EXPERIMENTAL STUDY ON THE EFFECT OF AIR-FUEL RATIO ON PERFORMANCE OF SPARK IGNITION ENGINE FUELED WITH H_2O_2-GASOLINE BLEND

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in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled “Experimental study on the effect of air-fuel ratio on performance of spark ignition engine fueled with H_2O_2-gasoline blend” is the result of my own work except as cited in the references

Signature : ....
Name : MUHAMMAD ZULFADLI BIN AHMAD ZAHIDI
Date : ....

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).

Signature : ....
Name of Supervisor : DR. ADNAN BIN ROSELI
Date : ....

DEDICATION

I would like to dedicate this thesis to my beloved mother, Mahmudah, and father, Ahmad Zahidi for endless support, to my brothers and sister for a constant encouragement to accomplish this work. Last but not least, people who have always been there to support, congratulate, and show me always the best path to follow.

ABSTRACT

This project was carried out to study the effect of air fuel ratio on the performance of an engine fueled with an additive of hydrogen peroxide blend with gasoline fuel. This project starts by finding the chemical properties of gasoline alone and hydrogen peroxide-gasoline blend in order to identify the different properties of additive fuel compared to gasoline alone. Experiments on the performance of the spark ignition engine ware carried out by using generator engine Precision GX420. Firstly, the spark ignition engine performance was tested starting with the gasoline alone and then followed by the addition of 5% and 10% of hydrogen peroxide blended with the gasoline. Pressure sensor and crank sensor had been installed on the engine set up in order to determine the in-cylinder pressure, volume and crank angle. Pressure sensor and crank sensor were connected to Data Acquisition System (DAS) which will display the result through DEWESOFTX2 software. The result was calculated using raw data that has been obtained from DEWESOFTX2 software and several parameters of engine performance such as indicated network, air fuel ratio and indicated specific fuel consumption. At the end of this project, it can be concluded that the use of hydrogen peroxide for gasoline engine must not exceed 10% in order to avoid lag during the combustion process.

ABSTRAK

Projek ini dijalankan untuk mengkaji kesan nisbah udara minyak terhadap prestasi enjin dengan diisi minyak campuran hydrogen peroksida bersama minyak petrol. Projek ini bermula dengan mengenal pasti sifat kimia minyak petrol dan minyak campuran hidrogen peroksida-petrol bagi mengenal pasti perbezaan sifat minyak campuran dibandingkan dengan minyak petrol. Eksperimen bagi mengenal pasti prestasi enjin menggunakan enjin penjana 'Precision GX420' untuk mengendali ujian. Pertamanya, eksperimen untuk ujian prestasi enjin nyalaan percikan dimulakan dengan penggunaan minyak petrol dan diukuti seterusnya dengan 5% dan 10% minyak campuran hydrogen peroksida dengan petrol. Sensor tekanan dan sensor engkol dipasang pada enjin bagi mengenal pasti tekanan, isipadu dan sudut engkol di dalam silinder. Sensor ini akan disambungkan kepada DAS yang akan memaparkan hasil melalui perisian DEWESOFTX2. Hasil akan dikira dengan dapatan data kasar daripada perisian tersebut dan juga dapat mengenal pasti beberapa parameter prestasi enjin sebagai contoh kerja bersih, nisbah udara minyak dan penggunaan bahan api tentu. Di akhir projek ini, menunjukkan penggunaan hidrogen peroksida bagi enjin petrol tidak boleh melebihi 10% campuran bagi mengelakkan lebih banyak kelewatan ketika proses pembakaran.

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I would like to express my deepest appreciation to my supervisor Dr. Adnan bin Roseli for giving me this opportunity to do final year project with him. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

Secondly, I would like to thank to my colleague for spending his time to guide me. They would share his knowledge in the field of spark ignition engine with me and guide me to do experiment. Also, I would like to thank assistant engineer, En. Junaidi for his kindness in suggesting me the suitable time to use laboratory equipment for his action saved me a lot of time.

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LIST OF ABBEREVATIONS

ICE	Internal Combustion Engine
SI	Spark Ignition
CI	Compressed Ignition
BSFC	Brake Specific Fuel Consumption
H_2O_2	Hydrogen Peroxide
AFR	Air Fuel Ratio
BP	Brake Power
BMEP	Brake Mean Effective Pressure
SFC	Specific Fuel Consumption
TSFC	Thrust Specific Fuel Consumption
OH	Hydroxide
CO	Carbon Monoxide
BTDC	Before Top Dead Center
ATDC	After Top Dead Center
TDC	Top Dead Center
EGT	Exhaust Gas Temperature
NOx	Nitrogen Oxide
MFB	Mass Fraction Burn
CNG	Compressed Natural Gas
DAS	Data Acquisition System
ASTM	American Society Testing Material
RON	Research Octane Number
HV	Heating Value
CA	Crank Angle
SFC	Specific Fuel Consumption
ISFC	Indicated Specific Fuel Consumption
GA	Gasoline Alone

RPM	Revolution per Minute
HRR	Heat Release Rate
PHRR	Peak Heat Release Rate
ITE	Indicated Thermal Efficiency
IP	Indicated Power

LIST OF SYMBOL

$\dot{m}_f$ = mass fuel of flow rate (kg/s)

$\dot{m}_a$ = mass air of flow rate (kg/s)

P_f = indicated power (W)

P_b = brake power (W)

n_f = thermal efficiency

P_{ig} = mechanical efficiency

N = number of revelation per minute (rev/min)

T = torque (Nm)

V_d = volume of cylinder (m^3)

$\dot{m}_{ath}$ = air mass flow rate pass throttle plate (kg/s)

P_0 = front of throttle pressure (Pa)

T_0 = front of throttle temperature (K)

A_{th} = area of throttle (m^2)

C_d = discharge coefficient (0-1)

R = gas constant (0.287 kJ/kg K)

γ = specific heat ratio

CHAPTER 1

INTRODUCTION

1.1 Background

Every single day from a few years ago, we can see the rising of the atmospheric carbon dioxide and atmospheric pollutant that leads to major problems to the society nowadays (Ć & Oros, 2012). These problems come from the vehicle in the world on the exhaust gasses. Most of the researchers studied about the diesel engine having higher thermal efficiency. The problem with this diesel engine is that they have higher emissions and exhaust temperature (Nagaprasad K. S., 2012). These emissions can be reduced with the increasing of engine compression ratio. Increasing compression ratio can provide better the thermal efficiency (Lattimore, Herreros, Xu, & Shuai, 2016)

Internal Combustion Engine (ICE) can be divided into two groups according to fuel type, power, type of ignition and so on. First group is separated into Spark Ignition (SI) engine and Compression Ignition (CI) engine. The difference between these two types of ignition was the classification of SI engine as two strokes and four strokes. CI will be divided into direct injection and indirect injection engine (Cholakov, n.d.). Most vehicles ware using the Spark Ignition (SI) engine. Everyone knows the SI engine is conducted by each injection that begins when the air went in the intake port valve to the cylinder (Richard et al., 2011). The most important factor that needs to be considered in the internal combustion engine was the thermal efficiency and catalytic efficiency because having higher thermal efficiency will lead to a low fuel consumption, whereas high catalytic efficiency will produce a low exhaust emission from the vehicle (Jansri & Sooraksa, 2012). The fuel used in internal combustion engine will give high impact to the engine efficiency and brake power. If the engine is having higher efficiency, it will provide more power to the vehicle. Each fuel has their own characteristic to perform well in the internal combustion engine (Curtis, Owen, Hess, & Egan, 2008).

The main fuel used in our daily life are diesel and gasoline. There are many ways to increase the efficiency of the vehicle. One of them is by mixing the additive to the normal fuel. The ethanol-gasoline blend fuels will increase the brake power causing a higher spark timings and improve the Brake Specific Fuel Consumption (BSFC). Having higher thermal efficiency will lead to a faster combustion compared to gasoline alone (Lattimore et al., 2016). Other than that, with 1-buthanol-gasoline blend also can give high thermal efficiency to the engine. Fuel economy will then decrease by the 1-butanol-gasoline blend and hence can reduce the particle number of concentration (Lattimore et al., 2016).

The other method that leads to the enhancement system of fuel in an engine is by using hydrogen peroxide, H_2O_2. It will blend together to overcome this problem (Nagaprasad K. S., 2012). Hydrogen peroxide can raise the efficiency and can reduce the emission or soot. This additive will change to steam and can give a high vapor pressure in ICE to increase the brake power or torque. It also provide a cooling effect that can reduce the temperature in the engine system (Dixon, 1977). Besides that, hydrogen peroxide is one of the metastable compounds which can be classified as a harmless catalyst compared to the others (Roth, Eckhardt, Franz, & Patschull, 1998).

Hydrogen peroxide effects a desirable benefit as it was considered a successful burning of the product fuel that can reduce the contamination and increase the power of the engine. It also can be useful as an oxidizer for the fuel vapor when it enters the engine combustion chamber (Cox, 1981). Hydrogen peroxide is the weak acid between a strong oxidizing properties and can be an effective bleaching agent. This additive has a density of

1.130 g/cm^3 higher than diesel. When this additive blend with the fuel, the density does not increase when H_2O_2 exceed more than 15% (Khan, Ahmed, Mutalib, & Bustum, 2013).

The researcher used aqueous trapping method to determine the validity of H_2O_2 in the air using aqueous traps technique. This validity of H_2O_2 in the air explained exclusively during photochemical gas phase reaction mechanism. H_2O_2 has a lower pressure and infinite solubility in water, and it is very difficult to extract from the air with water traps. Ozone decomposition rate will be affected by a concentration of H_2O_2 (Irvine & Attribution, 1982).

1.2 Problem Statement

The additive hydrogen peroxide is a weak acid in a solution of water. It can also become a strong oxidizer agent, by mean that the H_2O_2 will provide more atom of oxygen to the solution. Hydrogen peroxide can reduce the emission of an engine and increase the efficiency. Other than that, H_2O_2 can increase the brake power. Besides, it can also reduce the temperature in the engine system. H_2O_2 acts as prevailing part in the hot ignition from low temperature to a middle of the temperature dynamic conduct. It was formed at the fire termination and occur in the exhaust gas that can change the kinetic behaviour in turbulent responding frameworks.

This research will targeted optimum percentage of the hydrogen peroxides that can be blend together with gasoline. From this different percentage of hydrogen peroxide blend with gasoline, the mass of air and fuel will change to get the air-fuel ratio (AFR). Other than that, the optimum ratio can be determined through the test of which can result the best performance for the engine. In this research, used of hydrogen peroxide as an additive is to increase the operating performance for SI engine and decrease the emission.

1.3 Objective

The objectives of this project are as follows:

1. To study the effect of air-fuel ratio on performance of spark ignition engine with H_2O_2-gasoline blend.
2. To investigate the optimum air-fuel ratio on performance of spark ignition engine with H_2O_2-gasoline blend.
3. To compare the air-fuel ratio on the performance of spark ignition engine based on gasoline alone.

1.4 Scope of Project

The scopes of this project focuses on the air-fuel ratio on spark-ignition (SI) engine based hydrogen peroxide-gasoline blend. In this project, gasoline alone (0%) will be used as the reference. Hence, an amount of 5% and 10%(by volume) of hydrogen peroxide (H_2O_2) were being used in the gasoline (C_7H_{12}) blended. This project focuses on finding the operating performance such as indicated power (IP), indicated specific fuel consumption (ISFC), indicated thermal efficiency (ITE) and heat release rate (HRR) with 0W, 500W, 1000W, 1500W and 2000W of the load. Throughout this research, the different percentage of hydrogen peroxide are expected to change the AFR value which will be found to be closer to the stoichiometric value.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Background

2.1.1 Indicated Specific Fuel Consumption (SFC)

ISFC is the weight of the fuel burned per unit time. Turbojets and fan are also known as the Thrust Specific Fuel Consumption (TSFC). The SI unit for this ISFC is kg/kWh. The SFC for the piston can be calculated using the equation (2.1). MF is the flow rate of fuel and and p is the power that is applied to the propeller. It can be expressed as ISFC = rate of mass fuel / power output. SFC is defined as a measurement of the efficiency of fuel to improve the fuel consumption. In addition, the fuel consumption can be measured as a mass flow rate, m_f and ISFC is the fuel flow rate per unit power output. Equation (2.2), (2.3) and (2.4) allows the measurement of the efficiency of an engine by using fuel to produce work (Heywood, 1988). As a result, we can summarize that the lowest ISFC will results the highest brake power or power output. There are different types of ISFC in Internal Combustion Engine (ICE) which are the Indicated Specific Fuel Consumption (ISFC) and Brake Specific Fuel Consumption (BSFC).

$$sfc = \frac{\dot{m}_f}{P} \tag{2.1}$$

$$sfc\left(\frac{mg}{J}\right) = \frac{\dot{m}_f\left(\frac{g}{s}\right)}{P(kW)} \tag{2.2}$$

$$sfc\left(\frac{g}{kW.h}\right) = \frac{\dot{m}_f\left(\frac{g}{h}\right)}{P(kW)} = 608.3\ (\frac{lbm}{hp}.h) \tag{2.3}$$

or

$$sfc\left(\frac{lbm}{hp.h}\right) = \frac{\dot{m}_f\left(\frac{lbm}{h}\right)}{P(hp)} = 1.644\ \times 10^3\ sfc\ (\frac{g}{kW.h}) \tag{2.4}$$

2.1.2 Brake Specific Fuel Consumption (BSFC)

BSFC is the rate of fuel consumption that were divided into power output. The power output is also known as the brake power. BFSC is typically used to comparing the efficiency of internal combustion engine with a shaft output. BSFC will also decrease with the engine size due to the reduction of the heat losses from the gas to the cylinder wall. This BSFC is almost similar to SFC but BSFC has the mass of flow rate per unit brake power. On top of that, BSFC is a correlation proportion which can trace the efficiency of the fuel, how much fuel is used and lastly how much power was produced. From equation (2.5), the brake specific fuel consumption utilization was separated by the brake power. Usually, the outcomes are presented in kilograms per kilowatt hour. Normally dynamometer was used to calculate the BSFC transfer from the engine. Diesel motors regularly perform superior to any gas motors in terms of BSFC. The optimum value BSFC for Spark Ignition (SI) engine is about 75µg/J = 270 g/kW..h = 0.47 lbm/hp. h. The best value or the optimum value for Compression Ignition (CI) engine is about 55µg/J = 200 g/kW..h = 0.32 lbm/hp (Heywood, 1988).

$$bsfc = \frac{\dot{m}_f}{BP} \tag{2.5}$$

2.1.3 Thermal Efficiency

The efficiency of engine is converting the heat energy contained in the liquid fuel into mechanical energy. On top of that, thermal efficiency is the ratio of power produced in the burning fuel to produce power. It can be expressed as :

$$nf = \frac{W_C}{m_f}\frac{1}{Q_{HV}} = \left(\frac{P n_R/N}{(\dot{m}_f\, n_R/N)Q_{HV}}\right) = \frac{P}{\dot{m}_f\ Q_{HV}} \tag{2.6}$$

From equation (2.6), we know that m_f is the mass of flow rate and P, is the power. We can substitute the 1/SFC = power output / rate of mass fuel.

$$n_f = \frac{1}{sfc\ Q_{HV}} \tag{2.7}$$

Furthermore, from equation (2.7), it is used to calculate thermal efficiency which is known as the fuel conversion efficiency. It is the ratio of the work produced per cycle to the amount of fuel energy supplied per cycle. Quantity of the fuel supplied to the engine and the heating value of fuel are given. The fuel energy supplied can be released only through combustion. Heat transfer, Q_{HV} can be determined through a standardized. This combustion process produces the thermal energy and absorbed by a calorimeter when cool down to their original temperature (Heywood, 1988). The heating values for hydrocarbon fuels used in engine is commonly between 42 to 44 MJ/kg (18000 to 19000 Btu/lbm). The SFC for this hydrocarbon can be inversely proportional to fuel conversion efficiency or thermal efficiency for normal hydrocarbon fuel. Actual process in combustion process is incomplete because the energy supplied to the engine is not fully radiated as a thermal energy. At the point where enough air oxidize the fuel, almost 96 percent and above of fuel energy supplied were transferred as thermal energy to the working fluid. Insufficient of air oxidize the fuel completely and the absence of oxygen keeps this fuel vitality supplied from being completely discharged (Heywood, 1988). The petrol engine is not really efficient because it can only reach 25% efficiency than diesel engine with 35% efficiency due to the higher compression ratio, unthrottled operation and lean combustion. Unthrottled operation in the Diesel motor for all intents and purposes dispenses with the pumping circle in the P-V diagram found with Otto cycle motors running at stack part, since the cylinder doesn't need to conflict with a vacuum amid the admission stroke. The pumping circle speaks to negative work in the cycle. Lean combustion is a lower burning temperature and along these lines, it is a lower heat misfortunes in the cycle. Diesel additionally do not run wealthier than stoichiometry at high loads, not at all like Otto cycle motors, so are likewise more effective at high loads because of this. Otto cycle motors ordinarily keep running around 15 until 20% over rich at full load.

2.1.4 Mechanical Efficiency

From equation (2.8), in motion of engine, there are friction of the bearings, pistons, mechanical component and drive engine. Compilation for these frictions are called the friction power P_f. High-speed engines is to drive the engine with a dynamometer.

$$P_{ig} = P_b + P_f \tag{2.8}$$

This engine will be supplied with the dynamometer to overcome all these frictional losses.

Under firing conditions, we remain the engine speed, throttle setting, oil and water temperatures and lastly the ambient condition. The most inaccuracy result through this method was the gas pressure forces on the piston and rings that are lower in motored test.

On top of that, the oil temperatures on the cylinder wall are lower under motoring condition when engine is firing. Mechanical efficiency can be defined as a ratio of brake power delivered by the engine to the indicated power as an Equation (2.9). Mechanical efficiency usually lies in between 80% to 90%.

$$n_m = \frac{P_b}{P_{ig}} = 1 - \frac{P_f}{P_{ig}} \tag{2.9}$$

Mechanical efficiency is depends on throttle position as engine design also engine speed. In modern automotive the full throttle are 90 percent at speed below about 30 – 40 rev/s (1800 to 2400 rev/min), were decreasing to 75 percent at maximum rated speed. When the engine is throttled, the value of mechanical efficiency will decreases and sometimes eventually to zero at idle operation (Heywood, 1988).

2.1.5 Brake Power

It is the measure of an engine's horsepower before the loss in power caused by the gearbox and drive train. Brake refers to the device which was used to load an engine and hold it at a desired rotational speed. Dynamometer is used for torque measurement. During testing, the output torque and rotational speed were measured to determine the brake horsepower. The torque and the angular speed measurement of engine are involved in measurement of brake power. The engine were clamped to the test bed and shaft link to the dynamometer rotor. In this procedure we will coupling electromagnetically, hydraulically or by mechanical friction to a stator which can support low friction bearings. When the rotor turning, the torque was measured by balancing the stator with weights and spring. There are two type of dynamometer than we can use, absorption dynamometer and transmission dynamometer. As in Equation (2.10) the brake power can be described as work done. Where torque, T = Fb, N is the crankshaft rotational speed in rev/min.

$$P = 2\pi NT \tag{2.10}$$

Measure of an engine ability to do work is the torque and power which is the rate work is done. The value of engine power above was measured as a brake power P_b. This usable power delivered by the engine to the load and in this dynamometer test, the load was the brake (Heywood, 1988).

2.1.6 Air-Fuel Ratio (AFR)

Air fuel ratio is the ratio of mass flow rate of air m_a to the mass flow rate of fuel m_f as Equation (2.11) and (2.12). These flow rates is useful in defining engine operating conditions. The normal range for SI engine using gasoline fuel is $12 \leq A/F \leq 18$ ($0.056 \leq F/A \leq 0.083$) and for the CI engine with diesel fuel is $18 \leq A/F \leq 70$ ($0.014 \leq F/A \leq 0.056$) (Heywood, 1988).

$$Air/fuel\ ratio\ (A/F) = \frac{\dot{m}_a}{\dot{m}_f} \tag{2.11}$$

$$Fuel/air\ ratio\ (F/A) = \frac{\dot{m}_f}{\dot{m}_a} \tag{2.12}$$

AFR according to the stoichiometric value can improve the fuel economy and can provide more efficient to the torque of engine. Stoich or stoichiometric occur when the optimum air provided to completely burn all of the fuel. This AFR is the most important factor in the operating performance in engine because it's influenced for anti-pollution and performance tuning. The number of AFR lower than stoich are considered "rich", its mean less efficient but can produce more power/brake power to the engine and react as a burn cooler. If the AFR is higher than stoich are considered "lean" means more efficient but can cause engine harm or untimely wear and deliver larger amounts of nitrogen oxides. AFR is the term that common use in this day for mixtures in internal combustion engine. The term also use define as mixtures that used for industrial furnace heated by combustion. Pure octane the stoich is absolutely 14.7:1 and in naturally aspirated engine powered by octane can reach the AFR range from 12.5 to 13.3:1. The value of AFR 12:1 was considered as maximum output ratio, whereas the AFR of 16:1 was considered as maximum fuel economy ratio.

2.1.7 Brake Mean Effective Pressure (BMEP)

Brake Mean Effective Pressure can define the average pressure which, if imposed on the pistons uniformly from the top to the bottom of each power stroke, would produce the measured brake power output. BMEP is purely theoretical it's mean we cannot change their actual cylinder pressures. It is simply a tool to evaluate the efficiency of a given engine at producing torque from a given displacement. In the other meaning Equation (2.13) and (2.14) is the relative engine performance measure was obtained by dividing the work per cycle by the cylinder volume displaced per cycle.

$$Work\ per\ cycle = \frac{Pn_R}{N} \tag{2.13}$$

Where $^{n}{}_{R}$ is the number of crank revolutions for each power stroke per cylinder (2 for four-stroke cycles and 1 for two-stroke cycles) then,

$$mep = \frac{Pn_R}{V_d N} \tag{2.14}$$

$$mep\ (kPa) = \frac{P(kW)n_R \times 10^3}{V_d(dm^3)N(\frac{rev}{s})} \tag{2.15}$$

The maximum BMEP of good engine designs was established and use in a difference range of engine sizes. This engine can compare to the normal engine so that volume can be assessed. Equation (2.15) shows engine displacement was required to provide torque or power at specific speed and can assuming the values for BMEP. The typical value for BMEP in this world range in the range 850 to 1050 kPa (~ 125 to 150 $lb/in^{2)}$ at the engine speed where the maximum torque can occur about 3000 rev/min and 10 to 15 percent lower for SI engine. For turbocharged automotive SI engine, the maximum value for BMEP in range 1250 to 1700 kPa (180 to 250 lb/in^2). Maximum rated power is in 900 to 1400 kPa (130 to 200 lb/in^2). The maximum values BMEP for CI engine is in 700 to 900 kPa (100 to130 lb/in^2) which has maximum rated power about 700 kPa (100 lb/in^2). Also for turbocharged CI engine with the maximum value for BMEP in range 1000 to 1200 kPa (145 to 175 lb/in^2) and can increase to 1400 kPa after cooled. This turbocharged at maximum rated power is about 850 to 950 kPa (125 to 140 lb/in^2). The difference between two stroke cycles diesels have comparable performance to four-stroke cycle engines and has large low-speed for two stroke engine that can make about 1600 kPa (Heywood, 1988).

2.2 Hydrogen Peroxide Blend With Diesel

With the different crank angle, hydrogen peroxide (H_2O_2) with water blend diesel was injected into the combustion chamber. The result from the cylinder were increase the OH radiation compared to the normal engine condition. Amount H_2O_2 used always 40% of fuel volume. Using the hydrogen peroxide with water can decreases soot mass in 3% and if the water can reduce about 20%. But if the crank angle set to 20° BTDC, the difference between water and hydrogen peroxide with water slightly disappear. Moreover, temperature will not change when using hydrogen peroxide with water injection causes the effect of two combination which is energy used for the spray evaporation relate to the phase H_2O_2

decomposition and heat release. The compression ratio diesel engine also change from 1:18 to 1:19.5 and the slightly adjusted the volume flow of diesel fuel (Franz & Roth, 2000).

From the other sources, after addition of hydrogen peroxide blend with the diesel, energy content was reduce and more fuel injection is required. Mixed diesel with hydrogen peroxide also give higher cetane number will lead to cleaner combustion which can lowering the emission of carbon monoxide (CO). Viscosity of hydrogen peroxide much lower than diesel and the increased amount of hydrogen peroxide in mixed will decrease the viscosity of solution. Hydrogen peroxide improved the acidic nature of fuel blend. Effect of hydrogen peroxide blend with diesel have been carried out between 0 to 15 volume percent. The density fuel blend increases, while the viscosity will decreases due to the higher density of alter. Finally, the refractive index showed the small reducing as quantity hydrogen peroxide were increased in the solution (Khan, et al, 2013).

Density of hydrogen peroxide is greater than diesel, the energy content is appear in lower mass and volume compared to the base diesel fuel only. Reduction of the energy content, more fuel injection is needed.

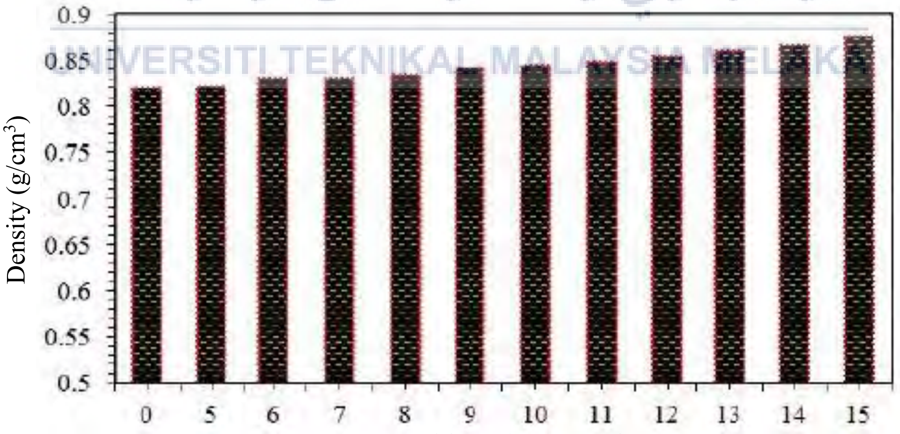

Figure 2.1: Density versus volumetric composition of H_2O_2 (Khan et al., 2013)

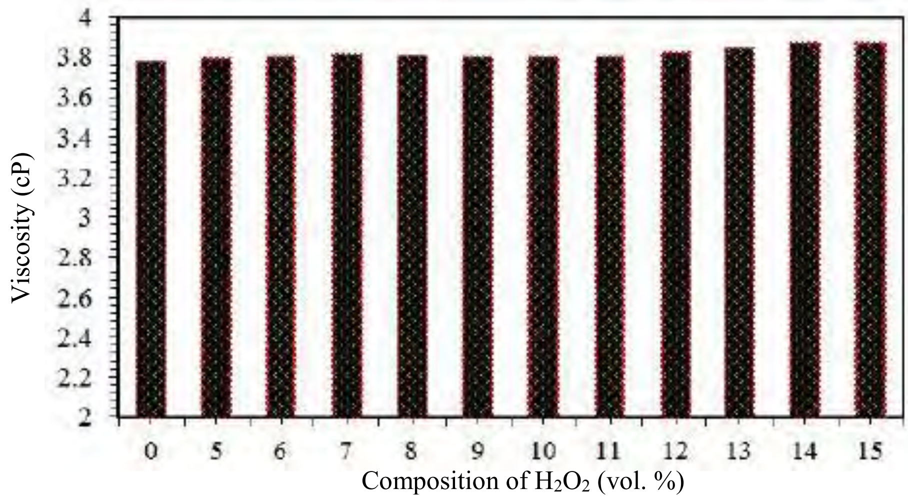

Figure 2.2: Viscosity versus volumetric compositions of H_2O_2 (Khan et al., 2013)

Other than that, due to presence of H_2O_2 in fuel make the brake thermal efficiency of engine increased. Hydrogen peroxide will starts decompose and release a large amount of oxygen. This oxygen helps reduce the lag of ignition for complete combustion of fuel. Highest efficiency was observed at full load with the using of 5% of hydrogen peroxide with diesel. Figure 2.3 shows the engine performance with difference of hydrogen peroxide with diesel. Also, Figure 2.4 shows when H_2O_2 increase the exhaust temperature engine will decreased due to addition of oxygen comes from releasing by hydrogen peroxide (Nagaprasad K. S., 2012).

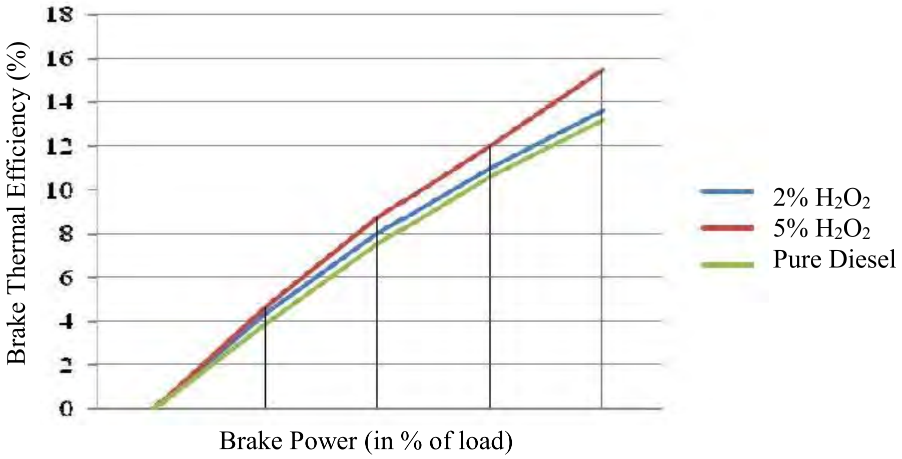

Figure 2.3: Brake thermal efficiency v/s Brake power for different blend H_2O_2

(Nagaprasad K. S., 2012)

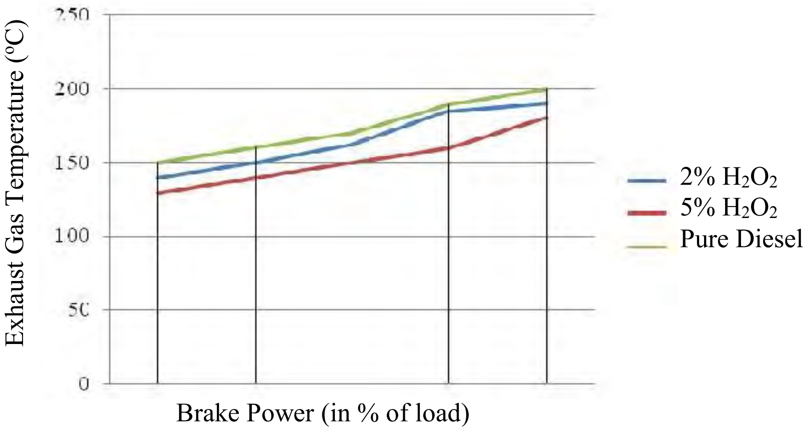

Figure 2.4: Exhaust gas temperature versus brake power for different blend of H_2O_2

(Nagaprasad K. S., 2012)

Engine cannot to start if 2% and 5% of hydrogen peroxide has inject to the diesel engine at injection timing 150 BTDC. Factor that situation occur when efficiency of engine increases with increase blend for injection timing. This can be proved in Figure 2.5 which shows the brake thermal efficiency for different blendings of hydrogen peroxide in diesel engine at the injection timings of 10^0 BTDC and 15^0 BTDC for 40% full load. Figure 2.6 shows EGT decreased due to increment in blend at 10^0 BTDC but it remained the same at 15^0 BTDC. The minimum EGT of 149°C were found at 10^0 BTDC, which is an appreciable value for a better performance device (Nagaprasad K. S., 2012).

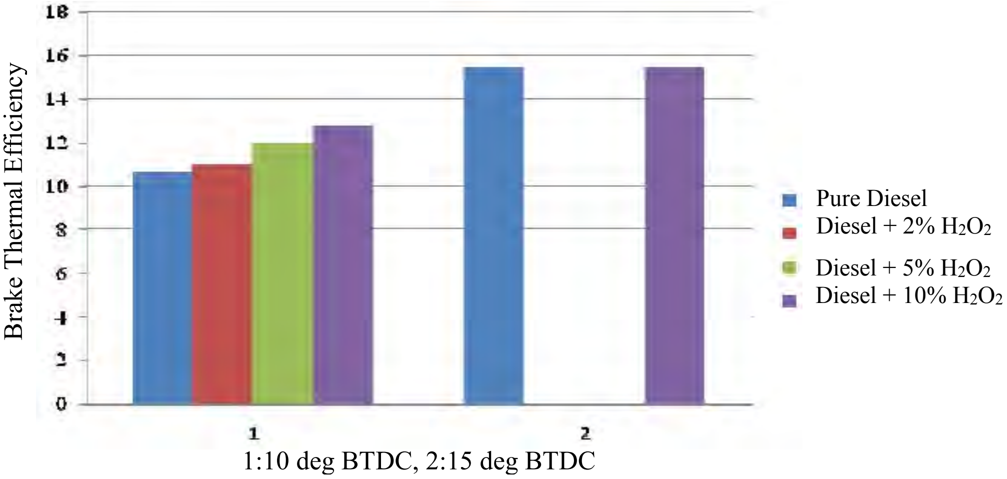

Figure 2.5: Effect of brake thermal efficiency on injection timing with different blend H_2O_2

(Nagaprasad K. S., 2012)

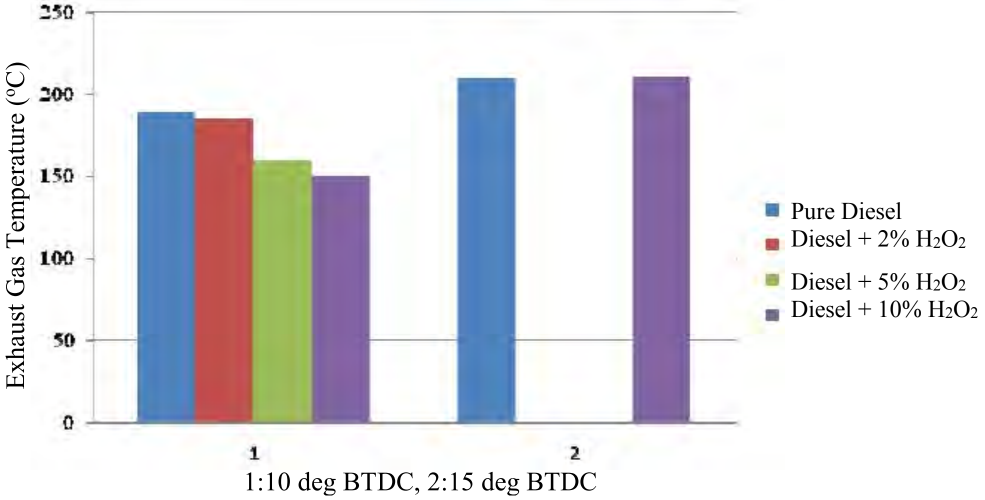

Figure 2.6: Effect of exhaust gas temperature on injection timing with different blend H_2O_2 (Nagaprasad K. S., 2012)

2.3 Hydrogen Peroxide Mixed With the Gasoline

Efficiency of the engine remain constant if it is blend with the hydrogen peroxide-water-ethanol blends. Hydrogen peroxide will give the negative impact on membranes properties of carburetor. If the hydrogen peroxide solution more than 10% with the 10% of water, engine will not function properly. Highest efficiency will occur when the ethanol comprising to 20% in gasoline because ethanol contains 35% of oxygen as a stand-alone fuel and oxygenated additive to hydrocarbon fuels for emission of nitrogen oxides (NOx), unburned total hydrocarbon and carbon monoxide (CO) will decreased. Ethanol, water and hydrogen peroxide (H_2O_2) blends are highly explosive caused H_2O_2 is very strong and storable oxidizer or monopropellant. More than 20% hydrogen peroxide in ethanol is not possible for the engine maintain running at 3600 RPM. With 50% of H_2O_2 and 50% of ethanol produce 1400 RPM but the speed rotation not remains constant (Ć & Oros, 2012).

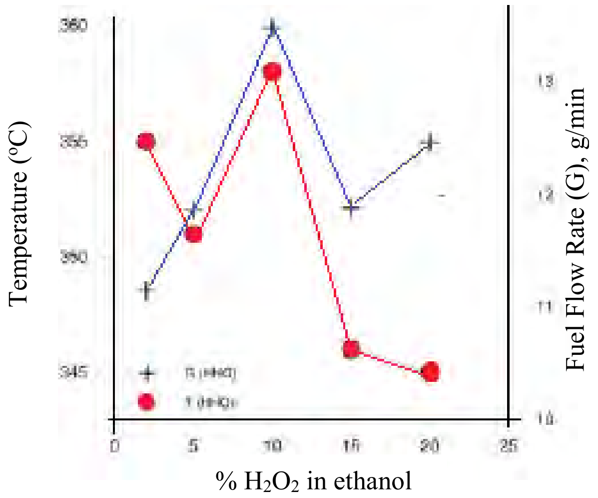

Figure 2.7: Effect of ethanol, water and hydrogen peroxide blending (Ć & Oros, 2012)

Besides that, to achieve varying degree of performance in gasoline engine 1 part of hydrogen peroxide, 8 parts of toluene and 16 parts alcohol needed. According to Figure 2.8, when the additive was used in the gasoline engine, octane increases approximately 5. With the usage of only 1 part of H_2O_2, this causes the substance to be strong and ready to oxidize. Figure 2.8 shows that, the different ratio of H_2O_2 to basic mixtures to a good blending. Commonly H_2O_2 used was 35% and 50% are safer for skin protection. This additive tends to burn more of element in the fuel thus to clean the exhaust emission (Cox, Jr., 1981).

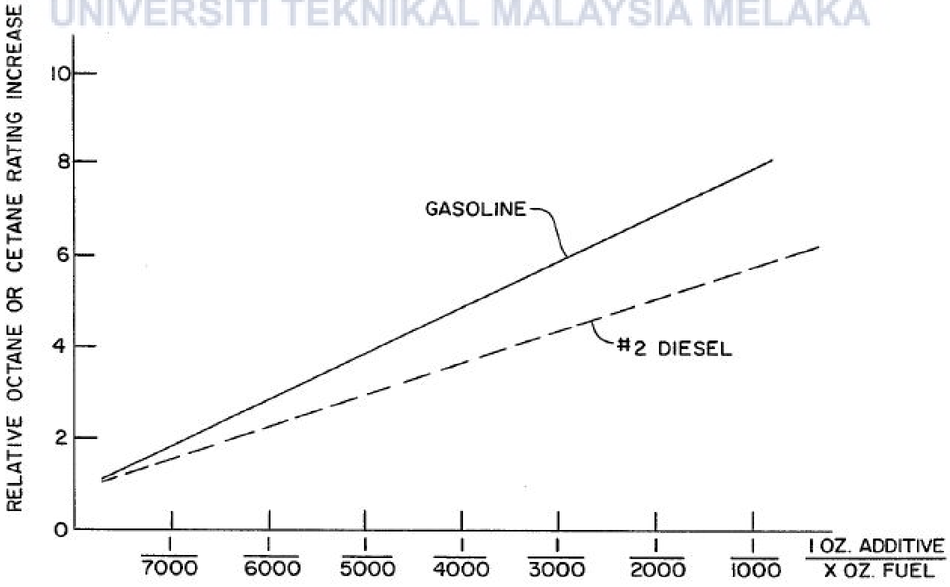

Figure 2.8: Relative octane versus additive used (Cox, Jr, 1981)

2.4 Properties of Hydrogen Peroxide

Hydrogen peroxide is an unstable substance even at moderate temperature. H_2O_2 assisted oxidative removal the soot particle in a low temperature. This solution also can be harmless compared to metal based catalyst (Roth et al., 1998). It preferred to use hydrogen peroxide with the percentage 35% to 50%. It is caused by oxygen atoms in H_2O_2 trying to escape and became oxidise for fuel vapour when enter the ICE. This solution also turn reduce contamination after complete burn and rises the power (Cox, Jr., 1981).

To improve fuel system in ICE, hydrogen peroxide was used to increase the efficiency and can reduces the emission in engine. Hydrogen peroxide was decomposed to produce additional oxygen which enable to complete full combustion. However this solution can provide power or torque that effect wash the cylinder wall and can minimize amount of NOx produced (Dixon, 1977).

Moreover, hydrogen peroxide is a pale blue liquid that little more viscous than water. This solution exist in colourless in dilute solution and consider as a weak acid among strong oxidizing properties and also can be as a powerful bleaching agent. It is widely used as antiseptic, disinfectant, oxidizer and rocketry as a propellant. In the oxygen species H_2O_2 are strong and it can considered the highly reactive oxygen (Khan et al., 2013).

Efficiency of the engine was increased by injecting the hydrogen peroxide at all fraction and can decreased the exhaust gas temperature. Table 2.1 shows the properties of hydrogen peroxide that can be identified as a solution that has a strong oxidizing agent and weak acid in water solution (Nagaprasad K. S., 2012). H_2O_2 is an important role in hot ignition where transition from low temperature to intermediate temperature kinetic energy. Furthermore, hydrogen peroxide formed during local flame extinction and present in exhaust gas recirculation can change the kinetic behaviour (Guo et al., 2013).

Table 2.1: Properties of Hydrogen Peroxide (Nagaprasad K. S., 2012)

Appearance	Colourless liquid, dilute solution
Density	1110 kg/m^3
Boiling point	226 °C
Freezing point	-27 °C
Viscosity	1.81 cp
Specific Gravity	1.11

2.5 Effect of Air Fuel Ratio in Performance Engine System

The most important variable on Spark Ignition (SI) engine is the AFR. This AFR will affect the emission and performance of the engine system. The best minimum of emission is needed by maintaining the target AFR at stoichiometric value in steady state and transient operation. This AFR also able to provide the balance of power output and fuel consumption (Zhai, Yu, Guo, & Yu, 2010).

In order to achieve the fuel economy and also lower emission, air fuel ratio need to be controlled in transient and steady state condition. The ways to control this AFR is through the mass of air or oxygen by using mass flow sensor as feedback. Air fuel ratio in-cylinder must be near to stoichiometric value to get the ideal performance of engine. There are several ways to control AFR could be around stoichiometric value (Akram, Bhatti, & Ahmed, 2013).

Proof for the effect of air fuel ratio on MFB to the engine can be seen at the initial state of combustion process at the lower speed which is at 1500 RPM. For mass fraction burn (MFB) the high speed can be seen on a rapid burning stage at 2100 RPM. Control of AFR can improve lower performance compared to the compressed natural gases (CNG). More influence on the MFB caused by the air fuel ratio and engine speed (Hagos, Aziz, & Sulaiman, 2014).

Based on the other source, power output of engine or brake power, theoretical power depend on the air fuel ratio and fuel injection method that are being used for the system. Stoichiometric value for the hydrogen is 34:1 and at this situation it could be less the energy content if fuel were gasoline. Figure 2.9 shows the brake thermal efficiency versus the air fuel ratio for different speed. It can be stated that brake thermal efficiency increases while close to the stoichiometric value of air fuel ratio. As value of AFR increase, the value of brake thermal efficiency start to decrease at certain point for different speed (Prasath et al, 2012).

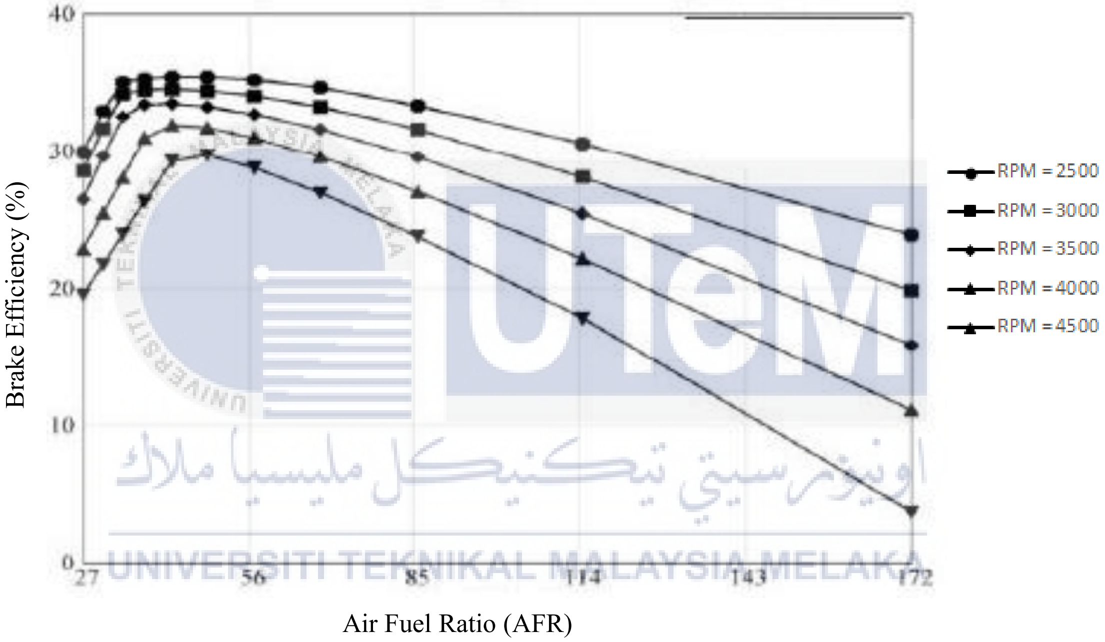

Figure 2.9: Different of brake thermal efficiency versus air fuel ratio for DI engine (Prasath et al., 2012)

In order to design an ICE, the main important that need to focus is the thermal efficiency and catalytic efficiency. High thermal efficiency provides low fuel consumption and high catalytic efficiency will give low exhaust emission. For is depending both efficiency depend on the AFR in cylinder combustion. Ideal stoichiometric value for SI engine need to be 14.7. Figure 2.10 shows the block diagram of SI engine with AFR control to improve modelling and control of AFR. Air mass flow rate can be determined with the area of throttle, pressure in before throttle, pressure at intake manifold, temperature, gas constant, specific heat ratio and discharge coefficient as equation below (Jansri & Sooraksa, 2012).

$$\dot{m}_{\mathrm{ath}} = \frac{CdAthP0}{\sqrt{RT0}} \left(\frac{2\gamma}{\gamma-1}\right)^{1/2} \left[\left(\frac{Pi}{P0}\right)^{2/\gamma} - \left(\frac{Pi}{P0}\right)^{(\gamma+1)/\gamma}\right]^{1/2} \tag{2.16}$$

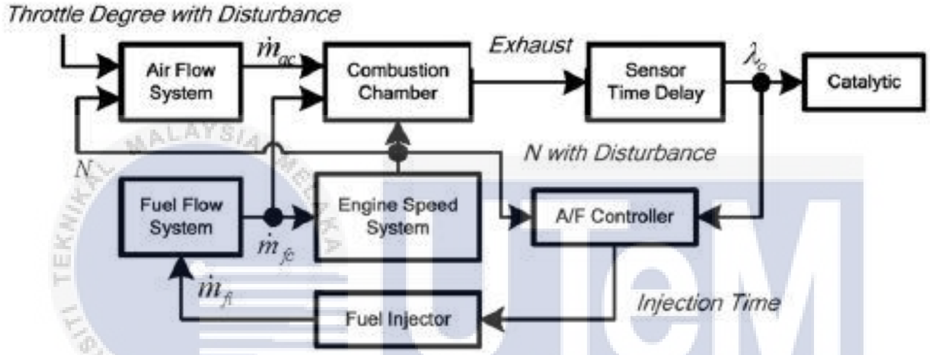

Figure 2.10: Block diagram SI engine with AFR control (Jansri & Sooraksa, 2012)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe the methodology used in this experiment to obtain the data from the DAS about the performance of the engine. This chapter also describes the equipment and the method used to find the mass of air flow. The performance of spark ignition engine is highly influenced by the gasoline alone and the blend of the gasoline with the hydrogen peroxide.

3.2 Experimental Procedure

Two types of experiment were carried out through this project. The first experiment is using the gasoline fuel alone. The second experiment focused on the mixture of the gasoline-hydrogen peroxide blend as the main fuel. The data from the performance of the engine and the mass of air from these two experiments is collected and analysed. Tests are conducted at different loads which are zero load, half load and full load. The engine speed was conducted at 2500 RPM, 3000 RPM and 3500 RPM. Next, the hydrogen peroxide are blend into5 vol % and 10 vol % with the gasoline.

First and foremost, the experiment will carried out by finding fundamental parameters of the engine such as density, viscosity, flash point, energy content of the gasoline alone and H_2O_2-gasoline blend. In order to find the density of this substance, hydrometer and manual bomb calorimeter were used for the energy content. All these properties were performed according to ASTM D-975 methods as shown in Table 3.1 below.

Table 3.1: ASTM standard for Gasoline fuel testing

S. No.	**Property**	**ASTM Method**
1	Density	ASTM D-1298
2	Viscosity	ASTM D-445
3	Flash Point	ASTM D-93

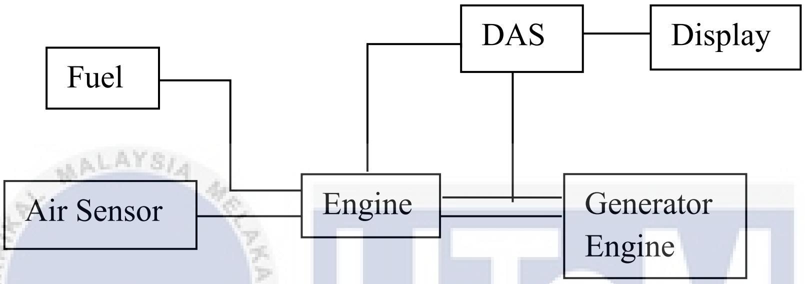

Figure 3.1: Experiment set up equipment

This experiment was carried out at the Fasa B laboratory, Faculty of Mechanical Engineering using the 4 strokes of the single cylinder engine. From the Figure 3.1, hot guns was used to increase the temperature of the intake air and a heater was used to increase the temperature of fuel. AFR can be calculated from the mass of air that has been taken by using air flow meter. The operating performance is shown at the display of the data acquisition system (DAS). At the end of the project, all the necessary elements and parameter needed were collected and finally, a report was written on this research.

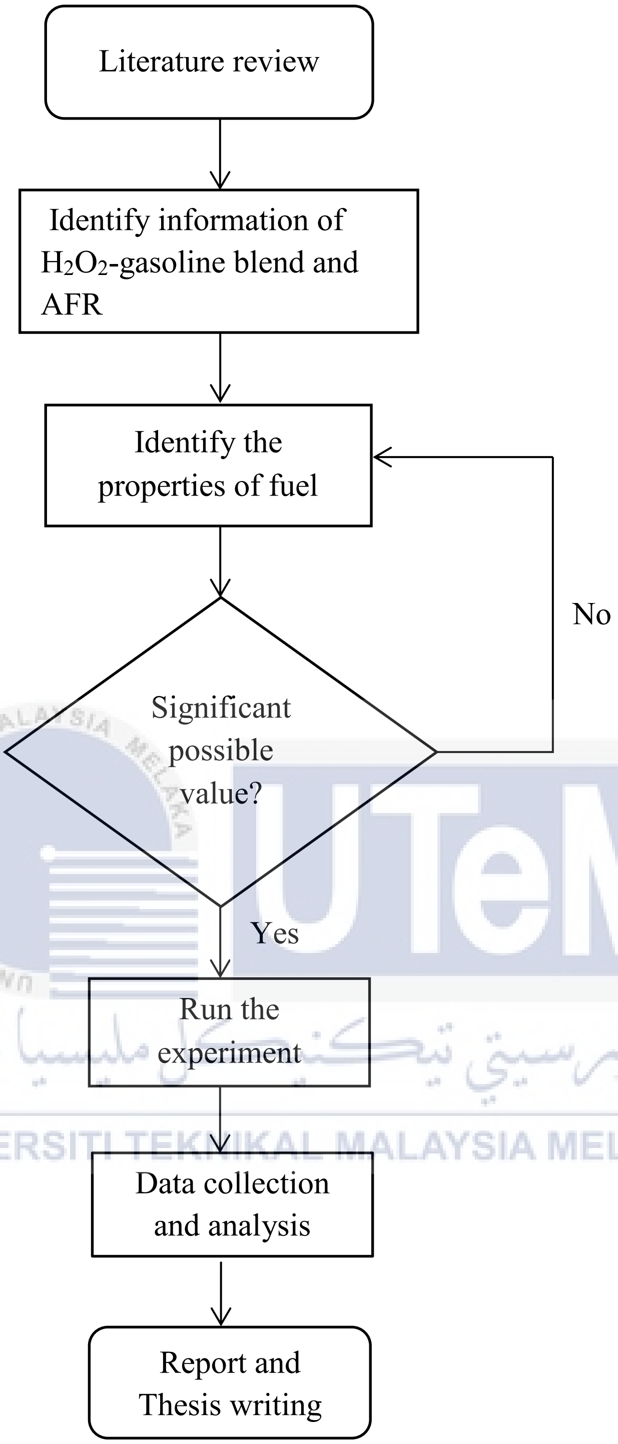

Figure 3.2: Flowchart of the experiment process

3.3 Equipment and Material

3.3.1 Generator Engine

Test engine that was used are the model Precision GX420 4.8kW, single cylinder, and 4 stroke, air-cooled. The specification of the engine are shown in the table below.

Table 3.2: Engine specification and parameters

Model	Precision GX420
Engine Type	Single cylinder, 4-stroke, air-cooled, OHV
Bore*Stroke	90x66 (mm)
Volume	419.87cm^3
Compression ratio	8.5:1
Maximum power output	(15HP) 11.2kW
Maximum torque	23.5Nm
Ignition system	Spark Plug
Starting system	Recoil and Key Start
Engine oil system capacity	1.1L
Fuel capacity	30L
Dimensions	770x555x570(mm)
Net weight	85kg

Figure 3.3: Generator engine model single cylinder

3.3.2 Hot Wire Anemometer

The mass flow rate of air can be determined by using hot wire anemometer, also known as thermal anemometer. Hot wire anemometer is the sensor that utilizes an electrically charged wire that was used to determine the velocity of airflow entering the air intake. This equipment was installed before installing the air filters because without the air filter, it will directly enter to the anemometer sensor and hence cause the backflow effect. The air filter is engineered to filter out any impurities in the air before it enters the engine, thus reducing excess wear and tear on the engine. A dirty air filter will not only allow impurities to enter the engine but it can also allow dirt to accumulate in the hot wire, which can reduce its effectiveness. Hot wire that has been inserted into the outlet fitting of the surge tank with an arrow indicated at its tip oriented downstream towards the engine's intake port.

Figure 3.4: Hot wire anemometer

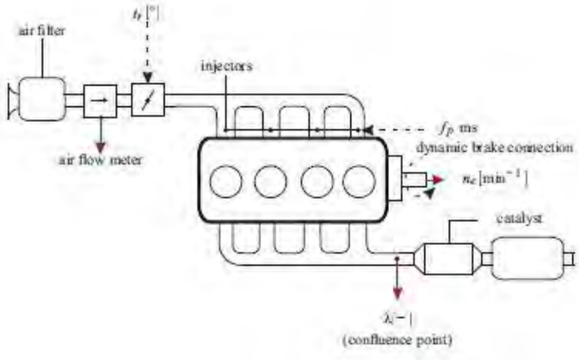

Figure 3.5: Installation space for anemometer

3.3.3 Magnetic Stirrer

Magnetic stirrer is a device used to mix components either solids and liquids or liquid and liquid to get homogeneous liquid mixtures. The concept of this equipment is almost the same as a blender but this equipment has more advantages. By using the magnetic stirrers, it can minimize the risk of contamination since there is only an inner magnet bar, which can be easily cleaned by putting it inside the sample or fluid. Magnetic stirrers mix the gasoline and hydrogen peroxide together using an external magnetic field that rotates a small magnetic bar that has been placed in the mixture of liquid. The test was continued with 5 vol % H_2O_2 95 vol % and 10 vol % H_2O_2 90 vol % gasoline. This magnetic bar can also adjust the speed for suitable use. After several minutes, this blend solution can proceed to properties test.

Figure 3.6: Magnetic stirrer

3.3.4 Bomb Calorimeter

Bomb calorimeter is a device that is important to determine the energy content of the oil. There are two types of bomb calorimeter which are the manual and the automatic. In order to find the energy content of H_2O_2-gasoline blend, manual bomb calorimeter was used. Experiment was carried out several times to find the energy content for gasoline and also the 5% and 10% of H_2O_2 blend. For the manual part, the bomb calorimeter device was set up and was let to operate for about 20 minutes. After the device has been operated for about 6 minutes, fuel was ignited in order to get the maximum value of temperature that can be reached by the fuel. Temperature for each minute was recorded to until the combustion process is completed. Energy content of the fuel will be calculated from the data temperature recorded. More information will be provided in Appendix H.

Figure 3.7: Manual bomb calorimeter

3.3.5 Hydrometer

Hydrometer was used to find the density of the solution. In this project, hydrometer was used to find the density of the gasoline alone and H_2O_2-gasoline blend. This fuel was placed in the conical flask after stirring for several times. A full fuel of 500ml conical flask was put in the water bath first to allow the temperature of fuel to reach about 14°C to 16°C. Hydrometer was then soaked in the conical flask and make sure that there is no external disturbance on the surface of the conical flask in order to obtain an accurate density reading. The result displayed on the reading scale is in unit g/cm^3.

Figure 3.8: Hydrometer

3.3.6 Data Acquisition System (DAS)

DAS used during the experiment was the SIRIUS type. Pressure transducer or pressure and crank sensors were installed on the engine and this sensor is connected to the DAS. The output of the DAS was connected to the display on the laptop that can be read through a DEWESOFTX2 software which can visualize the P-θ diagram while the experiment is running. The data that can be obtained from this software is the performance of the engine. They are the volume of the cylinder, the speed and all the other parameters needed.

Figure 3.9: Data Acquisition System

3.3.7 Polysaccharide

Polysaccharide was used as a catalyst to undergo an emulsifier process of blend H_2O_2-gasoline to produce a soluble solution. This catalyst was added due to incomplete process of the fuel blend. This additive can reduce the surface tension between the two solutions blend and can stabilize the blend for certain period.

Figure 3.10: Example mixture of emulsify process hydrogen peroxide-gasoline by using polysaccharide

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter consists of results of the experimental and numerical investigations, analysed and discuss the problem while running an experiment and conclusions at the end of this chapter. Discussions are made based on the data of the experiment that can get through this chapter. In this chapter, performance results will be discussed along with the effect of AFR in difference type of blend fuel based on gasoline alone. Experimental results include the performance characteristics of single cylinder SI engine with the variable of speed and load. It is then compared with gasoline alone and gasoline-hydrogen peroxide H_2O_2 operations.

4.2 Experimental Data

4.2.1 Properties of Fuel Blend

The fuel that used during the experiment was the gasoline from Caltex RON 95 and gasoline blend with the H_2O_2. The properties collected from this experiment was energy content, Q_{HV} of fuel and the density of difference type of fuel blend. The experiment of properties finding was conducted at Chemical Lab, Faculty of Mechanical Engineering. The result of density and energy content of fuel was tabulated as shown in Table 4.1.

Table 4.1: Results of density and energy content of fuel

Type of Fuel	Density (kg/m^3)	Energy Content, Q_{HV} (kJ/kg)
Gasoline Alone	735	38102
5% of H_2O_2 + Gasoline	755	33474
10% of H_2O_2 + Gasoline	765	28845

Based on Table 4.1 showed a result of density and energy content of fuel that is used in the experimental engine. The difference types of fuel will be resulting in the difference values of density of fuel and energy contents. Moreover, the density of 10% hydrogen peroxide- gasoline blend was higher than gasoline alone. Due to the higher density of H_2O_2 that are used it contain 50% of water. When the content of H_2O_2 has mixed with water that will give the density value close to the density of water 1000 kg/m3. Assuming of more percentage of H_2O_2 blend with gasoline will give the higher value of density that is close to the density of water.

Besides that, difference with the value energy content, Q_{HV} of fuel which is 10% H_2O_2-gasoline blend decrease more than the heating value of gasoline alone. This reduction of energy content on H_2O_2-gasoline blend due to the extra atom of oxygen in H_2O_2 is in suspension in water and place in the unstable condition where the oxygen are trying to escape unless held under slight pressure that keeps in stored (Charles P.Cox, 1981). Other than that, energy required for spray evaporation was influenced by the exothermal of gas phase H_2O_2 decomposition and H_2O_2-gasoline blend give that more reaction to the air that can sure more percentage of H_2O_2 blend with the gasoline will give lower value of energy content due to heat loss to the air before the ignition (Franz & Roth, 2000).

4.2.2 Exported Engine Data

Crank angle (CA) sensor and pressure sensor was install on the engine for finding pressure, volume and also crank angle in single cylinder by cycles. From this basic data will provide more related performance of engine. This sensor will connect to the DAS and the data from engine will shows through DEWESOFTX2 software. Table 4.2 shows the raw data that which exported from software to Microsoft excel.

Table 4.2: Raw data from software

X axis (deg)	Vol1 (dm^3)	AI 1 psmoAve (bar)
-360	0.049985	0.41769922
-359	0.050025	0.41504619
-358	0.050145	0.41369268
-357	0.050625	0.42785469
-356	0.050625	0.39943102
-355	0.050985	0.42102486
-354	0.051424	0.40997204
-353	0.051943	0.4104614
-352	0.05254	0.40752992

Moreover, the other raw data that collected from experiment was the fuel consumption that get from the Bernoulli ways which measure quantity of fuel used for engine running. Other than that, this fuel consumption can give higher effect of AFR data and specific fuel consumption (SFC). Experiment was running with three type of fuels which are gasoline alone (GA), 5% H_2O_2-gasoline and 10% H_2O_2-gasoline blend with variant load and different engine speed. Table 4.3 to 4.5 indicated raw data of fuel consumption which were fully exported to Microsoft Excel from DEWESOFTX2 software.

Table 4.3: Fuel consumption with different fuel and different load at 2500 RPM

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	41.0
2000	34.2	37.6	37.5

Table 4.4: Fuel consumption with different fuel and different load at 3000 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	25.0	24.3
1000	29.6	31.8	32.3
1500	32.6	42.0	45.5
2000	31.7	42.0	46.2

Table 4.5: Fuel consumption with different fuel and different load at 3500 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

4.3 Performance Analysis

The experimental investigation has been done on gasoline alone and hydrogen peroxide-gasoline blend fuel with different of load apply also different of engine speed to the effect of AFR was discussed in this section. The main objective of this investigation is to study effect to the AFR on performance when changing different type of fuel and determine the optimum AFR for better performance. This section will be used selected chart that represents similar pattern for each performance characteristics that will be interpreted and discussed. The extensive charts on performance of single cylinder SI engine for GA, 5% H_2O_2-gasoline blend and 10% H_2O_2-gasoline blend operations are presented in Appendix A to G.

4.3.1 Crank angle (CA) to Cylinder Pressure

The cylinder pressure was measured using DEWESOFTX2 pressure transducer and crank sensor, this input data was well-organized by DAS to visualize P-θ diagram while running the experiment. Figure 4.1 shows an example of the variation of cylinder pressure with crank angle at the speed of 3000RPM and 2000W load for GA operation, hydrogen peroxide with gasoline operation, for CASE 1 and 2. For CASE 1 which use 5% H_2O_2-gasoline blend and CASE 2 for 10% H_2O_2-gasoline blend.

From Figure 4.1 shows the results show that all curves move upwards with the same pattern before top dead center (TDC) which indicates normal combustion of fuel without pre-ignition. The GA and gasoline-hydrogen peroxide for CASE 1 and CASE 2 pressure curves has the tendency to shift to the right for CASE 1 and CASE 2 where the peak pressure for GA operation occurs in the range of 10° to 16°CA before than that of GA operation throughout all engine speeds. Injection of H_2O_2 shift the pressure increase to later CA which cause the delay in peak pressure of CASE 2 about 20° CA. This operations occurs is due to high auto-ignition temperature of hydrogen peroxide in cylinder charge causes late ignition of hydrogen peroxide after pilot ignition of gasoline fuel. Delay of peak pressure also due to water injection in hydrogen peroxide reduces combustion flame temperature during premixed combustion phase of the cylinder charge (Franz & Roth, 2000).

Moreover, the optimum AFR for the figure 4.1 was CASE 2 which is 12.3 without any load given. From the graph, the delay before start ignition for all fuel was almost close to each other is about -60° to -50°CA. From -50° to -40°CA the engine start to ignite and after that graph up rise immediately caused by combustion process occur in cylinder increase pressure in cylinder 7 to 7.5 bar for GA and CASE 2. A little bit different for CASE 1 which has early end of combustion process about 20° to 24°CA and caused the pressure in cylinder about 6.5 bar also the highest value of AFR. This can be logical the highest mass of air with the less mass of fuel make the lean combustion.

From Figure 4.2, the pressure to crank angle is close enough to the graph before but have an ignition delay from -60° to -50°CA make a right time for fully combustion process end without any problem. For this graph, the load is applied with 2kW and get the highest pressure occur at CASE 2 was about 17 bar with the AFR 15.53. Other than that, this graph make the better process of combustion which most increasing value of AFR that near to the stoichiometric value (14.7) will influence of the pressure also efficiency of the engine (Jansri & Sooraksa, 2012). This can be classified as rate of fuel mass and rate of air mass with adequate quantity.

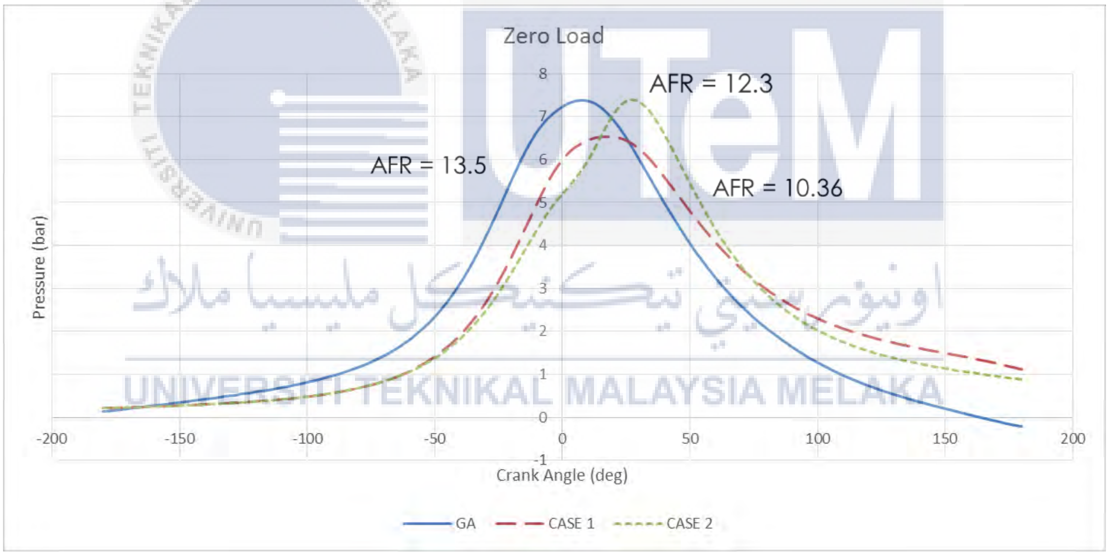

Figure 4.1: Variation of cylinder pressure with crank angle at 2500 RPM with 0W of load

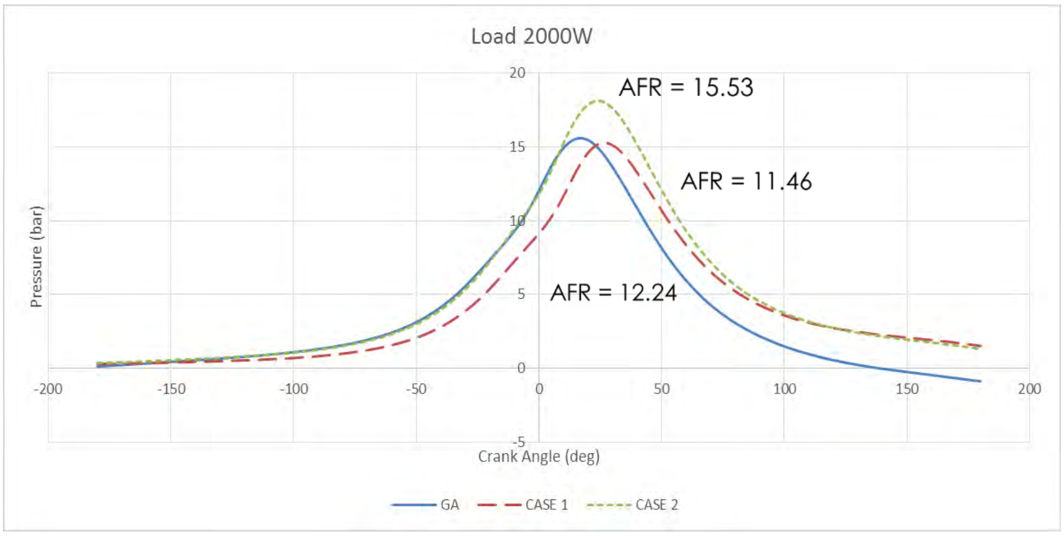

Figure 4.2: Variation of cylinder pressure with crank angle at 2500 RPM with 2kW of load

4.3.2 Maximum Pressure in Cylinder

The peak pressure was obtained from P-θ diagram or pressure to crank angle for every speed and load during experiments. The analysis of peak pressure is analysis in determining maximum force can be accepted for the engine piston and cylinder to identifying the best material for engine fabrication. The analysis of peak pressure is more important in finding safety factor of engine fabrication as compared to BMEP analysis since it really indicates the in-cylinder conditions.

Figure 4.3 showed that variation of peak pressure with engine speed at 500W of the load has been applied. The graph indicated that when engine speed at 2500 RPM, GA has the highest pressure and CASE 1 has the lowest pressure. According to Figure 4.3 at 2500 RPM, GA has the highest value of pressure about 11 to 12 bar and follow with the CASE 2 around 10.5 bar and 7.8 bar for CASE 1. This figure pattern showed the pressure for each case is decreasing below 9 bar at 3000 RPM. After that, the pressure increases slowly for certain pressure at 3500 RPM with not higher as at 2500 RPM. It could be concluded that the decrement of pressure is caused by sudden changes of fuel used to stabilize engine with the added more of hydrogen peroxide caused the pressure rise up again. Other than that, lower peak pressure for CASE 1 and CASE 2 operation is due to evaporative cooling of water affects the temperature during premixed combustion.

Figure 4.4 is almost same with Figure 4.3, which GA has the highest pressure in cylinder around all cases when combustion process occur with the 12.2 bar at 2500 RPM. This figure showed the in-cylinder pressure were decreasing with about 10 bar and rise up again to 10.3 bar. The pattern is same for CASE 2 and CASE 1 but they are slightly difference in pressure value. At the early stage, for both figures it showed that pressure for the Figure 4.4 has 12.2 bar which is higher than pressure in Figure 4.3 that is 11.5 bar. It can be described that the increasing of pressure for Figure 4.4 due to a highest peak pressure produce higher heat release rate and more complete combustion as the effect of optimum equivalent ratio of the cylinder charge with hydrogen and water droplet.

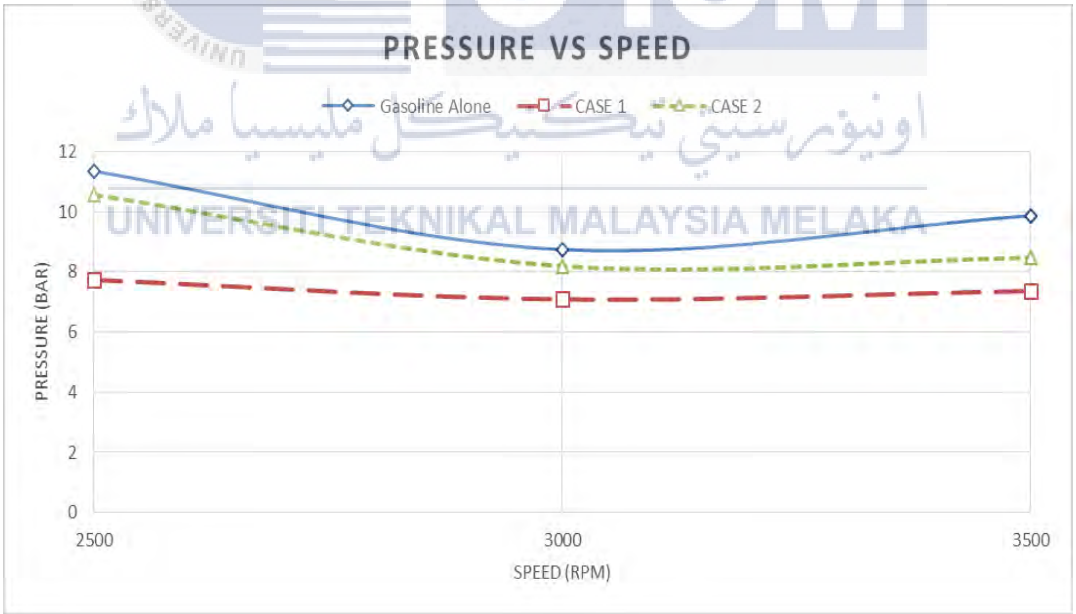

Figure 4.3: Variation of peak pressure to engine speed with 500W of load

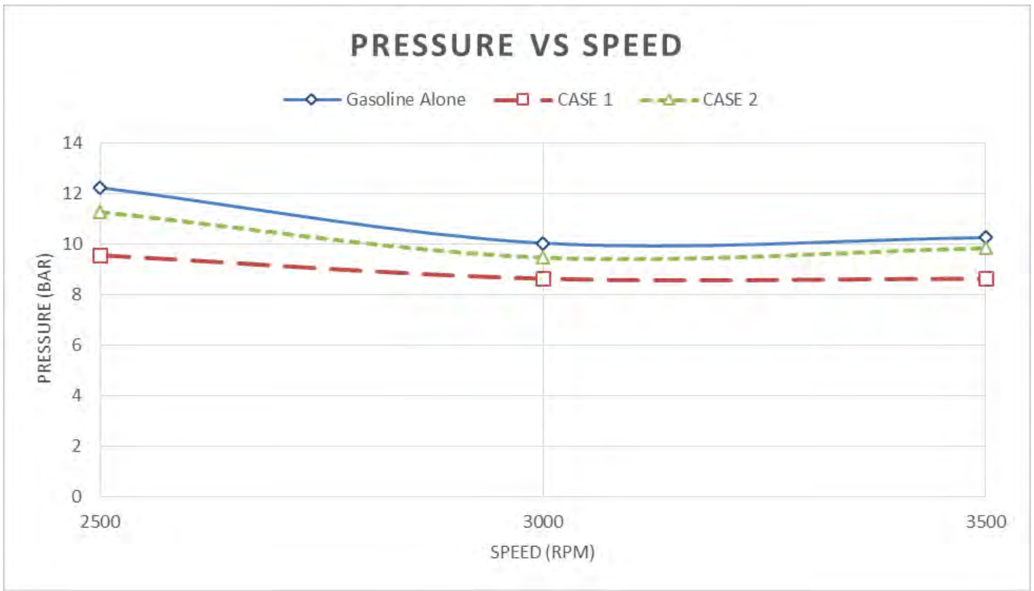

Figure 4.4: Variation of peak pressure with engine speed at 1000W of load

4.3.3 Heat Release Rate

Heat release rate (HRR) was calculated from the average pressure with respect to crank angle for one minute cycles. It is important to identifying the rate of chemical energy released from combustion of fuels. Figure 4.5 and 4.6 demonstrates the heat release rate of SI engine in present investigation running on GA, CASE 1 and CASE 2 with duration of 180° BTDC and 180°ATDC at 2500 RPM and 3000 RPM with apply 2kW and 500W of load.

Figure 4.5 demonstrates for all cases which GA has the lowest of peak heat release rate (PHRR) with value 7 Joule per degree (J/° deg) with AFR 12.72. The highest value of PHRR was the CASE 2 that has 11.6 Joule per degree (J/° deg) with the AFR 17.29. For CASE 1 and CASE 2 can be seen the PHRR was shift to right compare to the GA caused by late of combustion phase where small fraction of fuel not yet burned. Moreover, from the graph also a gap different of AFR for CASE 2 with the other cases that has 17.29 which highest value from GA, this because combustion have the extra air that give the lean combustion.

It have almost same pattern with Figure 4.6 but have different of PHRR for CASE 2 has the highest value which is about 5.3 Joule per degree (J/° deg) with the AFR value 17.06 and GA has the lowest value of PHRR with 3.4 Joule per degree (J/° deg) and has the lowest value of AFR 12.02. The little bit different about this two different of graph caused by the changes of engine speed. It was also given an effect to the AFR with an increasing and still GA has optimum AFR. Besides that, negative heat release rate have been observed before the start of ignition due to gasoline fuel and hydrogen peroxide droplet initiates its vaporization process resulting in heat absorption from the cylinder charge.

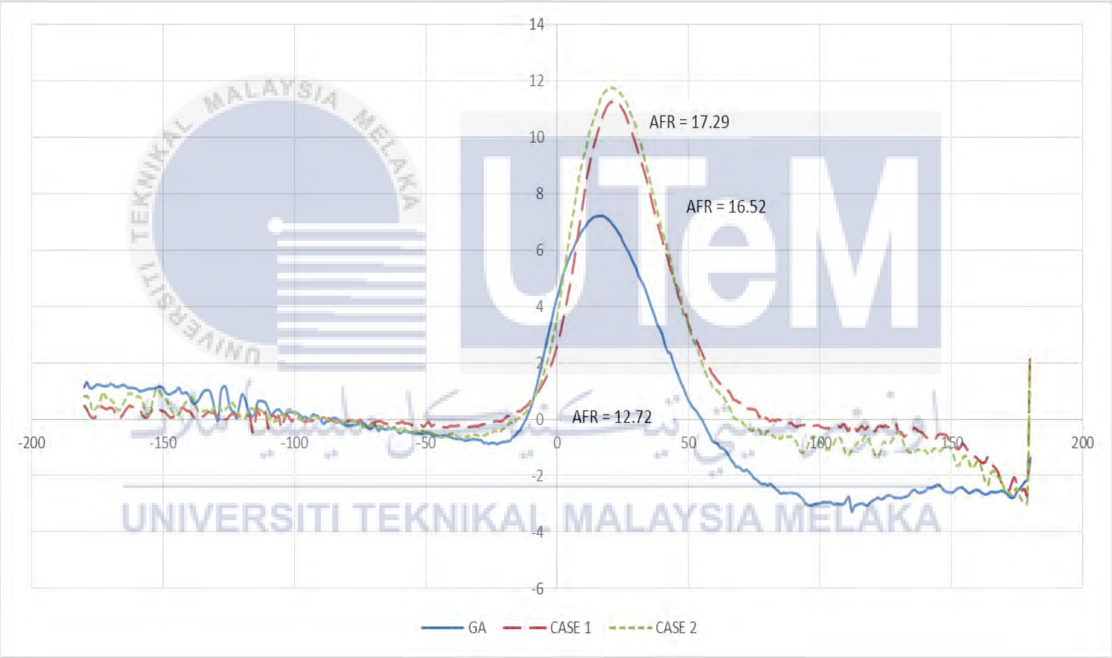

Figure 4.5: Variation of heat release rate again crank angle at 2500 RPM with 2kW

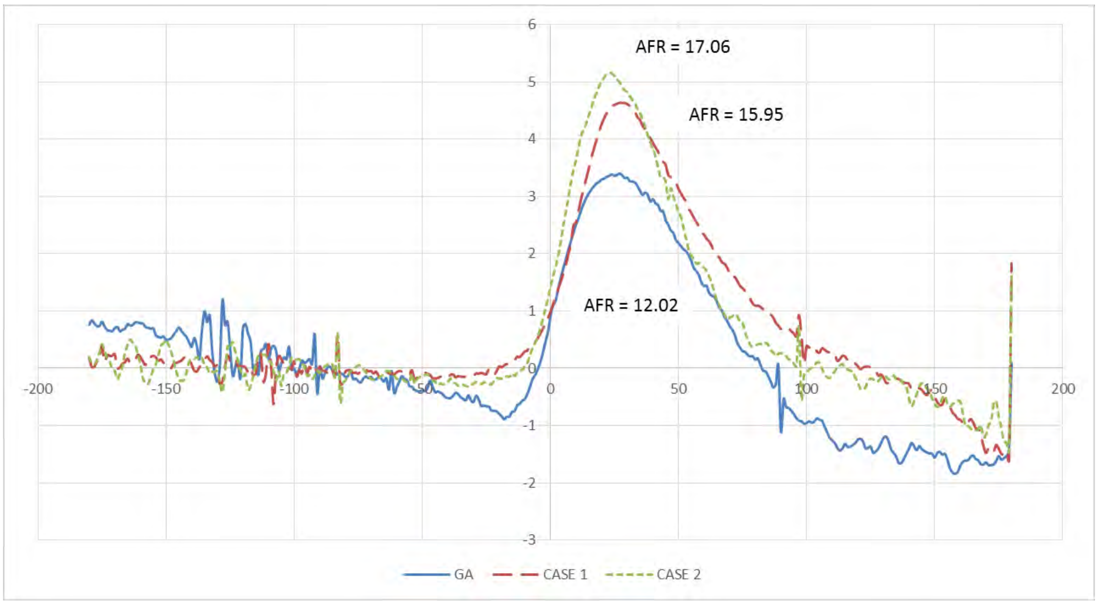

Figure 4.6: Variation of heat release rate again crank angle at 3000 RPM with 500W

4.3.4 Indicated Work

Gross indicated work is known as work delivered to the piston during compression and expansion strokes namely crank angle in between 180°BTDC and 180°ATDC. It also is known as useful shaft work available for an engine. It is determined from enclosed area on PV diagram as shown in Figure 4.7. Figure 4.8 and 4.9 shows the variation of gross indicated work (in unit Joule) for all cases at each engine speed for 0W and 2kW of the load.

From Figure 4.8 showed the GA has the lowest gross indicated network around 46 Joule to 48 Joule at each engine speed than CASE 1 and CASE 2 which has the highest value of gross indicated network about 100 Joule to 105 Joule for 2500 RPM. After that, network was decreasing for CASE 1 and CASE 2 and have almost same indicated network about 90 J to 92 J at 3000 RPM. Decreasing for CASE 1 and CASE 2 caused by the friction loss because of the problem occur while running an experiment (Heywood, 1988) and increasing with the almost same gross indicated network about 93 J to 95 J. This pattern was same for the GA that decrease at 3000 RPM and highest rate of rising up at 3500 RPM from 45 J to 62 J.

Moreover, Figure 4.9 can be observed that the higher gross indicated network was the CASE 2 which has about 212 J at 2500 RPM. GA has the lowest gross indicated work about 110 J. For this pattern of the graph for CASE 1 and CASE2 was almost same that decreasing at 3000 RPM and continuously decrease for 3500 RPM. A little bit difference pattern for GA that decreasing at 3000 RPM and make it increase for indicated network at 3500 RPM. From this Figure 4.8 and Figure 4.9, can be concluded that gross indicated network for Figure 4.8 has the highest value in each difference speed compare to the Figure 4.9 that increase a load made the gross indicated network higher than expected.

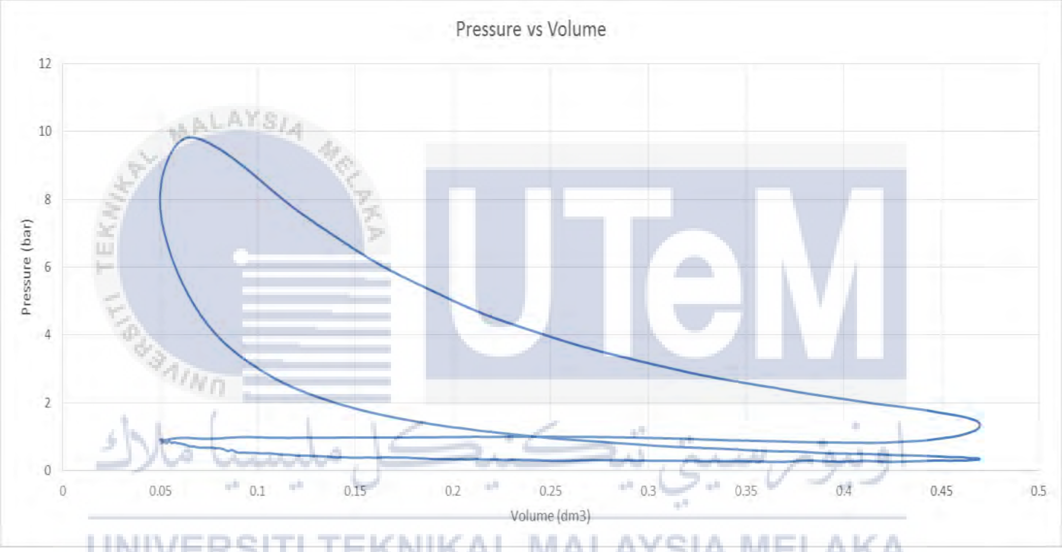

Figure 4.7: P-V diagram at 3500 RPM with 1kW load for CASE 2

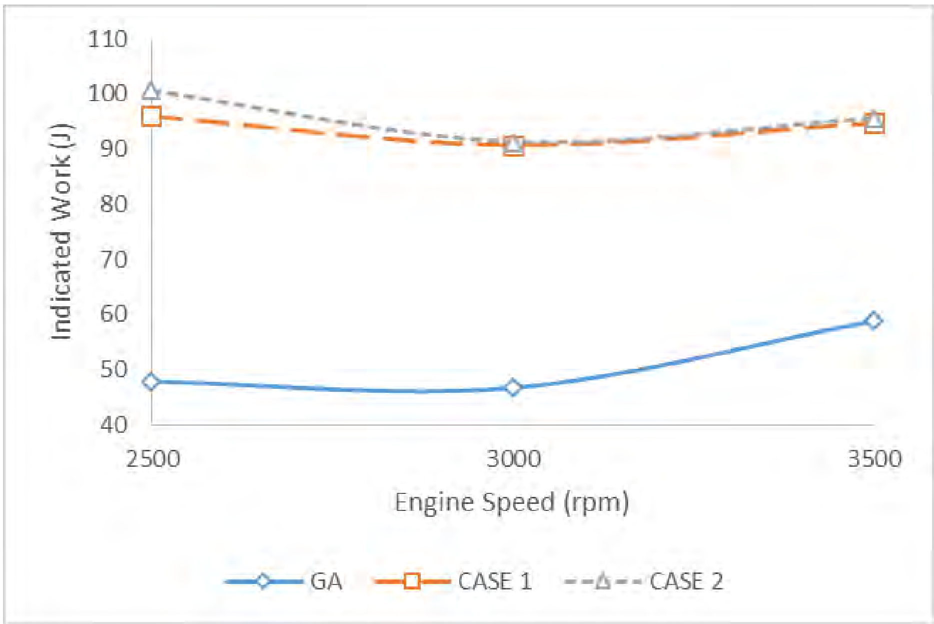

Figure 4.8: Gross Indicated Work with different engine speed at 0W load

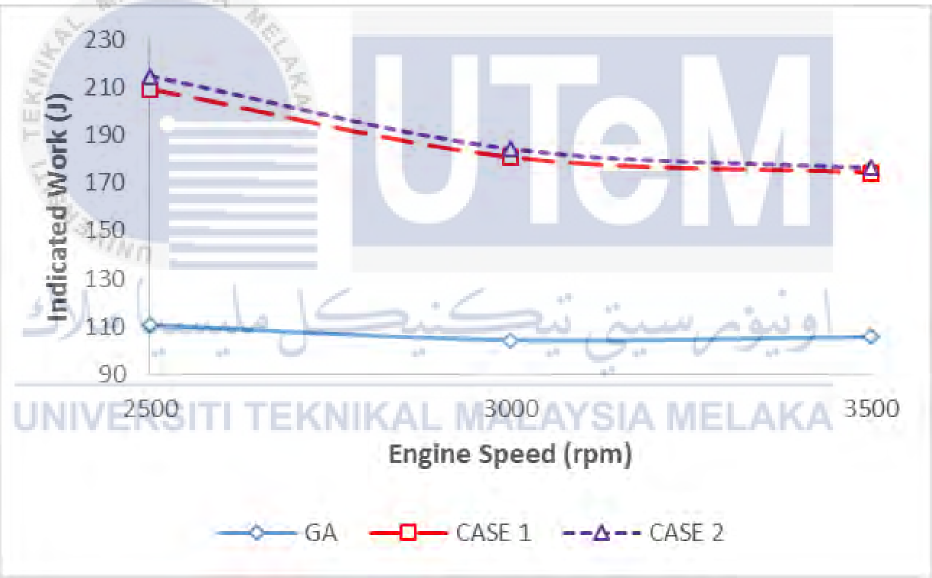

Figure 4.9: Gross Indicated Work with different engine speed at 2000W load

4.3.5 Indicated Thermal Efficiency

Indicated thermal efficiency (ITE) is determined from the ratio of gross indicated work and total heat generated from combustion of fuels. Figure 4.10 and 4.11 illustrates the variation of ITE with carburettor flow for all cases at different engine speed with different of load.

It can be seen from Figure 4.10, at 2500 RPM the highest value of ITE was CASE 1 which has 33.4% and decrease steadily 24.9% at 3500 RPM. A result different for CASE 2 that increase rapidly from 31.2% at 2500 PM to 37.6% at 3500 RPM. Besides that, GA has the lowest thermal efficiency with 16.3% and the pattern same with the CASE 2 that increase gradually to 17.2% at 3500 RPM. Effect of decreasing of CASE 1 caused by increase of inlet charge temperature (Pan et al, 2015) and the pattern increase for GA and CASE 2 caused by advanced ignition timing air furl mixture get sufficient time to ignite (Khalefa, 2011).

Figure 4.11 showed that CASE 2 has highest thermal efficiency among the other cases. This figure shown based thermal efficiency with 2kW load applied. At 2500 RPM, CASE 2 which effect 36% thermal efficiency and decrease slowly at 300 RPM with 30.1% then rise up again for 3500 RPM. This pattern for CASE 2 was almost same with CASE 1 that has only a few low value from CASE 2. Moreover, the lowest value of thermal efficiency for this graph was GA that has 16% and climbed up instantly to 19.6% at 3000 RPM and continues increase to 21.3% at 3500 RPM.

This can be concluded the thermal efficiency for 0W load and applied 2kW of load did not give much more different with other. It can be classified for have the same effect to the engine for thermal efficiency with load or without load.

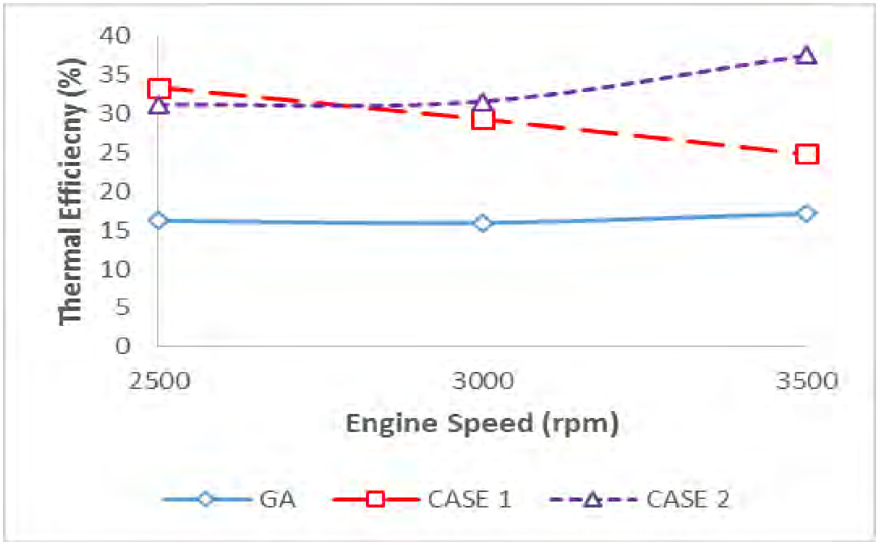

Figure 4.10: Thermal efficiency with different engine speed at 0W load

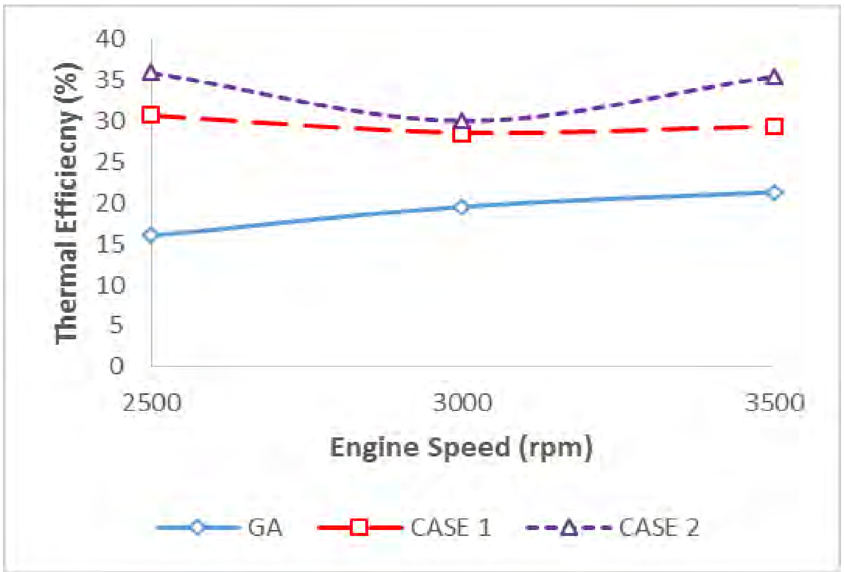

Figure 4.11: Thermal efficiency with different engine speed at 2kW load

4.3.6 Indicated Power (IP)

The other important thing in performance of engine to determine energy that were related to load. This power is the usable power delivered by engine to the load and can be describe as brake. Indicated power can be obtained by adding some friction power to the brake power. It can be classified average rate of work gases transfer in cylinder during expansion and compression process occur (Heywood, 1988).

Figure 4.12 indicated that the highest power (kW) output was for CASE 2 about 2.1 kW at 2500RPM and growth up linearly for 3000RPM and continues again increase to 2.78 kW at 3500RPM. It not have much different for CASE 1 which has 2 kW at the begin of engine speed and increasing at 300RPM at which has same value of IP with CASE 2 and continues increase until 3500RPM with a little low from the CASE 2. With has the lowest values of power for GA at 2500RPM with 1 kW and also has same pattern with the other cases that increase linearly for 1.17 kW at 3000RPM and increasing again to 1.7 kW at 3500RPM.

Figure 4.13 and 4.12 has the same pattern. It shows the increasing value of power from 2500RPM to 3500RPM. Figure 4.13 have much higher value of IP which starting at 2500RPM for CASE 2 was 4.47 kW and end up at 3500RPM with 5.14 kW. Furthermore, same also for CASE 1 and GA that has 2.3 kW in starting and end up with 3.08 kW for 3500RPM.

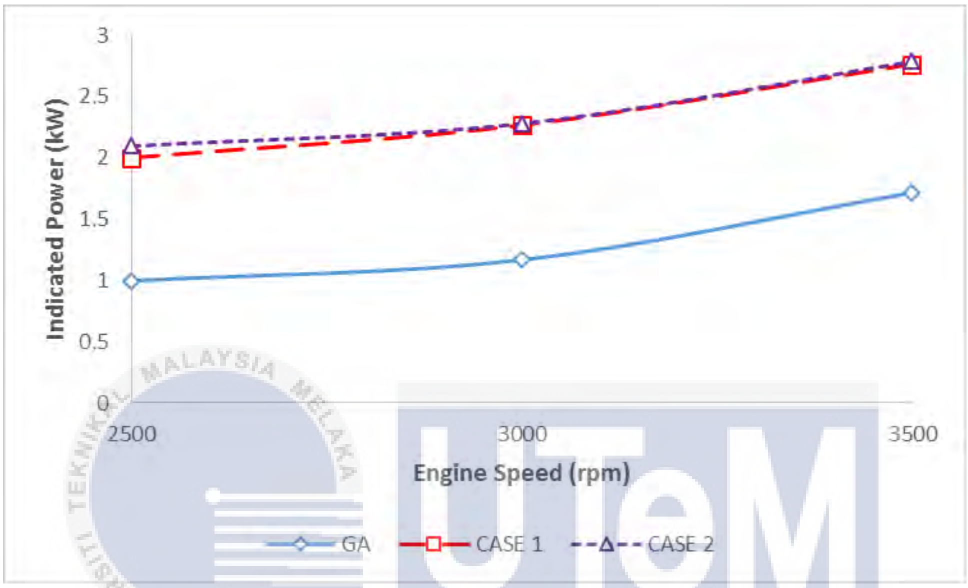

Figure 4.12: Indicated power at different speed with 0W load

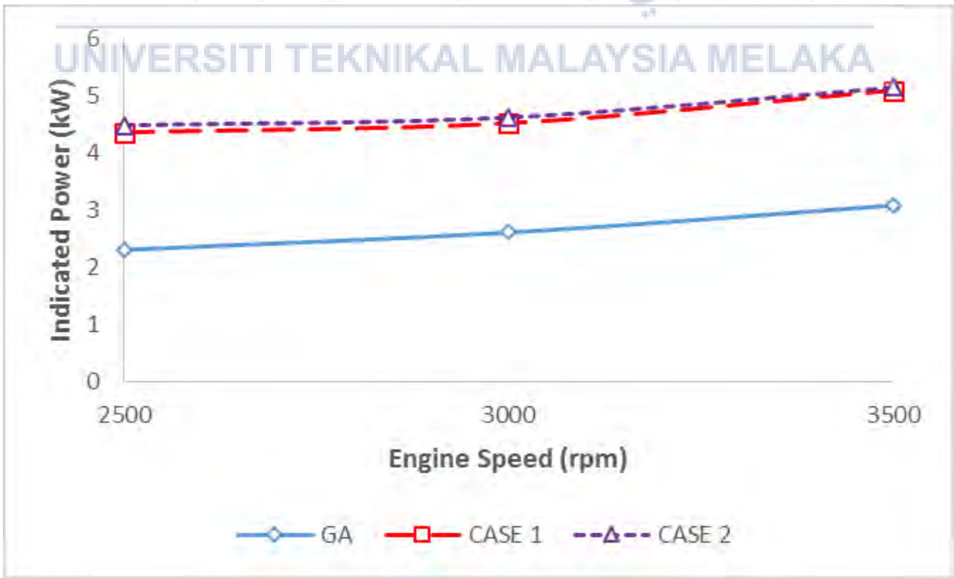

Figure 4.13: Indicated power at different speed with 2kW load

4.3.7 Indicated Specific Fuel Consumption (ISFC)

The other parameter must be included in performance of the engine and was measured as a flow rate which is mass flow per unit time. The accurate define for this parameters was fuel flow rate per unit power output. This parameter can determined how efficiently an engine was using the fuel supplied to produce work. Low value of ISFC are most desirable.

From Figure 4.14 and 4.15 showed that ISFC versus the engine speed. This figure indicate the different result with load and without load. As can been see, Figure 4.14 indicates that GA has the highest ISFC again other cases with 645.74 g/kWh at 2500 RPM and decrease at 3500 RPM with 611.45 g/kWh. The lowest ISFC at 2500 RPM was CASE 1 that used only 357.13 g/kWh. CASE 1 suddenly have increase dramatically at 2500 RPM and end up at 3500 RPM with 480.34 g/kWh. The stable condition for engine without load was the CASE 2. It can be proved which has a low value at 2500 RPM and decrease linearly at 3000 RPM and decrease again at 3500 RPM with 368.75 g/kWh.

Figure 4.15 showed that ISFC with the 2kW load applied have a completely different of result. It can be proved that GA has the highest ISFC at 2500 RPM with 654.36 g/kWh and rapidly decrease at 3000 RPM with 535.74 g/kWh and end up at 3500 RPM with 492.18 g/kWh. CASE 1 and CASE 2 has slightly difference value of ISFC at 2500 RPM and were differently at 3000 RPM with 418.34 g/kWh for CASE 1 and 460.01 g/kWh for CASE 2. Furthermore, CASE 2 was dropped at 3500 RPM with the 389.96 g/kWh below than CASE 1 with 406.58 g/kWh.

This can be concluded that CASE 2 has the best ISFC because less used of fuel for engine output during highest engine speed. This can be proved by the best value of ISFC for SI engine are about 270 g/kWh (Heywood, 1988). From this fact, the suitable case for ISFC was CASE 2 that were used 10% of hydrogen peroxide blend with the gasoline.

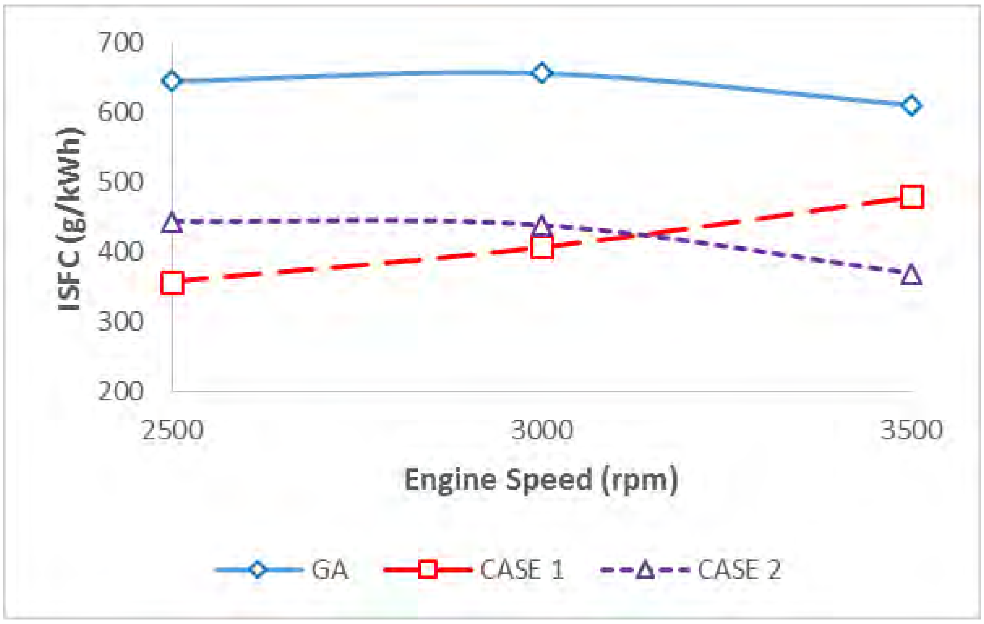

Figure 4.14: Indicated specific fuel consumption with different engine speed without load

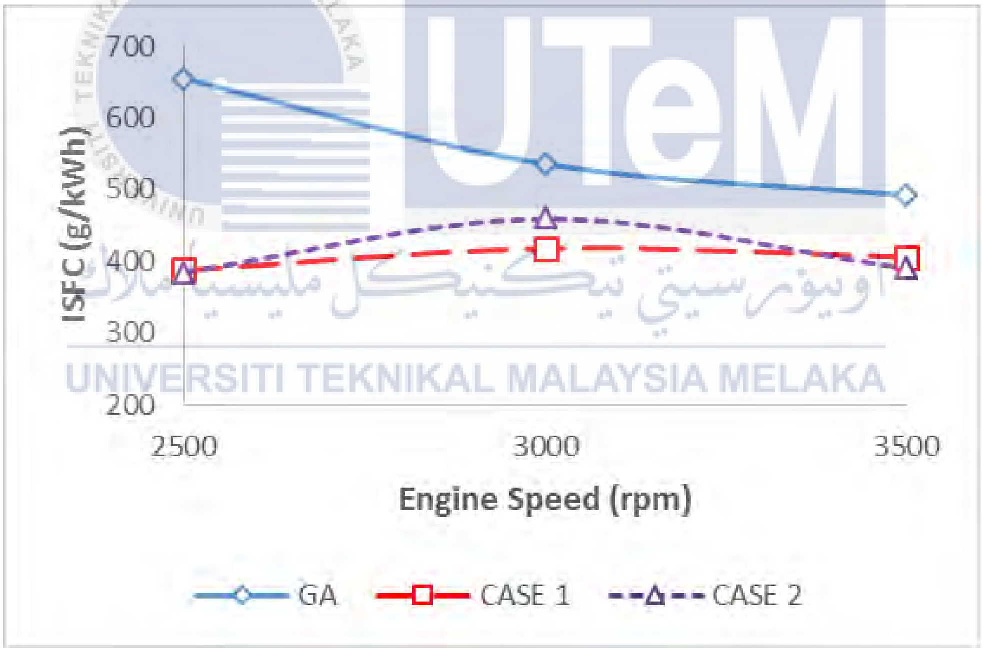

Figure 4.15: Indicated specific fuel consumption with different engine speed on 2kW load

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As a conclusion, in order to complete the experiment of this research using the additive hydrogen peroxide, we need to consider a few factors. It can clearly be seen that when the hydrogen peroxide is blending with gasoline, it will eventually produce some effects of pressure in-cylinder and to AFR where the pressure in-cylinder can be lower or higher from GA but somehow it needs a little more time to undergo the process of combustion compared to GA. This problem was due to the high auto-ignition temperature of H_2O_2 in the cylinder charges and hence causes the pressure to ignite later than GA. Next, based on the result of the experiment when using a 10% of H_2O_2 – gasoline blend, it can be concluded that the highest pressure in-cylinder will produce the highest AFR.

On top of that, it can also be concluded that by each of the engine speeds, the pressure in-cylinder will decrease and will not rise higher than the original engine speed. HRR can identify the rate of chemical energy released from combustion. Through the experiment, it was proven that H_2O_2 produced a good result since it has a lower value compared to GA that has higher HRR. Besides that, we can also determine the optimum value of AFR where the value can be considered close to the stoichiometric value which is about 17 for SI engine and 9 for 10% H_2O_2-gasoline blend.

Next, for the result of the optimum work, it can be seen that when we are using the 10% H_2O_2, it obtained the highest of work compared to GA. This can be concluded that when we increase the load given to the engine, we will also get a higher value of indicated work. For the result of the thermal efficiency, when using the hydrogen peroxides blend, it shows that the thermal efficiency are higher than GA but having only slight differences in value when using or without using the load. The optimum value of thermal efficiency is about 30% to 35%.

H_2O_2-gasoline blending will give more power compared to GA and this power will increase due to the increment of engine speed and load given. During certain periods of timing the engine is running. The ISFC is considered the best if they consume the least amount of fuel when the engine is running. The usage of the 10% of hydrogen peroxide blend with gasoline shows better ISFC value output with the increment of the engine speed compared to GA. Although hydrogen peroxide shows great performance of engine, but it has a lower energy content compared to GA. The best energy content for fuel is 44000 kJ/kg and above. The energy content result proves that the increment percentage of hydrogen peroxide blend with gasoline will make a lower of energy content.

Some recommendations for future study are as follows. Chemical H_2O_2 blend with gasoline should not be more than 10 vol %. This is due to the properties of the hydrogen peroxide. This is to avoid time-lag during combustion process due to the energy that evaporated easily to the air and dry faster. On top of that, having a better polysaccharide that can act as an emulsifier in the process of blending the hydrogen peroxide with gasoline during the experiment would be good either.

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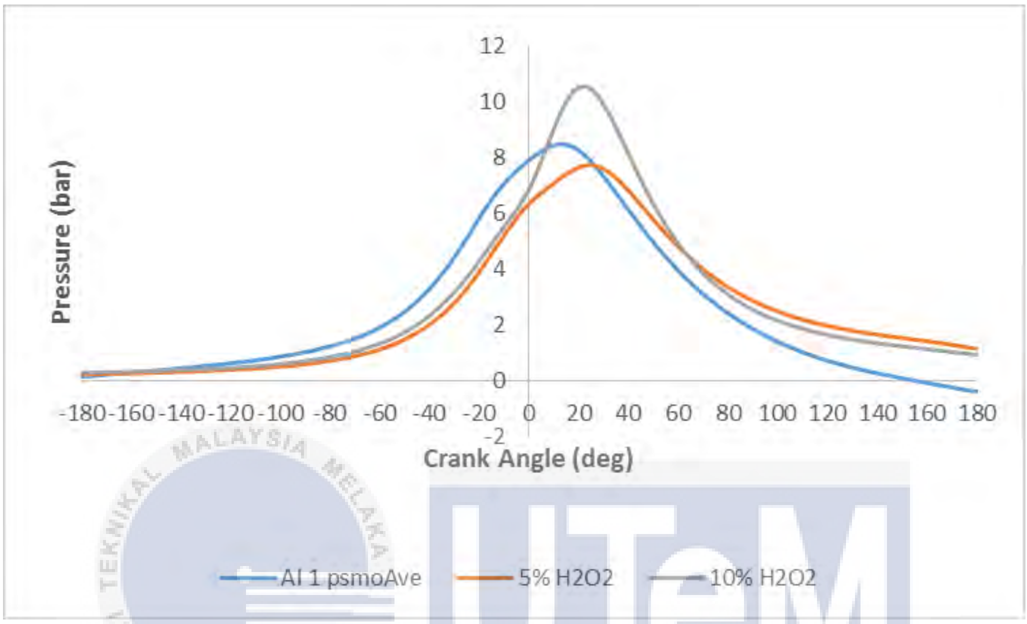
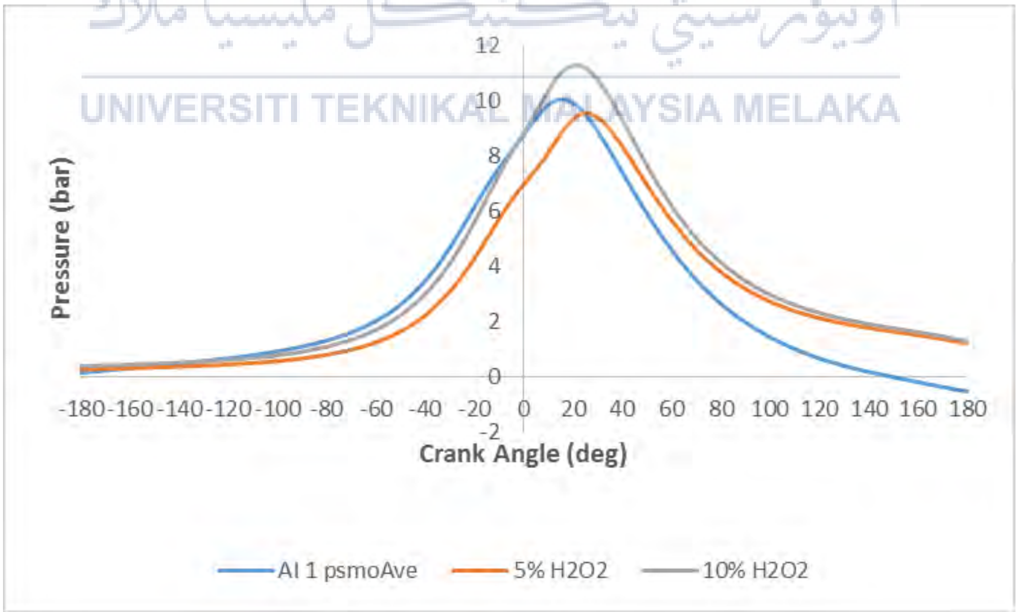
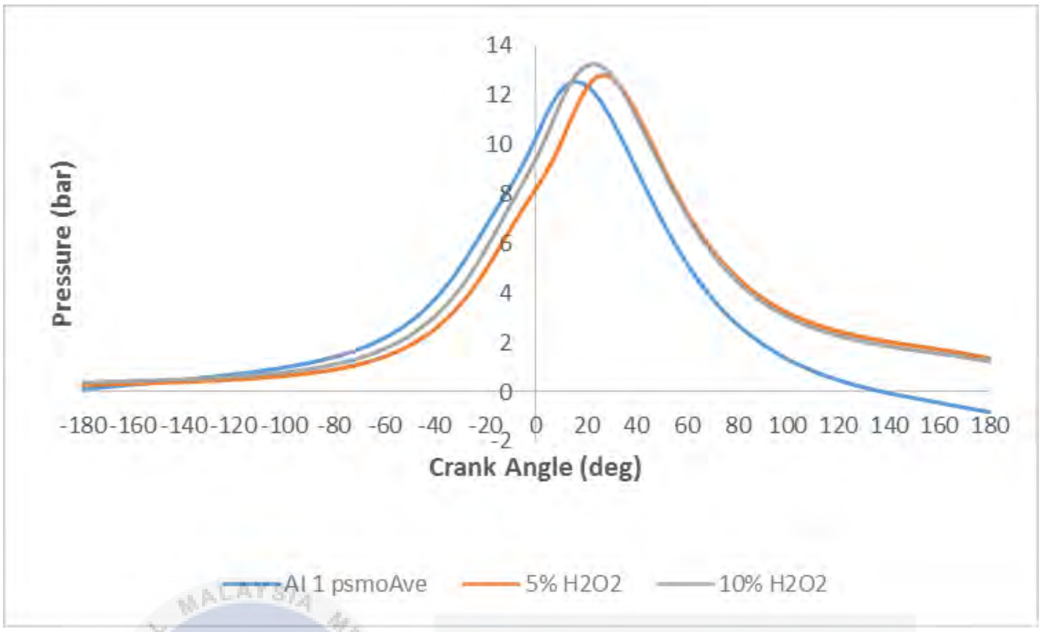
APPENDIX A

Variation of cylinder pressure with crank angle



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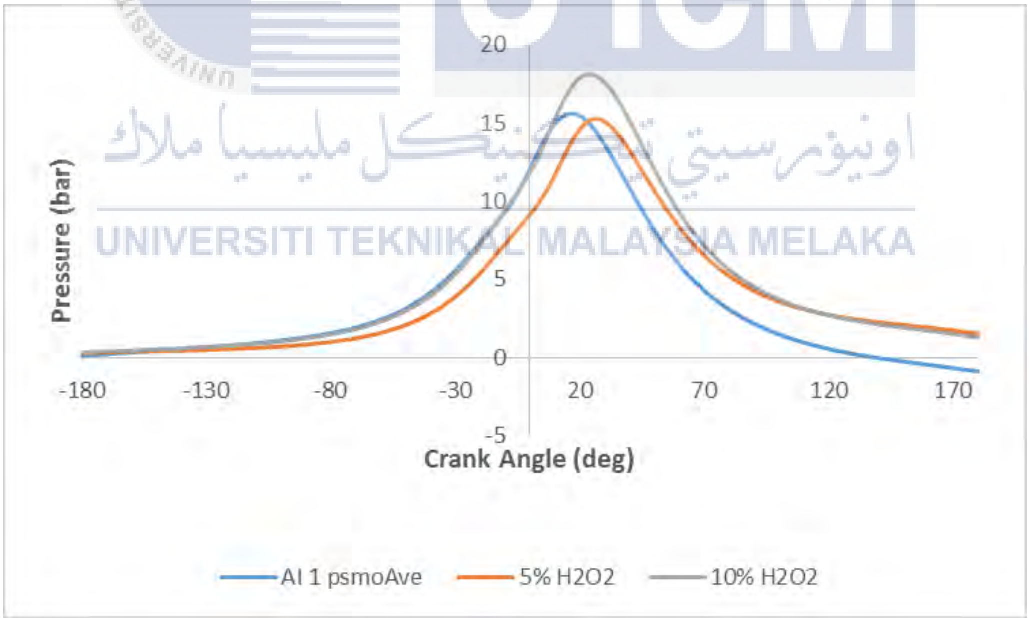
Pressure (bar)
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2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Crank Angle (deg)
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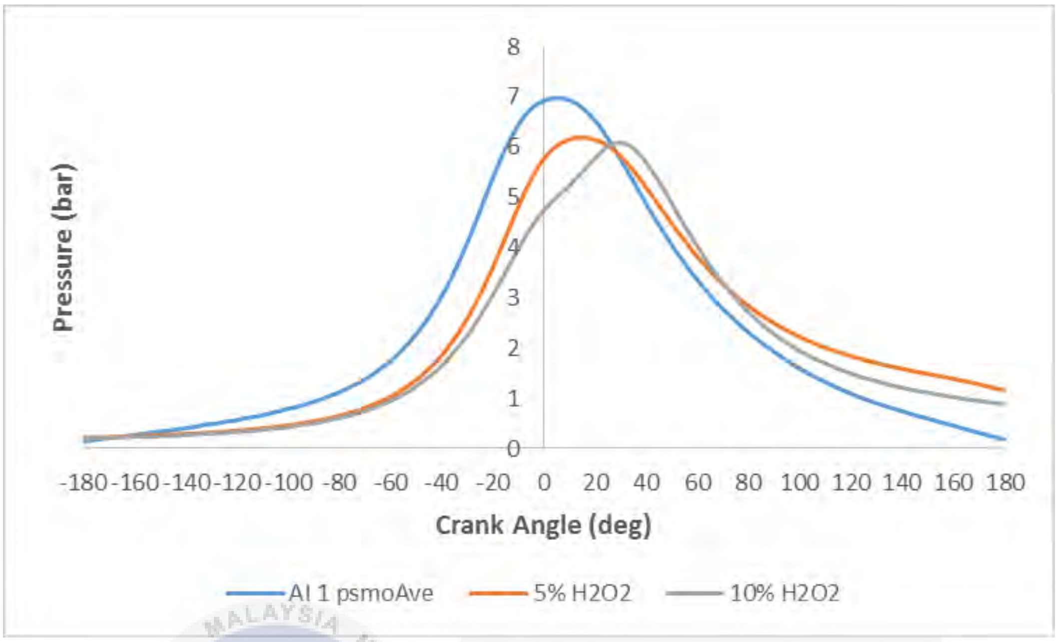
5% H2O2
10% H2O2



Pressure (bar)
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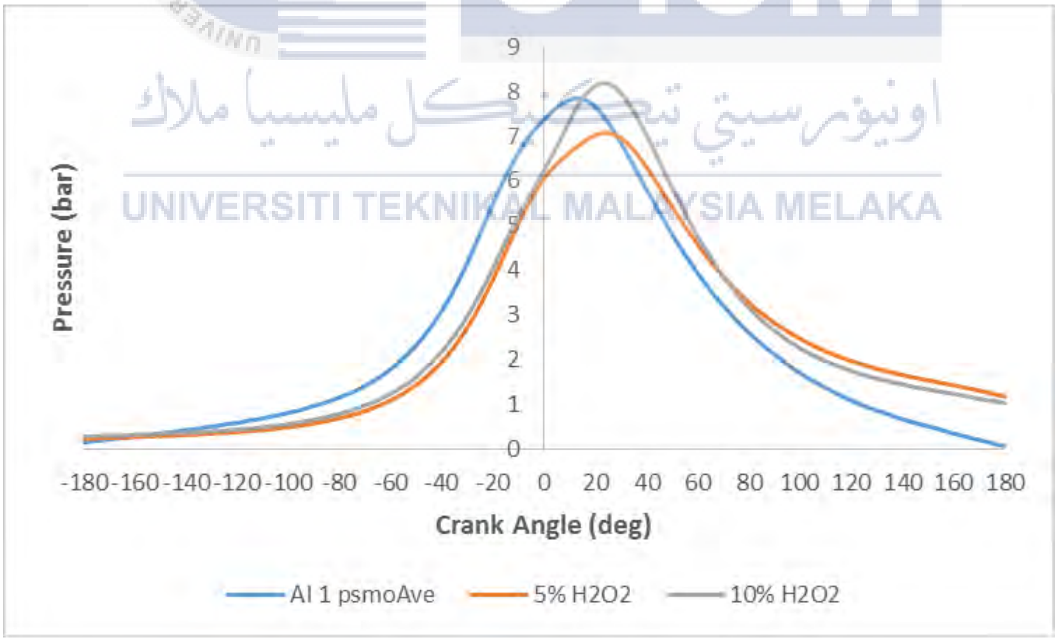
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2



Pressure (bar)
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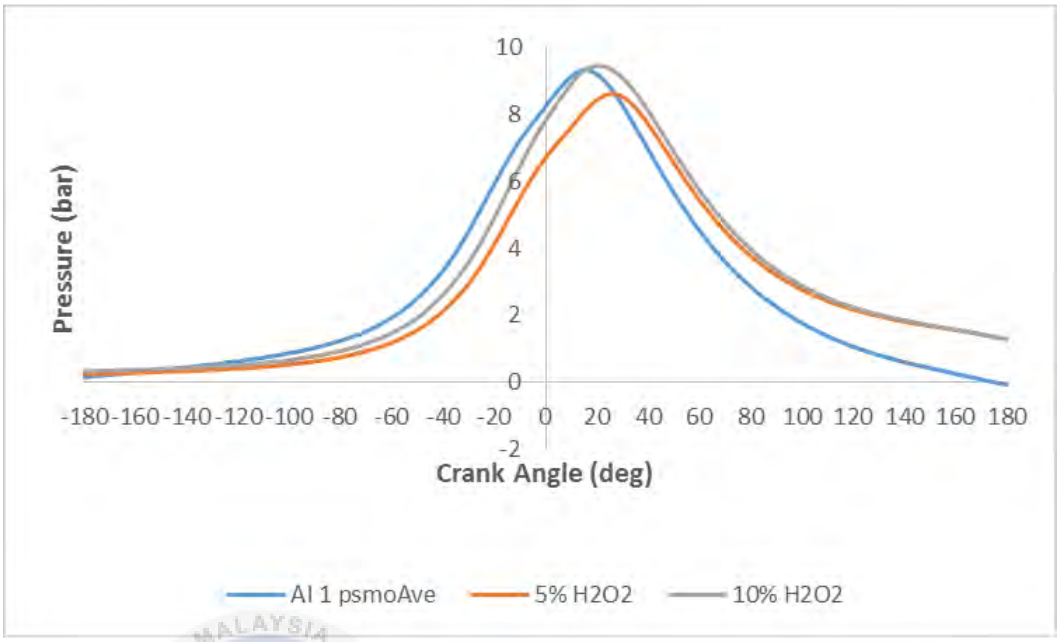
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2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Pressure (bar)
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Crank Angle (deg)
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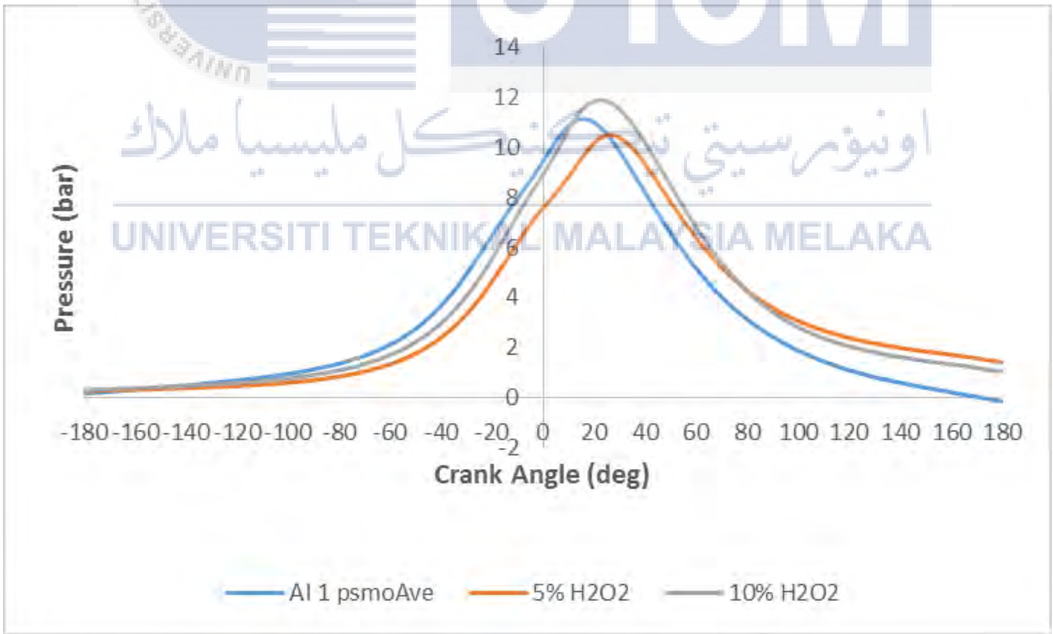
5% H2O2
10% H2O2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Crank Angle (deg)
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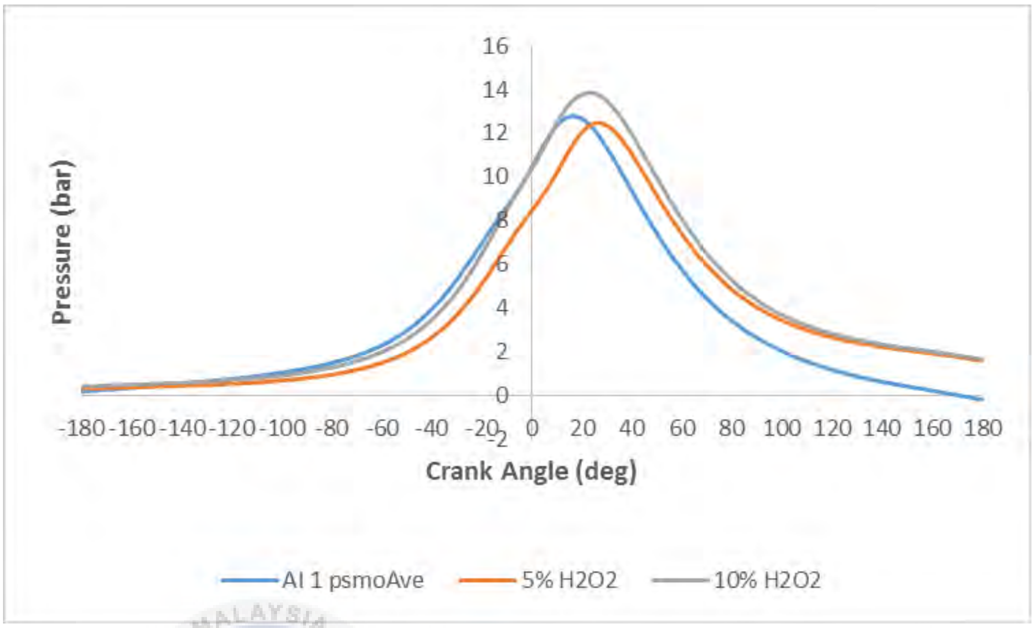
10% H2O2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Crank Angle (deg)
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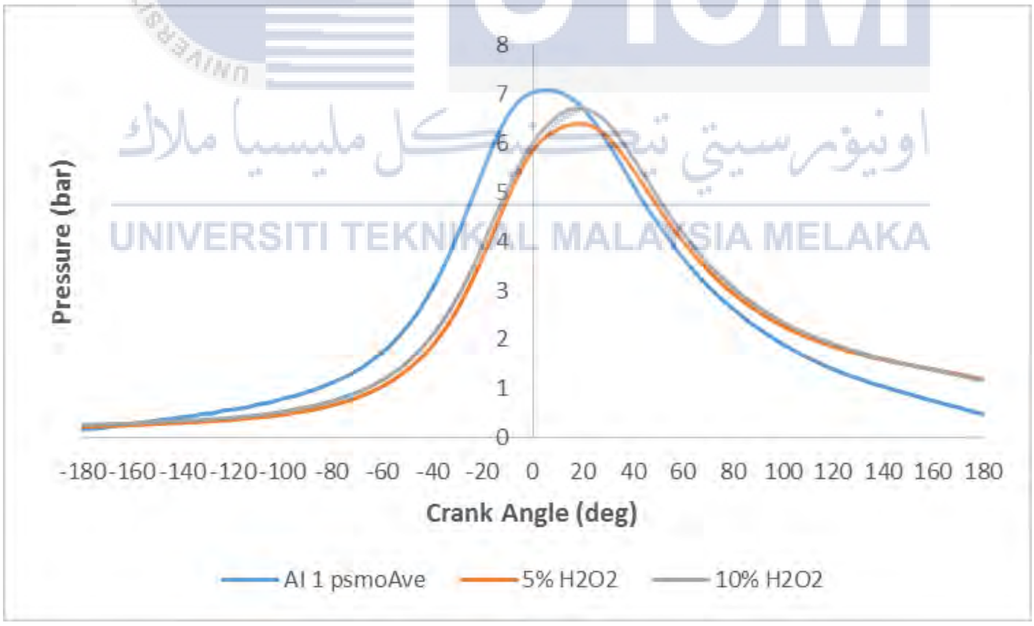
5% H2O2
10% H2O2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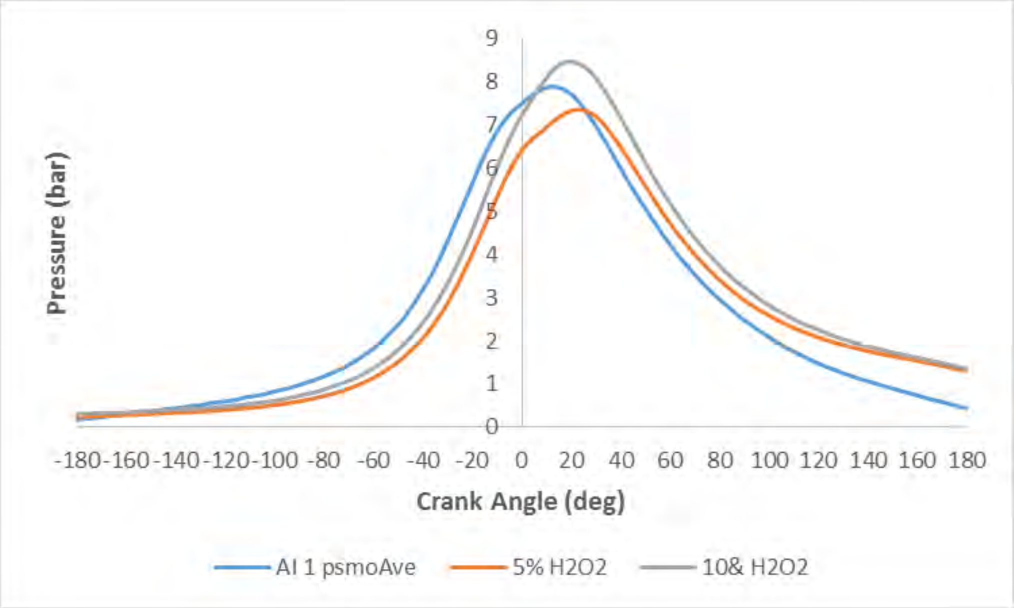
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2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Crank Angle (deg)
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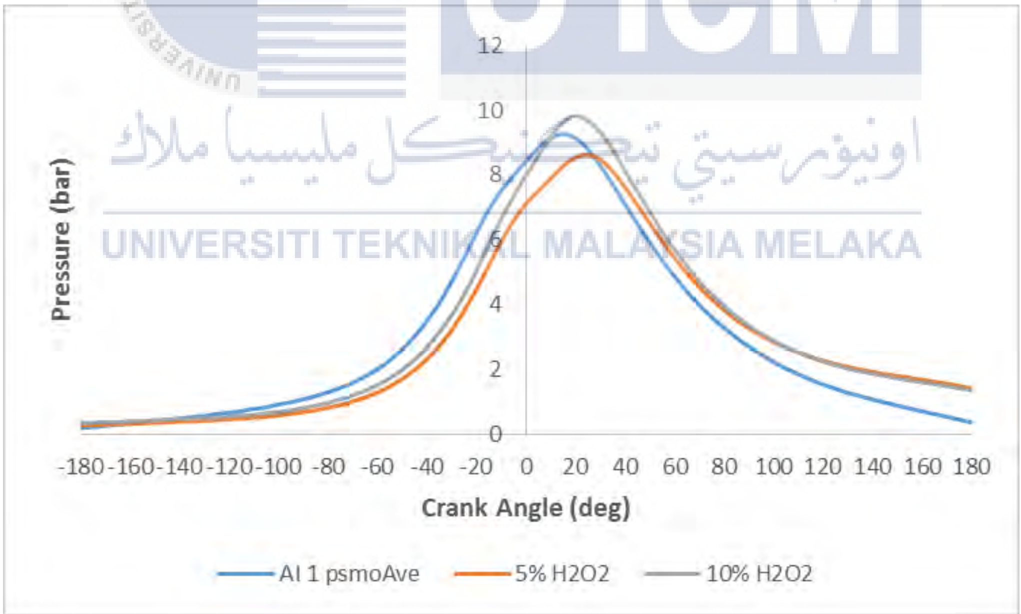
5% H2O2
10& H2O2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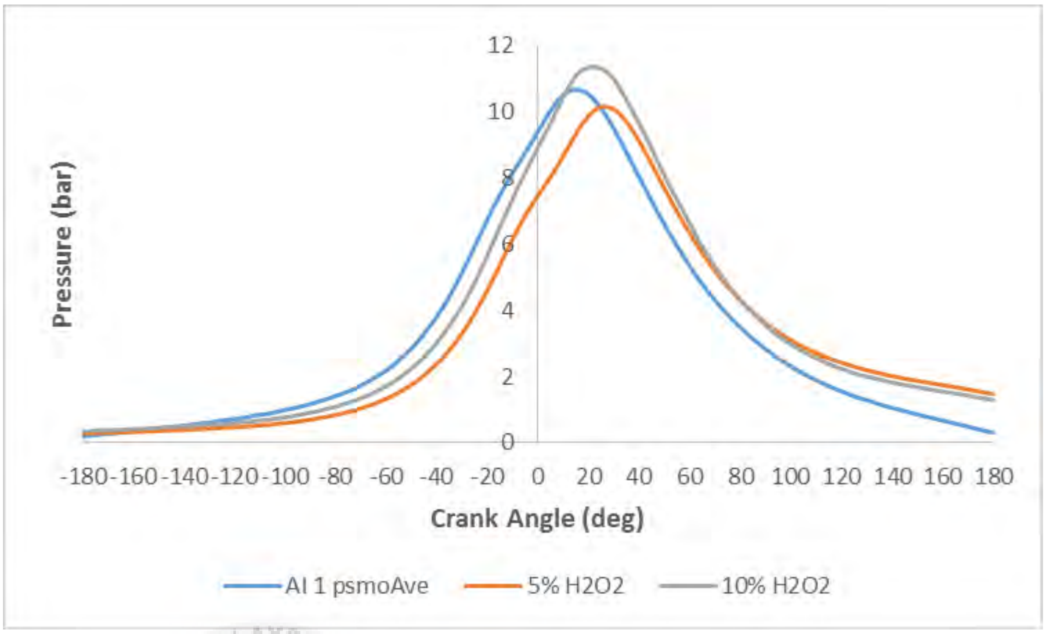
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2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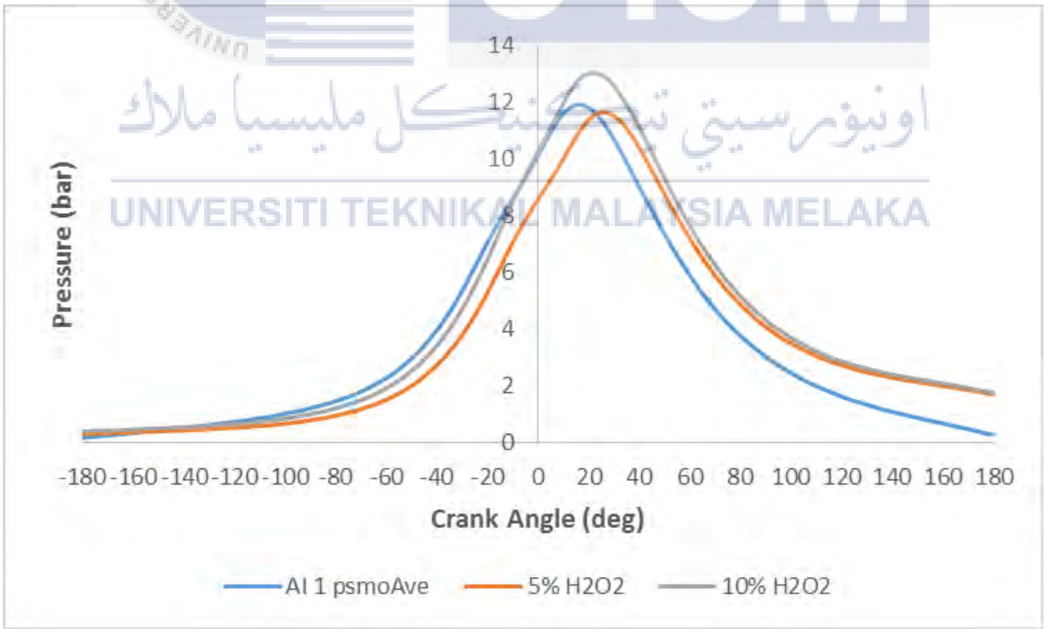
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2


Pressure (bar)
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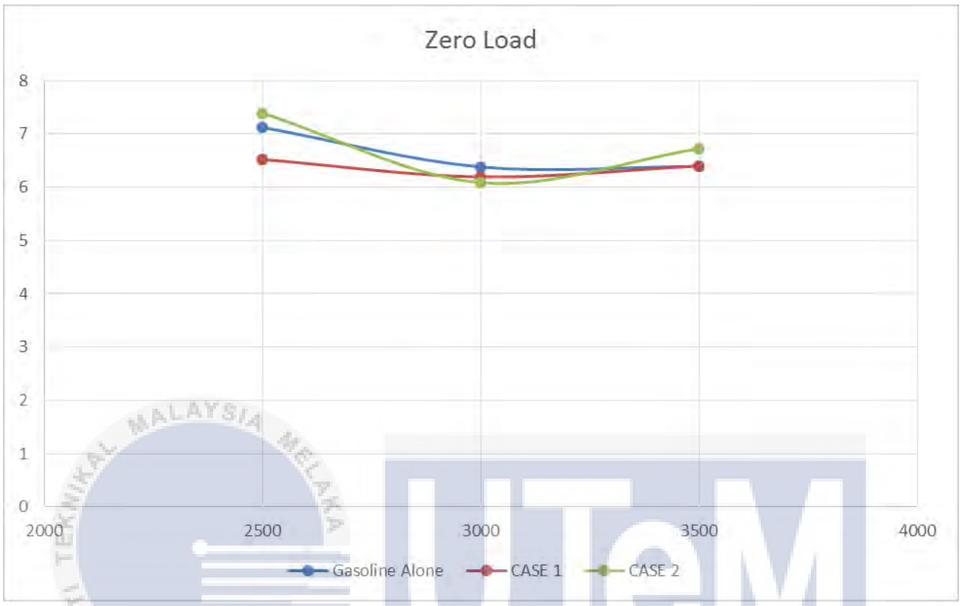
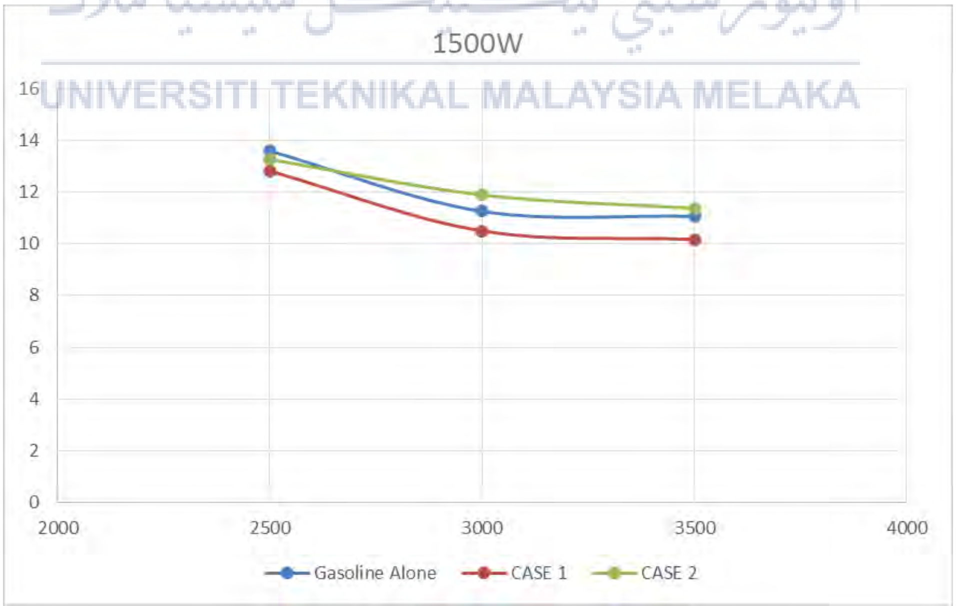
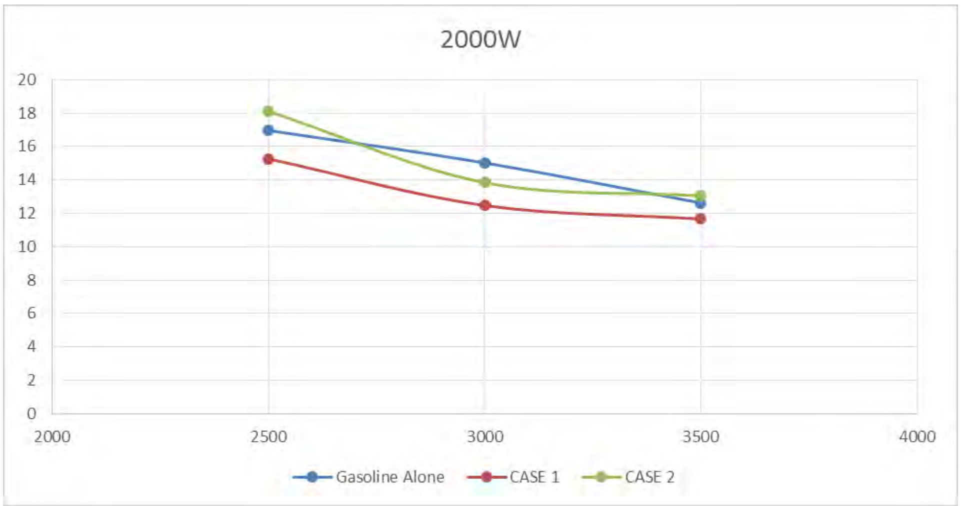
Crank Angle (deg)
Al 1 psmoAve
5% H2O2
10% H2O2

APPENDIX B

Maximum pressure in cylinder again engine speed

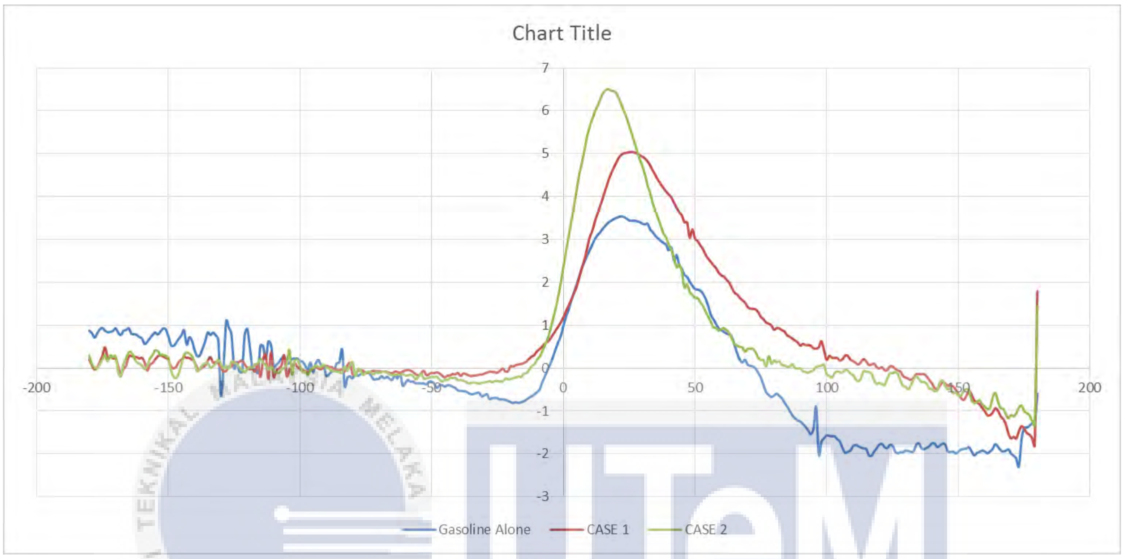


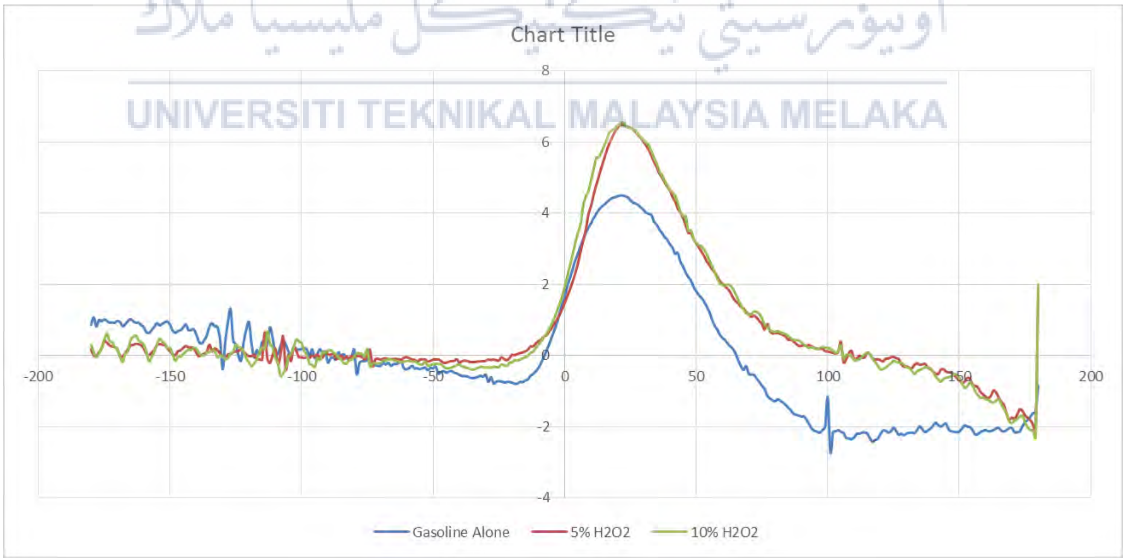



2000W
20
18
16
14
12
10
8
6
4
2
0
2000
2500
3000
3500
4000
Gasoline Alone
CASE 1
CASE 2

APPENDIX C

Heat Release Rate





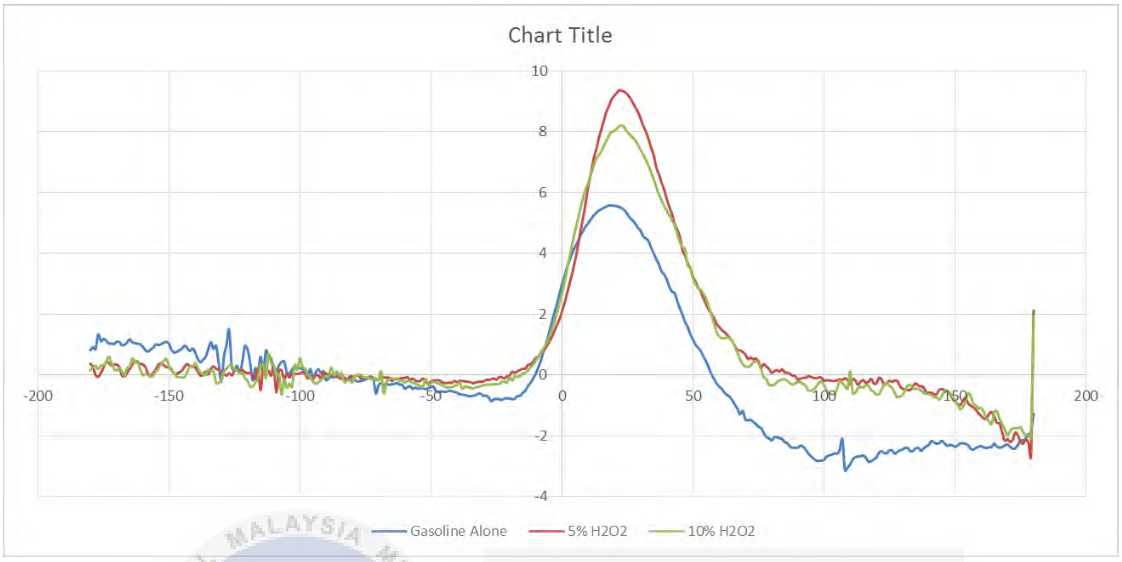
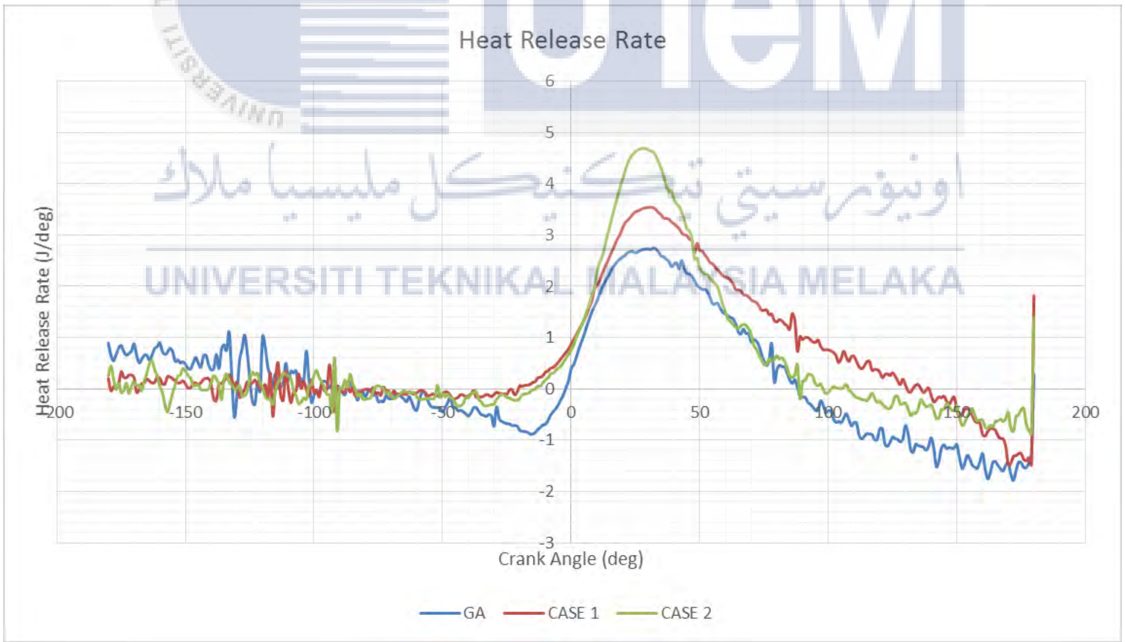


Chart Title
10
8
6
4
2
0
-2
-4
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
5% H2O2
10% H2O2


Heat Release Rate
Heat Release Rate (J/deg)
6
5
4
3
2
1
0
-1
-2
-3
-200
-150
-100
-50
0
50
100
150
200
Crank Angle (deg)
GA
CASE 1
CASE 2

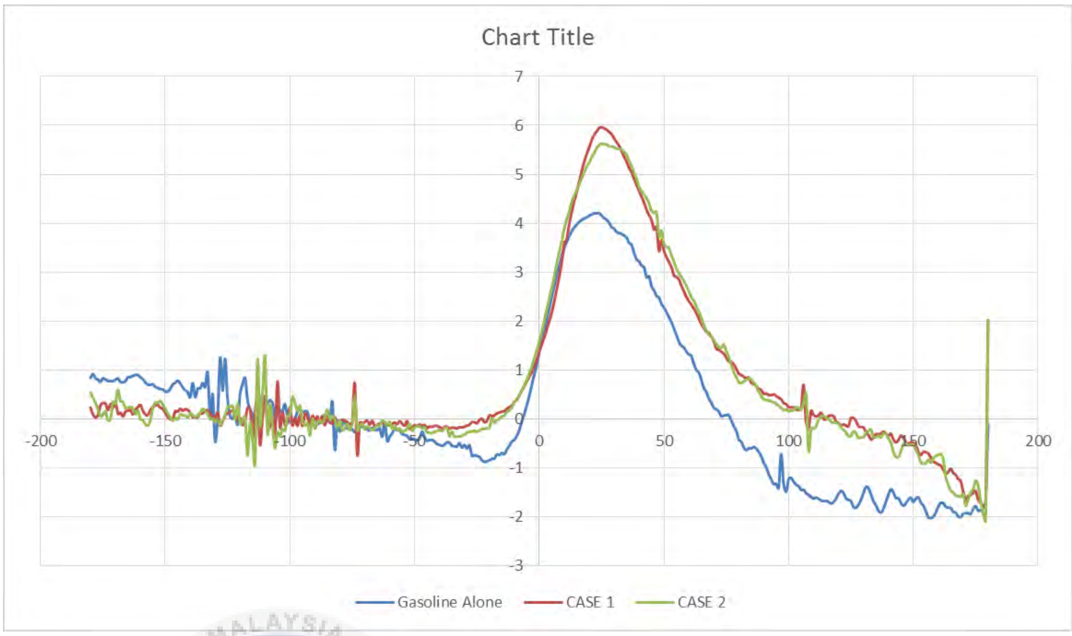


Chart Title
7
6
5
4
3
2
1
0
-1
-2
-3
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
CASE 1
CASE 2

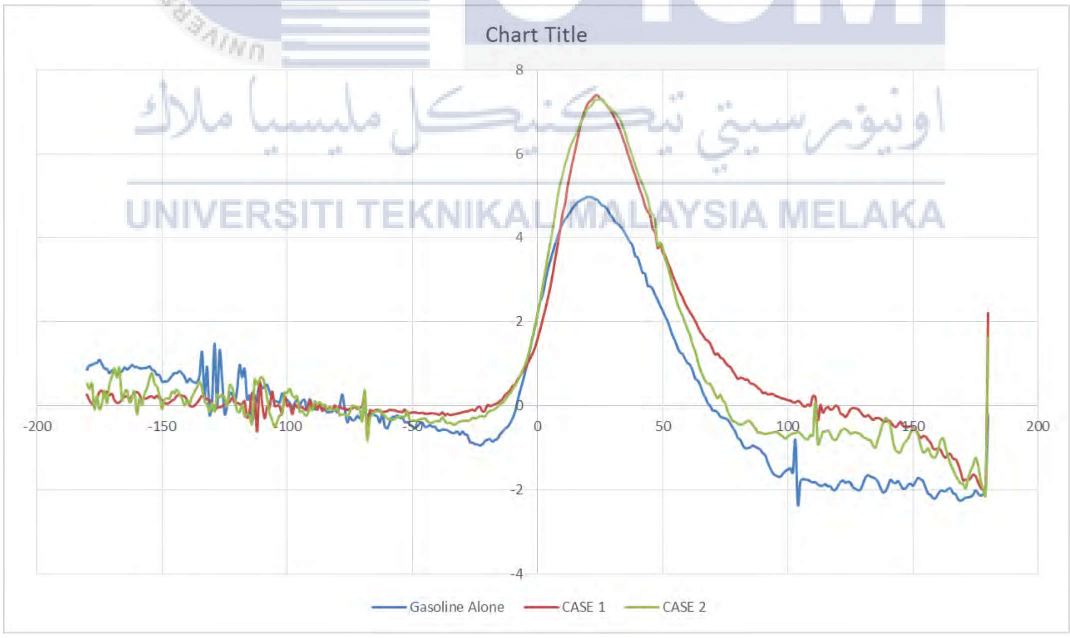


Chart Title
8
6
4
2
0
-2
-4
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
CASE 1
CASE 2

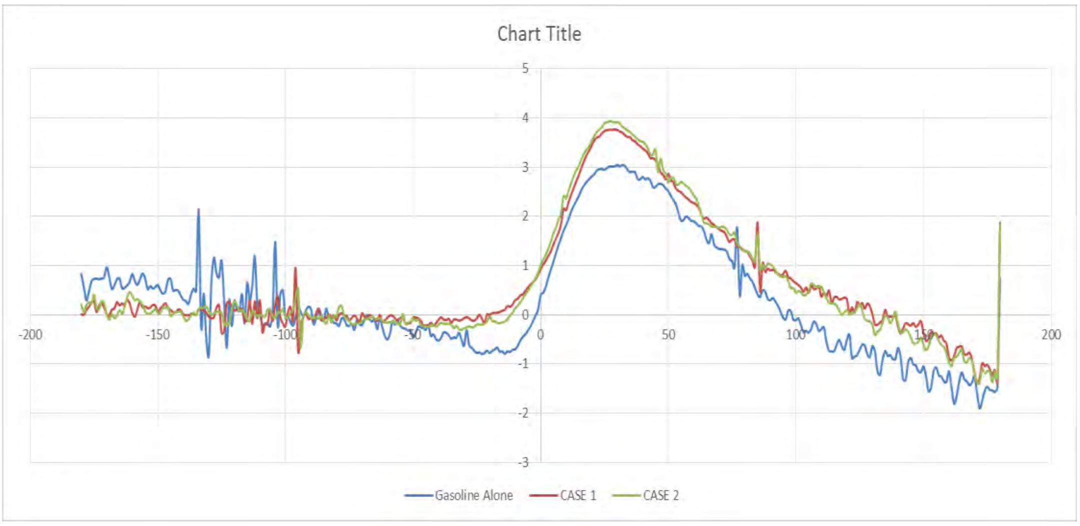


Chart Title
5
4
3
2
1
0
-1
-2
-3
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
CASE 1
CASE 2

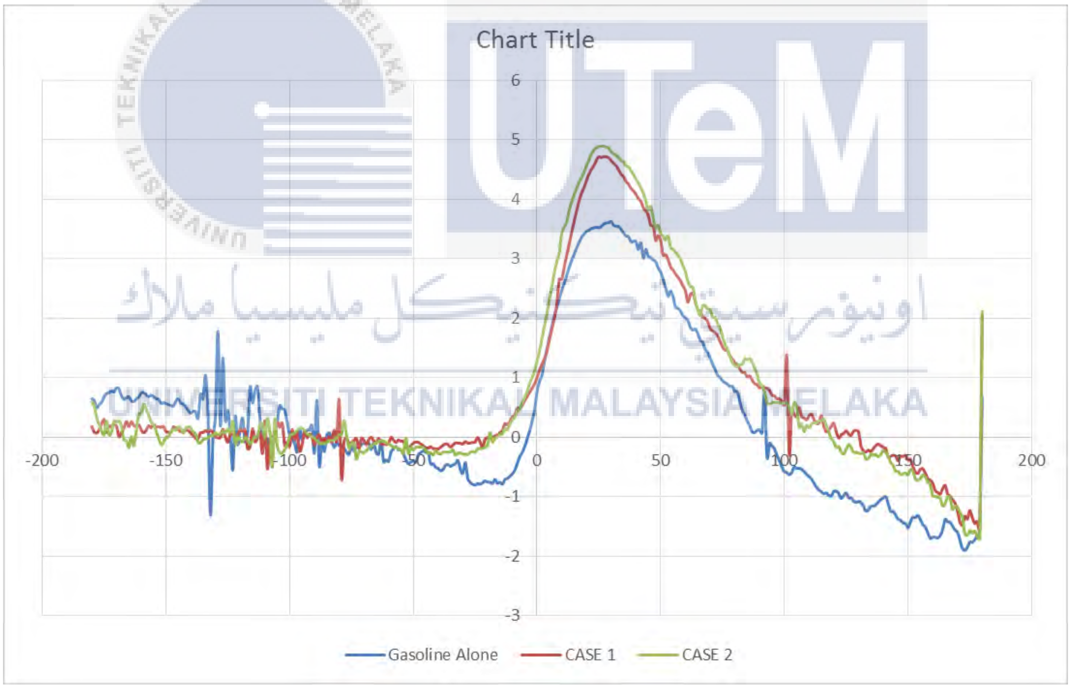


Chart Title
6
5
4
3
2
1
0
-1
-2
-3
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
CASE 1
CASE 2

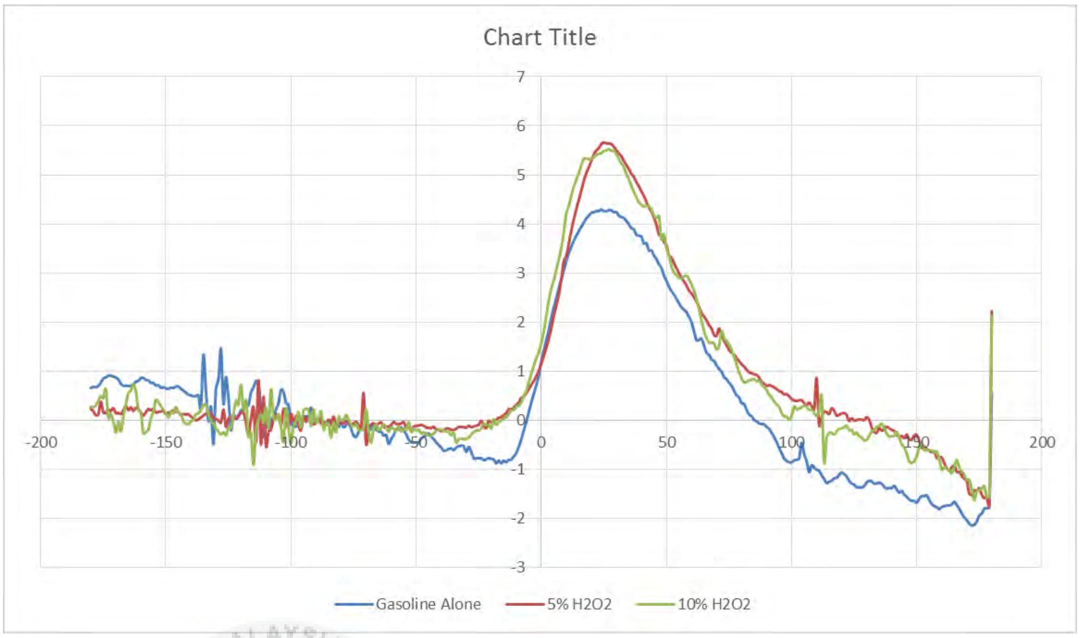


Chart Title
7
6
5
4
3
2
1
0
-1
-2
-3
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
5% H2O2
10% H2O2

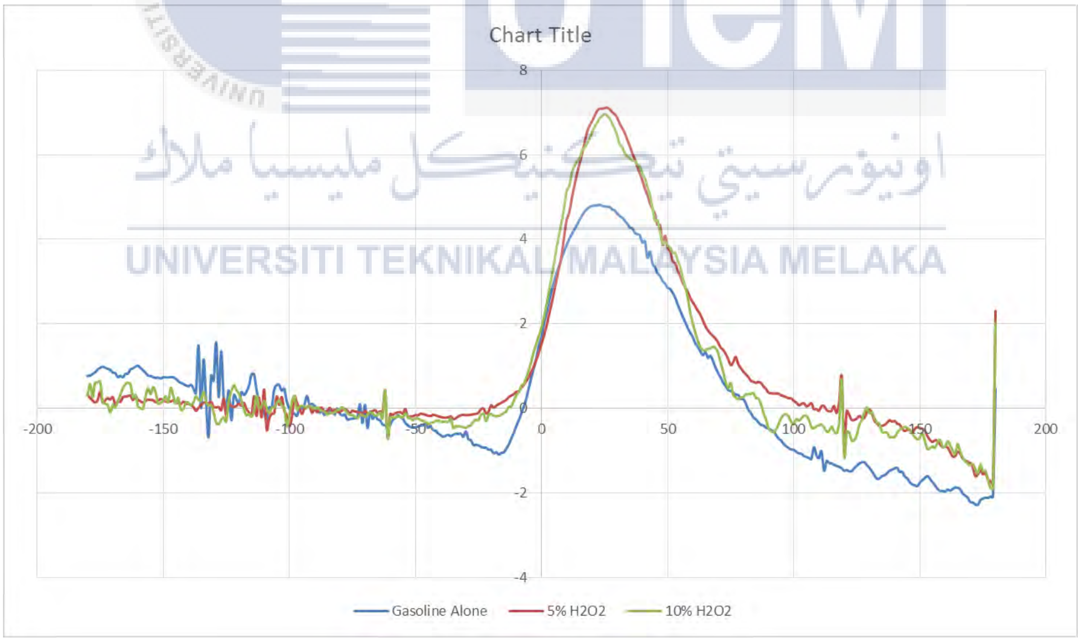


Chart Title
8
6
4
2
0
-2
-4
-200
-150
-100
-50
0
50
100
150
200
Gasoline Alone
5% H2O2
10% H2O2

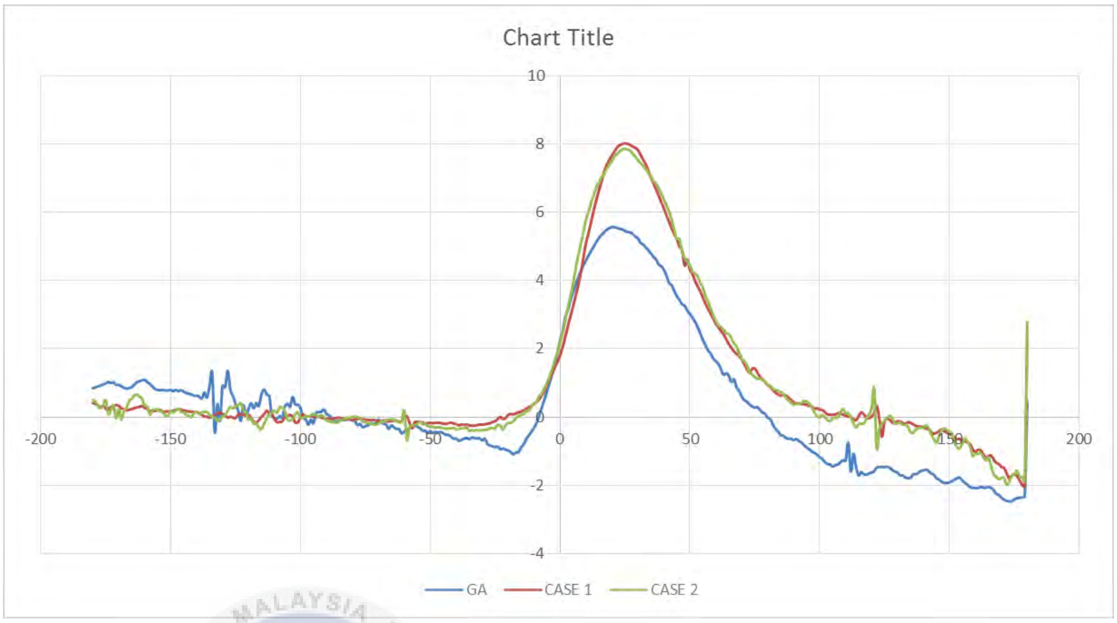
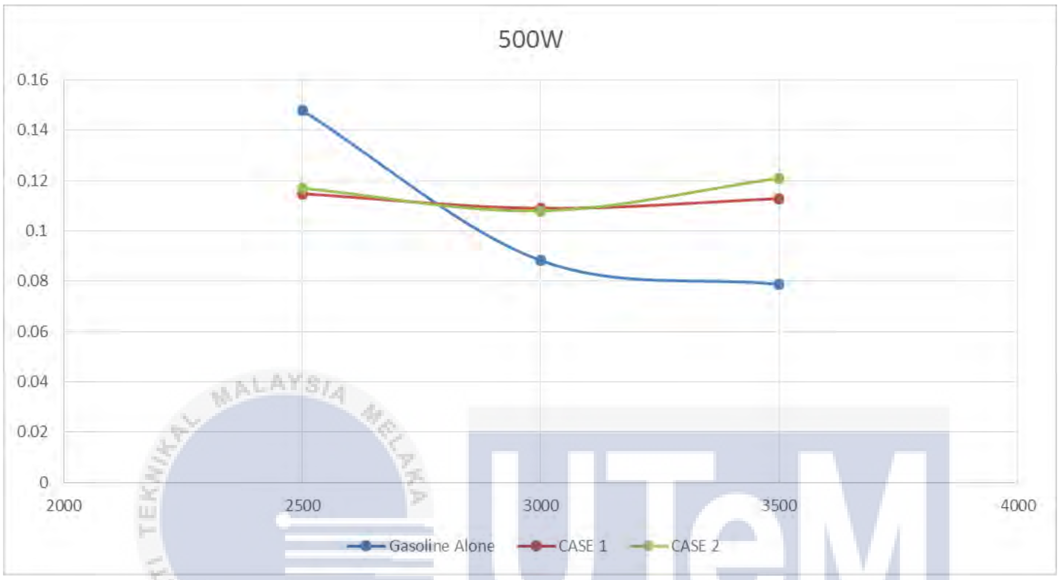
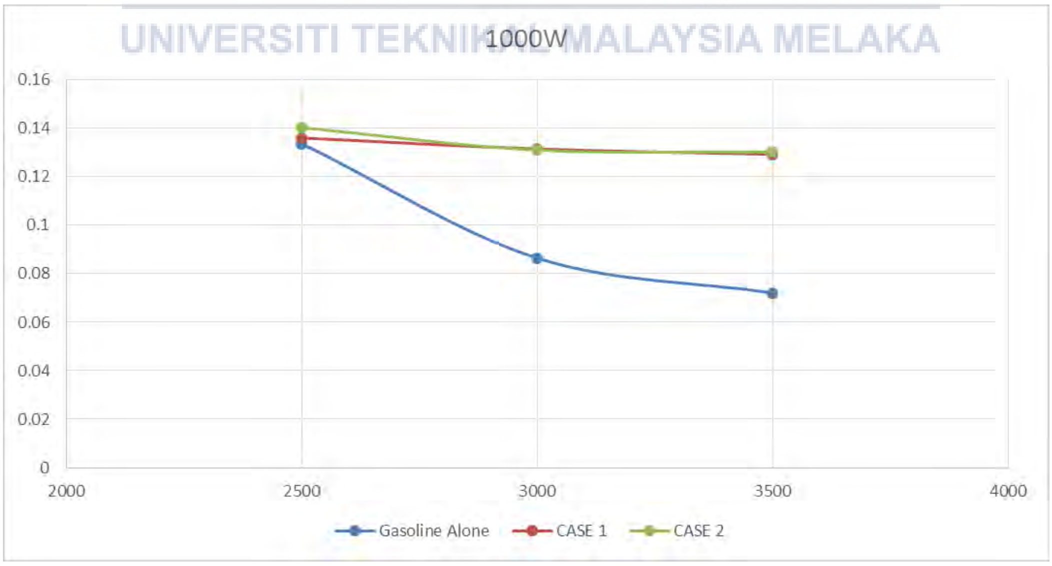


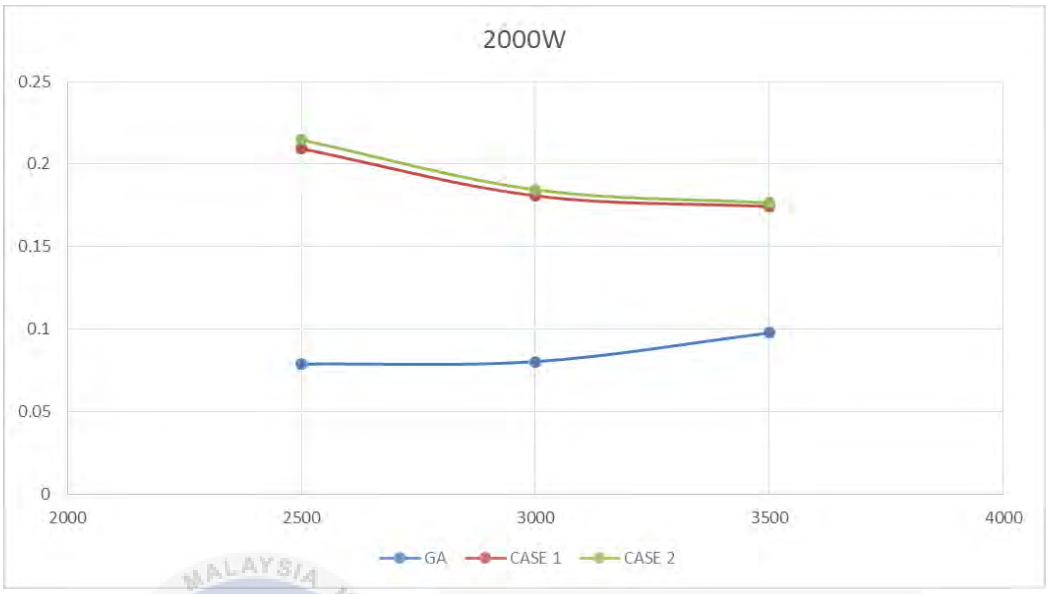
Chart Title
10
8
6
4
2
0
-2
-4
-200
-150
-100
-50
0
50
100
150
200
GA
CASE 1
CASE 2

APPENDIX D

Indicated work

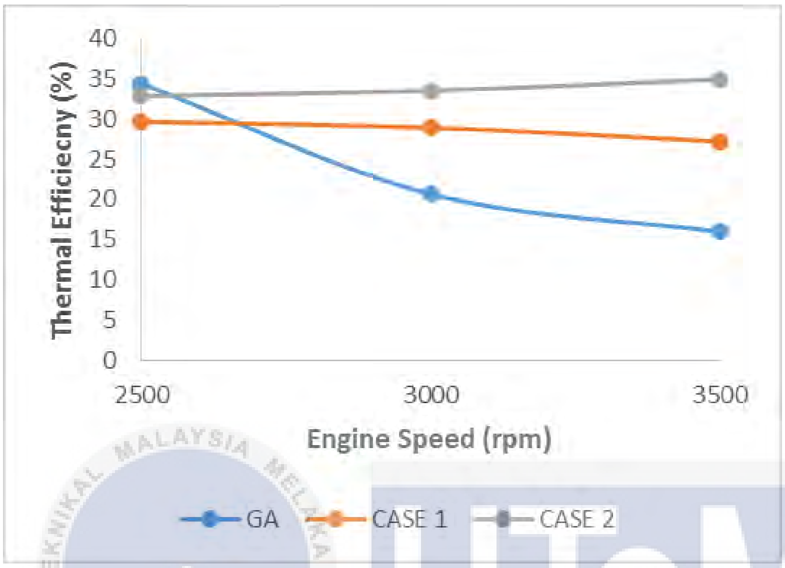


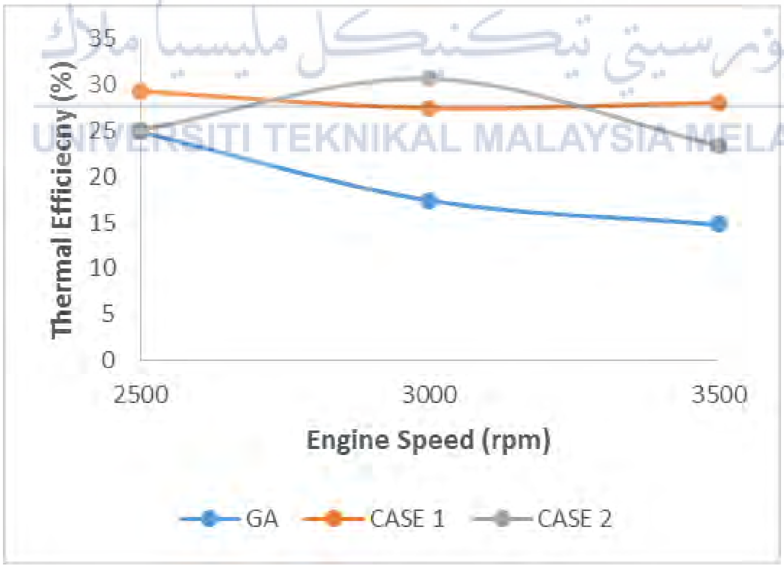


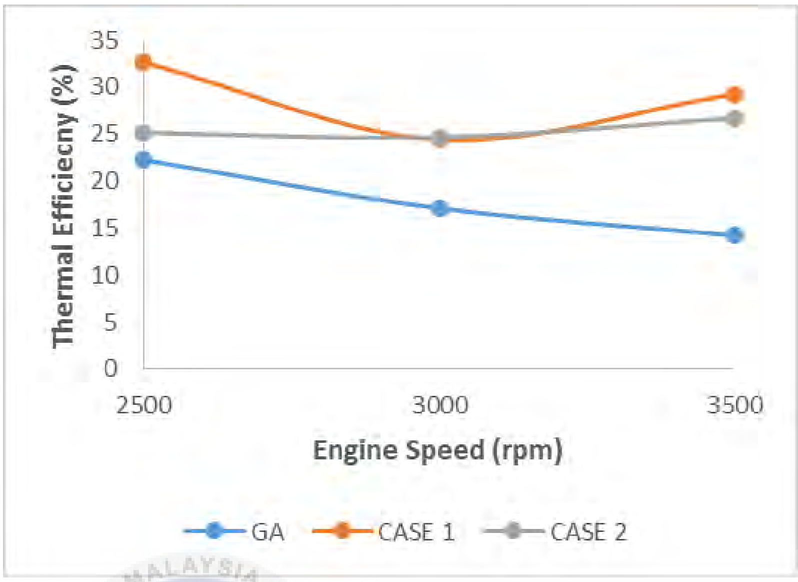

2000W
0.25
0.2
0.15
0.1
0.05
0
2000
2500
3000
3500
4000
GA
CASE 1
CASE 2

APPENDIX E

Indicated thermal efficiency

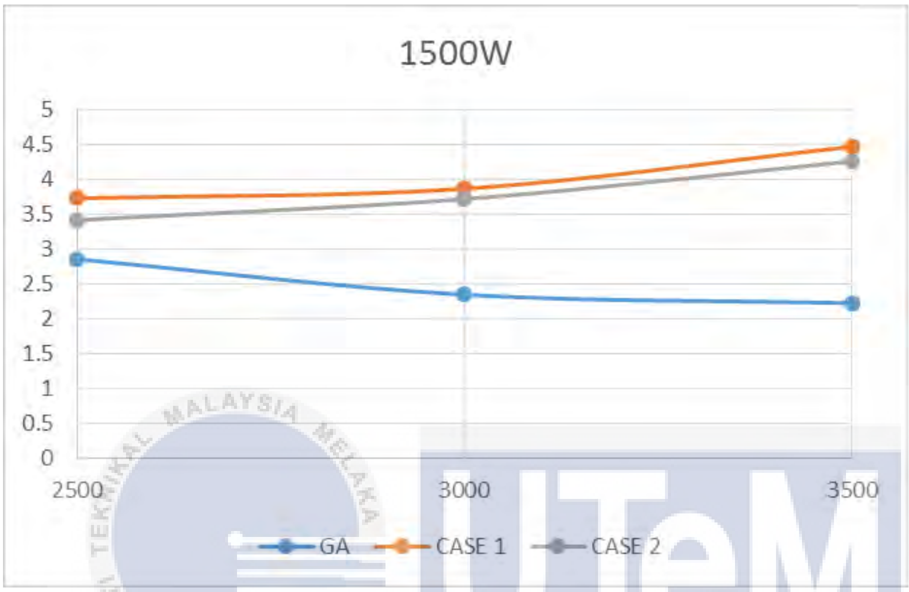


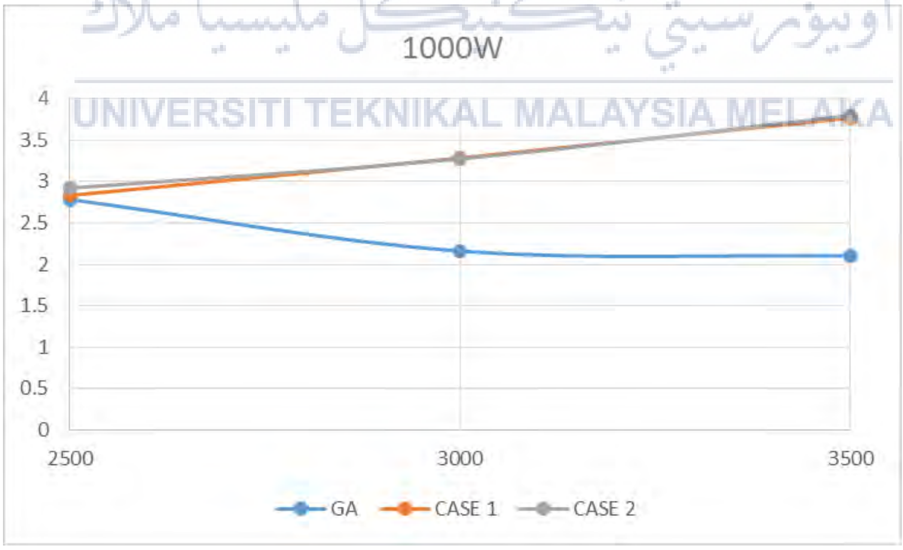


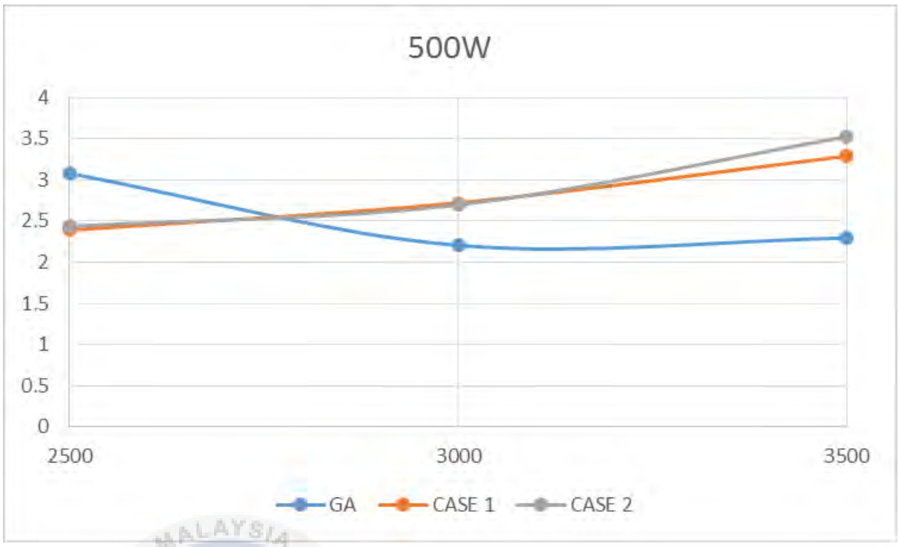

Thermal Efficiecny (%)
35
30
25
20
15
10
5
0
2500
3000
3500
Engine Speed (rpm)
GA
CASE 1
CASE 2

APPENDIX F

Indicated power

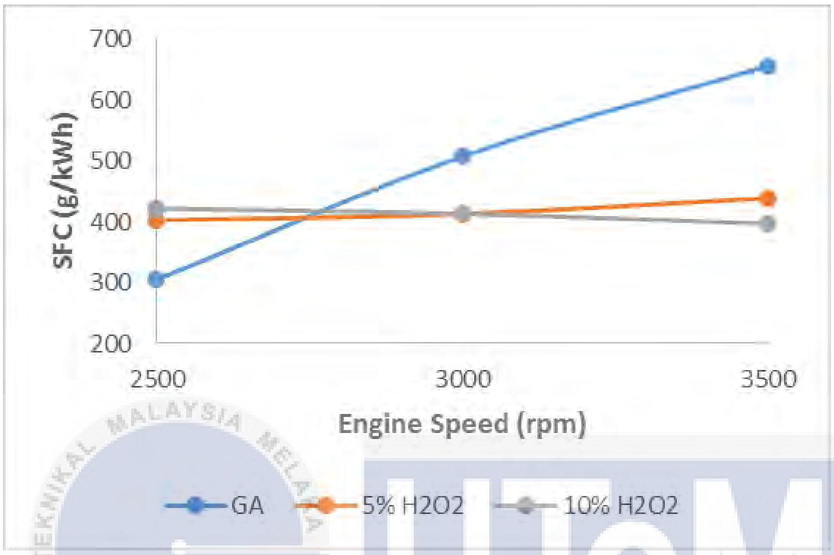


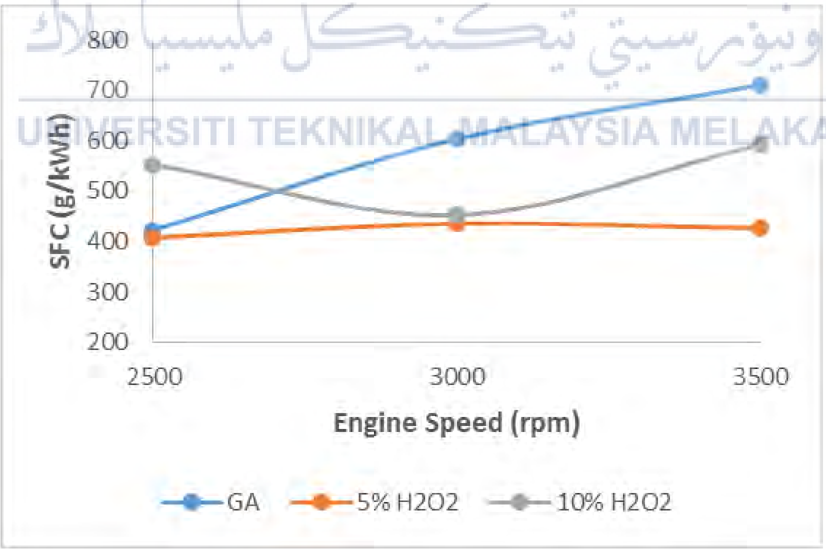


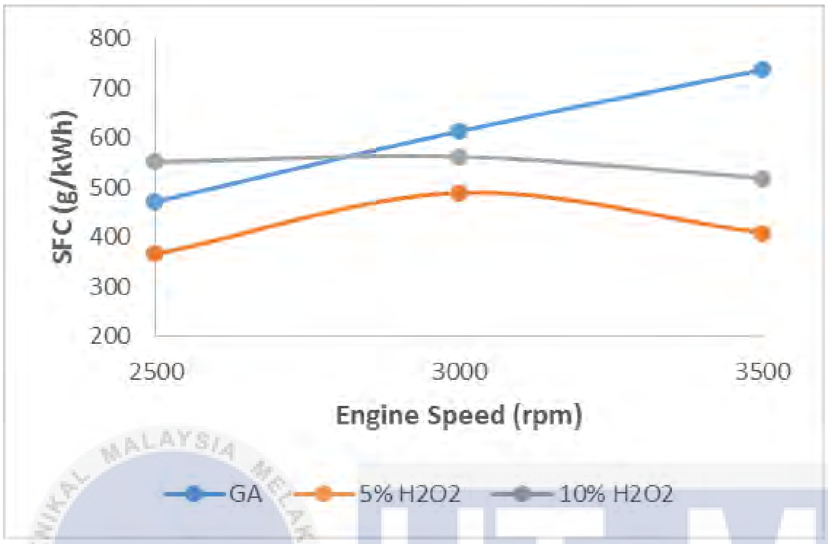

500W
4
3.5
3
2.5
2
1.5
1
0.5
0
2500
3000
3500
GA
CASE 1
CASE 2

APPENDIX G

Indicated specific fuel consumption






800
700
600
500
400
300
200
SFC (g/kWh)
2500
3000
3500
Engine Speed (rpm)
GA
5% H2O2
10% H2O2

APPENDIX H

204M

Parr Instrument Company

1341

Plain Jacket Calorimeter

Operating Instruction Manual

Table of Contents

Customer Service

Questions concerning the installation or operation of this instrument can be answered by the Parr Customer Service Department:

1-309-762-7716 • 1-800-872-7720
Fax: 1-309-762-9453
E-mail: parr@parrinst.com
www.parrinst.com

2 Parr Instrument Company

Preface

Scope

These instructions cover the steps to be taken in setting up and operating a Parr 1341 Plain Jacket Calorimeter. The user should study these instructions carefully before starting to use the calorimeter so that they will fully understand the capabilities of the equipment, and be well aware of the safety precautions to be observed in its operation. Instructions covering the operation of the 1108 Oxygen Combustion Vessel and the use of other related apparatus are provided in separate instruction manuals listed below. The separate manuals which apply to a particular calorimeter installation should be added to and made a part of these instructions.

Related Instructions

No.	Description
205M	*Operating Instructions for the 1108 Oxygen Combustion Vessel*
207M	*Analytical Methods for Oxygen Bombs*
545M	*Operating Instructions for 6775/6775A Digital Thermometer*
201M	*Limited Warranty*

Important Information

Your Parr 1341 Plain Jacket Calorimeter has been designed with function, reliability, and safety in mind. It is your responsibility to install it in conformance with local electrical codes.

This manual contains important operating and safety information. You must carefully read and understand the contents of this manual prior to the use of this equipment. For safe operation, please pay attention to the alert signals throughout the manual.

Intended Usage

Do not use this equipment for anything other than its intended usage. Protection provided by the equipment may be impaired if used in a manner not specified by Parr Instrument Company. This instrument is to be used indoors.

Note About Nomenclature:
Historically, burning a sample enclosed in a high pressure oxygen environment is known as Oxygen Bomb Calorimetry and the vessel containing the sample is known as an Oxygen Bomb. The terms bomb and vessel are used interchangeably.

Q = 2kg x

kJ/kg·K

Explanation of Symbols

⚠	This **CAUTION** symbol may be present on the Product Instrumentation and literature. If present on the product, the user must consult the appropriate part of the accompanying product literature for more information.
⏚	**Protective Earth (PE) terminal.** Provided for connection of the Protective Earth (green or green/yellow) supply system conductor.

Safety Information

To avoid electrical shock, always:

1. Use a properly grounded electrical outlet of correct voltage and current handling capability.
2. Ensure that the equipment is connected to electrical service according to local national electrical codes. Failure to properly connect may create a fire or shock hazard.
3. For continued protection against possible hazard, replace fuses with same type and rating of fuse.
4. Disconnect from the power supply before maintenance or servicing.

To avoid personal injury:

1. Do not use in the presence of flammable or combustible materials; fire or explosion may result. This device contains components which may ignite such material.
2. Refer servicing to qualified personnel.

General Specifications

Electrical Ratings

Plain Jacket Calorimeters:
Model 1341EB: 115VAC, 0.30 Amps, 60 Hz
Model 1341EE: 230VAC, 0.15 Amps, 50/60 Hz

Ignition Units:
2901EB: 115 VAC, 50/60 Hz, 4.0 Amps
2901EE: 230 VAC, 50/60 Hz, 2.0 Amps
2901EU: 230 VAC, 50/60 Hz, 2.0 Amps
2901EX: 230 VAC, 50/60 Hz, 2.0 Amps
2901EZ: 230 VAC, 50/60 Hz, 2.0 Amps

Before connecting the calorimeter to an electrical outlet, the user must be certain that the electrical outlet has an earth ground connection and that the line, load and other characteristics of the installation do not exceed the following limits:

Voltage: Fluctuations in the line voltage should not exceed 10% of the rated nominal voltage shown on the data plate.

Frequency: Calorimeters can be operated from either a 50 or 60 Hertz power supply without affecting their operation or calibration.

Current: The total current drawn should not exceed the rating shown on the data plate on the calorimeter by more than 10 percent.

Environmental Conditions

Operating: 15 °C to 40 °C; maximum relative humidity of 80% non-condensing.

Installation Category II (over voltage) in accordance with IEC 664.

Pollution degree 2 in accordance with IEC 664.

Altitude Limit: 2,000 meters.

Storage: -25 °C and 65 °C; 10% to 85% relative humidity.

Provisions for Lifting and Carrying

Before moving the instrument, disconnect all connections from the rear of the apparatus. Lift the instrument by grabbing underneath each corner.

Assemble the Calorimeter

1. **Unpack the calorimeter** carefully and check the individual parts against the packing list. If shipping damage is discovered, report it immediately to the delivering carrier. Unpack the jacket first and set it on a sturdy bench or table in a location that is reasonably free from drafts and is protected from sources of radiant heat, preferably in an air conditioned room. Temperature changes in the room should be minimal.

   There should be convenient access to running water, to a drain and to an appropriate grounded electrical outlet. About 8 square feet of workspace will be required. Access to a chemical balance sensitive to 0.1 mg and to a solution, trip or torsion balance capable of weighing up to 3.0 kg with 0.1 g sensitivity will be required. A standard 1A cylinder with a purity of 99.5% is usually sufficient for bomb combustion purposes.

2. **Set the cover on the jacket.** Remove the two screws from the side of the jacket and attach the stirrer drive motor. Check the stirrer shaft to be sure that it turns freely and slip the drive belt onto the motor and stirrer pulleys.

3. **Assemble the cover support stands.** Two stands are furnished, each consisting of a base, a support rod and ring to be clamped to the upper end of the rod. The A37A stand with the large ring is used to support the calorimeter cover when it is removed from the jacket, while the A38A stand with the smaller ring supports the bomb head when attaching the fuse wire and arranging the fuel capsule.

4. **Install the thermistor** by sliding it through the opening in the calorimeter cover. Adjust the length of the thermistor to match the length of the stirring shaft. Hand tighten the nut to secure the thermistor.

   Note: *Do not over tighten the nut.*

   Once installed, the thermistor can remain attached to the cover during all operations. Do not lay the cover on the tabletop. Always set it in the supporting ring on the A37A stand to protect the thermistor and stirring shafts.

5. **Check the calorimeter bucket**, noting the three dimples in the bottom of the bucket which rest on supporting pins in the bottom of the jacket. The single dimple must always face forward when setting the bucket in the jacket.

6. **Connect the ignition unit.** While any electrical system capable of furnishing approximately 23 volts can be used to ignite the fuse in the oxygen bomb, most users will prefer to use a Parr 2901 Ignition Unit for this purpose. This unit operates from any standard electrical outlet to provide the proper low voltage firing current, providing also a convenient push switch, indicating lamp and connecting terminals.

   Connect one of the lead wires from the calorimeter jacket to the terminal labeled "10CM". Connect the second lead to the terminal labeled "Common". Plug the power cord into an appropriately grounded electrical outlet. The power supply cord is the main electrical disconnect device for the ignition unit. After the unit has been plugged into an outlet do not press the firing button unless the lead wires inside the jacket are connected to the combustion vessel.

   Caution!
   If the bare terminals on these wires happen to be in contact with each other or with a metal object when the circuit is closed, the resulting short-circuit may cause serious damage to the ignition system.

7. **Attach the oxygen filling connection.** Unscrew the protecting cap from the oxygen tank and inspect the threads on the valve outlet to be sure they are clean and in good condition. Place the ball end of the 1825 Oxygen Filling Connection into the outlet socket and draw up the union nut tightly with a wrench, keeping the 0-55 atm. gage in an upright position.

   Operating instructions for the 1825 Oxygen Filling Connection are provided in Instruction Manual 205M for the 1108 Oxygen Combustion Vessel.

Operating the 1108 Oxygen Vessel

Detailed instructions for preparing the sample and charging the 1108 Oxygen Combustion Vessel are given in Instruction Manual, No. 205M. Follow these instructions carefully, giving particular attention to the precautions to be observed in charging and handling the bomb.

Operating the Calorimeter

All operations required to test a sample or to standardize the 1341 Plain Jacket Calorimeter should proceed step-wise in the following manner:

1. **Prepare the sample and charge the oxygen combustion vessel** as described in Instruction Manual No. 205M.

2. **Fill the calorimeter bucket by first taring the dry bucket** on a solution or trip balance; then add 2000(+/-0.5) grams of water. Distilled water is preferred, but demineralized or tap water containing less than 250 ppm of dissolved solid is satisfactory. The water temperature should be approximately 1.5°C below room temperature, but this can be varied to suit the operator's preference. It is not necessary to use exactly 2000 grams, but the amount selected must be duplicated within +/-0.5 gram for each run. Instead of weighing the bucket it can be filled from an automatic pipet or from any other volumetric device if the repeatability of the filling system is within +/-0.5 ml. and the water temperature is held within a 1°C range.

3. **Set the bucket in the calorimeter.** Attach the lifting handle to the two holes in the side of the screw cap and partially lower the bomb in the water. Handle the bomb carefully during this operation so that the sample will not be disturbed. Push the two ignition lead wires into the terminal sockets on the bomb head. Orient the wires away from the stirrer shaft so they do not become tangled in the stirring mechanism. Lower the bomb completely into the water with its feet spanning the circular boss in the bottom of the bucket. Remove the lifting handle and shake any drops of water into the bucket and check for gas bubbles.

4. **Set the cover on the jacket.** Turn the stirrer by hand to be sure that it runs freely; then slip the drive belt onto the pulleys and start the motor. Turn on the 6775 Digital Thermometer.

5. **Let the stirrer run for 5 minutes** to reach equilibrium before starting a measured run. At the end of this period record the time on the timer of the 6775 Digital Thermometer and read the temperature.

6. **Read and record temperatures** at one-minute intervals for 5 minutes. Then, at the start of the 6th minute...

7. **Stand back from the calorimeter and fire the bomb** by pressing the ignition button and holding it down until the indicator light goes out. Normally the light will glow for only about ½ second but release the button within 5 seconds regardless of the light.

   Caution!
   Do not have the head, hands or any parts of the body over the calorimeter when firing the bomb; and continue to stand clear for 30 seconds after firing.

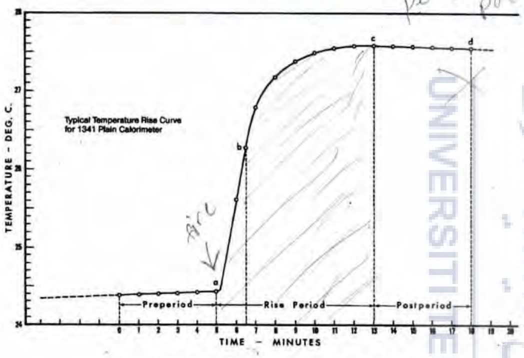
8. **The bucket temperature will start to rise** within 20 seconds after firing. This rise will be rapid during the first few minutes; then it will become slower as the temperature approaches a stable maximum as shown by the typical temperature rise curve below. It is not necessary to plot a similar curve for each test, but accurate time and temperature observations must be recorded to identify certain points needed to calculate the calorific value of the sample.

9. **Measure the time required to reach 60 percent of the total rise** by estimating the temperature at the 60% point and observing the time when the temperature reading reaches that point. If the 60% point cannot be estimated before ignition, take temperature readings at 45, 60, 75, 90 and 105 seconds after firing and interpolate between these readings to identify the 60% point after the total rise has been measured.

10. **After the rapid rise period** (about 4 or 5 minutes after ignition) record temperatures at one minute intervals until the **difference** between successive readings has been constant for five minutes. Usually the temperature will reach a maximum; then drop very slowly. But this is not always true since a low starting temperature may result in a slow continuous rise without reaching a maximum. As stated above, the **difference** between successive readings must be noted and the readings continued at one-minute intervals until the **rate** of the temperature change becomes constant over a period of 5 minutes.

temperature air 20 - 30

peak paling tinggi



Graph displaying typical temperature rise curve

11. **After the last temperature reading**, stop the motor, remove the belt and lift the cover from the calorimeter. Wipe the thermistor shaft and stirrer with a clean cloth and set the cover on the A37A support stand. Lift the bomb out of the bucket; remove the ignition leads and wipe the bomb with a clean towel.

12. **Open the knurled knob on the bomb head** to release the gas pressure before attempting to remove the cap. This release should proceed slowly over a period of not less than one minute to avoid entrainment losses. After all pressure has been released, unscrew the cap; lift the head out of the cylinder and place it on the support stand. Examine the interior of the bomb for soot or other evidence of incomplete combustion. If such evidence is found, the test will have to be discarded.

> ***Caution!***
> ***Do not have any part of the body in the pressure relief path.***

13. **Wash all interior surfaces** of the bomb with a jet of distilled water and collect the washings in a beaker.

14. **Remove all unburned pieces of fuse wire** from the bomb electrodes; straighten them and measure their combined length in centimeters. Subtract this length from the initial length of 10 centimeters and enter this quantity on the data sheet as the net amount of wire burned. Alternatively, the correction in calories is located on the card of the 45C10 fuse wire.

15. **Titrate the bomb washings** with a standard sodium carbonate solution using methyl orange or methyl red indicator. A 0.0709N sodium carbonate solution is recommended for this titration to simplify the calculation. This is prepared by dissolving 3.76 grams Na_2CO_3 in water and diluting to one liter NaOH or KOH solutions of the same normality may be used.

16. **Analyze the bomb washings** to determine the sulfur content of the sample if it exceeds 0.1 per cent. Methods for determining sulfur are discussed in Instruction Manual No. 207M.

Calculating the Heat of Combustion

Assembly of Data

The following data should be available at the completion of a test in a 1341 calorimeter:

a = time of firing

b = time (to nearest 0.1 min.) when the temperature reaches 60 per cent of the total rise

c = time at beginning of period (after the temperature rise) in which the rate of temperature change has become constant

t_a = temperature at time of firing

t_c = temperature at time c

r_1 = rate (temperature units per minute) at which the temperature was rising during the 5-min. period before firing

r_2 = rate (temperature units per minute) at which the temperature was rising during the 5-min. period after time c. If the temperature was falling instead of rising after time c, r is negative and the quantity -r (c-b) becomes positive and must be added when computing the corrected temperature rise

c_1 = milliliters of standard alkali solution used in the acid titration

c_2 = percentage of sulfur in the sample

c_3 = centimeters of fuse wire consumed in firing

W = energy equivalent of the calorimeter, determined under standardization

M = mass of sample in grams

Temperature Rise

Compute the net corrected temperature rise, t, by substituting in the following equation:

$$t = t_c - t_a - r_1 (b-a) - r_2 (c-b)$$

Thermochemical Corrections
Compute the following for each test:

e_1 = correction in calories for heat of formation of nitric acid (HNO_3)
= c_1 if 0.0709N alkali was used for the titration

e_2 = correction in calories for heat of formation of sulfuric acid (H_2SO_4)
= (13.7) (c_2) (m)

e_3 = correction in calories for heat of combustion of fuse wire
= (2.3) (c_3) when using Parr 45C10 nickel chromium fuse wire, or
= (2.7) (c_3) when using No. 34 B. & S. gage iron fuse wire

$E = V \times I \times t$
[illegible]

$= 230V \times 2A \times \overset{0.1}{\cancel{0.3}} s$

Gross Heat of Combustion

Compute the gross heat of combustion, H_g, in calories per gram by substituting in the following equation:

$$H_g = \frac{tW - e_1 - e_2 - e_3}{m}$$

Example:

a = 1:44:00 = 1:44.0
b = 1:45:24 = 1:45.2
c = 1:52:00 = 1:52.0
t_a = 24.428 + .004 = 24.432 °C
t_c = 27.654 + .008 = 27.662 °C
r_1 = + .010 °C /5 min. = + .002 °C /min
r_2 = - .004 °C /5 min. = .001 °C /min.
c_1 = 23.9 ml.
c_2 = 1.02% Sulfur
c_3 = 7.6 cm. Parr 45C10 wire
W = 2426 calories/ °C
m = .9936 grams
t = 27.662-24.432-(.002) (1.4)-(-.001) (6.6)
= 3.234 °C
e_1 = 23.9 calories
e_2 = (13.7) (1.02) (.9936) = 13.9 calories
e_3 = (2.3) (7.6) = 17.5 calories

$$H_g = \frac{(3.234)(2426) - 23.9 - 13.9 - 17.5}{.9936}$$

= 7841 calories/ gram
= (1.8) (7841) = 14,114 Btu/lb

22.65 kJ

26.57 kJ

Conversion to Other Bases

The calculations described above give the calorific value of the sample with moisture as it existed when the sample was weighed. For example, if an air-dried coal sample was tested, the results will be in terms of heat units per weight of air-dry sample. This can be converted to a moisture free or other dry basis by determining the moisture content of the air-dry sample and using conversion formulae published in ASTM Method D3180 and in other references on fuel technology.

The calorific value obtained in a calorimeter test represents the gross heat of combustion for the sample. This is the heat produced when the sample burns, plus the heat given up when the newly formed water vapor condenses and cools to the temperature of the bomb. In nearly all industrial operations this water vapor escapes as steam in the flue gases and the latent heat of vaporization which it contains is not available for useful work. The net heat of combustion obtained by subtracting the latent heat from the gross calorific value is therefore an important figure in power plant calculations. If the percentage of hydrogen, H, in the sample is known, the net heat of combustion, H_n in Btu per pound can be calculated as follows:

$$H_n = 1.8H_g - 91.23H \quad \text{(ASTM D240)}$$

10 kJ

Standardizing the Calorimeter

The Energy Equivalent Factor

The term "standardization" as used here denotes the operation of the calorimeter with a standard sample from which the energy equivalent or effective heat capacity for the system can be determined. The energy equivalent factor (W) represents the energy required to raise the temperature of the calorimeter one degree, usually expressed as calories per degree Celsius. This factor for the 1341 calorimeter with an 1108 Oxygen Combustion Vessel will usually fall within a range from 2410 to 2430 calories per degree Celsius, with the exact value for each installation to be determined by the user. This requires a series of at least four standardization tests (and preferably more) from which an average can be taken to represent the true W value for the user's calorimeter. This will provide a factor which can be used with confidence in subsequent tests with unknown materials. Standardization tests should always be repeated after changing any parts of the calorimeter, and occasionally as a check on both the calorimeter and the operating technique.

Standard Samples

A vial of 100 one-gram benzoic acid pellets is furnished with each calorimeter for standardization purposes. Additional benzoic acid pellets or powder can be obtained from Parr. For high precision measurements, a primary standard benzoic acid powder can be purchased from the National Institute of Standards and Technology (NIST), Washington, D.C. The NIST also offers standard 2,2,4-trimethly-pentane (Isooctane) as a calorific standard for testing volatile fuels.

Caution!
Benzoic acid must always be compressed into a pellet before it is burned in an oxygen bomb to avoid possible damage from rapid combustion of the loose powder.

Compressing benzoic acid into a pellet is best accomplished by using a Parr 2811 Pellet Press. If a pellet press is not available, melt the powder into a lump by heating it carefully to the melting point, but do not overheat the powder as this will change the calorific value.

Standardization Procedure

The procedure for a standardization test is exactly the same as for testing a fuel sample. Use a pellet of calorific grade benzoic acid weighing not less than 0.9 nor more than 1.25 grams. Determine the corrected temperature rise, t, from the observed test data, also titrate the bomb washings to determine the nitric acid correction and measure the unburned fuse wire. Compute the energy equivalent by substituting in the following equation:

$$W = \frac{Hm + e_1 + e_3}{t}$$

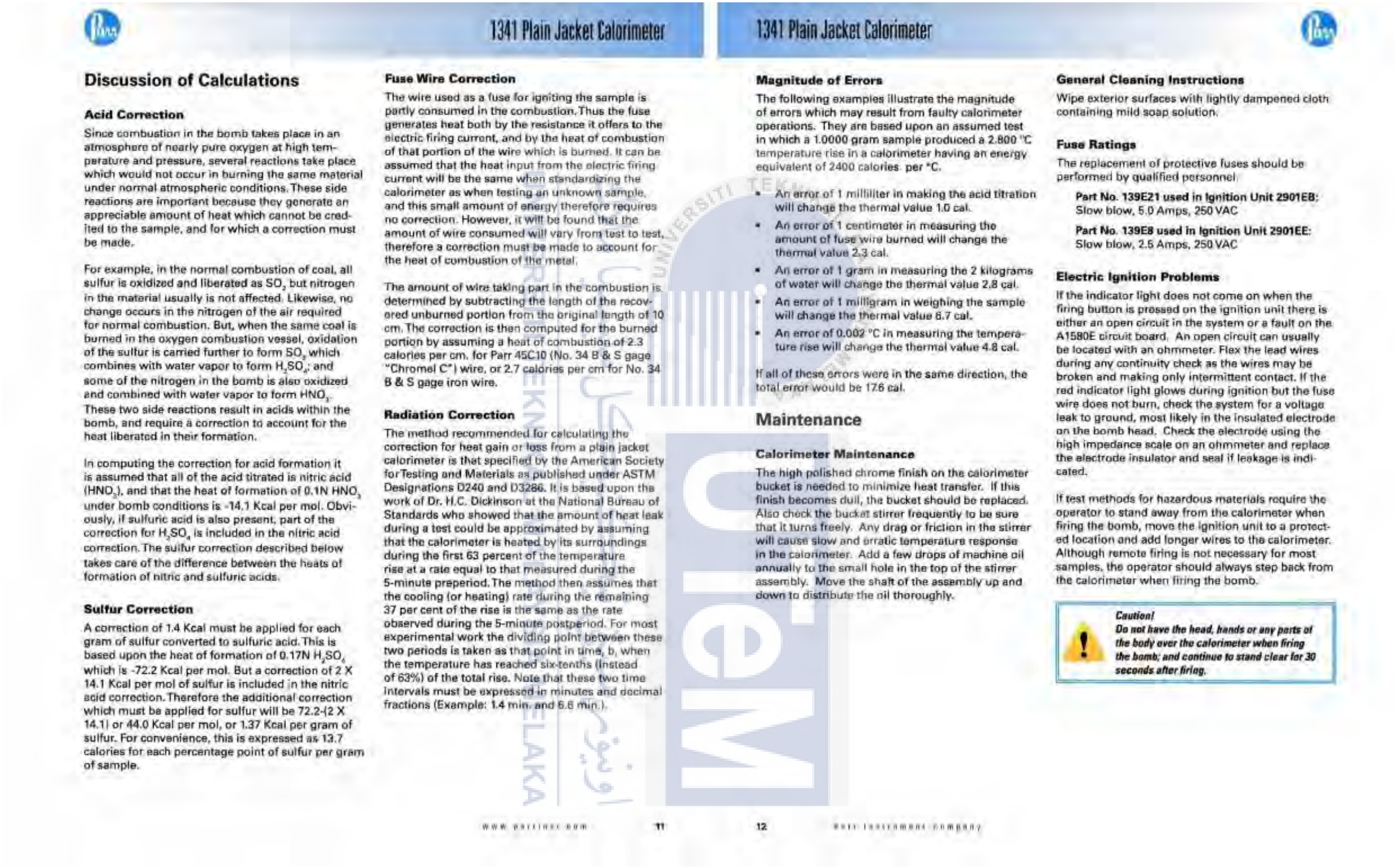
W = energy equivalent of the calorimeter in calories per °C (Centigrade)
H = heat of combustion of the standard benzoic acid sample in calories per gram
m = mass of the standard benzoic acid sample in grams
t = net corrected temperature rise in °C
e_1 = correction for heat of formation of nitric acid in calories
e_3 = correction for heat of combustion of the firing wire in calories

Example:
Standardization with a 1.1651 gram benzoic acid sample (6318 cal/ gm) produced a net corrected temperature rise of 3.047 °C. The acid titration required 11.9 ml of standard alkali and 8 cm of fuse wire were consumed in the firing. Substituting in the standardization equation:

H = 6318 cal/ gram
m = 1.1651 gram
e_1 = (11.9 ml) (1 cal/ ml) = 11.9 cal
e_3 = (8 cm) (2.3 cal/ cm) = 18.4 cal
t = 3.047° C

$$W = \frac{(6318)(1.1651) + 11.9 + 18.4}{3.047}$$

= 2426 cal per °C



Discussion of Calculations

Acid Correction

Since combustion in the bomb takes place in an atmosphere of nearly pure oxygen at high temperature and pressure, several reactions take place which would not occur in burning the same material under normal atmospheric conditions. These side reactions are important because they generate an appreciable amount of heat which cannot be credited to the sample, and for which a correction must be made.

For example, in the normal combustion of coal, all sulfur is oxidized and liberated as SO_2 but nitrogen in the material usually is not affected. Likewise, no change occurs in the nitrogen of the air required for normal combustion. But, when the same coal is burned in the oxygen combustion vessel, oxidation of the sulfur is carried further to form SO_3 which combines with water vapor to form H_2SO_4; and some of the nitrogen in the bomb is also oxidized and combined with water vapor to form HNO_3. These two side reactions result in acids within the bomb, and require a correction to account for the heat liberated in their formation.

In computing the correction for acid formation it is assumed that all of the acid titrated is nitric acid (HNO_3), and that the heat of formation of 0.1N HNO_3 under bomb conditions is -14.1 Kcal per mol. Obviously, if sulfuric acid is also present, part of the correction for H_2SO_4 is included in the nitric acid correction. The sulfur correction described below takes care of the difference between the heats of formation of nitric and sulfuric acids.

Sulfur Correction

A correction of 1.4 Kcal must be applied for each gram of sulfur converted to sulfuric acid. This is based upon the heat of formation of 0.17N H_2SO_4 which is -72.2 Kcal per mol. But a correction of 2 X 14.1 Kcal per mol of sulfur is included in the nitric acid correction. Therefore the additional correction which must be applied for sulfur will be 72.2-(2 X 14.1) or 44.0 Kcal per mol, or 1.37 Kcal per gram of sulfur. For convenience, this is expressed as 13.7 calories for each percentage point of sulfur per gram of sample.

Fuse Wire Correction

The wire used as a fuse for igniting the sample is partly consumed in the combustion. Thus the fuse generates heat both by the resistance it offers to the electric firing current, and by the heat of combustion of that portion of the wire which is burned. It can be assumed that the heat input from the electric firing current will be the same when standardizing the calorimeter as when testing an unknown sample, and this small amount of energy therefore requires no correction. However, it will be found that the amount of wire consumed will vary from test to test, therefore a correction must be made to account for the heat of combustion of the metal.

The amount of wire taking part in the combustion is determined by subtracting the length of the recovered unburned portion from the original length of 10 cm. The correction is then computed for the burned portion by assuming a heat of combustion of 2.3 calories per cm. for Parr 45C10 (No. 34 B & S gage "Chromel C") wire, or 2.7 calories per cm for No. 34 B & S gage iron wire.

Radiation Correction

The method recommended for calculating the correction for heat gain or loss from a plain jacket calorimeter is that specified by the American Society for Testing and Materials as published under ASTM Designations D240 and D3286. It is based upon the work of Dr. H.C. Dickinson at the National Bureau of Standards who showed that the amount of heat leak during a test could be approximated by assuming that the calorimeter is heated by its surroundings during the first 63 percent of the temperature rise at a rate equal to that measured during the 5-minute preperiod. The method then assumes that the cooling (or heating) rate during the remaining 37 per cent of the rise is the same as the rate observed during the 5-minute postperiod. For most experimental work the dividing point between these two periods is taken as that point in time, b, when the temperature has reached six-tenths (instead of 63%) of the total rise. Note that these two time intervals must be expressed in minutes and decimal fractions (Example: 1.4 min. and 6.6 min.).

Magnitude of Errors

The following examples illustrate the magnitude of errors which may result from faulty calorimeter operations. They are based upon an assumed test in which a 1.0000 gram sample produced a 2.800 °C temperature rise in a calorimeter having an energy equivalent of 2400 calories per °C.

- An error of 1 milliliter in making the acid titration will change the thermal value 1.0 cal.
- An error of 1 centimeter in measuring the amount of fuse wire burned will change the thermal value 2.3 cal.
- An error of 1 gram in measuring the 2 kilograms of water will change the thermal value 2.8 cal.
- An error of 1 milligram in weighing the sample will change the thermal value 6.7 cal.
- An error of 0.002 °C in measuring the temperature rise will change the thermal value 4.8 cal.

If all of these errors were in the same direction, the total error would be 17.6 cal.

Maintenance

Calorimeter Maintenance

The high polished chrome finish on the calorimeter bucket is needed to minimize heat transfer. If this finish becomes dull, the bucket should be replaced. Also check the bucket stirrer frequently to be sure that it turns freely. Any drag or friction in the stirrer will cause slow and erratic temperature response in the calorimeter. Add a few drops of machine oil annually to the small hole in the top of the stirrer assembly. Move the shaft of the assembly up and down to distribute the oil thoroughly.

General Cleaning Instructions

Wipe exterior surfaces with lightly dampened cloth containing mild soap solution.

Fuse Ratings

The replacement of protective fuses should be performed by qualified personnel.

Part No. 139E21 used in Ignition Unit 2901EB:
Slow blow, 5.0 Amps, 250 VAC

Part No. 139E8 used in Ignition Unit 2901EE:
Slow blow, 2.5 Amps, 250 VAC

Electric Ignition Problems

If the indicator light does not come on when the firing button is pressed on the ignition unit there is either an open circuit in the system or a fault on the A1580E circuit board. An open circuit can usually be located with an ohmmeter. Flex the lead wires during any continuity check as the wires may be broken and making only intermittent contact. If the red indicator light glows during ignition but the fuse wire does not burn, check the system for a voltage leak to ground, most likely in the insulated electrode on the bomb head. Check the electrode using the high impedance scale on an ohmmeter and replace the electrode insulator and seal if leakage is indicated.

If test methods for hazardous materials require the operator to stand away from the calorimeter when firing the bomb, move the ignition unit to a protected location and add longer wires to the calorimeter. Although remote firing is not necessary for most samples, the operator should always step back from the calorimeter when firing the bomb.

Caution!
Do not have the head, hands or any parts of the body over the calorimeter when firing the bomb; and continue to stand clear for 30 seconds after firing.

6772 Calorimetric Thermometer

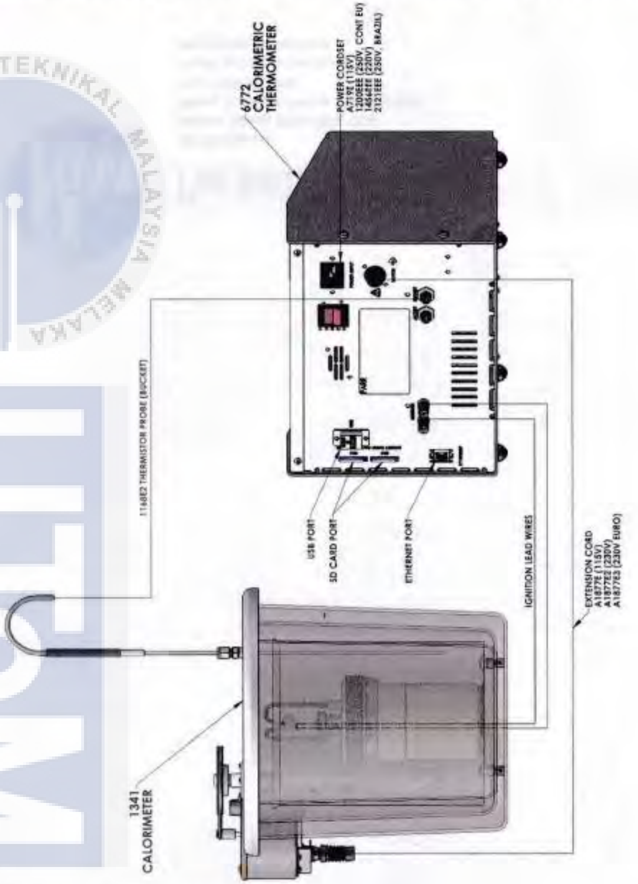
To improve the precision and simplify the procedure for measuring and recording the temperature rise in a 1341 Calorimeter, Parr offers the 6772 Calorimetric Thermometer. Readings are taken with a thermistor sealed in a stainless steel probe. This two-channel precision calorimetric thermometer features Parr's newest generation microprocessor control. The thermometer uses a Linux operating system with communication and file management systems comparable to a PC. A bright, color, touch screen display and data input system utilizes a graphical interface for easy instrument setup and operation. A USB port is available for use with a balance, printer, or barcode reader. (For more information on barcode capability, please contact Parr's sales staff.) An Ethernet port is available for data transfer using TCP/IP communications. No additional ignition source is required as the 6772 Calorimetric Thermometer acts as an ignition unit.

Specifications:

- Thermistor Probe
- One Probe – Standard, Two Probes – Optional
- 0.0001 °C Temperature Resolution
    - **Absolute Accuracy:**
      ±0.1 °C (without calibration)
      ±0.05 °C (with calibration)
    - **Repeatability:**
      ±0.002 °C (Single Point)
    - **Linearity:**
      ±0.002 °C (10 °C Span)
- SD memory and network communications
- Balance & Printer Port: USB
- Updates via the Internet

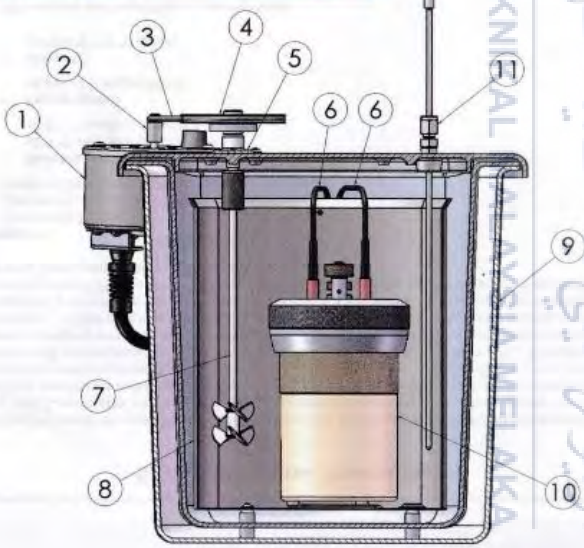
Please refer to Parr Bulletin 6700 for complete details on the 6772 Calorimetric Thermometer.

Electrical Hookup of 6772 Calorimetric Thermometer to 1341 Calorimeter



Parts for the 1341 Calorimeter

Key No.	Part No.	Description
1	A50MEB	Motor Assembly with Pulley, 115V 60 Hz
	A50MEE	Motor Assembly with Pulley, 230V 50/60 Hz
2	355C	Motor Pulley
3	37M2	Stirrer Drive Belt
4	37C2	Stirrer Pulley
5	A27A	Stirrer Bearing Assembly
6	A468E	Ignition Wire
7	A30A3	Stirrer Shaft with Impeller
8	A391DD	Oval Bucket
9	A1100DD	Calorimeter Jacket with Cover
10	1108	Oxygen Combustion Vessel
11	182VBAD	Male Connector
12	1168E2	Thermistor



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28.6875
28.6875
28.6875
28.6875

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