# EFFECT OF SWIRL AT INTAKE MANIFOLD ON ENGINE PERFORMANCE USING ETHANOL FUEL BLEND

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# ABSTRACT

Ethanol fuel is widely used as an alternative fuel for gasoline engines. The use of ethanol can reduce dependence on fuel from the fraction of hydrocarbons. The use of ethanol as fuel, however, causes increased fuel consumption. This increase is a result of the low calorific value and a shorter carbon chain. It also raises the value of Reid's vapor, making it difficult to mix with air. Adding swirl generators to the intake manifold aims to make the interior airflow more turbulent. The mixture of fuel with air will also improve. Given these drawbacks, the study analyses the effect of adding a swirl generator to the intake manifold on engine performance, fuel consumption, and emissions produced.

The experiment is done on a port injection gasoline engine, four-stroke, SOHC four cylinder connected to the engine dynamometer, which is used to measure the power and emissions produced. To get a good form of swirl generator, experiments were performed using a flow bench. A method has also been developed simultaneously to quantify the swirl characteristics of a swirl generator under steady flow conditions in a flow laboratory using the cylinder head, intake manifold, and swirl generator from the engine experiments. A refined swirl meter is installed under the cylinder head to measure the compressive load of the swirl, allowing for the calculation of angular momentum of the incoming air at varying intake valve lifts, thus producing the swirl number. A correlation is then sought between the engine and flow experiments to help quantify the impact of swirl motion on combustion and cyclic variation. The airflow rate into the cylinder, discharge coefficient of the intake system, and flow loss coefficient across the blockage are also analyzed for different levels of swirl motion. The validity of this method under steady flow condition is confirmed by comparison of the results with the engine experiments.

An engine using ethanol blend fuel has higher fuel consumption, E10 fuel consumption average increase is 12%, and E20 fuel consumption increase is 14%. Increasing the ethanol content further in fuels however will reduce the emissions productions. Performance in relation to the torque, E10 in the case Half Open Throttle at 2000 rpm reduces the engine torque by 3.8 %, at 4000 rpm the engine torque is reduced by 1.6%. E10 in the case of Wide Open Throttle at 2000 rpm reduce the engine torque by 3.4%, and at 4000 rpm reduces the torque by 1.2%. In the case of E20 at Half Open Throttle and rpm 2000 the engine torque reduces by 5.8%, and at 4000 rpm increases by 2.7%.

The addition of a swirl generator will increase the engine performance in the case of E20 at Half Open Throttle. The average engine torque increases from 10 until 13 %, in the case of Wide Open Throttle the engine torque increases by 9%. In the case of E10 with Half Open Throttle the engine torque increases by 9%, and with Wide Open Throttle increases by 8,5%. But the emissions generated will be higher in the case of HC at Wide Open Throttle, increasing by 50% .

# ABSTRAK

Etanol digunakan secara meluas sebagai bahan api alternatif untuk enjin petrol. Penggunaan etanol boleh mengurangkan pergantungan kepada bahan api daripada hidrokarbon. Penggunaan etanol sebagai bahan api menyebabkan peningkatan penggunaan bahan api. Peningkatan ini adalah disebabkan oleh nilai kalori yang rendah, rantaian karbon pendek, dan seterusnya nilai wap Reid yang lebih tinggi oleh itu ia akan menjadi sukar untuk bercampuran dengan udara. Penambahan penjana pusaran pada pancarongga pengambilan bermaksud untuk mengubah aliran udara di dalam pancarongga pengambilan untuk menjadi lebih pergolakan. Dengan aliran pergolakan dalam pancarongga pengambilan, akan meningkatkan aliran pusaran di dalam kebuk pembakaran. Walau bagaimanapun campuran bahan api dengan udara akan menjadi lebih baik. Memandangkan kelemahan ini, kajian ini dilakukan untuk menganalisis kesan penambahan penjana pusaran pada pancarongga pengambilan untuk prestasi enjin, penggunaan bahan api, dan pengeluaran yang dihasilkan.

Eksperimen dilakukan pada suntikan port enjin petrol, 4 strok, SOHC 4 silinder, yang disambungkan kepada enjin dynamometer digunakan untuk mengukur kuasa dan pelepasan dihasilkan. Untuk mendapatkan bentuk penjana pusaran yang baik, eksperimen dilakukan dengan menggunakan bangku aliran. Satu kaedah juga telah dibangunkan serentak untuk mengukur ciri-ciri pusaran penjana pusaran di bawah keadaan aliran mantap dalam makmal aliran, dengan menggunakan kepala silinder, pancarongga pengambilan, dan penjana pusaran dari eksperimen enjin yang sama . Pengukur pusaran yang tepat dipasang di bawah kepala silinder untuk mengukur beban mampatan pusaran, membolehkan pengiraan momentum sudut udara masuk di pelbagai pengambilan lif injap, dan jumlah pusaran. Kemudian diperolehi Korelasi persamaan antara enjin dan aliran eksperimen untuk membantu mengukur kesan gerakan pusaran pada pembakaran dan perubahan kitaran. Kadar aliran udara ke dalam silinder, pekali kadar alir sistem pengambilan, dan pekali kehilangan aliran merentasi sekatan juga dianalisis untuk pelbagai peringkat gerakan pusaran. Kesahihan kaedah ini di bawah keadaan aliran mantap disahkan oleh perbandingan keputusan dengan eksperimen enjin.

Enjin yang menggunakan bahan api etanol gabungan mempunyai penggunaan bahan api yang lebih tinggi, peningkatan purata penggunaan bahan api E10 adalah 12%, dan E20 peningkatan penggunaan bahan api ialah 14%. Meningkatkan kandungan etanol lanjut dalam bahan api bagaimanapun akan mengurangkan pengeluaran pelepasan. Prestasi berhubung dengan tork, E10 dalam kes Separuh Terbuka Throttle pada 2000 rpm mengurangkan tork enjin sebanyak 3.8%, pada 4000 rpm tork enjin akan berkurangan sebanyak 1.6%. E10 dalam kes Throttle Terbuka Luas di 2000 rpm mengurangkan tork enjin sebanyak 3.4%, dan pada 4000 rpm mengurangkan tork sebanyak 1.2%. Dalam kes E20 di Separuh Terbuka Throttle dan rpm 2000 enjin tork mengurangkan sebanyak 5.8%, dan pada 4000 rpm meningkat sebanyak 2.7%.

Penambahan penjana pusaran akan meningkatkan prestasi enjin dalam kes E20 di Separuh Terbuka Throttle. Purata kenaikan enjin tork dari 10 hingga 13%, dalam kes Throttle Terbuka Luas enjin tork meningkat sebanyak 9%. Dalam kes E10 dengan Separuh Terbuka Throttle enjin tork meningkat sebanyak 9%, dan dengan peningkatan Throttle Wide Open oleh 8,5%. Tetapi pengeluaran yang dihasilkan akan lebih tinggi dalam kes HC di Throttle Wide Open, meningkat sebanyak 50%.

## TABLE OF CONTENT

## LIST OF TABLES

# LIST OF FIGURES

# LIST OF SYMBOLS

| | |
|---|---|
| 3D | Three dimension |
| $\Pi$ | Ratio of absolute pressure |
| $\rho_b$ | Density |
| $\alpha$ | Power correction factor |
| $\alpha_a$ | Correction factor for spark ignition engine |
| $\alpha_d$ | Correction factor for compression ignition engine |
| $f_a$ | Atmosphere factor |
| $f_m$ | Engine factor |
| $\ell$ | Integral length scale |
| $m_f$ | Mass flow rate fuel |
| $N$ | Rotation per minute |
| $P$ | Total barometric pressure |
| $P_s$ | Saturated water vapors pressure |
| $P_r$ | Power correction |
| $P_y$ | Power observed |
| $q_c$ | Fuel delivery per cycle |
| $Q_f$ | Fuel Capacity |
| $r$ | Value under standard |
| SI | Spark ignition |
| $S_L$ | Laminar flame speed |
| $t$ | Time |
| $T$ | Absolute air temperature |
| $T_r$ | Ambient temperature |
| $u'$ | Burn rate |
| $v$ | Kinematic viscosity |
| $y$ | Value under ambient test condition |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of variance |
| ABDC | After bottom dead center |
| ATDC | After top dead center |
| BBDC | Before bottom dead center |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| $C_2H_5OH$ | Ethanol |
| $C_aO$ | Calcium oxide |
| DOE | Design of experiment |
| E0 | Gasoline 100% |
| E10 | Ethanol 10% and gasoline 90% |
| E20 | Ethanol 20% and gasoline 80% |
| E30 | Ethanol 30% and gasoline 70% |
| EFI | Electric fuel injection |
| EGR | Exhaust gas recirculation |
| HC | Hydrocarbon |
| HOT | Half open throttle |
| IMEP | Indicated mean effective pressure |
| ISFC | Indicated specific fuel consumption |
| ISO | The international organization for standard |
| MFB | Mass fraction burned |
| MBT | Maximum brake torque |
| MTBE | Methyl tert butyl ether |
| NOx | Nitrogen oxide |
| OH | Hydroxyl |
| OHV | Overhead valve |
| RVP | Reid vapor pressure |
| SOHC | Single Overhead Camshaft |
| TDC | Top dead center |

| | |
|---|---|
| TWC | Three way catalyst |
| THC | Total hydrocarbon |
| UHC | Un-burn Hydrocarbon |
| VOC | Volatile Organic Compounds |
| WOT | Wide open throttle |

# CHAPTER 1

# INTRODUCTION

## 1.1 RESEARCH BACKGROUND

Global concern due to the air pollution has generated a great deal of interest in environmentally friendly alternative fuels. Alternative fuels for internal combustion engines have also become important because of diminishing petroleum reserves and increasing air pollution. Methanol and ethanol are good candidates as alternative fuels because they are liquids and they have several physical and chemical properties similar to those of gasoline and diesel fuel. Indeed, Henry Ford's first automobile (the Model T) was designed to run on both gasoline and pure ethanol (Sward, 1948). In the past and even currently, however, ethanol is not widely used due to its insufficient production and high price.

Alcohol fuels such as ethanol in particular can be produced from renewable sources such as sugar cane, cassava, corn, barley, and certain types of waste biomass materials. Ethanol has some advantages over gasoline, such as the reduction of carbon monoxide (CO), volatile organic compounds (VOC), and unburned hydrocarbon (UHC) emissions and better anti-knocks characteristics, which allow for the use of a higher compression ratio of engines. Because it is a liquid fuel, the storage and dispensing of ethanol is similar to that of gasoline. At the present time, ethanol is used in spark ignition engines by blending it with gasoline at low concentrations without any modification. Pure ethanol can be used in spark ignition engines but necessitates some modifications to the engine. (Yung-Chen Yao at al., 2009)

Ethanol has been used as motor fuel almost since the invention of the automobile. By definition, ethanol contains the hydroxyl (OH) group. This gives the ethanol certain common characteristic of OH group including high latent heat of vaporization and high solubility in water. These characteristics can be advantageous or disadvantageous, depending on the ethanol's intended function. The wide flammability limits and high latent heat of ethanol make it attractive as a racing fuel. The high motor octane number and modest water affinity of tertiary butyl alcohol make it attractive as an octane blending component. (Hsieh et al., 2002). However, none of the alcohols have ever been used as primary energy sources on a wide scale because they are too expensive relative to gasoline. Nevertheless, since the world petroleum situation has changed, alcohol has become an increasingly viable fuel and studies continue to explore its viability as a potential alternative fuel. Investigations in the 1970s found that it is possible to develop efficient engine vehicle designs based on alcohol fuels. These designs can be expected to be superior to today's gasoline engines in the following aspects:

- Better thermal efficiency
- Higher power output
- Improved exhaust emissions

Ethanol added in the fuel would increase specific fuel consumption and will reduce the heating value content. (Al-Hasan, 2003). To attain the same power as a gasoline fuel, the engines require more of the ethanol/gasoline blend. The increase in brake-specific fuel consumption, caused by carbon chains on ethanol, is shorter. Fuel with a shorter carbon chain has a higher Reid vapor pressure; therefore, more energy is required to convert liquid fuel into a gas that is ready to mix with air in the combustion chamber. Thus, ethanol will be more difficult to mix with air, decreasing engine performance.

To simplify the process of blending ethanol fuel with air, this study developed an intake manifold with a swirl generator. It was expected that the addition of a swirl generator would change the shape of airflow inside the intake manifold. The change in the form of airflow would also produce changes in the process of mixing fuel with air, and the mixture of air with a more homogeneous fuel engine would result in better performance.

## 1.2 PROBLEM STATEMENT

Ethanol has nearly the same properties as gasoline. It is as easy to use ethanol on its own as fuel or directly by blending it with gasoline. The addition of ethanol causes the fuel properties to change. These changes will affect to the engine performance, and emissions produced. As a fuel, ethanol has low Reid vapor pressure, high octane number, and lower low heating value than gasoline. Fuel with low heating value will increase fuel consumption.

The use of fuel ethanol/gasoline has some advantages over gasoline, such as the reduction of CO, and unburned HC emissions and better anti-knock characteristics, which allow for the use of higher compression ratio of engines, however used ethanol gasoline blend decreases engine performance. There are several methods through which to solve this problem, such as improving the process of air–fuel mixing. At the port injection engines, the process of air/fuel mixing begins at the intake manifold; thus, the airflow in the intake manifold greatly affects the process of air/fuel mixing. In this research, the development of the intake manifold is carried out by adding a swirl generator at the intake manifold. This addition aims to increase the turbulence of the induction process. Turbulence flow will increase with air/fuel mixing.

The intake manifold will be tested with a flow bench to measure the airflow in the cylinder in order to determine the effect of adding swirl generators. After determining the effect of the swirl generator on the intake manifold and the airflow, the experiments will continue with the engine dynamometer. Ultimately, the test aims to determine the effect of a swirl generator on engine performance.

## 1.3 SIGNIFICANCE OF STUDY

The addition of ethanol in gasoline fuels would affect engine performance and reduce emissions. The research outcome could result in significant decrease in fuel consumption but lower emissions. Data from the experiments conducted in this study on the effect of ethanol on engine performance will be used to continue development of the intake manifold to improve engine performance with gasoline fuel and an ethanol/gasoline blend.

This is achieved by adding swirl generators to the intake manifold. Swirl generators will increase the swirl flow in the combustion chamber. A higher swirl in the combustion process will produce more powerful and more efficient combustion. Using a swirl generator in the intake manifold could improve engine performance when using a fuel ethanol/gasoline blend.

## 1.4 RESEARCH OBJECTIVES

The objectives of the research are:

i. To develop a swirl generator at the intake manifold
ii. To analyze the effect of ethanol addition on engine performance and emissions
iii. To investigate the effect of different angles of attack for swirl generators on engine performance and emissions using ethanol blended fuel.

## 1.5 SCOPE OF WORK

To achieve optimal results of the research on the influence of ethanol blended fuel with the addition of a swirl generator to the intake manifold, the project scopes are:

i. Development of the test rig for engine performance
ii. Analysis of the influence of ethanol blended fuel in engine performance
iii. Development of the swirl generator to integrate with an intake manifold system
iv. Analysis of the effect of adding swirl generators to an intake manifold on super flow, engine performance, and exhaust emissions

## 1.6 HYPOTHESIS

Ethanol as fuel contains oxygen and has a higher octane number and higher density, but the heating value is lower than gasoline. The addition of ethanol in fuel will increase fuel consumption and minimize greenhouse gas emissions generated. Quite a few studies show that an ethanol/gasoline blend has lower penetration compared to pure gasoline. The process of mixing lower fuel combustion processes that cause less than perfect.

To improve of the air–fuel mixing process in the combustion chamber, this study will be carried out on a modified intake manifold. Swirl generators will be added to the intake manifold to produce a swirl flow and turbulence in the cylinder. The addition of swirl flow in the compression process will improve the air–fuel mixing process; the air–fuel mixture will be homogeneous. In addition, a higher swirl flow will increase the burning process and burn rate, and it will increase efficiency. Increasing air–fuel mixing can improve performance and reduce emission.

## 1.7 RESEARCH CONTRIBUTION

Research on the swirl generator in the intake manifold is expected to solve the problems of increased fuel consumption with the use of ethanol blended fuel. Ethanol gasoline fuel blend as alternative fuel used produced from renewable resources. Ethanol have been used as a fuel for engines since 19th century. Among the various alcohols, ethanol is known as the most suited fuel for spark ignition (SI) engines. The most attractive properties of ethanol as an SI engine fuel are that it can be produced from renewable energy sources such as sugar, cane, cassava, many types of waste biomass materials, corn and barley Manzini F. (2006).

## 1.8 ORGANIZATION OF THESIS

Chapter 1 outlines the background, statement of problem, objective, scopes, and limitations of this thesis. The importance of research on the development of the new intake manifold for port injection gasoline engine is also discussed.

Chapter 2 presents a literature review relating to ethanol as an alternative fuel, combustion with swirl and tumble, combustion duration, cyclic variations, thermal efficiency, turbulence generation, swirl motion, tumble motion, generation of swirl and tumble, helical ports, directed ports, variable swirl/tumble ports, valve shrouding and masking, flow blockages and vanes, determination of flow intensity, steady flow testing, and effect of charge motion.

Chapter 3 the research methodology, is devoted to the brief description of an experimental setup and engine testing method. This chapter also describes the static flow testing for the development of the intake manifold with swirl generator.

Chapter 4 explains the effect of an ethanol/gasoline blend on engine performance and emission. This chapter also includes a description of the effect of a swirl generator in an intake manifold on airflow into the combustion chamber. The last discussion examines the effect of a swirl generator in an intake manifold on engine performance and emission using gasoline and an ethanol/gasoline blend fuel.

Chapter 5 is the conclusion of the work undertaken. The conclusion explains the answer to the question in the problem statement, the objective, the research method, the result, and the discussion of this thesis.

# CHAPTER 2

# LITERATURE REVIEW

This gives an overview of existing literature on ethanol blended fuel, effect of fuel properties, effect of ethanol blended fuel on engine performance, swirl and tumble in spark-ignition engine and their effect on turbulence generation, and burn duration. The effects of charge motion on combustion (such as burn duration, cyclic variation, and thermal efficiency) and turbulence enhancement are introduced first followed by a review of mechanisms to produce swirl and tumble. Next the approaches to determine swirl/tumble intensity are presented. Finally review in design expert, this review about optimization.

## 2.1 ETHANOL FUEL

Ethanol ($C_2H_5OH$) is more reactive than hydrocarbon fuels, such as gasoline. Since it is an alcohol, its molecular structure shows a polar fraction due to the hydroxyl radical and a non polar fraction in its carbon chain. That explains why ethanol can be dissolved in both gasoline (non polar) and in water (polar). Due to its short carbon chain, the properties of ethanol polar fraction overcome the non polar properties. The formation of hydrogen bridges in ethanol molecule results in higher boiling temperature in comparison to that of gasoline as shown in the Table 2.1 Ethanol is less toxic than other alcohol used as fuel.

**Table 2.1** Fuel Property Comparison for Ethanol, and Gasoline

| **Property** | **Ethanol** | **Gasoline** |
|---|---|---|
| Chemical Formula | $C_2H_5OH$ | $C_4$ to $C_{12}$ |
| Molecular Weight | 46.07 | 100–105 |
| Carbon | 52.2 | 85–88 |
| Hydrogen | 13.1 | 12–15 |
| Oxygen | 34.7 | 0 |
| Specific gravity, 60° F/60° F | 0.796 | 0.72–0.78 |
| Density, lbs./gal @ 60° F | 6.61 | 6.0–6.5 |
| Boiling temperature, °F | 172 | 80–437 |
| Reid vapour pressure, psi | 2.3 | 8–15 |
| Research octane no. | 108 | 90–100 |
| Motor octane no. | 92 | 81–90 |
| (R + M)/2 | 100 | 86–94 |
| Cetane no.(1) | -- | 5–20 |
| Fuel in water, volume % | 100 | Negligible |
| Water in fuel, volume % | 100 | Negligible |
| Freezing point, °F | -173.2 | -40 |
| Centipoise @ 60° F | 1.19 | 0.37–0.44a |
| Flash point, closed cup, °F | 55 | -45 |
| Auto ignition temperature, °F | 793 | 495 |
| Lower | 4.3 | 1.4 |
| Higher | 19 | 7.6 |
| Btu/gal @ 60° F | 2,378 | ≈900 |
| Btu/lbs. @ 60° F | 396 | ≈150 |
| Btu/lbs. air for stoichiometric mixture @ 60° F | 44 | ≈10 |
| Mixture in vapour state, Btu/cubic foot @68°F | 92.9 | 95.2 |
| Fuel in liquid state, Btu/lbs. or air | 1,280 | 1,290 |
| Specific heat, Btu/lbs. °F | 0.57 | 0.48 |
| Stoichiometric air/fuel, weight | 9 | 14.7a |
| Volume % fuel in vaporized stoichiometric mixture | 6.5 | 2 |

Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels Data Center
http://www.eere.energy.gov/afdc/altfuel/fuel_properties.html

The simple structure of ethanol molecule makes it suitable for spark ignition internal combustion engine's operation. The high octane number of ethanol allows for higher compression ratios in comparison to gasoline fueled engines as shown in Table

2.1. In Brazil, ethanol is produced from sugar-cane, a renewable energy source. Sugar cane molasses contains about 40% sucrose, which hydrolysis by an enzyme called inverses produces glucose or fructose as shown Equation 2.1. The enzyme is elaborated by brewers yeast. Ethanol is formed by glucose ($C_6H_{12}O_6$) fermentation in the presence of another enzyme called zymase as shown Equation 2.2.

$$\underset{(sucrose)}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{invertase} \underset{(glucose)}{xC_6H_{12}O_6} + \frac{(2-x)C_6H_{12}O_6}{(fructose)} \qquad (2.1)$$

$$\underset{(glucose)}{C_6H_{12}O_6} \xrightarrow{zymase} \underset{(ethanol)}{2C_2H_5OH} + 2CO_2 \qquad (2.2)$$

From distillation of the liquid resulting from fermentation in high fractioning columns, hydrous ethanol with 6.8% of water by mass can be obtained. This blend behaves as a pure substance during evaporation, and its evaporation temperature is lower than that of 100% ethanol. In order to obtain pure ethanol, hydrous ethanol must be treated by calcium oxide (CaO) and, then, be distilled.

### 2.1.1 Role of Oxygenated Fuel Properties

The addition of oxygenates influences the physical and chemical properties of the fuel. Properties like boiling temperature, vapor pressure, latent heat of vaporization, energy content, flame temperature, and flame speed are affected. These changes in fuel properties are expected to influence the combustion characteristics, and therefore, the engine performance and exhaust emissions as discuses by Petterson and Henein, 1979; Dom, Mourao, 1984; Thring, 1983; Watson, 1996; Bata ; Elrod; Rice, 1989; Hamid, and Ali, 1985. To understand these influences, we need to examine the effects of oxygenates on the original properties of gasoline.

### 2.1.2 Effect on Stoichiometric Air-Fuel Ratio

Oxygenates have lower stoichiometric air-fuel ratio than gasoline, therefore, blends of gasoline and oxygenates will have lower air-fuel ratios than that of gasoline.

The decrease in air-fuel ratio is proportional to the ratio of the oxygenate in the blend. The use of blends of gasoline and oxygenates, as a replacement of gasoline on unmodified engines, will shift the actual equivalence ratio to the lean side of operation. This shift results in what is called the leaning effect. The leaning effect is a result of the existence of oxygen in the oxygenated blend. The shift in equivalence ratio is proportional to the oxygen weight in the blend.

Modern engines operating with unleaded fuels can be equipped with a three way catalyst (TWC). This catalyst can significantly reduce the concentrations of CO, HC, and $NO_X$ emissions provided that the engine operates with a close to stoichiometric mixture. A conversion efficiency of 80% or more can be achieved in a very narrow range of equivalence ratios (0,998-1.008). This narrow range is called the TWC 80% efficiency window. Conventional mixture formation system can’t handle this strict range therefore more sophisticated closed-loop feedback control systems are currently applied.

### 2.1.3 Effect on Heating Value

The heating value of the fuel is the amount of heat released pursuant to complete combustion of the fuel. Oxygenates usually have lower heating values than gasoline. The ratios of heating values of MTBE, ethanol, methanol to that of gasoline is 80%, 60%, and 45% respectively. It blends of gasoline and oxygenates have lower heating values than that of gasoline. The decrease in the heating value is proportional to the ratio of the oxygenate in the blend. Lower heating value results in less heat release during combustion, and therefore, lower flame temperature. The decrease in flame temperature is expected to reduce the formation of nitrogen oxides because of their strong dependence on temperature. In addition, lower heating value means that more fuel is needed to produce the same amount of power. In other words, the volume – based fuel consumption will increase. (Piel, and Thomas, 1990; Thring, 1983).

### 2.1.4 Effect on Latent Heat of Vaporization

The latent heat of vaporization is the amount of heat required to evaporate certain mass of a substance. In the case of SI engine operating with liquid fuels, the fuel is normally introduced, in liquid phase, to the air in the intake manifold before entering the combustion chamber. In order to evaporate, the liquid fuel absorbs the necessary heat from the manifold walls and from the intake air lowering its temperature and thus increasing its density. The increase in air density allows more air to fill the engine cylinders increasing the volumetric efficiency and thus increasing engine output. This role of latent heat of vaporization is usually referred to as the cooling effect. The MTBE has a value of latent heat of vaporization comparable to that of typical gasoline. Methanol and ethanol, on the other hand, have much higher value than that of gasoline. This makes the methanol and ethanol more effective in cooling the intake air and thus producing higher engine output. This is more evident in the case of gasoline fuel injection systems where the atomized liquid fuel is injected to the air just before the combustion chamber allowing most of the heat to be absorbed from the intake air rather than the intake walls. The cooling effect, however, has a disadvantage during the cold-start conditions. Methanol and ethanol blend will be more difficult to evaporate during cold conditions resulting in lower combustion quality and possibly starting problem particularly with high blending ratios. The lower combustion quality increases the unburned HC emission.

### 2.1.5 Effect on Boiling Temperature

Oxygenates are single compounds that have certain boiling temperatures. Gasoline, however, is a mixture of compounds that have different boiling temperatures. The boiling process of gasoline takes place in temperatures typically ranging from $25^0$C to $225^0$C. The addition of oxygenates to gasoline changes the boiling behavior of gasoline causing a distortion in the boiling curve at the point where the added oxygenate starts to boil.

In general, addition of oxygenates decreases the temperature required to evaporate the first 50% of the fuel. This decrease in the boiling temperature of the front end (first 50%) is expected to have a good impact on the cold start conditions because of better evaporation of fuel. In addition, the better evaporation of fuel improves the combustion resulting in less unburned hydrocarbons. However, this advantage is offset in the case of ethanol and methanol by their high latent heat of vaporization, which

# CHAPTER 1

# INTRODUCTION

## 1.1 RESEARCH BACKGROUND

Global concern due to the air pollution has generated a great deal of interest in environmentally friendly alternative fuels. Alternative fuels for internal combustion engines have also become important because of diminishing petroleum reserves and increasing air pollution. Methanol and ethanol are good candidates as alternative fuels because they are liquids and they have several physical and chemical properties similar to those of gasoline and diesel fuel. Indeed, Henry Ford’s first automobile (the Model T) was designed to run on both gasoline and pure ethanol (Sward, 1948). In the past and even currently, however, ethanol is not widely used due to its insufficient production and high price.

Alcohol fuels such as ethanol in particular can be produced from renewable sources such as sugar cane, cassava, corn, barley, and certain types of waste biomass materials. Ethanol has some advantages over gasoline, such as the reduction of carbon monoxide (CO), volatile organic compounds (VOC), and unburned hydrocarbon (UHC) emissions and better anti-knocks characteristics, which allow for the use of a higher compression ratio of engines. Because it is a liquid fuel, the storage and dispensing of ethanol is similar to that of gasoline. At the present time, ethanol is used in spark ignition engines by blending it with gasoline at low concentrations without any modification. Pure ethanol can be used in spark ignition engines but necessitates some modifications to the engine. (Yung-Chen Yao at al., 2009)

Ethanol has been used as motor fuel almost since the invention of the automobile. By definition, ethanol contains the hydroxyl (OH) group. This gives the ethanol certain common characteristic of OH group including high latent heat of vaporization and high solubility in water. These characteristics can be advantageous or disadvantageous, depending on the ethanol's intended function. The wide flammability limits and high latent heat of ethanol make it attractive as a racing fuel. The high motor octane number and modest water affinity of tertiary butyl alcohol make it attractive as an octane blending component. (Hsieh et al., 2002). However, none of the alcohols have ever been used as primary energy sources on a wide scale because they are too expensive relative to gasoline. Nevertheless, since the world petroleum situation has changed, alcohol has become an increasingly viable fuel and studies continue to explore its viability as a potential alternative fuel. Investigations in the 1970s found that it is possible to develop efficient engine vehicle designs based on alcohol fuels. These designs can be expected to be superior to today's gasoline engines in the following aspects:

- Better thermal efficiency
- Higher power output
- Improved exhaust emissions

Ethanol added in the fuel would increase specific fuel consumption and will reduce the heating value content. (Al-Hasan, 2003). To attain the same power as a gasoline fuel, the engines require more of the ethanol/gasoline blend. The increase in brake-specific fuel consumption, caused by carbon chains on ethanol, is shorter. Fuel with a shorter carbon chain has a higher Reid vapor pressure; therefore, more energy is required to convert liquid fuel into a gas that is ready to mix with air in the combustion chamber. Thus, ethanol will be more difficult to mix with air, decreasing engine performance.

To simplify the process of blending ethanol fuel with air, this study developed an intake manifold with a swirl generator. It was expected that the addition of a swirl generator would change the shape of airflow inside the intake manifold. The change in the form of airflow would also produce changes in the process of mixing fuel with air, and the mixture of air with a more homogeneous fuel engine would result in better performance.

## 1.2 PROBLEM STATEMENT

Ethanol has nearly the same properties as gasoline. It is as easy to use ethanol on its own as fuel or directly by blending it with gasoline. The addition of ethanol causes the fuel properties to change. These changes will affect to the engine performance, and emissions produced. As a fuel, ethanol has low Reid vapor pressure, high octane number, and lower low heating value than gasoline. Fuel with low heating value will increase fuel consumption.

The use of fuel ethanol/gasoline has some advantages over gasoline, such as the reduction of CO, and unburned HC emissions and better anti-knock characteristics, which allow for the use of higher compression ratio of engines, however used ethanol gasoline blend decreases engine performance. There are several methods through which to solve this problem, such as improving the process of air–fuel mixing. At the port injection engines, the process of air/fuel mixing begins at the intake manifold; thus, the airflow in the intake manifold greatly affects the process of air/fuel mixing. In this research, the development of the intake manifold is carried out by adding a swirl generator at the intake manifold. This addition aims to increase the turbulence of the induction process. Turbulence flow will increase with air/fuel mixing.

The intake manifold will be tested with a flow bench to measure the airflow in the cylinder in order to determine the effect of adding swirl generators. After determining the effect of the swirl generator on the intake manifold and the airflow, the experiments will continue with the engine dynamometer. Ultimately, the test aims to determine the effect of a swirl generator on engine performance.

## 1.3 SIGNIFICANCE OF STUDY

The addition of ethanol in gasoline fuels would affect engine performance and

# CHAPTER 3

# METHODOLOGY

To optimize result of the research, this study was divided into several stages, namely to stage the engine performance. This process can be used to determine the effect of ethanol on performance and emissions in gasoline engines. Testing is conducted using a four-cylinder gasoline engine injection port four strokes coupled with the dynamometer. The experiment is carried out in half load and full load conditions. This experiment resulted in some of the performance engines, engine power, torque, fuel consumption, engine temperature, exhaust temperature, and exhaust gas emissions by using gasoline fuel, ethanol 10.0% (E10), ethanol 20.0% (E20), and ethanol 30.0% (E30).

The experiment on steady flow is intended to determine the form of the flow as it enters the combustion chamber. Testing is done using a flow bench. The type of airflow in the engine cylinder head and intake manifold is taken from the engine experiment. The flow form in the intake manifold was determined using the intake manifold standard and the swirl generator, which is done in computer fluid dynamic (CFD). The intake manifold was tested using variations of the intake valve lift and the airflow speed difference.

## 3.1 ENGINE TEST BED

### 3.1.1 Ethanol Fuel Preparation

In this study, the ethanol used is ethanol 95.0% purity with the specifications for the laboratory grade. To get ethanol with guaranteed quality, in this study ethanol purchased from chemical suppliers. Ethanol was chosen to obtain ethanol with a fairly good quality with minimum water content; high water content in ethanol led to the mixture of gasoline and ethanol which would be more difficult. To get a better fuel mixture, to prepare for the fuel with care, especially equipment that is used as a measuring cup, mixer and so forth.

In this study, E10, E20 and E30 were obtained by mixing ethanol with a gasoline using the volume ratio of the fuel. To get the E10, 900 ml gasoline fuel was put into the burette and ethanol was added until the fuel reached 1,000 ml. Next, the fuel was shaken to mix the gasoline and ethanol perfectly. More fuel can be obtained by scaling-up in this process. Results of testing the properties of gasoline fuel and the ethanol/gasoline blend is show in Table 3.1.

**Table 3.1.** Properties of different ethanol/gasoline blended fuels (E0, E10, E20, E30)

| | Test fuel | | | | Method |
|---|---|---|---|---|---|
| Property item | E0 | E10 | E20 | E30 | |
| Density (kg/l at 15.5°C) | 0.7575 | 0.7608 | 0.7645 | 0.7682 | ASTM D4052 |
| RON (octane number) | 95.4 | 98.1 | 100.7 | 102.4 | ASTM D2699 |
| RVP (kPa at 37.8°C) | 53.7 | 59.6 | 58.3 | 56.8 | ASTM D5191 |
| Sulfur (wt%) | 0.0061 | 0.0055 | 0.0049 | 0.0045 | ASTM D5453 |
| Washed gum (mg/100 ml) | 0.2 | 0.2 | 0.6 | 0.2 | ASTM D381 |
| Unwashed gum (mg/100 ml) | 18.8 | 17.4 | 15 | 14.4 | |
| Lead content (g/l) | <0.0025 | <0.0025 | <0.0025 | <0.0025 | ASTM D3237 |
| Corrosivity (3 h at 50°C) | 1a | 1a | 1a | 1a | ASTM D130 |
| | | | | | |
| Distillation temperature (°C) | | | | | ASTM D86 |
| IBP | 35.5 | 37.8 | 36.7 | 39.5 | |
| 10 vol% | 54.5 | 50.8 | 52.8 | 54.8 | |
| 50 vol% | 94.4 | 71.1 | 70.3 | 72.4 | |
| 90 vol% | 167.3 | 166.4 | 163 | 159.3 | |
| End point | 197 | 197.5 | 198.6 | 198.3 | |
| | | | | | |
| Heating value (cal/g) | 10176 | 9511 | 9316 | 8680 | |
| Carbon (wt%) | 86.6 | 86.7 | 87.6 | 86 | |
| Hydrogen (wt%) | 13.3 | 13.2 | 12.3 | 13.9 | |
| Residue (vol%) | 1.7 | 1.5 | 1.5 | 1.5 | |
| Color | Yellow | Yellow | Yellow | Yellow | Visual |

### 3.1.2 Specification for the Engine Test

The engine used in this study is a Mitsubishi 4G92 port injection four-cylinder gasoline engine, inline over head valve (OHV), single over head camshaft (SOHC) spark ignition rated 63 horsepower (hp) at 5,500 revolutions per minute (rpm), with the specifications given in Table 3.2. Testing is done using gasoline fuel Ron 95, followed by the addition of E10 and E20. The addition of ethanol 30% (E30) or greater is less economical and E30 will reduce engine performance.

The engine is connected at the eddy current dynamometer; lay out experiment as shown in Figure 3-1 and for detail experiment shown at appendix. The analysis for the experiment finds the effect of engine torque, engine speed, fuel consumption, and throttle position. The eddy current dynamometer is a dry-gap rotor machine with either single or twin rotors, which operates in the air gap and is inherently capable of bidirectional operational.

**Table 3.2.** Engine specification

| **Engine Parameter** | **Value** |
|---|---|
| Type | In-line OHV, SOCH |
| Motor Construction | 4 cylinders, water cooled |
| Bore and Stroke | 81 x 77.5 mm |
| Compression ratio | 10: 1 |
| Intake open | $200^0$(BTDC) |
| Intake close | $420^0$ (ABDC) |
| Exhaust open | $520^0$( BBDC) |
| Exhaust close | $20^0$(ATDC) |

An outstanding feature of dry-gap eddy current dynamometer is its very wide performance characteristics. The capacity of the dynamometer is maximum torque of 150 Nm at 1,500–2,500 rpm and maximum power of 100 kW at 2,500–13,000 rpm. The overall size of the mechanical specification is 510 mm wide and 660 mm high from the platform to the center of the dynamometer shaft. The electrical specification for maximum excitation current is 6 amp dc. Coil resistance is 12–15 ohms and coil dynamometer is 500 m ohm.