A NUMERICAL STUDY ON THE EFFECT OF GASOLIE-HYDROGEN FUEL BLEND ON ENGINE POWER AND TORQUE AT MEDIUM AND HIGH ENGINE SPEED

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
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AWARD FOR DEGREE

Bachelor Final Year Project Report

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Mechanical Engineering.

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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Name of Supervisor: MUHAMAD MAT NOOR
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Date: 24 NOVEMBER 2009

STUDENT’S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

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Dedicated, truthfully for supports,
encouragements and always be there during hard times,
my beloved family.

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ABSTRACT

This thesis presented about the effect of gasoline-hydrogen fuel blend on engine power and torque at medium and high engine speed. The experiment had been done by using different ratios of gasoline and hydrogen fuel. The engine modelling was drawn by GT-Power software and was analyzed by GT-Post software. In this analysis, the ratio of gasoline and hydrogen were varied in order to analyze the power and torque of the engine. The ratios that had been used in this analysis were by increment of 10% for hydrogen fuel and decrement of 10% for gasoline fuel until both fuel reached 50%. The engine that has been used was a single cylinder engine with four stroke cycle, by using SI-inject. After the analyzation, we found that the power and torque of the engine is increased by the increasing of fuel ratio at both engine speeds. The values of engine power were increasing eventhough we run it at 3000 rpm and 6000 rpm but as for the torque, the values were higher at 3000 rpm but decreasing at 6000 rpm.

ABSTRAK

Tesis ini membentangkan tentang pengaruh campuran petrol dan minyak hidrogen terhadap kelancaran enjin kereta dari segi kuasa dan tenaga putaran pada kelajuan enjin yang sederhana dan tinggi. Ujian ini telah dijalankan dengan menggunakan nisbah minyak yang berbeza pada lain-lain masa. Model enjin ini dilukiskan dengan menggunakan perisian GT-Power manakala akan dianalisis dengan menggunakan perisian GT-Post. Dalam analisis ini, nisbah yang akan digunakan ialah dengan menggunakan kenaikan sebanyak 10% bagi minyak hidrogen dan penurunan sebanyak 10% bagi petrol sehingga kedua-duanya mencapai 50%. Model enjin yang digunakan dalam perisian ini ialah enjin satu silinder, empat strok proses dengan menggunakan penyalaan pencucuh. Selepas dianalisis, didapati nilai kuasa dan tenaga putaran semakin meningkat pada kedua-dua kelajuan enjin. Nilai kuasa yang didapati ketika kelajuan enjin 3000 revolusi per minit akan bertambah apabila kelajuan enjin ditinggikan sehigga 6000 revolusi per minit, tetapi sebaliknya terjadi kepada tenaga putaran. Nilai tenaga putaran pada 3000 revolusi per minit didapati lebih tinggi berbanding nilai tenaga putaran pada 6000 revolusi per minit.

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γ	Ratio of specific heats
λ	Air fuel ratio
Φ	Equivalence ratio

LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
ICE	Internal Combustion Engine
SI	Spark Ignition
NOx	Nitrogen Dioxide
HC	Hydrocarbon
H2ICE	Hydrogen-Fueled Internal Combustion Engine
HHV	Higher Heating Value
LHV	Lower Heating Value
V_1/V_2	Compression Ratio
T_1	Absolute Initial Temperature
T_2	Absolute Final Temperature
CR	Compression Ratio

UNIVERSITI MALAYSIA PAHANG
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I certify that the project entitled "*A Numerical Study on the Effect of Gasoline-Hydrogen Blend on Engine Power and Torque at Medium and High Engine Speed*" is written by *Asmahani Binti Abdul Kadir*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

(Azizuddin Abd Aziz)
Examiner Signature

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The incentives for a hydrogen economy are the emissions, the potentially CO_2-free use, the sustainability and the energy security. In this paper the focus is on the use of hydrogen in internal combustion engines (ICE), or more precisely, hydrogen fuelled spark ignition (SI) engines. Currently the hydrogen production is the cheapest through the steam reforming of methane. But CO_2 emissions cannot be avoided. Renewable energy, e.g. solar power, hydroelectric, tidal, can give “CO_2-free” electricity to electrolyze water to hydrogen. The downside is that these electricity costs are mostly expensive. Interesting is also the application of peak shaving of wind turbine power. Other possibilities are solar thermal, biomass, bacterial. Several solutions are possible for the hydrogen storage. Liquid storage gives a high mass density but asks a high energy demand. Mostly used is the compressed storage, vessels with a compression pressure of 350 bar are homologated and up to 700 bar are demonstrated.

There are some research have been done on hydrogen in order to introduce it as the transportation fuel. They are based on abnormal combustion, mixture formation, load control strategies and finally dedicated hydrogen spark-ignition engines. The suppression of abnormal combustion in hydrogen engines has proven to be quite a challenge and measures taken to avoid abnormal combustion have important implications for engine design, mixture formation and load control. For spark-ignition engines, three regimes of abnormal combustion exist: knock (auto-ignition of the end gas region), pre-ignition (uncontrolled ignition induced by a hot spot, premature to the spark ignition) and backfire (also referred to as backflash, flashback and induction ignition, this is a premature ignition during the intake stroke, which could be seen as an early form of pre-ignition).

A range of mixture formation methods has been tested for hydrogen engines, mostly in the pursuit of backfire-free operation. During the last decade, only timed port injection and direct injection (during the compression stroke or later) have been used, as the other methods are less flexible and less controllable. External mixture formation by means of port fuel injection has been demonstrated to result in higher engine efficiencies, extended lean operation, lower cyclic variation and lower NOx production compared to direct injection.

Hydrogen is a very versatile fuel when it comes to load control. The high flame speeds of hydrogen mixtures and its wide flammability limits permit very lean operation and substantial dilution. The engine efficiency and the emission of NOx are the two main parameters used to decide the load control strategy. To improve efficiency, combustion stability and emissions – an experimental study had been done by adding hydrogen fuel on a 4-cylinder gasoline-fueled spark ignited (SI). The engine was modified to be fueled with the mixture of gasoline and hydrogen injected into the intake ports simultaneously. Various hydrogen enrichment levels were selected to investigate the effect of hydrogen addition on engine speed fluctuation, thermal efficiency, combustion characteristics, cyclic variation and emissions under idle and stoichiometric conditions. NOx emissions are improved with the increase of hydrogen addition level. The HC and CO emissions first decrease with the increasing hydrogen enrichment level.

1.2 PROBLEM STATEMENT

In today’s modern world, where new technologies are introduced every day, transportation’s energy use is increasing rapidly. Fossil fuel particularly petroleum fuel is the major contributor to energy production and the primary fuel for transportation. Rapidly depleting reserves of petroleum and decreasing air quality raise questions about the future. As world awareness about environment protection increases so does the search for alternative to petroleum fuels. Hydrogen can be used as a clean alternative to petroleum fuels and its use as a vehicle fuel is promising in the effects to establish environmentally friendly mobility systems. So far, many extensive studies investigated hydrogen fueled internal combustion engines (H2ICE) with external mixture formation fuel delivery system.

Different types of fuel may produce different output of power and torque from the same engine used. Gasoline is one type of fuel that widely used for the internal combustion engine. Under circumstances, hydrogen fuel is added to the gasoline internal combustion engine. It is important to study about the power and torque produce by combination of these two fuels together in one engine.

1.3 OBJECTIVE OF THE PROJECT

This research is focus on the effect of gasoline-hydrogen fuel blend on engine power and torque at medium and high engine speed. In this research, we want to determine the power and torque produced by the engine under different ratios of hydrogen fuel added to gasoline fuel at two different speeds.

1.4 PROJECT SCOPES

i. The simulation of the model will be run by using GT-Suite 6.1 (GT-Power) software.

ii. The power and torque produced by the engine will be determined and analyzed by using GT-Post software.

iii. The geometry of an engine must be taken and the properties of air and fuels are being considered too in order to develop a GT model.

iv. Study on a four stroke cycle, single cylinder engine.

v. The fuels that we will be focusing are gasoline and hydrogen.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROGEN FUEL

Hydrogen fuel is one of the alternatives for petroleum fuel in order to maintain our clean environment. This is because hydrogen fuel use hydrogen which is the fundamental element in nature and it can be found in many materials such as water, our main materials in order to live. Hydrogen did not contribute to any pollution like petroleum did because the petroleum itself contains a mixture of hydrocarbons of different weights such as alkanes, cycloalkanes aromatic hydrocarbons or asphaltenes, also organic compounds and it is a naturally occurring and flammable liquid that we found in the Earth. Such components will contribute to the environment pollution and this is against the world awareness about environment protection. It is said to be a clean alternative because it will cause less air pollution, friendly environmentally mobility systems and also it gives near to zero CO2 emissions for traffic applications (Wietschel, 2009; Taylor, 2008).

There were a lot of studies about effect of adding hydrogen blended into other fuel in order to increase the efficiency but reducing the rate of pollutant they cause. It is proven that by adding hydrogen blended with natural gas is a viable alternative to pure fossil fuels because of the expected reduction of the rate of pollutant emissions but increasing in efficiency. These blends will offer a valid opportunity for tackling sustainable transportation, in view of the future stringent emission limits for road vehicles (Wang, 2008; Morrone, 2009; Sierens, 2005). The aim of this paper is to investigate the engine power and torque after mixing gasoline fuel with hydrogen fuel blended at certain ratios of hydrogen added. The testing will conduct by adding increment of 5% hydrogen fuel but starting with pure gasoline fuel first.

The first oil well in the United States was struck by Edwin L. Drake near Titusville, Pennsylvania, in 1859 at a depth of almost 70 feet (21 m). With the development of the four-stroke internal combustion engine by Nikolaus Otto in 1876, gasoline became essential to the automotive industry. Today, almost all gasoline is used to fuel automobiles, with a very small percentage used to power agricultural equipment and aircraft (McGraw Hill).

Additives are incorporated into commercial gasoline blends, for example to inhibit oxidation and gum formation during storage. Dyes may be added for identification purposes. Alcohol and surfactants are used to reduce carburetor icing and corrosion. Detergent additives remove from the engine and fuel injector some of the deposits produced by gasoline combustion (McGraw Hill).

In order to improve efficiency, combustion stability and emissions, an experimental study had been done by adding hydrogen fuel on a 4-cylinder gasoline-fueled spark ignited (SI) (Ji, 2009; Thurnheer, 2009). The engine was modified to be fueled with the mixture of gasoline and hydrogen injected into the intake ports simultaneously. Various hydrogen enrichment levels were selected to investigate the effect of hydrogen addition on engine speed fluctuation, thermal efficiency, combustion characteristics, cyclic variation and emissions under idle and stoichiometric conditions. NOx emissions are improved with the increase of hydrogen addition level. The HC and CO emissions first decrease with the increasing hydrogen enrichment level. Hydrogen energy fraction exceeds 14.44%, it begins to increase again at idle and stoichiometric conditions (Ji, 2009).

Different types of fuel may produce different output of power and torque from the same engine used. Gasoline is one type of fuel that widely used for the internal combustion engine. Under circumstances, hydrogen fuel is added to the gasoline internal combustion engine. It is important to study about the power and torque produce by combination of these two fuels together in one engine.

2.1.1 Advantages of Hydrogen

There are a lot of advantages for using hydrogen as fuel for transportation. Hydrogen is taken into consideration because its abundance and also its ability to produce electricity for some applications but at the same time there is no harmful emissions occurred. From economy side, hydrogen production is one of the cheapest ways which is through the steam reforming of methane. Hydrogen will add diversity to the supply of transportation fuels, thus making the states less dependent on petroleum as the main source for transportation's fuel. This will also make fuel costs more stable and predictable in the future (Hughes, 2001; White, 2006). As we known, by reducing the usage of petroleum as the main fuel for transportation, it will also reducing the environmental impacts of exploring for, producing, transporting and refining petroleum, including the potential contamination of groundwater and also surface water. Besides that, we can use renewable energy such as solar power, hydroelectric and tidal instead of methane to produce hydrogen without CO2 emissions by electrolyze them with water. Figure 2.1 below shows the process of electrolysis of water to produce hydrogen. Another way to produce hydrogen is by peak sharing of wind turbine power, solar thermal and also biomass.

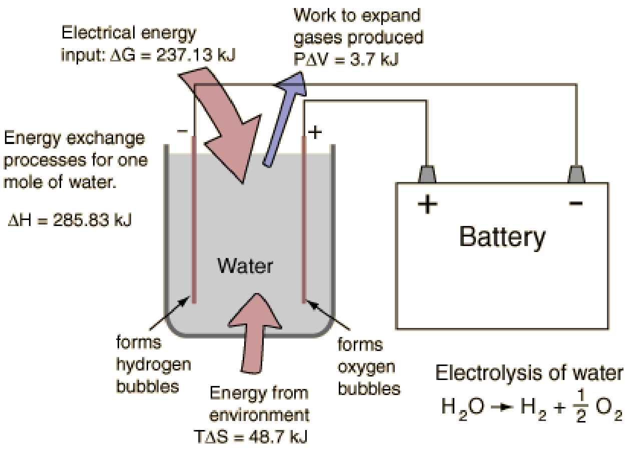


Figure 2.1: Electrolysis of water

Source: http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/electrol.html

Having wide flammability limits compared to other gases such as gasoline and methane also is one of the advantages of hydrogen as an alternative to petroleum fuels. It means that the possible mixture compositions for ignition and flame propagation are very wide for this gas. This also means that the load can be controlled by the air to fuel ratio, and wide open throttling engine will resulting in high efficiency of engine (Astbury, 2008; Lanz, 2001; Sierens, 2005). Figure 2.2 below shows the ranges of flammability of comparative fuels at atmospheric temperature and as been told, we can see that hydrogen has the highest wide flammability which is 75% compared to other fuels.

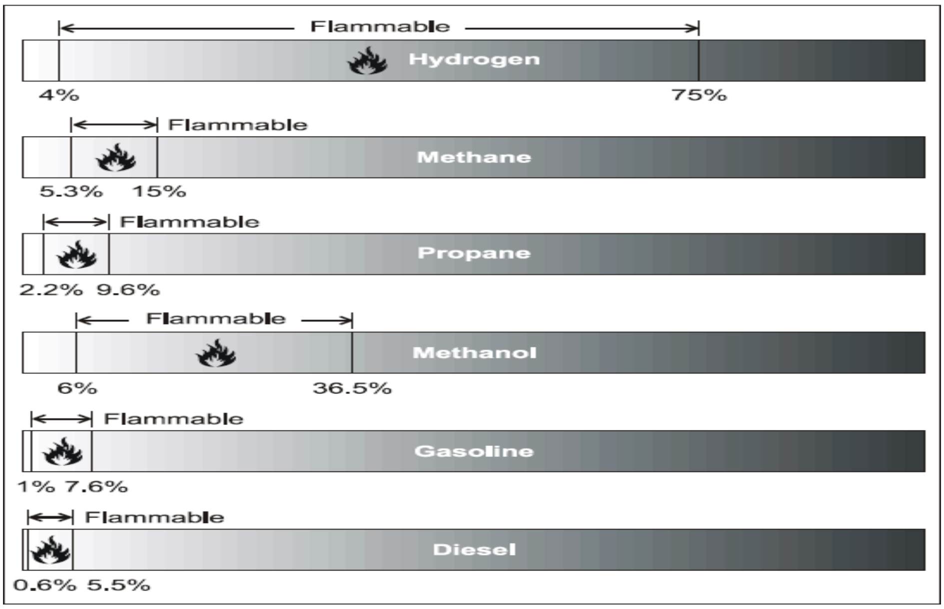


Figure 2.2: Flammability Ranges of Comparative Fuels at Atmospheric Temperature

Source: Lanz 2001

By having high number of octane will increase the compression ratio of the engine, and accidentally increase the engine's efficiency (Lanz, 2001; White, 2006). Table 2.1 below shows the comparison of octane number for six different fuels and we can see that hydrogen got the highest number of octane compared to the others.

Table 2.1: Octane number of different fuels

Fuel	Octane Number
Hydrogen	130+ (lean burn)
Methane	125
Propane	105
Octane	100
Gasoline	87
Diesel	30

Source: Lanz 2001

The emissions of a hydrogen engine are very clean but only the noxious component of NOx is emitted. Lean hydrogen is called a mixture where the amount of fuel in it is less than theoretical, also said to be a mixture near stoichiometric condition (λ=1, ϕ=1). The combustion that this mixture produce are almost a constant volume combustion that resulting in increasing efficiency. At this rate, it will cause flame acceleration due to the cellularity and no turbulence enhancing methods need to be used to get the engine to start on hydrogen. It is also said that by using lean mixture, the combustion reaction is more complete and fuel economy also become greater than before. When the temperature of the final combustion is lower, it also will reduce the pollutant rates such as the nitrogen oxides that will be emitted in the exhaust (Sierens, 2005).

The amount of energy needed to start an engine by using gasoline is higher compared to hydrogen because hydrogen has very low ignition energy compared to gasoline. These properties of hydrogen will enable hydrogen engines to ignite lean mixtures and at the same time to ensure the prompt ignition (Lanz, 2001).

Advantages of using hydrogen as engine's fuel also including its small quenching distance that smaller than gasoline. Thus the flames of hydrogen will travel closer to the cylinder wall compared to other fuels before they extinguish. Having high flame speed at stoichiometric ratios will make the hydrogen flame speed that nearly an order of magnitude higher or faster than that of gasoline. It means that the engine can more closely approach the thermodynamically ideal engine cycle (Lanz, 2001).

High diffusivity of hydrogen will give an advantage to hydrogen to disperse in air considerably greater than gasoline. This shows that hydrogen facilitates the formation of a uniform mixture of fuel and air. Also if there is a hydrogen leak, the hydrogen will disperses rapidly. Thus the unsafe conditions can either be avoided or minimized. We can see the differences of gaseous diffusivity between hydrogen, propane and gasoline at Figure 2.3.

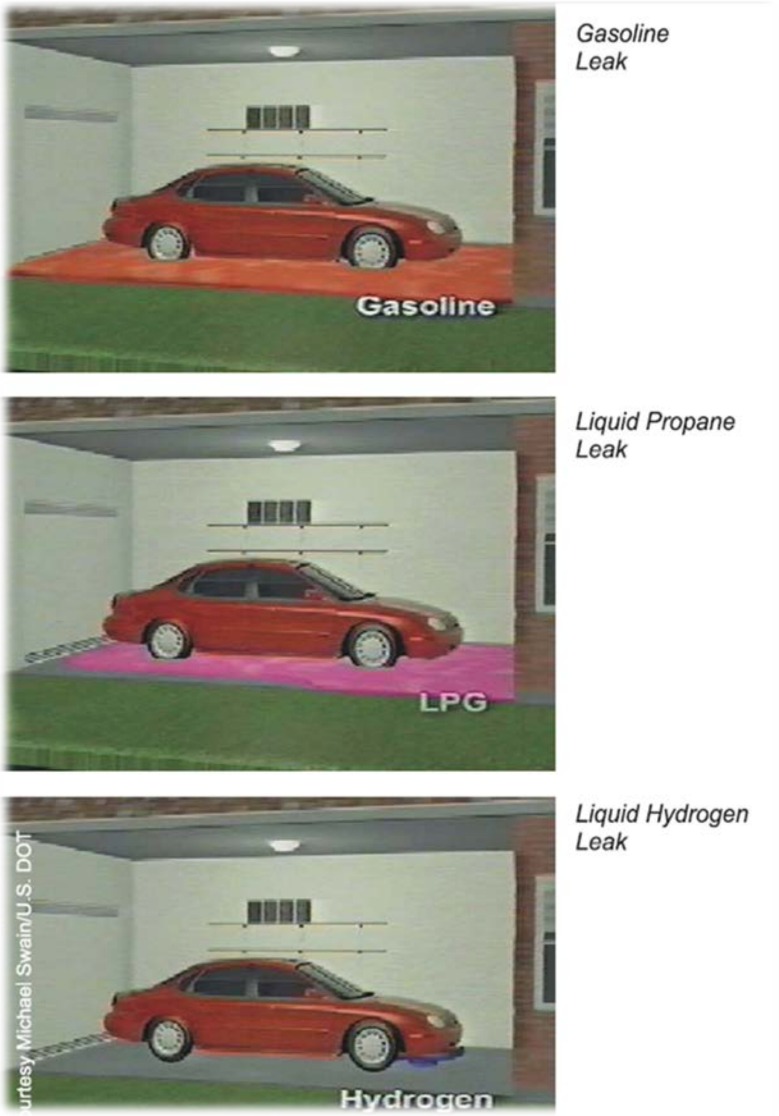


Figure 2.3: Fuel leak simulations

Source: Lanz 2001

Energy content of fuel is important in determining the power produced by an engine. Every fuel will have different energy content based on their properties. They also can liberate a fixed amount of energy when it reacts completely with oxygen to form water. This energy content is measured experimentally and is quantified by a fuel's higher heating value (HHV) and lower heating value (LHV). The difference between the HHV and the LHV is the "heat of vaporization" and represents the amount of energy required to vaporize a liquid fuel into a gaseous fuel, as well as the energy used to convert water to steam. The higher and lower heating values of comparative fuels are indicated in Table 2.2 below.

Table 2.2: Heating values of comparative fuels

Fuel	Higher Heating Value (at 25˚C and 1 atm / kJ/g)	Lower Heating Value (at 25˚C and 1 atm / kJ/g)
Hydrogen	141.86	119.93
Methane	55.53	50.02
Propane	50.36	45.60
Gasoline	47.50	44.50
Diesel	44.80	42.50
Methanol	19.96	18.05

Source: Lanz 2001

Both the higher and lower heating values denote the amount of energy (in Btu's or Joules) for a given weight of fuel (in pounds or kilograms). Hydrogen has the highest energy-to-weight ratio of any fuel since hydrogen is the lightest element and has no heavy carbon atoms. Specifically, the amount of energy liberated during the reaction of hydrogen, on a mass basis, is about 2.5 times the heat of combustion of common hydrocarbon fuels (gasoline, diesel, methane, propane, etc.) The high energy content of hydrogen also implies that the energy of a hydrogen gas explosion is about 2.5 times that of common hydrocarbon fuels. Thus, on an equal mass basis, hydrogen gas explosions are more destructive and carry further. However, the duration of a conflagration tends to be inversely proportional to the combustive energy, so that hydrogen fires subside much more quickly than hydrocarbon fires (Lanz, 2001).

2.1.2 Disadvantages of Hydrogen

Hydrogen will give an abnormal combustion which had been proven to be quite a challenge and measures had been taken to avoid this. Abnormal combustion has important implications for engine design, mixture formation and also load control. Three regimes of abnormal combustion that will exist for spark-ignition engines are knock, pre-ignition and backfire. Knock is an auto-ignition of the end gas region, uncontrolled ignition that induced by a hot spot, also a premature to spark ignition is called pre-ignition. Backfire also known as backflash, flashback and induction ignition, which is a premature ignition during the intake stroke which could also be seen as an early form of pre-ignition. Backfire has been a particularly tenacious obstacle to the development of hydrogen engines (Bortnikov, 2007; Sierens, 2005).

Having low ignition energy also means that hot gases and hot spots in the cylinder can serve as sources to create ignition problems such as premature ignition and also flashback. Wide flammability range of hydrogen also means that almost any mixture can be ignited by a hot spot. Backfire can happen if there is a tendency that cause by a smaller quenching distance since the flame from a hydrogen-air mixture already surpassed a nearly closed intake valve than a hydrocarbon-air flame (Lanz, 2001; Sierens, 2005).

Hydrogen has a relatively high autoignition temperature. This has important implications when a hydrogen-air mixture is compressed. In fact, the autoignition temperature is an important factor in determining what compression ratio an engine can use, since the temperature rise during compression is related to the compression ratio. The temperature rise is shown by the equation 2.1 below:

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} \tag{2.1}$$

where:

V_1/V_2 = the compression ratio
T_1 = absolute initial temperature
T_2 = absolute final temperature

γ = ratio of specific heats

The temperature may not exceed hydrogen's autoignition temperature without causing premature ignition. Thus, the absolute final temperature limits the compression ratio. The high autoignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine. This higher compression ratio is important because it is related to the thermal efficiency of the system. On the other hand, hydrogen is difficult to ignite in a compression ignition or diesel configuration, because the temperatures needed for those types of ignition are relatively high (Lanz, 2001).

Hydrogen only has high flame speed at stoichiometric ratios, but at leaner mixtures, the flame velocity decreases significantly. Another property of hydrogen that gives it a disadvantage is that it is very low density gas that had been shown by Table 2.3 below. When we used hydrogen in an internal combustion engine, there is a very large volume of hydrogen needed to store to give a vehicle an adequate driving range. Low density of hydrogen will also result in the energy density of a hydrogen-air mixture and thus the power output is reduced (Lanz, 2001; White, 2006).

Table 2.3: Vapor and liquid densities of comparative substances

Substance	Vapor Density (at 68˚F; 20˚C, 1 atm / kg/m^3)	Liquid density (at normal boiling point, 1 atm / kg/m^3)
Hydrogen	0.08376	70.8
Methane	0.65000	422.8
Gasoline	4.40000	700.0

Source: Lanz 2001

2.2 ENGINE MODEL

Four-stroke engines are used in many different applications. Virtually all highway motorcycles, automobiles, trucks and most buses are powered by four-stroke SI engines. Four-stroke engines are also common in off-road motorcycles, all-terrain vehicles (ATVs), boats, airplanes, and numerous nonroad applications such as lawn mowers, lawn and garden tractors, and generators, pressure washers and water pumps to name just a few.

A “four-stroke” engine gets its name from the fact that the piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, expansion or power, and exhaust. Two of the strokes are downward (intake & expansion) and two of the strokes are upward (compression & exhaust). The four strokes are completed in two revolutions of the crankshaft. Valves in the combustion chamber open and close to route gases into and out of the combustion chamber or create compression.

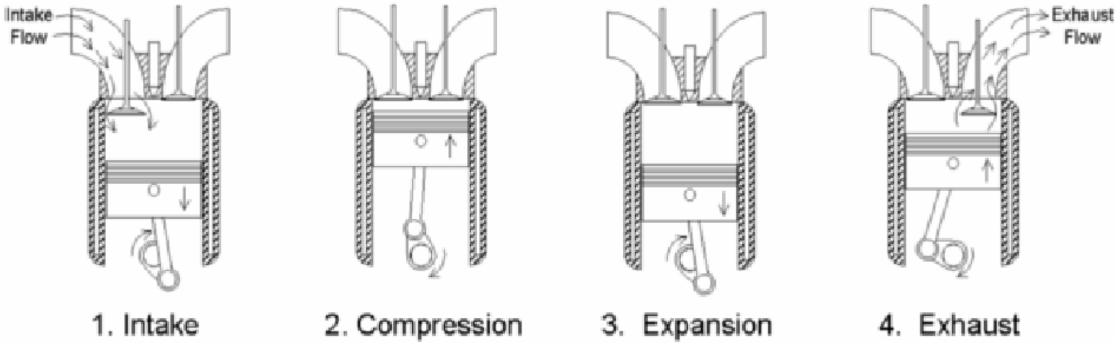


Figure 2.4: Four stroke cycle

Source: EPA

Figure 2.4 shows the steps taken by a four stroke cycle engine which included four processes. The first step of the cycle is for an intake valve to open during the intake stroke allowing a mixture of air and fuel to be drawn into the cylinder while an exhaust valve is closed and the piston moves down the cylinder. The piston moves from top dead center (TDC) or the highest piston position to bottom dead center (BDC) or lowest piston position. This displacement of the piston draws air and fuel past the open intake valve into the cylinder.

During the compression stroke, the intake valve closes and the momentum of the crankshaft moves the piston up the cylinder from BDC to TDC, compressing the air and fuel mixture. As the piston nears TDC, at the very end of the compression stroke, the air and fuel mixture is ignited by a spark plug and the air and fuel mixture begins to burn. As the air and fuel mixture burns, pressures and temperatures increase and the products of combustion expand in the cylinder, which causes the piston to move back down the cylinder, transmitting power to the crankshaft during the expansion or power stroke. Near the bottom of the expansion stroke, an exhaust valve opens and as the piston moves back up the cylinder, exhaust gases are pushed out through the exhaust valve to the exhaust manifold to complete the exhaust stroke, finishing a complete four-stroke cycle.

2.3 GT-POWER

GT-Power which is a short form for Gamma Technologies Power software is an industry-standard engine simulation that is widely used among engine and vehicle makers, their suppliers, ship and power-generation engines, either small 2 or 4 stroke engines and also racing engines cars such as F1, NASCAR and also IRL. GT-Power also one of the components in GT-Suite which is there are about five others components in it. They are GT-Drive, GT-Vrain, GT-Fuel, GT-Cool and finally GT-Crank. Each one of them has their own purpose.

As for GT-Power, it has a capability to simulate the engine's performances and also acoustic analysis with control capabilities. It provides us with many components for us to model any advanced concept. Because of its ease of use and also its tight integration with the rest of GT-Suite, which give GT-Power a virtual engine perspective. The environment of GT-Suite also provides GT-Power with a proven set of high-productivity features for pre- and post-processing, DOE/optimization, neural networks and also control modeling. This software is specifically design for both steady state and also transient simulations. It also can be used for analysis of engine or powertrain control. It can either be a standalone tool coupled with GT-Drive, GT-Fuel and GT-Cool as the GT-Suite / flow product.

GT-Power applications included torque curve and fuel consumption. Besides that, we can also do the manifold design and tuning. Transient performance and response also can be determined by using this software. Another application are valve profile and timing optimization, combustion and emissions, turbocharger response and matching, EGR system design, acoustic analysis which is intake / exhaust noise, full vehicle performance (acceleration), thermal analysis of cylinder components, exhaust system warm-up, control system analysis, real-time engine modeling, design analysis by combining user with DOE, and lastly coupled 1-D / 3-D simulations.

CHAPTER 3

METHODOLOGY

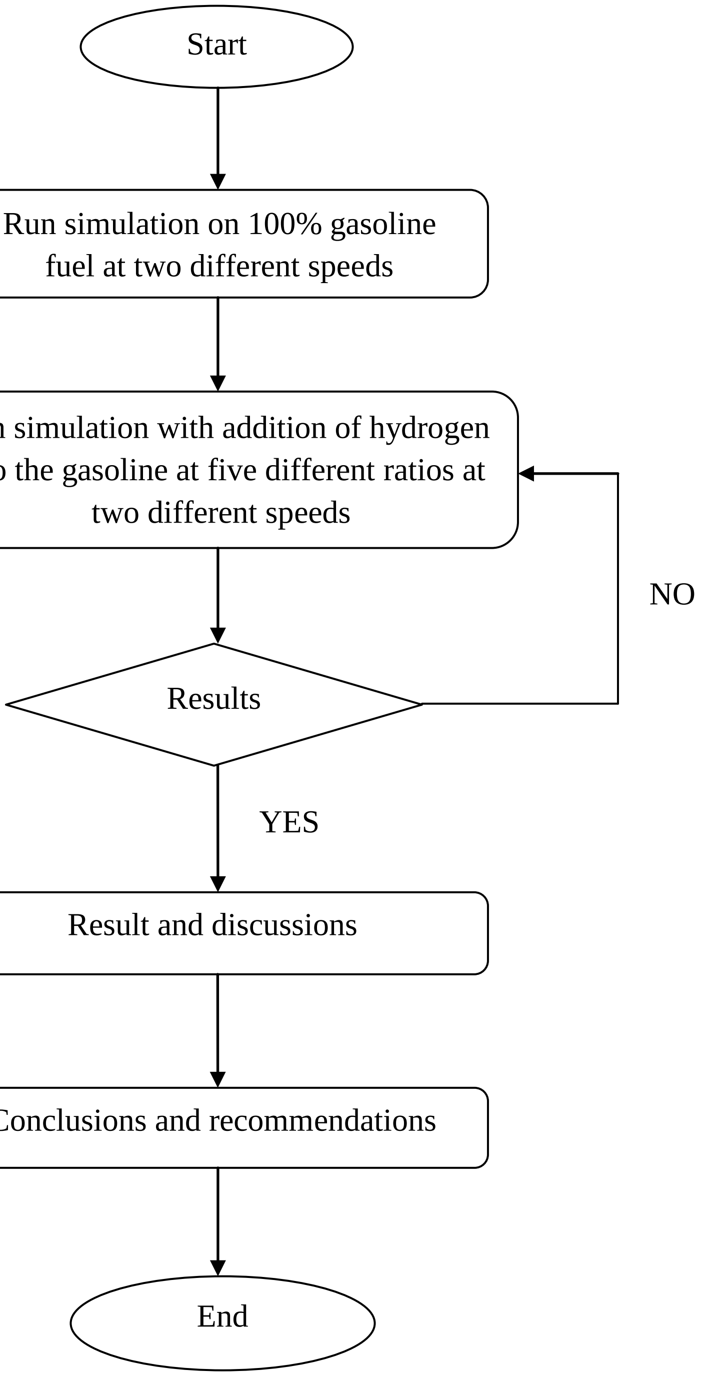
3.1 INTRODUCTION

This chapter will further describe the study of the effect of gasoline-hydrogen fuel blend on engine power and torque using GT-Power software. In order to complete a project, methodology is one of the most important things to be considered to ensure that the project will run smoothly and will get the expected results which the one that we needed the most. For this chapter, it will be the discussion on the process of the project due to the flow chart or more specifically due to the Gantt chart. In this methodology, there are several steps that we must followed in order to ensure that the objective of the project can be achieved starting from the literature finding until submitting the report. The steps of the project which briefly being shortlisted into the flow chart schematic diagram will be shown in this chapter.

3.2 METHOD

For the analysis method, this project will focus on the power and torque of the engine that we had already taken all the parameters of it. We will develop a GT model by inserting the parameters of the engine, the air properties and also the fuel properties. After that, we will first run the analysis by using gasoline fuel and find out the outcome results. Next, we will run the analysis by adding hydrogen fuel into the gasoline fuel at different ratios and find out the outcome results also. Then we can make the comparison of before and after adding hydrogen fuel to gasoline fuel.

3.3 PROJECT FLOW CHART



3.4 NUMERICAL ANALYSIS

Numerical analysis for this project is a process to analyze the engine efficiency by using GT-Suite (GT-Power) software. We will determine the power and torque of the engine. The engine that we used in this project is a four stroke cycle, single cylinder engine. This process needs all the engine parameters such as stroke x bore, the displacement of the engine, compression ratio (CR), maximum power, maximum torque, the length of the connecting rod, diameter of the exhaust and intake valve and etc. In this project, we will determine the effect of gasoline-hydrogen fuel blend on engine power and torque by using GT-Power software.

i. Four stroke cycle engine – a single cylinder four-stroke engine produces power once every two revolutions. A four-stroke engine has to be larger than a two-stroke engine to produce an equivalent amount of power.
ii. Engine efficiency – relationship between the total energy contained in the fuel, and the amount of energy used to perform useful work.
iii. Torque = term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of force multiplied by the length of the lever through which it acts.
iv. Power = the rate of doing work. Power equals to work divided by time.

3.4.1 Save File

Firstly, click File/New and select GT Project Map. This will bring up a box that allows the user to select what kind of project is being started. Select GT-Power and empty project map and library will be opened.

3.4.2 Importing Templates Into the Project

Select Window and then Tile With Template Library from the menu. This will place the GT-POWER template library on the left hand side of the screen. The template library contains all of the available templates that can be used in GT-POWER. Click on the icons listed below and drag them from the template library into the project library.

Some of these are templates and some are objects that have already been defined and included in the GT-POWER template library.

Flow Folder

EndEnvironment
EngCylinder
Pipe
InjAF-RatioConn
InjProfileConn
OrificeConn - def (object)
OrificeConn – bellmouth (object)
ValveCamConn
FPropGas - indolene-vap (object)
FPropGas - diesel-vap (object)
FPropGas - n2-vap (object)
FPropGas - o2-vap (object)
FPropLiqIncomp - indolene-combust (object)
FPropLiqIncomp - diesel2-combust (object)
FPropMixtureCombust - air (object)

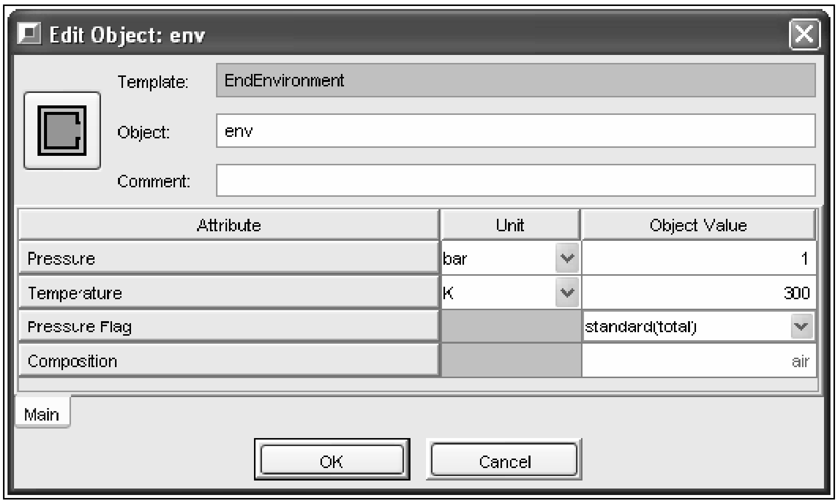
Mech Folder

EngineCrankTrain

3.4.3 Defining Objects

The first step in building the model of the single cylinder engine is to describe the inlet boundary condition. In this model an ‘EndEnvironment’ template will be used. To create the inlet and outlet boundary conditions, double click on the ‘EndEnvironment’ template. Name the object “env” and fill in the attributes with the following values as shown in Table 3.1:

Table 3.1: Inlet boundary condition

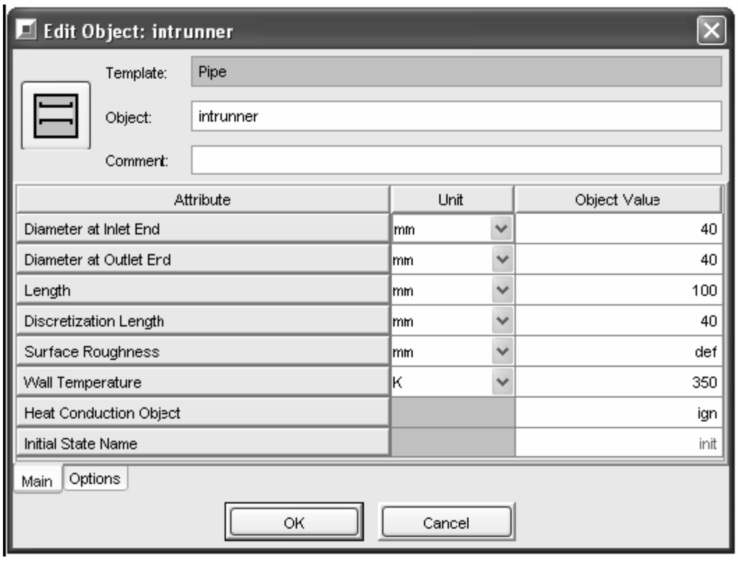


Template: EndEnvironment
Object: env
Comment:

Attribute	Unit	Object Value
Pressure	bar	1
Temperature	K	300
Pressure Flag		standard(total)
Composition		air

Now we will create an intake runner that will connect the ‘EndEnvironment’ to the intake port. Double click on the ‘Pipe’ template within the project library in order to create a pipe object. Fill in the attributes with the following values in Table 3.2.

Table 3.2: Intake runner from inlet environment

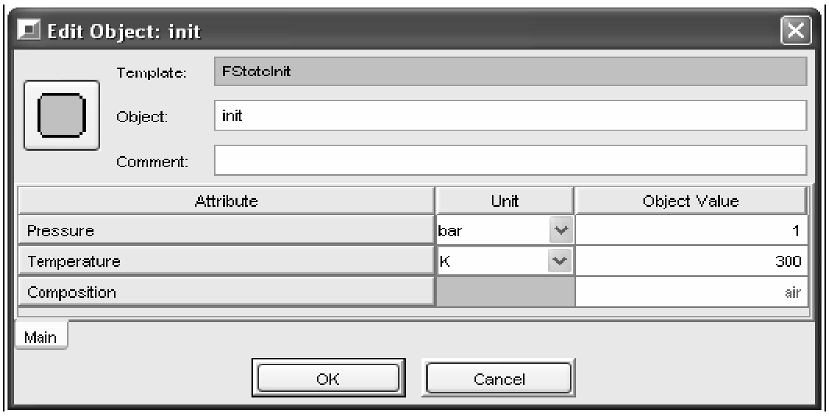


Template: Pipe
Object: intrunner
Comment:

Attribute	Unit	Object Value
Diameter at Inlet End	mm	40
Diameter at Outlet End	mm	40
Length	mm	100
Discretization Length	mm	40
Surface Roughness	mm	def
Wall Temperature	K	350
Heat Conduction Object		ign
Initial State Name		init

When the word “init” was typed for the Initial State Name, the word turned green which again denotes the need for a reference object to describe that attribute. Double clicking on the word “init” brings up a box that shows the available reference templates for this attribute. In this case, only one template is available. By selecting ‘FStateInit’ and then OK, the ‘FStateInit’ reference template will automatically be imported into the project. We can fill in the attributes as shown in Table 3.3, which describes the initial conditions in this pipe object at the start of the simulation. This reference object can now be used to define the initial conditions of any other part in the model.

Table 3.3: Initial conditions of inlet pipe

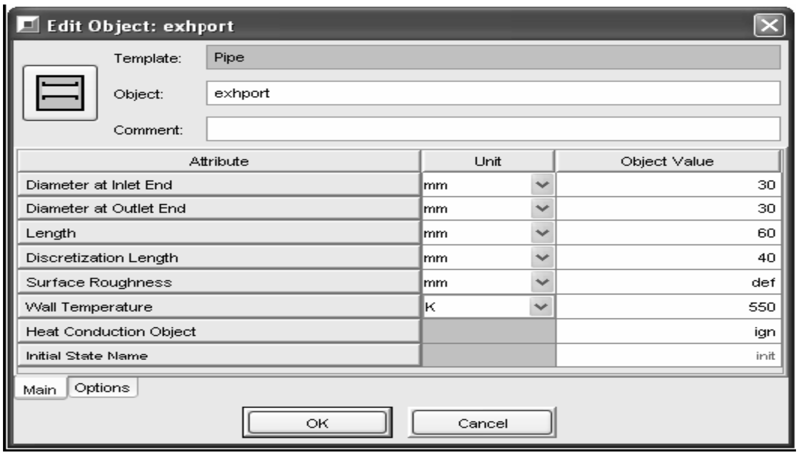


Template: FStateInit
Object: init
Comment:

Attribute	Unit	Object Value
Pressure	bar	1
Temperature	K	300
Composition		air

Right click on the “intport” object, select Clone Object, and input the attributes for the “exhport” object as been shown in Table 3.4 below. We can also now create the exhaust runner by cloning the “intrunner” object. Make the following changes and hit OK when complete.

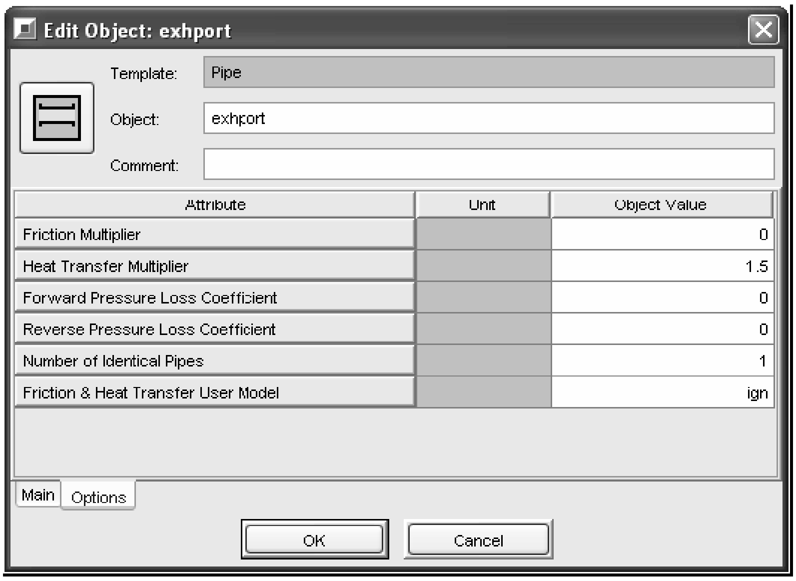
Table 3.4: Initial condition for exhaust port (main folder)



Template: Pipe
Object: exhport
Comment:

Attribute	Unit	Object Value
Diameter at Inlet End	mm	30
Diameter at Outlet End	mm	30
Length	mm	60
Discretization Length	mm	40
Surface Roughness	mm	def
Wall Temperature	K	550
Heat Conduction Object		ign
Initial State Name		init

Table 3.5: Initial condition for exhaust port (options folder)



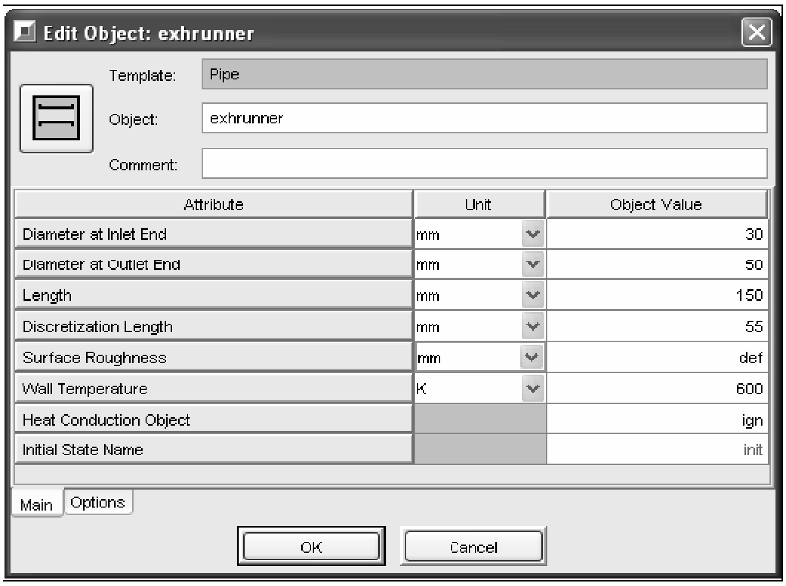
Template: Pipe

Object: exhport

Comment:

Attribute	Unit	Object Value
Friction Multiplier		0
Heat Transfer Multiplier		1.5
Forward Pressure Loss Coefficient		0
Reverse Pressure Loss Coefficient		0
Number of Identical Pipes		1
Friction & Heat Transfer User Model		ign

Table 3.6: Initial condition for exhaust runner (main folder)



Template: Pipe

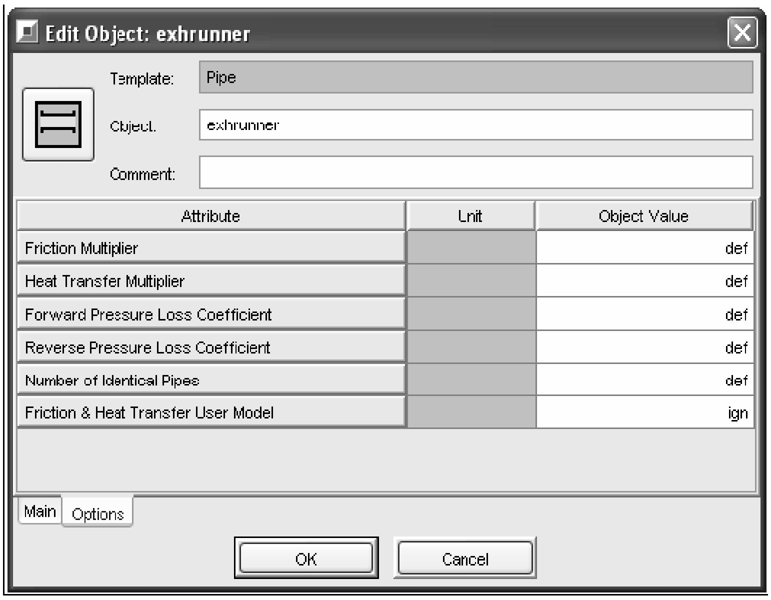
Object: exhrunner

Comment:

Attribute	Unit	Object Value
Diameter at Inlet End	mm	30
Diameter at Outlet End	mm	50
Length	mm	150
Discretization Length	mm	55
Surface Roughness	mm	def
Wall Temperature	K	600
Heat Conduction Object		ign
Initial State Name		init

Table 3.5 and 3.6 above show the attributes that we need to fill in the options folder (for exhaust port) and also main folder (for exhaust runner)

Table 3.7: Initial condition for exhaust runner (options folder)



Template: Pipe

Object: exhrunner

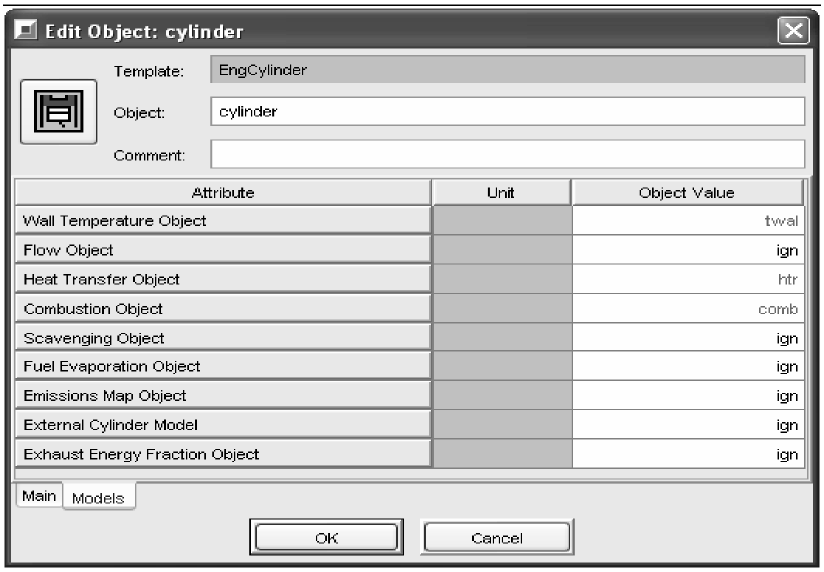
Comment:

Attribute	Unit	Object Value
Friction Multiplier		def
Heat Transfer Multiplier		def
Forward Pressure Loss Coefficient		def
Reverse Pressure Loss Coefficient		def
Number of Identical Pipes		def
Friction & Heat Transfer User Model		ign

Table 3.7 above shows the attributes that we need to fill in the options folder, after we completed fill in the main folder for exhaust runner.

Double click on the 'EngCylinder' template located in the project library and fill in the attributes with the following names and values as been shown in the Table 3.8.

Table 3.8: Initial condition in engine cylinder (main folder)



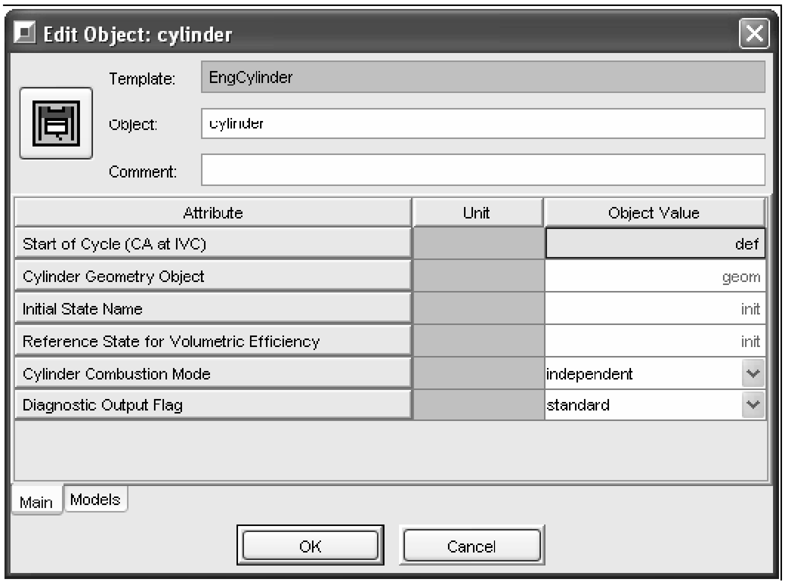
Template: EngCylinder

Object: cylinder

Comment:

Attribute	Unit	Object Value
Wall Temperature Object		twal
Flow Object		ign
Heat Transfer Object		htr
Combustion Object		comb
Scavenging Object		ign
Fuel Evaporation Object		ign
Emissions Map Object		ign
External Cylinder Model		ign
Exhaust Energy Fraction Object		ign

Table 3.9: Initial condition in engine cylinder (models folder)



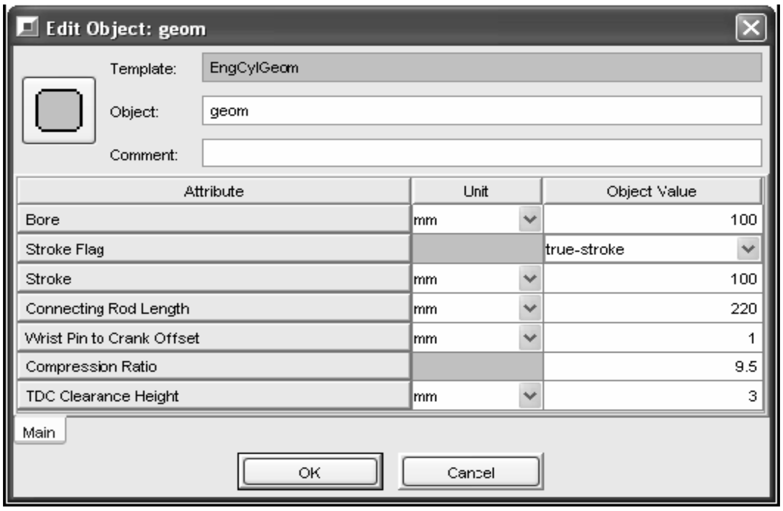
Template:	EngCylinder
Object:	cylinder
Comment:	

Attribute	Unit	Object Value
Start of Cycle (CA at IVC)		def
Cylinder Geometry Object		geom
Initial State Name		init
Reference State for Volumetric Efficiency		init
Cylinder Combustion Mode		independent
Diagnostic Output Flag		standard

As for Table 3.9, it shows the attributes for initial conditions in the models folder of the engine cylinder

Double click on “geom” located in the Cylinder Geometry Object attribute and select ‘EngCylGeom’. This will import the reference object used to describe the in-cylinder geometry. Fill in the following values as been shown in Table 3.10 and select OK when finished.

Table 3.10: Engine cylinder geometry

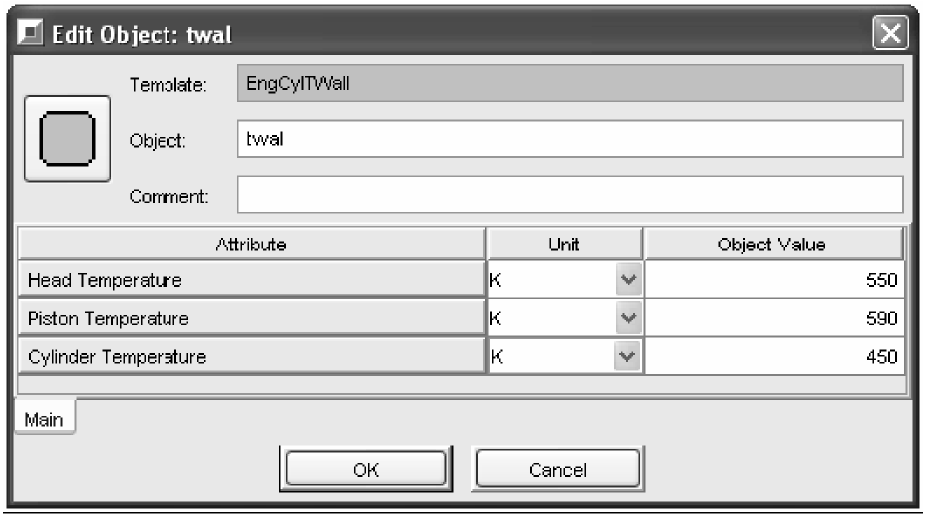


Template:	EngCylGeom
Object:	geom
Comment:	

Attribute	Unit	Object Value
Bore	mm	100
Stroke Flag		true-stroke
Stroke	mm	100
Connecting Rod Length	mm	220
Wrist Pin to Crank Offset	mm	1
Compression Ratio		9.5
TDC Clearance Height	mm	3

Now double click on “twal” and notice that for this attribute three reference objects are available to either define or calculate the in-cylinder wall temperatures. Select ‘EngCylTWall’. For further details on the differences between these templates, consult the manual or online help. Type in the following values in Table 3.11 and select OK when finished.

Table 3.11: Initial condition for engine cylinder temperature wall



Template: EngCylTWall

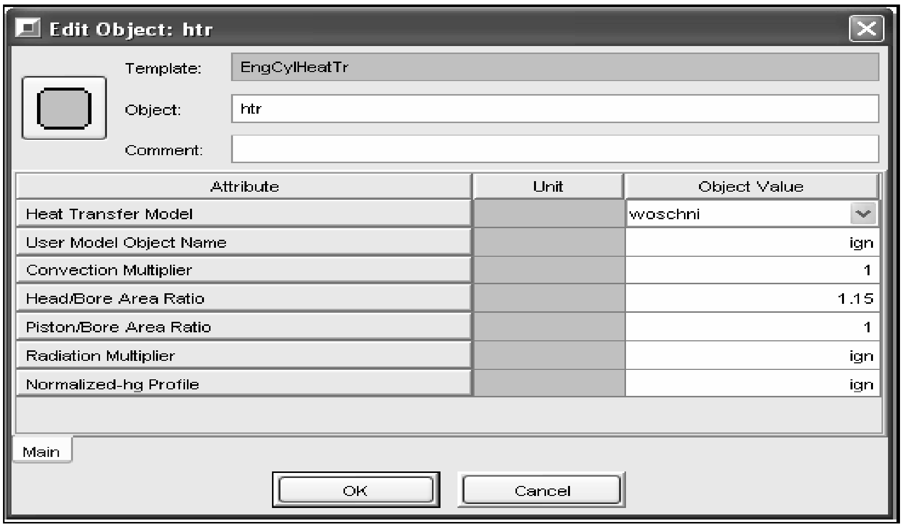
Object: twal

Comment:

Attribute	Unit	Object Value
Head Temperature	K	550
Piston Temperature	K	590
Cylinder Temperature	K	450

Double click on “htr” and select the available reference template. Type in the following values in Table 3.12 and select OK when finished.

Table 3.12: Initial condition for engine cylinder heat transfer



Template: EngCylHeatTr

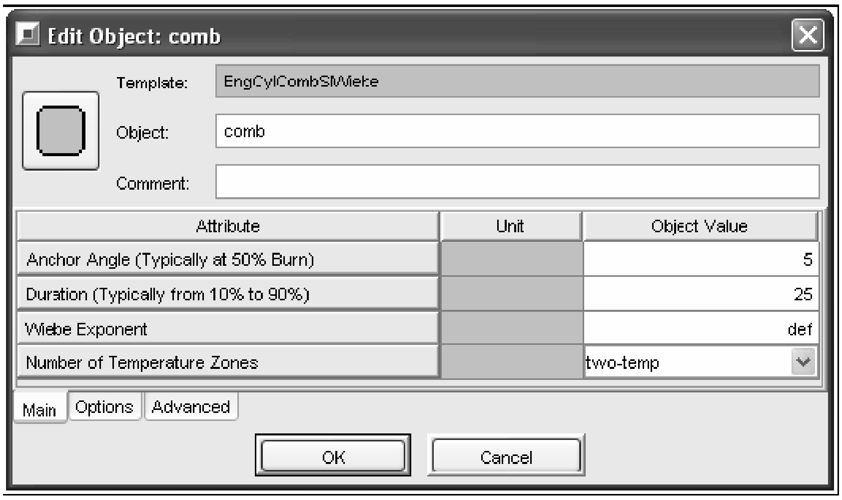
Object: htr

Comment:

Attribute	Unit	Object Value
Heat Transfer Model		woschni
User Model Object Name		ign
Convection Multiplier		1
Head/Bore Area Ratio		1.15
Piston/Bore Area Ratio		1
Radiation Multiplier		ign
Normalized-hg Profile		ign

Double click on “comb” and select the reference object ‘EngCylCombSIWiebe’. Type in the following values in Table 3.13 for main folder, values in Table 3.14 for options folder and values in Table 3.15 for advanced folder. Select OK when finished.

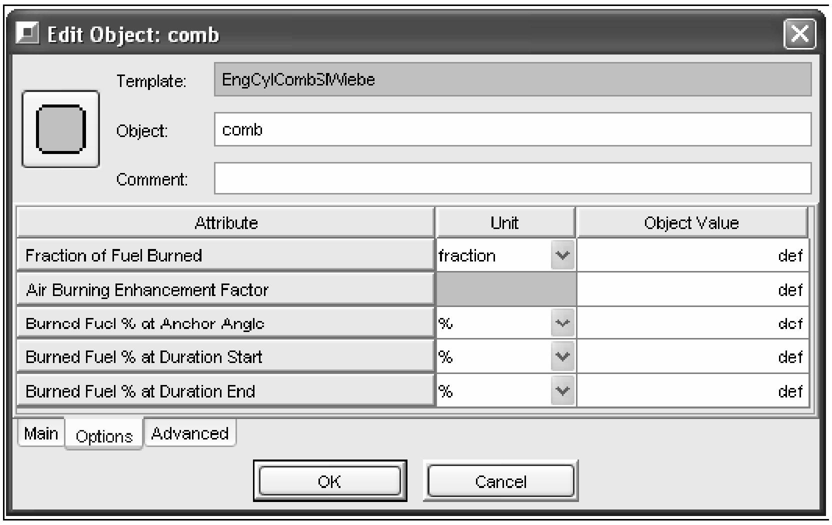
Table 3.13: Initial condition for engine cylinder (main folder)



Template: EngCylCombSIWiebe
Object: comb
Comment:

Attribute	Unit	Object Value
Anchor Angle (Typically at 50% Burn)		5
Duration (Typically from 10% to 90%)		25
Wiebe Exponent		def
Number of Temperature Zones		two-temp

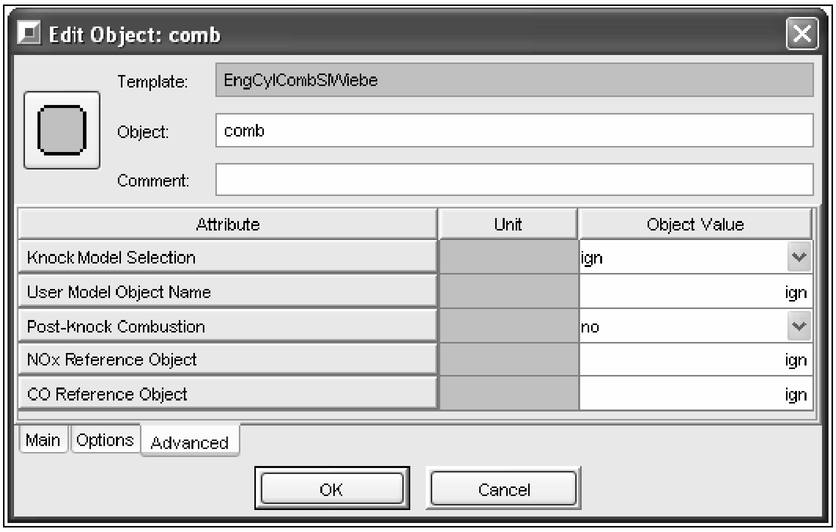
Table 3.14: Initial condition for engine cylinder (options folder)



Template: EngCylCombSIWiebe
Object: comb
Comment:

Attribute	Unit	Object Value
Fraction of Fuel Burned	fraction	def
Air Burning Enhancement Factor		def
Burned Fuel % at Anchor Angle	%	def
Burned Fuel % at Duration Start	%	def
Burned Fuel % at Duration End	%	def

Table 3.15: Initial condition for engine cylinder (advanced folder)



Template: EngCylCombSIWiebe

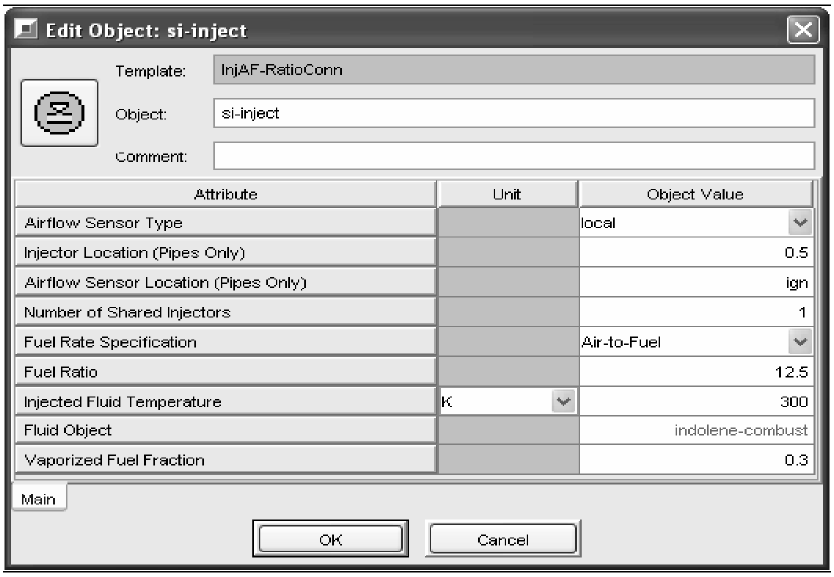
Object: comb

Comment:

Attribute	Unit	Object Value
Knock Model Selection		ign
User Model Object Name		ign
Post-Knock Combustion		no
NOx Reference Object		ign
CO Reference Object		ign

Double click on the ‘InjAF-RatioConn’ template in the tut1*.gtm project library. Type in the information in Table 3.16 and select OK when complete.

Table 3.16: Initial condition for SI-inject



Template: InjAF-RatioConn

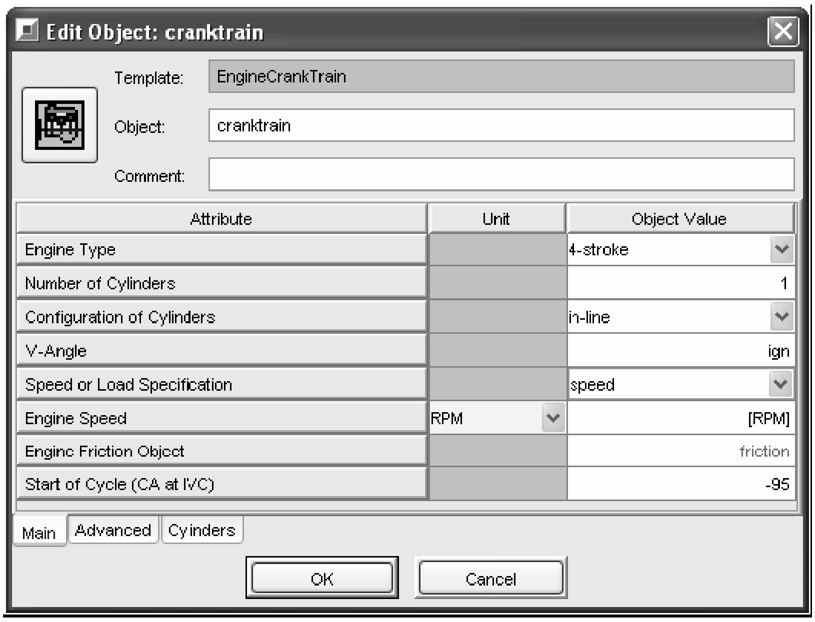
Object: si-inject

Comment:

Attribute	Unit	Object Value
Airflow Sensor Type		local
Injector Location (Pipes Only)		0.5
Airflow Sensor Location (Pipes Only)		ign
Number of Shared Injectors		1
Fuel Rate Specification		Air-to-Fuel
Fuel Ratio		12.5
Injected Fluid Temperature	K	300
Fluid Object		indolene-combust
Vaporized Fuel Fraction		0.3

To create the final object for this model, double click on the 'EngineCrankTrain' template. Type in the following values in Table 3.17 for main folder, values in Table 3.18 for advanced folder and values in Table 3.19 for cylinders folder:

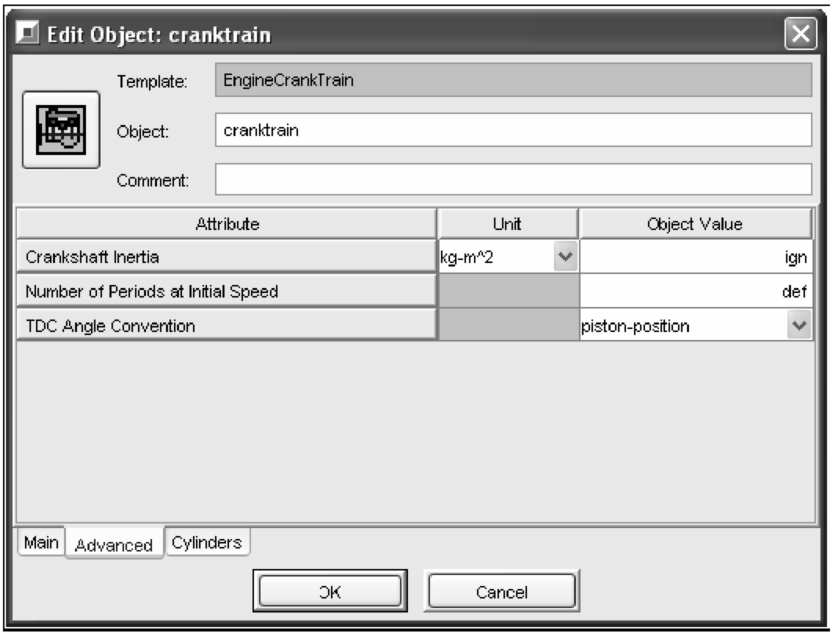
Table 3.17: Initial condition for engine crank train (main folder)



Template: EngineCrankTrain
Object: cranktrain
Comment:

Attribute	Unit	Object Value
Engine Type		4-stroke
Number of Cylinders		1
Configuration of Cylinders		in-line
V-Angle		ign
Speed or Load Specification		speed
Engine Speed	RPM	[RPM]
Engine Friction Object		friction
Start of Cycle (CA at IVC)		-95

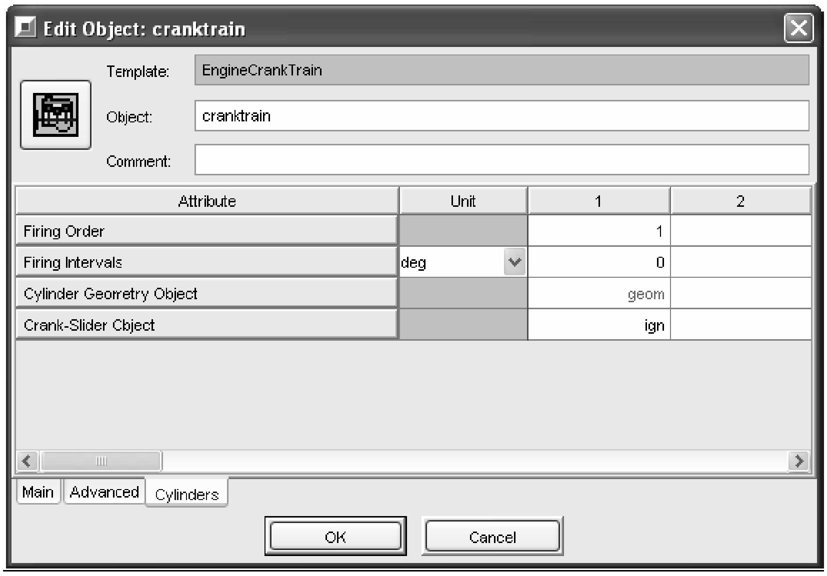
Table 3.18: Initial condition for engine crank train (advanced folder)



Template: EngineCrankTrain
Object: cranktrain
Comment:

Attribute	Unit	Object Value
Crankshaft Inertia	kg-m^2	ign
Number of Periods at Initial Speed		def
TDC Angle Convention		piston-position

Table 3.19: Initial condition for engine crank train (cylinders folder)



Template: EngineCrankTrain

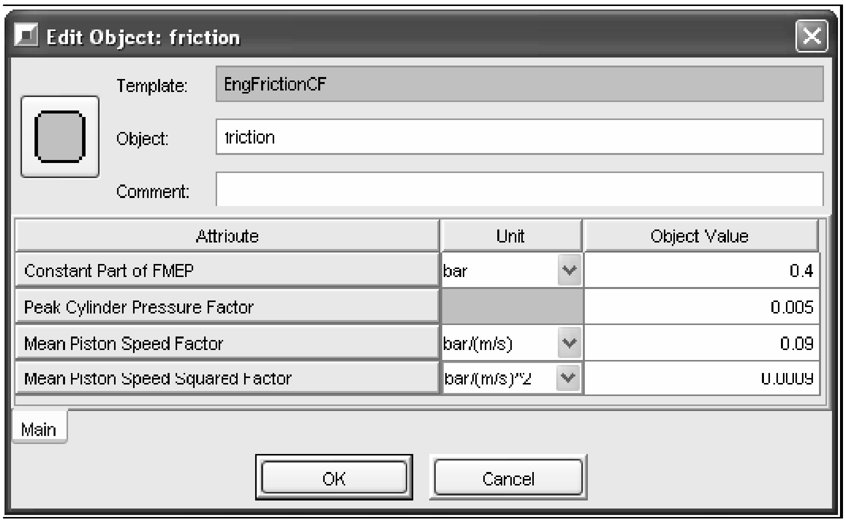
Object: cranktrain

Comment:

Attribute	Unit	1	2
Firing Order		1	
Firing Intervals	deg	0	
Cylinder Geometry Object		geom	
Crank-Slider Object		ign	

To finish the “cranktrain” object, double click on “friction” and import and define this object with the following values in Table 3.20.

Table 3.20: Friction in engine crank train



Template: EngFrictionCF

Object: friction

Comment:

Attribute	Unit	Object Value
Constant Part of FMEP	bar	0.4
Peak Cylinder Pressure Factor		0.005
Mean Piston Speed Factor	bar/(m/s)	0.09
Mean Piston Speed Squared Factor	bar/(m/s)^2	0.0009

3.4.4 Placing parts

Click and hold on the ‘EndEnvironment’ object named "env" and drop it on the middle left side of the map. Repeat this with the items listed, in the order listed, from left to right:

intrunner, intport, intvalve, cylinder, exhvalve, exhport, exhrunner, env

Leave at least 3 points between each icon to allow room for the connections. Drag and drop the injector connection above the “intport” pipe connected to the intake valve. For the cylinder, change the part name to “cylinder” and for the cranktrain change the part name to “Engine.” Figure 3.1 below shows the arrangement of the parts that we made in the project map, by following the correct order sequence.

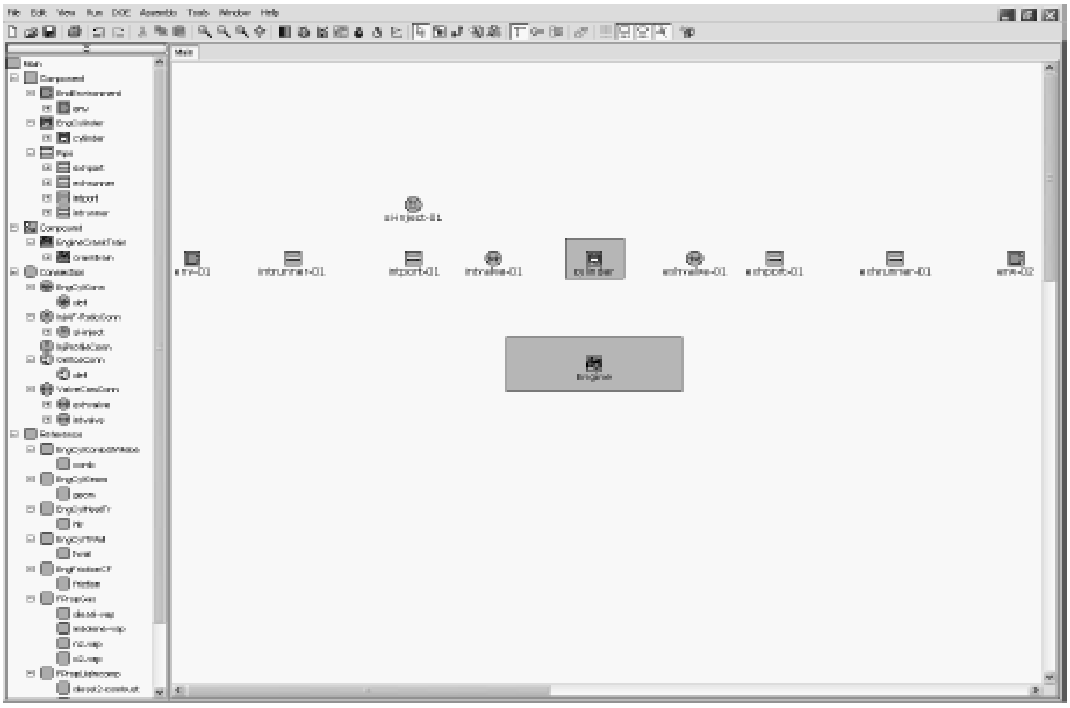


Figure 3.1: Placing parts from project library into project map

3.4.5 Linking Parts

Now the components need to be connected together. In the tool bar for GT-ISE, there is a button called Create Links which needs to be pressed. Once this is done the mouse pointer turns into crosshairs. Click on the part created from the "env" object and then on the part created from the "intrunner" object. A default orifice connection was placed between the 'EndEnvironment' and the first pipe. Continue connecting the parts together from left to right in the general flow direction. The direction is not essential, but it helps in understanding the results. After the main section has been connected, connect the injector to part 3 and the cylinder to the "cranktrain". A default 'EngCylConn' connection should appear between the cylinder and cranktrain. The pipe's inlet and outlet are defined by the port numbers next to the pipe part on the map; 1 for inlet and 2 for outlet. The final engine modeling after we connected all parts by using links had been shown in Figure 3.2 below.

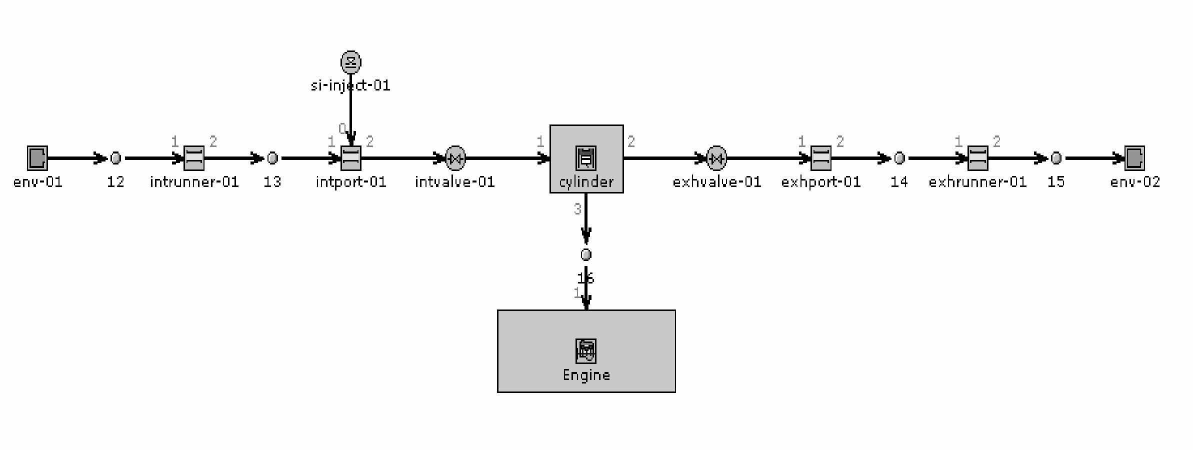
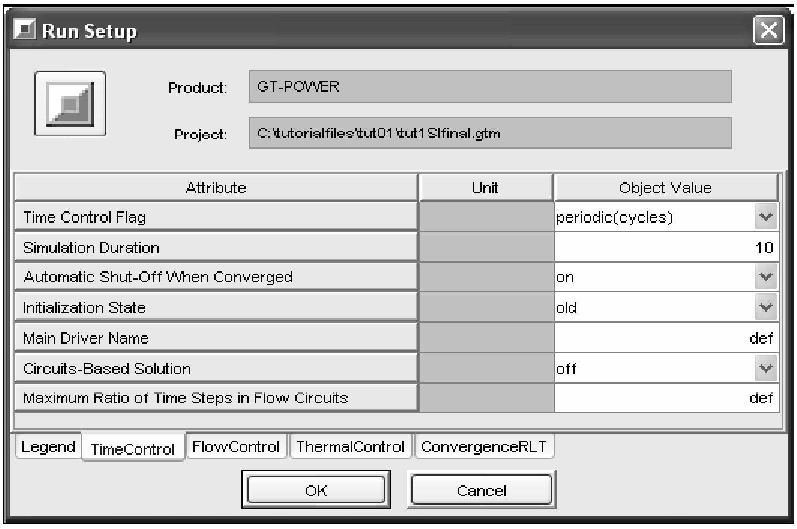


Figure 3.2: Final engine modeling after linking all parts together with links.

3.4.6 Run Setup/ Case Setup/ Plot Setup

To begin, select Run/Run Setup. A total of five folders are inside Run Setup and several of the folders have values that are required in order to run the model. For the Case Legend attribute in the Legend folder, enter a sentence that describes the model or type of simulation being performed - “Single Cylinder Tutorial #1 [rpm] RPM.” The parameter [rpm] has been included in the legend so that engine speed will be placed at the top of each plot created. "ign" can be entered for the Short Case Legend. The second and third folders are TimeControl and FlowControl. Fill in the following values in Table 3.21 for time control folder, Table 3.22 for flow control folder, Table 3.23 for thermal control folder, Table 3.24 for convergenceRLT folder..

Table 3.21: Initial condition in Run Setup (time control folder)

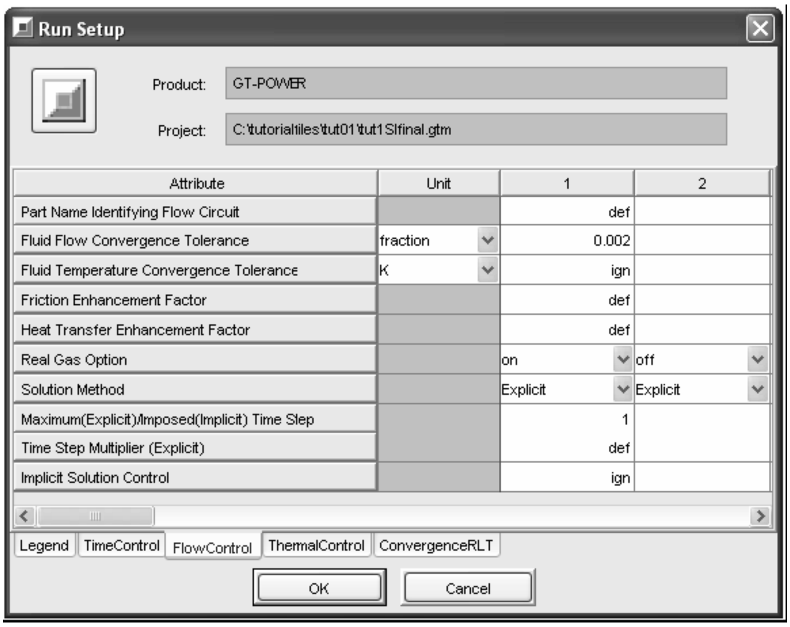


Product: GT-POWER

Project: C:\tutorialfiles\tut01\tut1SIfinal.gtm

Attribute	Unit	Object Value
Time Control Flag		periodic(cycles)
Simulation Duration		10
Automatic Shut-Off When Converged		on
Initialization State		old
Main Driver Name		def
Circuits-Based Solution		off
Maximum Ratio of Time Steps in Flow Circuits		def

Table 3.22: Initial condition in Run Setup (flow control folder)

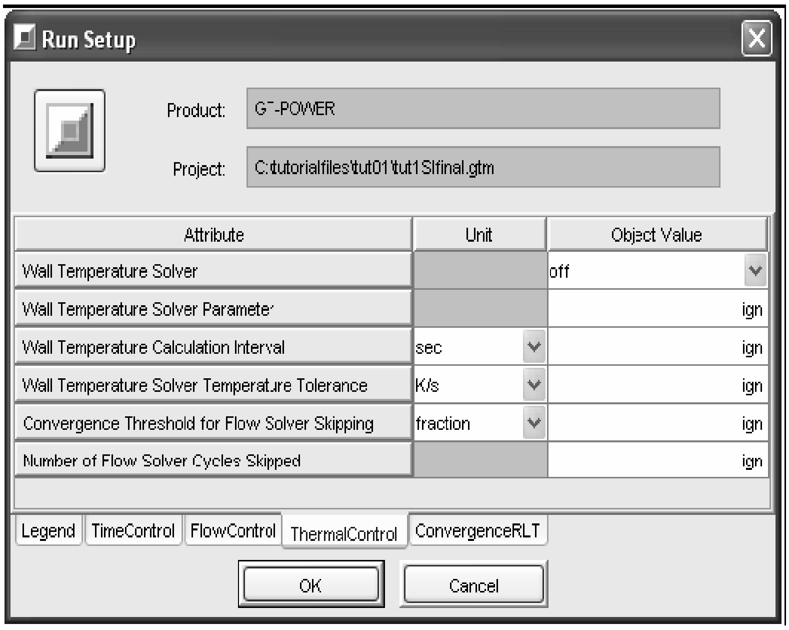


Product: GT-POWER

Project: C:\tutorialfiles\tut01\tut1SIfinal.gtm

Attribute	Unit	1	2
Part Name Identifying Flow Circuit		def	
Fluid Flow Convergence Tolerance	fraction	0.002	
Fluid Temperature Convergence Tolerance	K	ign	
Friction Enhancement Factor		def	
Heat Transfer Enhancement Factor		def	
Real Gas Option		on	off
Solution Method		Explicit	Explicit
Maximum(Explicit)/Imposed(Implicit) Time Step		1	
Time Step Multiplier (Explicit)		def	
Implicit Solution Control		ign	

Table 3.23: Initial condition in Run Setup (thermal control folder)

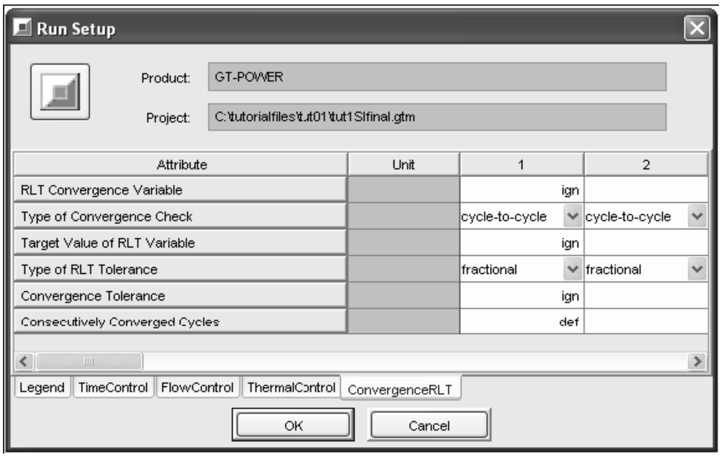


Product: GT-POWER

Project: C:\tutorialfiles\tut01\tut1SIfinal.gtm

Attribute	Unit	Object Value
Wall Temperature Solver		off
Wall Temperature Solver Parameter		ign
Wall Temperature Calculation Interval	sec	ign
Wall Temperature Solver Temperature Tolerance	K/s	ign
Convergence Threshold for Flow Solver Skipping	fraction	ign
Number of Flow Solver Cycles Skipped		ign

Table 3.24: Initial condition in Run Setup (convergenceRLT folder)



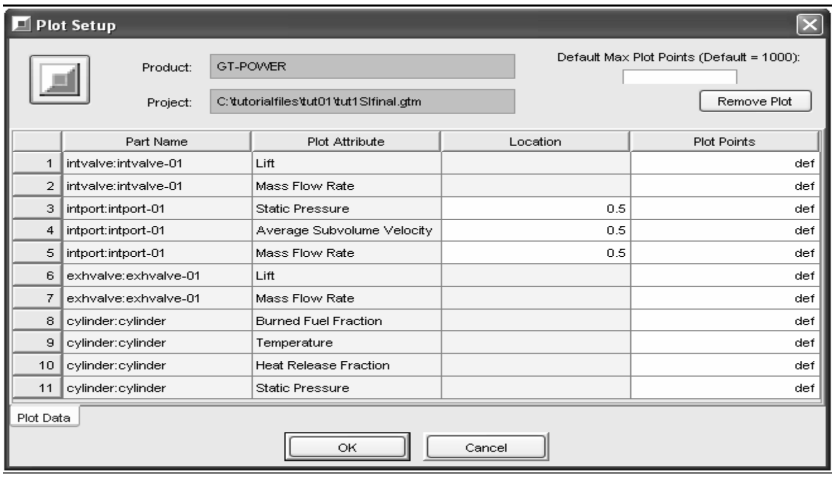
Product: GT-POWER

Project: C:\tutorialfiles\tut01\tut1SIfinal.gtm

Attribute	Unit	1	2
RLT Convergence Variable		ign	
Type of Convergence Check		cycle-to-cycle	cycle-to-cycle
Target Value of RLT Variable		ign	
Type of RLT Tolerance		fractional	fractional
Convergence Tolerance		ign	
Consecutively Converged Cycles		def	

Next, go to the Run menu and select Case Setup. For the rpm parameter, enter 3600 for the attribute and make sure that the "Run It" box for Case #1 is checked. Then double click on the intake port part (intport-01), and go to the Plot Options folder. Select Static Pressure, Average Subvolume Velocity and Mass Flow Rate. For the intake and exhaust valves, select Mass Flow Rate and Lift. For the cylinder, select Static Pressure, Temperature,Burned Fuel Fraction, and Heat Release Fraction. Once all plot selections have been made, go back to the Run menu and select Plot Setup. The Plot Setup window should look similar to the Table 3.25 below.

Table 3.25: Initial condition in Plot Setup



Product: GT-POWER

Project: C:\tutorialfiles\tut01\tut1SIfinal.gtm

Default Max Plot Points (Default = 1000):

	Part Name	Plot Attribute	Location	Plot Points
1	intvalve:intvalve-01	Lift		def
2	intvalve:intvalve-01	Mass Flow Rate		def
3	intport:intport-01	Static Pressure	0.5	def
4	intport:intport-01	Average Subvolume Velocity	0.5	def
5	intport:intport-01	Mass Flow Rate	0.5	def
6	exhvalve:exhvalve-01	Lift		def
7	exhvalve:exhvalve-01	Mass Flow Rate		def
8	cylinder:cylinder	Burned Fuel Fraction		def
9	cylinder:cylinder	Temperature		def
10	cylinder:cylinder	Heat Release Fraction		def
11	cylinder:cylinder	Static Pressure		def

Press the Run Simulation button on the GT-ISE Toolbar.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discussed about the result obtained from the simulation of single cylinder engine with four stroke cycle by using GT-Power software. The objective of this chapter is to determine the power output and also torque produced by the engine at different ratios of gasoline and hydrogen fuels. In this analysis, five different ratios of hydrogen fuel are added to five different ratios of gasoline. But first, we run the simulation by using 100% gasoline fuel.

4.2 FUEL RATIO

Gasoline hydrogen fuel ratio is being calculated by using volumetric ratio analysis. Gasoline fuel will decrease by 10% of its volume while hydrogen fuel will increase by 10% of its volume. Below are the results of the calculation for the addition values at different ratios of each fuel by using volumetric ratio analysis. The values of mixing fuel properties are then inserted into the properties needed in SI-inject icon in the modeling. Table 4.1 will shows the variety of fuel ratio mixture that we had calculated before and the value need to be insert while we change the properties of the fuel that we used in the experiment.

Table 4.1: Properties of 90% gasoline mixing with 10% hydrogen fuel

Properties	**Value**
Molecular weight	Ignore
Carbon Atoms per Molecule	7.137
Hydrogen Atoms per Molecule	13.520
Oxygen Atoms per Molecule	0.000
Nitrogen Atoms per Molecule	0.000
Lower Heating Value (J/kg)	5.1549e7
Critical Temperature (K)	515.240
Critical Pressure (bar)	23.710
Minimum Valid Temperature (K)	100.000
Maximum Valid Temperature (K)	1480.000
Minimum Valid Pressure (bar)	0.010
Maximum Valid Temperature (K)	300.000
Absolute Entropy at 298K	Ignore

Table 4.1 and 4.2 show the addition values of hydrogen and gasoline fuel after we calculated the value of 90% gasoline mixed with 10% hydrogen, and 80% gasoline mixed with 20% hydrogen fuel.

Table 4.2: Properties of 80% gasoline mixing with 20% hydrogen fuel

Properties	**Value**
Molecular weight	Ignore
Carbon Atoms per Molecule	6.344
Hydrogen Atoms per Molecule	12.240
Oxygen Atoms per Molecule	0.000
Nitrogen Atoms per Molecule	0.000
Lower Heating Value (J/kg)	5.9148e7
Critical Temperature (K)	461.680
Critical Pressure (bar)	22.520
Minimum Valid Temperature (K)	100.000
Maximum Valid Temperature (K)	1760.000
Minimum Valid Pressure (bar)	0.010
Maximum Valid Temperature (K)	300.000
Absolute Entropy at 298K	Ignore

Table 4.3: Properties of 70% gasoline mixing with 30% hydrogen fuel

Properties	**Value**
Molecular weight	Ignore
Carbon Atoms per Molecule	5.551
Hydrogen Atoms per Molecule	10.960
Oxygen Atoms per Molecule	0.000
Nitrogen Atoms per Molecule	0.000
Lower Heating Value (J/kg)	6.6747e7
Critical Temperature (K)	408.120
Critical Pressure (bar)	21.330
Minimum Valid Temperature (K)	100.000
Maximum Valid Temperature (K)	2040.000
Minimum Valid Pressure (bar)	0.010
Maximum Valid Temperature (K)	300.000
Absolute Entropy at 298K	Ignore

Table 4.3 and 4.4 show the addition values of hydrogen and gasoline fuel after we calculated the value of 70% gasoline mixed with 30% hydrogen, and 60% gasoline mixed with 40% hydrogen fuel.

Table 4.4: Properties of 60% gasoline mixing with 40% hydrogen fuel

Properties	**Value**
Molecular weight	Ignore
Carbon Atoms per Molecule	4.758
Hydrogen Atoms per Molecule	9.680
Oxygen Atoms per Molecule	0.000
Nitrogen Atoms per Molecule	0.000
Lower Heating Value (J/kg)	7.4346e7
Critical Temperature (K)	354.560
Critical Pressure (bar)	20.140
Minimum Valid Temperature (K)	100.000
Maximum Valid Temperature (K)	2320.000
Minimum Valid Pressure (bar)	0.010
Maximum Valid Temperature (K)	300.000
Absolute Entropy at 298K	Ignore

Table 4.5: Properties of 50% gasoline mixing with 50% hydrogen fuel

Properties	**Value**
Molecular weight	Ignore
Carbon Atoms per Molecule	3.965
Hydrogen Atoms per Molecule	8.400
Oxygen Atoms per Molecule	0.000
Nitrogen Atoms per Molecule	0.000
Lower Heating Value (J/kg)	8.1945e7
Critical Temperature (K)	301.000
Critical Pressure (bar)	18.950
Minimum Valid Temperature (K)	100.000
Maximum Valid Temperature (K)	2600.000
Minimum Valid Pressure (bar)	0.010
Maximum Valid Temperature (K)	300.000
Absolute Entropy at 298K	Ignore

Table 4.5 above shows the addition values of hydrogen and gasoline fuel after we calculated the value of 50% gasoline mixed with 50% hydrogen fuel.

From the tables above, we can see that the values for carbon and hydrogen atoms per molecule are decreasing because each fuel has different values of carbon and hydrogen atom, thus after the calculation, the value for the addition for both fuels are different. Same pattern goes to critical temperature and pressure of both fuels, which are also decreasing. The values obtained for lower heating value and maximum temperature are increasing for each ratios of the fuel.

4.3 RESULTS

Table 4.6: Effect of fuel ratio on power and torque at medium engine speed (3000 rpm)

Fuel ratio	Power (kW)	Torque (Nm)
100% Gasoline	20.6	65.4
90% Gasoline : 10% Hydrogen	24.6	78.3
80% Gasoline : 20% Hydrogen	28.2	89.7
70% Gasoline : 30% Hydrogen	31.1	99.1
60% Gasoline : 40% Hydrogen	33.7	107.4
50% Gasoline : 50% Hydrogen	36.0	114.6

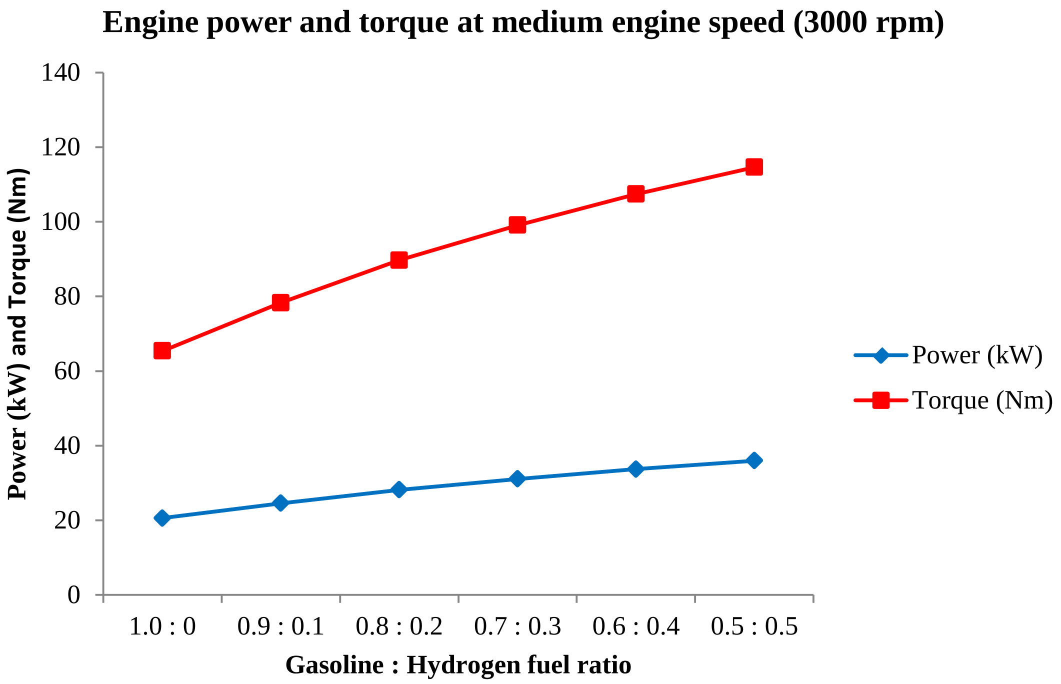


Figure 4.1: Effect of gasoline-hydrogen fuel ratio on engine power and torque at medium speed (3000 rpm)

From Table 4.6 and Figure 4.1 above, we can see that the value of engine power and torque are increasing from fully gasoline fuel until 50% gasoline mixing with 50% hydrogen. The highest value of power is 36kW while the highest value of torque is 114.6Nm where both highest values were located at fuel ratio 50% gasoline and 50% hydrogen. The lowest value of power is 20.6kW while the lowest value of torque is 65.4Nm where both lowest values were located at fuel ratio 100% gasoline without any addition of hydrogen fuel.

Table 4.7: Effect of fuel ratio on power and torque at high engine speed (6000 rpm)

Fuel ratio	Power (kW)	Torque (Nm)
100% Gasoline	19.8	31.5
90% Gasoline : 10% Hydrogen	26.0	41.3
80% Gasoline : 20% Hydrogen	31.4	50.0
70% Gasoline : 30% Hydrogen	35.8	57.0
60% Gasoline : 40% Hydrogen	39.6	63.0
50% Gasoline : 50% Hydrogen	42.8	68.1

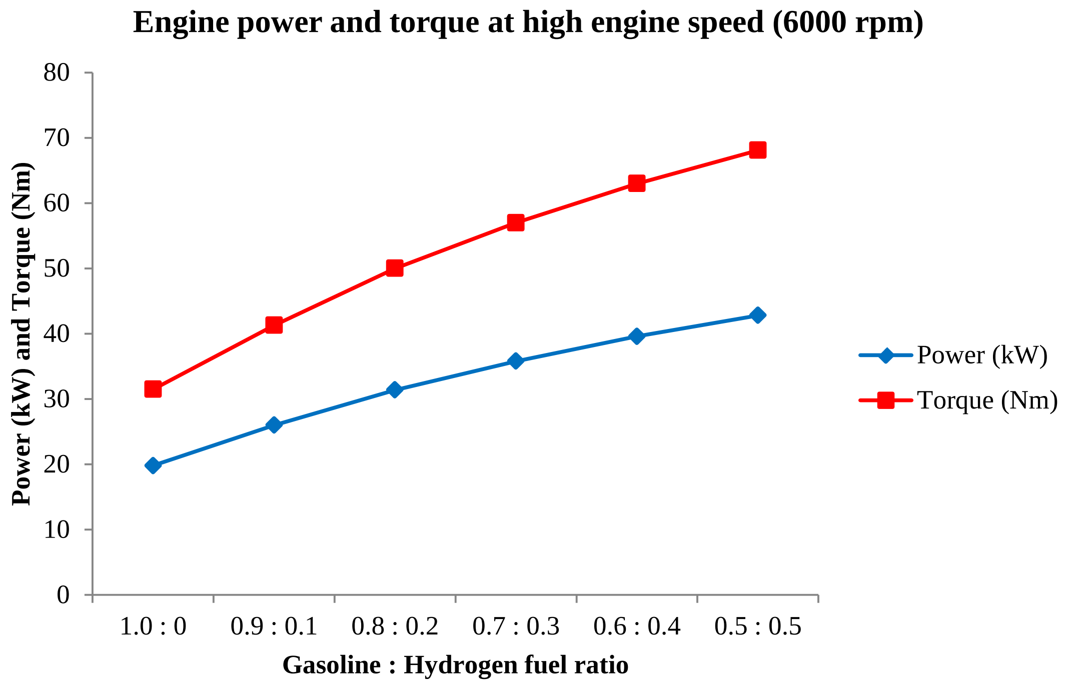


Figure 4.2: Effect of gasoline-hydrogen fuel ratio on engine power and torque at high speed (6000 rpm)

From Table 4.7 and Figure 4.2 above, we can see that the value of engine power and torque are increasing from fully gasoline fuel until 50% gasoline mixing with 50% hydrogen. The highest value of power is 42.8kW while the highest value of torque is 68.1Nm where both highest values were located at fuel ratio 50% gasoline with 50% hydrogen. The lowest value of power is 19.8kW while the lowest value of torque is 31.5Nm where both were located at fuel ratio 100% gasoline fuel without any addition of hydrogen fuel.

Table 4.8: Power (kW) at different ratios and engine speed (rpm)

Fuel ratio	3000 rpm	6000 rpm
100% Gasoline	20.6	19.8
90% Gasoline : 10% Hydrogen	24.6	26
80% Gasoline : 20% Hydrogen	28.2	31.4
70% Gasoline : 30% Hydrogen	31.1	35.8
60% Gasoline : 40% Hydrogen	33.7	39.6
50% Gasoline : 50% Hydrogen	36	42.8

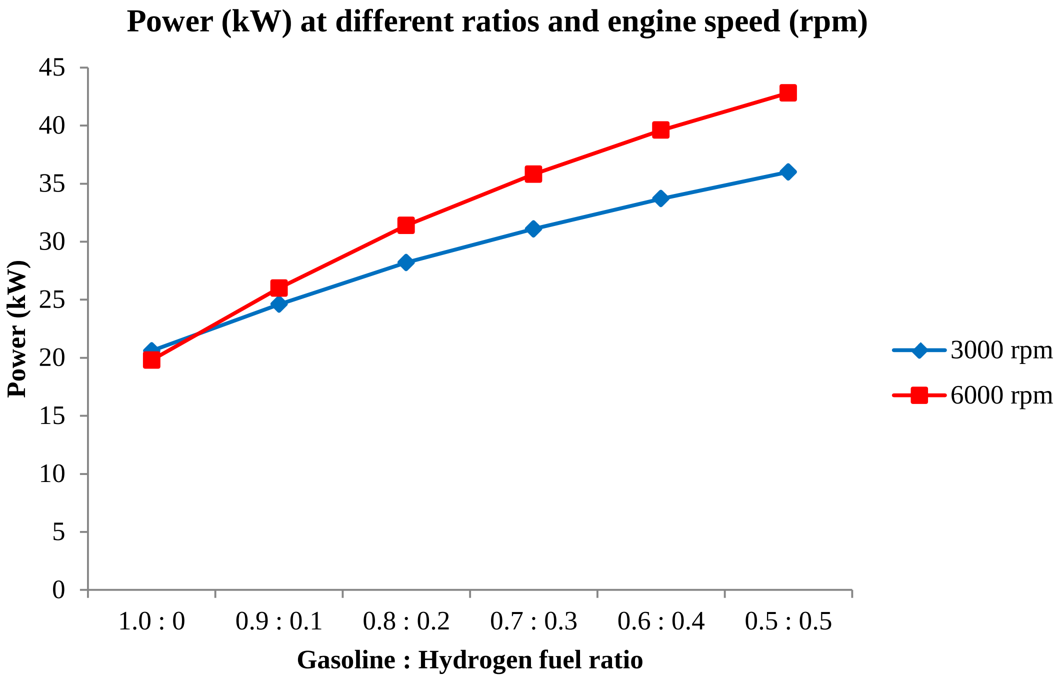


Figure 4.3: Power of engine at different fuel ratios and engine speeds

From Table 4.8 and Figure 4.3 above, we can see that the value of power when engine was running at 100% gasoline is decreasing from speed 3000 rpm to 6000 rpm by 0.8kW. After adding hydrogen fuel by increment of 10% each, the value of speed at 3000 rpm will increase when the engine was running at 6000 rpm. The highest value of power we can get at 50% gasoline and 50% hydrogen is 36kW (3000 rpm) and 42.8kW (6000 rpm). The lowest value of power we can get at 100% gasoline is 20.6kW (3000 rpm) and 19.8kW (6000 rpm).

Table 4.9: Torque (Nm) at different ratios and engine speed (rpm)

Fuel ratio	3000 rpm	6000 rpm
100% Gasoline	65.4	31.5
90% Gasoline : 10% Hydrogen	78.3	41.3
80% Gasoline : 20% Hydrogen	89.7	50
70% Gasoline : 30% Hydrogen	99.1	57
60% Gasoline : 40% Hydrogen	107.4	63
50% Gasoline : 50% Hydrogen	114.6	68.1

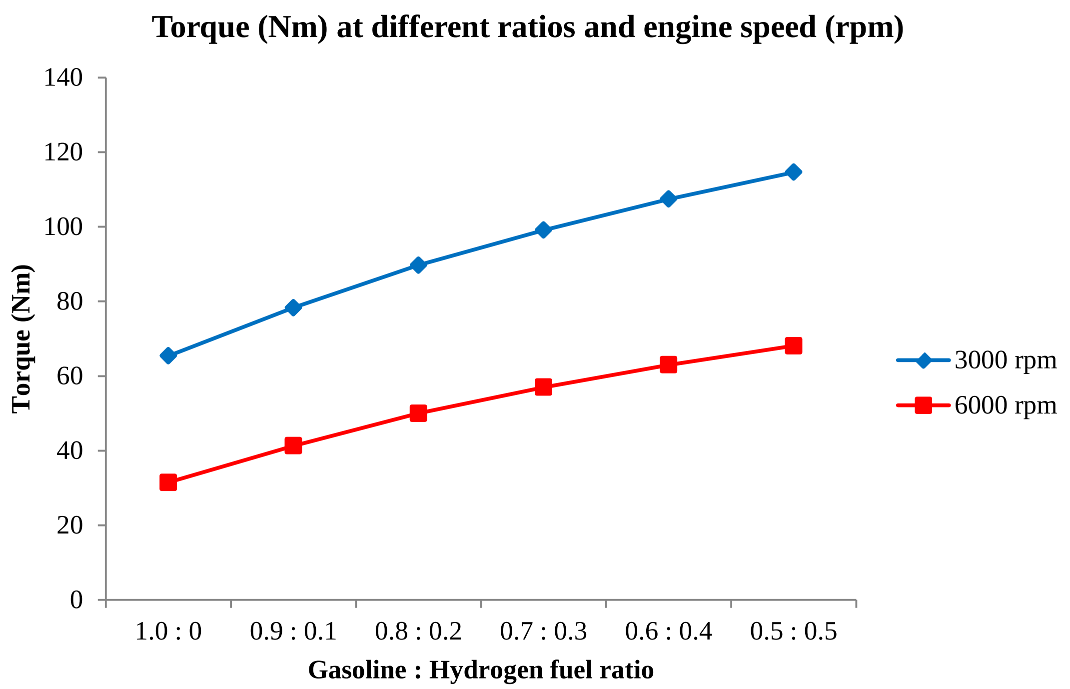


Figure 4.4: Torque of engine at different fuel ratios and engine speeds.

From Table 4.9 and Figure 4.4 above, we can see that the value of engine torque are decreasing when the engine were running from 3000 rpm to 6000 rpm. The highest value of torque which is 114.6Nm at 3000 rpm and 68.1Nm at 6000 rpm can be found when the engine was running at fuel ratio 50% gasoline and 50% hydrogen while the lowest value of torque which is 65.4Nm at 3000 rpm and 31.5Nm at 6000 rpm can be found when the engine was running at fuel ratio 100% gasoline.

4.4 DISCUSSIONS

As we can see from the results that we obtained from Table 4.6 until Table 4.9, there were increasing values for power when we increasing the engine speed from 3000 rpm to 6000 rpm. The values of power said to be increased because the higher the engine speed, the turbulent flame velocity is also higher thus resulting in less time to burn the entire mixture of the fuels.

Another reason for the increasing value for power at different ratios of addition hydrogen fuel into gasoline fuel is because of the properties of the hydrogen itself. From the literature review, we found that hydrogen has the highest value of HHV and LHV compared to other fuels which gives hydrogen an advantage (Lanz, 2001).

By having the highest value for both HHV and LHV, means that hydrogen has the highest energy-to-weight ratio (lightest element and has no heavy carbon atoms) and at the same time the amount of energy liberated during the reaction is quicker compared to other hydrocarbon fuels. High energy content of hydrogen implies that the energy of hydrogen explosion is higher than common hydrocarbon fuels.

Hydrogen has the capability to fires subside much more quickly than hydrocarbon fuels and this is what makes by adding hydrogen into hydrocarbon fuels, it will increase the value of engine power (Ji, 2009). As we all know, the formula of power that we can get by computational analysis is by dividing the value of work done with the time taken to get the work done.

Besides that, another property of hydrogen that can increase the value of power is that the burning speed of hydrogen is higher than any hydrocarbon fuels (Lanz, 2001; Ji, 2009). By having a burning speed that higher, it will help gasoline fuel to burn faster, thus the time taken for the work done will be shorter, hence will increase the engine power.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of this study is to determine the effect of gasoline-hydrogen fuel blend on engine power and torque at medium and high engine speed. A computational technique developed and has been applied to predict the effect of gasoline-hydrogen fuel blend on engine power and torque at 3000 rpm and 6000 rpm. The analysis had been done by running the engine modeling first by 100% of gasoline fuel with no addition of hydrogen fuel, followed by an increment of 10% hydrogen fuel added to the gasoline. The engine was running at these different ratios twice at 3000 rpm and also 6000 rpm. We found that by increasing the ratio of hydrogen added to the gasoline, it will increase the value of power produced by the engine. But increasing in power, it will decrease the value of torque produced. The results show that the engine power and torque were influence by the ratio of hydrogen added to the gasoline. The power and torque of the engine will keep increase if we keep on adding the hydrogen into the gasoline but we known that using 100% hydrogen will put us into a high danger considering we run the engine at fully hydrogen fuel. Most studies found that the convenience ratio of hydrogen added is 14.44% only for our car nowadays.

5.2 RECOMMENDATIONS

Studies of engine power and torque can be expanded by using another type of fuel instead of hydrogen because not only hydrogen has the potential to increase the power output of an engine. The fuel mixture must vary with the throttle setting because at maximum throttle, the mixture needs to be rich for maximum power. As for normal throttle, the mixtures need lean for best economy and as for closed throttle, the mixture need to be rich for reliable ignition.

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APPENDICES

APPENDIX A: FUEL RATIO

Properties	10% Hydrogen	90% Gasoline
Molecular weight	Ignore	Ignore
Carbon Atoms per Molecule	0	7.137
Hydrogen Atoms per Molecule	0.2	13.32
Oxygen Atoms per Molecule	0	0
Nitrogen Atoms per Molecule	0	0
Lower Heating Value (J/kg)	1.1994e7	3.9555e7
Critical Temperature (K)	3.32	511.92
Critical Pressure (bar)	1.3	22.41
Minimum Valid Temperature (K)	10	90
Maximum Valid Temperature (K)	400	1080
Minimum Valid Pressure (bar)	0.001	0.009
Maximum Valid Temperature (K)	30	270
Absolute Entropy at 298K	Ignore	ignore

Properties	20% Hydrogen	80% Gasoline
Molecular weight	Ignore	Ignore
Carbon Atoms per Molecule	0	6.344
Hydrogen Atoms per Molecule	0.4	11.84
Oxygen Atoms per Molecule	0	0
Nitrogen Atoms per Molecule	0	0
Lower Heating Value (J/kg)	2.3988e7	3.516e7
Critical Temperature (K)	6.64	455.04
Critical Pressure (bar)	2.6	19.92
Minimum Valid Temperature (K)	20	80
Maximum Valid Temperature (K)	800	960
Minimum Valid Pressure (bar)	0.002	0.008
Maximum Valid Temperature (K)	60	240
Absolute Entropy at 298K	Ignore	ignore

Properties	30% Hydrogen	70% Gasoline
Molecular weight	Ignore	Ignore
Carbon Atoms per Molecule	0	5.551
Hydrogen Atoms per Molecule	0.6	10.36
Oxygen Atoms per Molecule	0	0
Nitrogen Atoms per Molecule	0	0
Lower Heating Value (J/kg)	3.5982e7	3.0765e7
Critical Temperature (K)	9.96	398.16
Critical Pressure (bar)	3.9	17.43
Minimum Valid Temperature (K)	30	70
Maximum Valid Temperature (K)	1200	840
Minimum Valid Pressure (bar)	0.003	0.007
Maximum Valid Temperature (K)	90	210
Absolute Entropy at 298K	Ignore	ignore

Properties	40% Hydrogen	60% Gasoline
Molecular weight	Ignore	Ignore
Carbon Atoms per Molecule	0	4.758
Hydrogen Atoms per Molecule	0.8	8.88
Oxygen Atoms per Molecule	0	0
Nitrogen Atoms per Molecule	0	0
Lower Heating Value (J/kg)	4.7976e7	2.637e7
Critical Temperature (K)	13.28	341.28
Critical Pressure (bar)	5.2	14.94
Minimum Valid Temperature (K)	40	60
Maximum Valid Temperature (K)	1600	720
Minimum Valid Pressure (bar)	0.004	0.006
Maximum Valid Temperature (K)	120	180
Absolute Entropy at 298K	Ignore	ignore

Properties	50% Hydrogen	50% Gasoline
Molecular weight	Ignore	Ignore
Carbon Atoms per Molecule	0	3.965
Hydrogen Atoms per Molecule	1	7.4
Oxygen Atoms per Molecule	0	0
Nitrogen Atoms per Molecule	0	0
Lower Heating Value (J/kg)	5.997e7	2.1975e7
Critical Temperature (K)	16.6	284.4
Critical Pressure (bar)	6.5	12.45
Minimum Valid Temperature (K)	50	50
Maximum Valid Temperature (K)	2000	600
Minimum Valid Pressure (bar)	0.005	0.005
Maximum Valid Temperature (K)	150	150
Absolute Entropy at 298K	Ignore	ignore