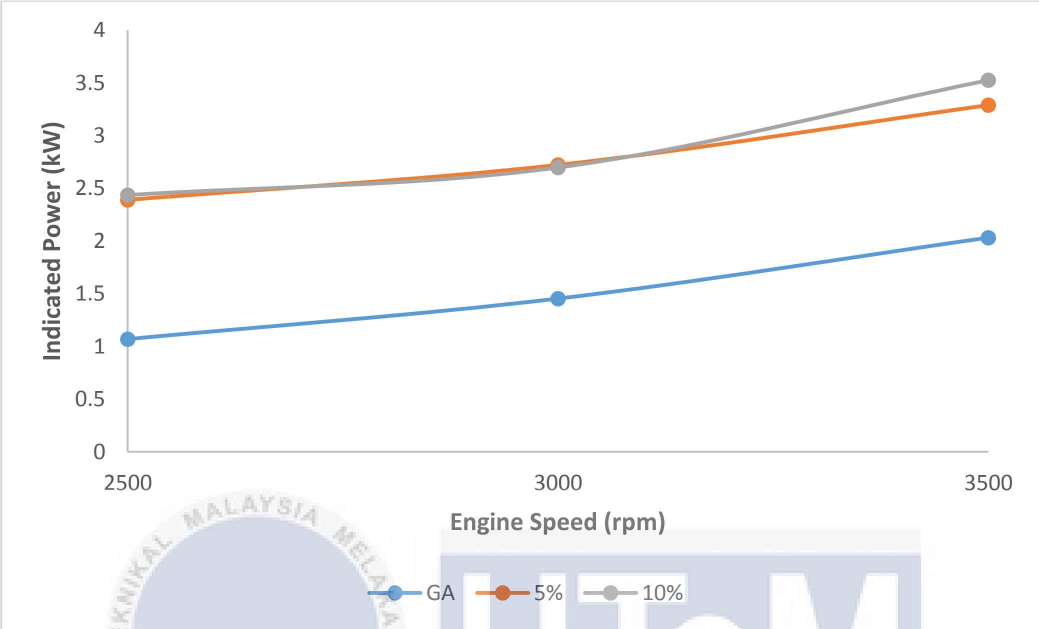


Figure E1: Variation of indicated power at 500 W load for all test fuels.



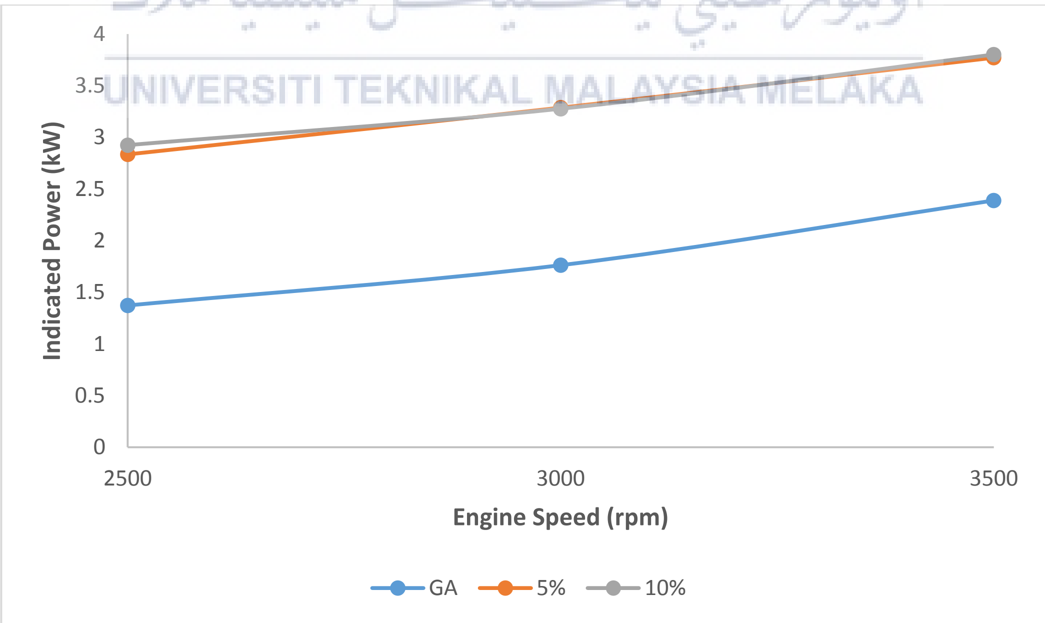


Figure E2: Variation of indicated power at 1 kW load for all test fuels.

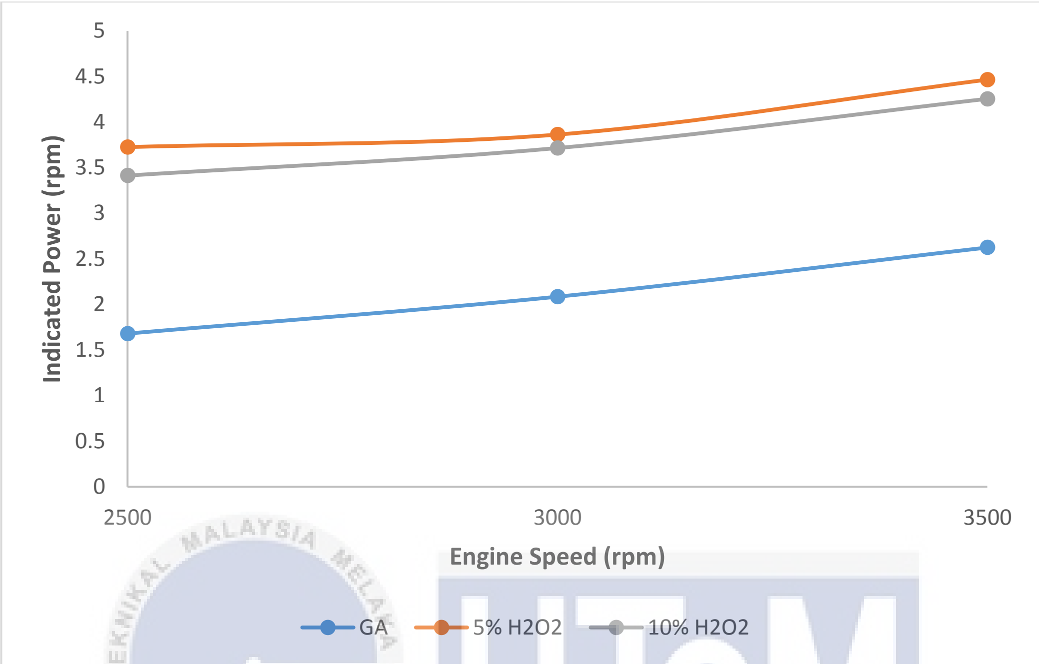


Figure E3: Variation of indicated power at 1.5 kW load for all test fuels.

## APPENDIX F

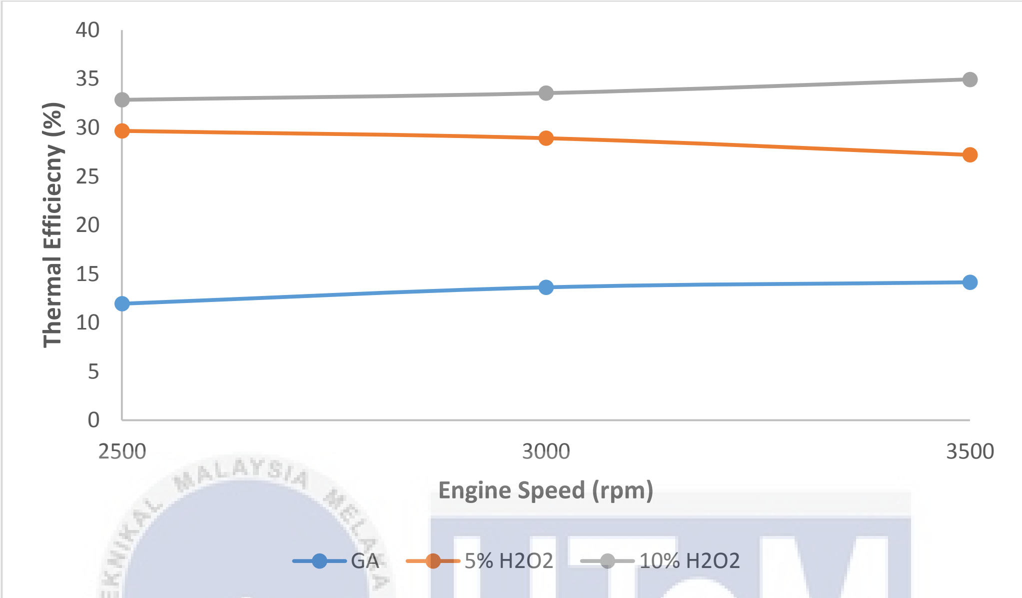


Figure F1: Variation of indicated thermal efficiency at 500 W load for all test fuels



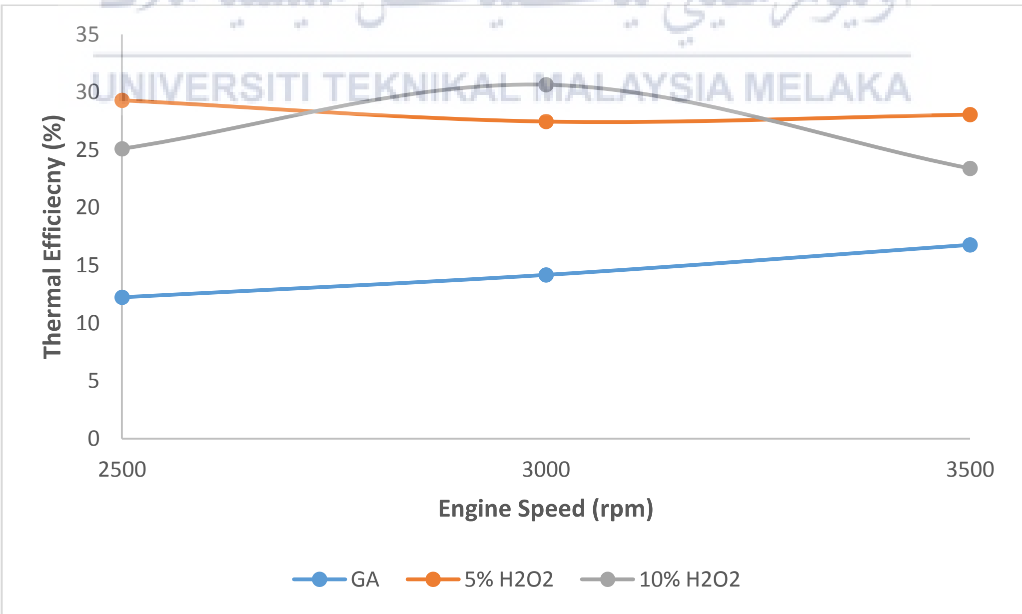


Figure F2: Variation of indicated thermal efficiency at 1 kW load for all test fuels

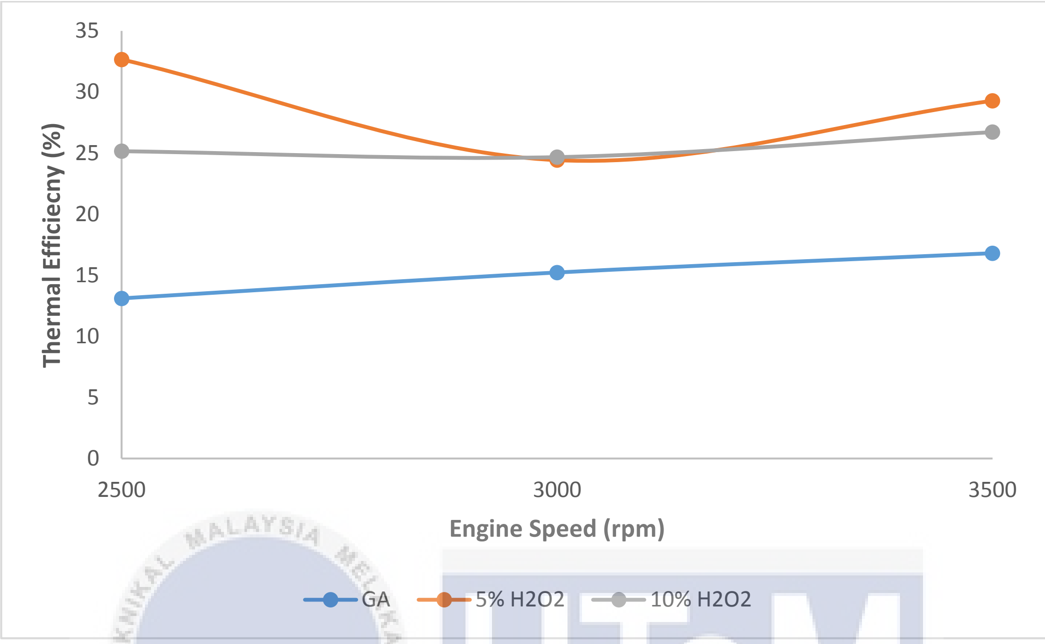


Figure F3: Variation of indicated thermal efficiency at 1.5 kW load for all test fuels

## APPENDIX G

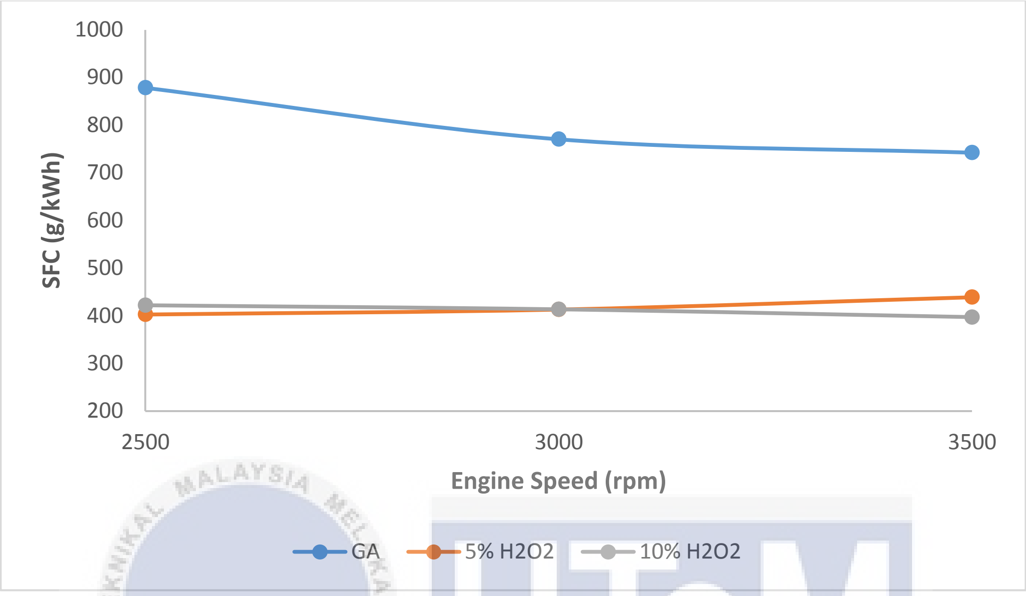


Figure G1: Variation of indicated specific fuel consumption at 500 W load for all test fuels



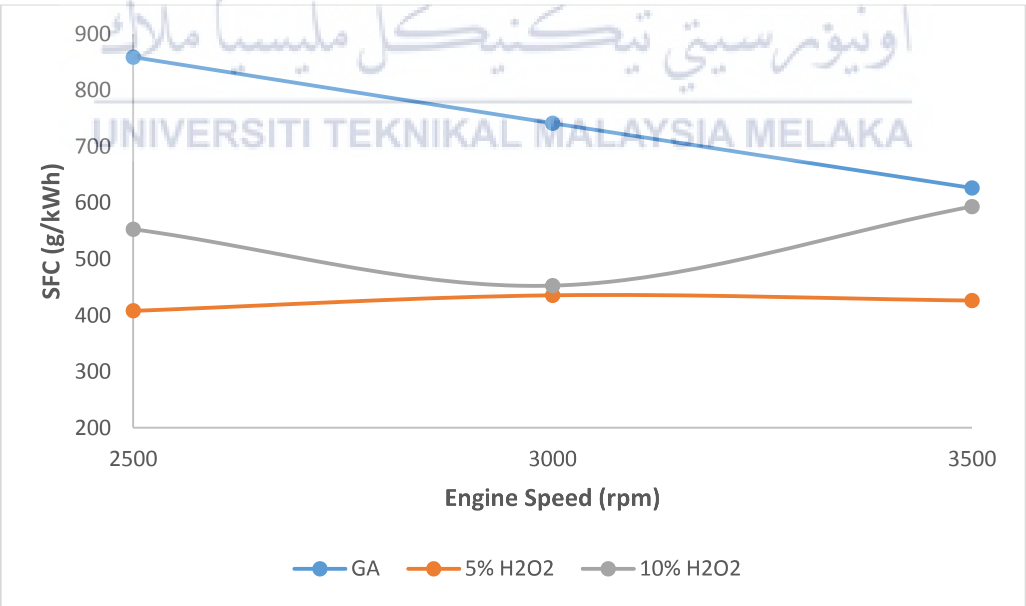


Figure G2: Variation of indicated specific fuel consumption at 1 kW load for all test fuels

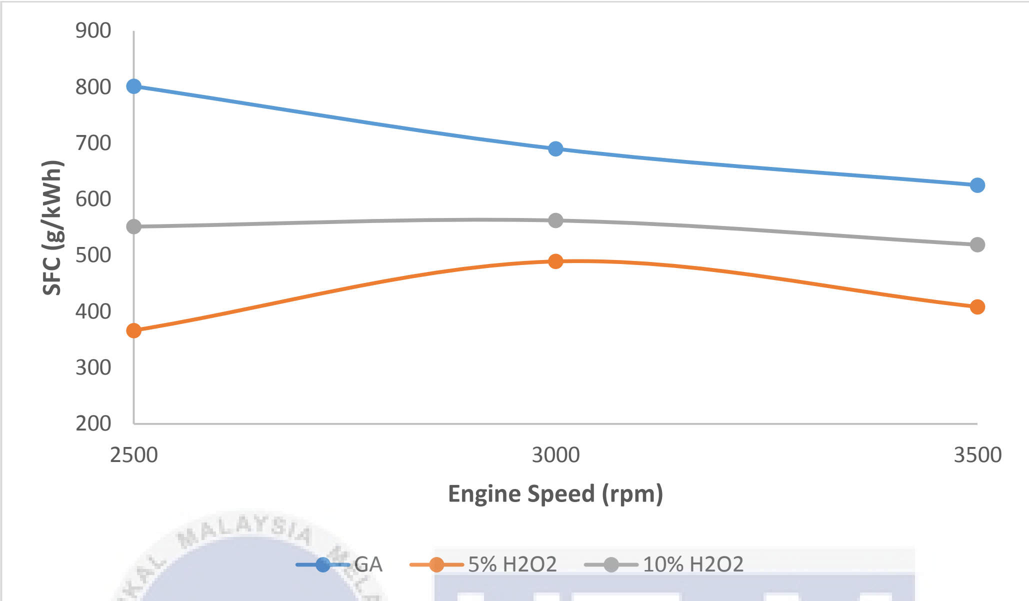


Figure G3: Variation of indicated specific fuel consumption at 1.5 kW load for all test fuels