CHAPTER 1
INTRODUCTION

1.1 Background

The function of exhaust system is to guide waste exhaust gases away from a controlled combustion inside an engine. In any engine operation, backpressure is created. Backpressure is created when there are restrictions in the exhaust pipe that can slow down the gases flow.

Backpressure is proportional to the pumping loses. Small backpressure will reduce pumping losses. Pumping losses refer to the amount of energy used to push the exhaust gasses out from the cylinders on the engine's exhaust stroke.

There are two crucial parts in exhaust design; length and the diameter of the pipe. Both criteria are important to ensure that the gasses can move effective and efficiently.

1.2 Problem Statement

Low backpressure is good for engine because it can save some of the engine power. Backpressure is created due to the restriction in the gas flow and it is related with the gas movement in the pipe. The movement patterns of the gasses depend on the diameter and the length of the pipe. Slightly too big may be better than too small and slightly too long may be better than too short. It is because different cross section area and length will produce different result in term of exhaust system efficiency. The system is efficient if the gasses can move freely at the short period of time and with small pumping loss.

This project will focus on the length of the pipe. So, different length of mid-pipe will be used while maintaining the diameter of the pipe and also the other exhaust components.

1.3 Objective

The objective of this project is:

- To investigate the effect of the exhaust middle pipe length with respect to the engine output produced

1.4 Scope of Study

The function of the exhaust system is to guide the waste gasses from the engine to the environment. That waste gasses actually can be manipulated to improve the efficiency of the engine. The crucial part in exhaust system design is the tube length and diameter but tube length is more critical to tune than tube diameter. This study will focus more on the length of the middle pipe. This project will examined how the length of the exhaust pipe can influence the output by the engine and also the flow characteristic created in the pipe.

This project is not to improve the existing exhaust system but to show the relationship of different length of the exhaust pipe to the power produced. So, the exhaust system for the engine test bed will be used as a subject studied. It is because length can influence the characteristic of the gasses flow as well as the pressure loss. If we can understand the situation within the pipe by referring to the pipe length, we can utilize it to improve the exhaust flow. Thus, more horsepower is available by recovering the pump loss which is previously used to push out the gasses from the cylinder.

CHAPTER 2
LITERATURE REVIEW

In engine tuning, exhaust system is one of the main parts that need to be considered. It is because exhaust system help to guide waste gasses from the engine in order to help the engine to run effectively.

Some researches have proved that if the exhaust system is tuned properly, it will reduce the power required by the piston to push out the gasses. Thus, more power will be available at the flywheels which increase the top speed of the car. Below is some of the previous research done in exhaust system field.

2.1 Previous research

2.1.1 Exhaust Backpressure Study

The topic of Exhaust Backpressure study has been done by Thrasher Company (1999). The purpose of the study is to examine the amount of backpressure created in the exhaust component.

The 1997 Buick Regal GS 3800SC engine with stock exhaust system has been used in the experiment. Its exhaust system consists of a cast iron exhaust manifold on the left side of the engine which connects into a tuned tubular header on the right side, both banks connected to a single down pipe into a catalyst. The output of the catalyst runs into a resonator and then into a single muffler; all pipes are 2.25 inch.

They claimed that for every inch of Hg of backpressure (that's Mercury - inches of Hg is a unit for measuring pressure) approximately 1-2 HP is lost depending on the displacement and efficiency of the engine. (1 inch Hg backpressure = 1 HP lost)

There are three phase in the experiment. In the first phase, full factory exhaust system consist of catalyst, resonator and muffler was tested. In the second phase, resonator and muffler has been removed. So the test is carried out on the pipe system just with the catalyst. The last test is done by maintained the system with resonator, catalyst, and tubing while the muffler was removed. In that experiment, the catalyst was never removed because the test only interested in achieving an optimal cat-back system.

From the experiment, they found that the muffler is costing approximately 10HP loss while the resonator accounts for a 6HP drop, with everything from catalyst to the engine costing 14-15HP. It is also shown that a free-flow system will gain about 10HP extra.

2.1.2 Effect of Exhaust System to the Power Produced

The experiment was done by A. Graham Bell [1997] to show the effect of exhaust manifold and exhaust system change to the power produced. The tested engine is 229cu in V6 Chevrolet with stock 4 barrel carb and manifold, stock cylinder heads milled to raise compression to a true 8.8:1 with a valve seat and throat job, stock back cut inlet and exhaust valve, exhaust duration at 0.050in lift and 0.460in inlet and exhaust lift and 1.52:1 budget roller tip rocker arms.

The test is divided into 4 parts. The first test is done by using Chevrolet cast iron manifold, single 2.5in exhaust and muffler while Chevrolet cast iron manifold, dual 2.25in exhaust and mufflers and 2.0in balance pipe is used in second experiment. For the third part, tubular 3 into 1 header with 1.625in diameter x 28in long primaries, single 2.5in exhaust and muffler was tested. The fourth test is carried out by using tubular

3 into 1 header with 1.625in diameter x 28in long primaries, dual 2.25in exhaust and muffler and 2.0in balance pipe.

The result of the experiment shown that header raised the power level only a little over what was produced with stock cast iron manifold. However, swapping to a free flow dual exhaust gave very good result. At cruise speed the engine developed about 5hp more and in the upper range power was up by 10 to 16hp.

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2.1.3 CFD analysis of the dynamic behavior of a pipe system

This study was done by T.Ogorevc, M.Sekavcnik, and L.Skerget from Mechanical Engineering Faculty, Slovenia [2005]. They studied unsteady flow of viscous-compressible fluid through a pipe system induced by a transient disturbance at the pipe intake with ANSYS-CFX Navier-Stokes code. The flow of the fluid in a straight pipe with circular 630 mm long pipe with a 30 mm diameter has been examined.

In the experiment, viscous compressible fluid within the straight circular pipe was excited by an impulse disturbance at the inlet of the pipe, and the dynamic response was analyzed. The flow through the pipe is calculated using a system of Reynolds-averaged Navier-Strokes (RANS) equations combined with various turbulence models.

The pressure responses of complex, periodically excited systems are observed under various boundary conditions. So, from the data obtained by analyzed a single straight, circular pipe, advanced systems of three and seven pipes was modeled and systematically analyzed. Finally, Time domain result was transformed into the frequency-domain in order to determine the frequency content of the dynamic response for each simulation.

From their analysis, they found that a single pipe excited with a single disturbance has a periodic response with a constant frequency, and a certain degree of damping was noticed. They also claimed that the dynamic behaviors of the fluid are influenced by the pipe length.

From the previous research, it shown that there is backpressure exist in the exhaust system. Properly tune might lead to better performance of the engine by reducing the backpressure. Backpressure is related to pumping loss which the power required for the piston to push out the exhaust gasses. Higher force was required for higher resistant in the system. The resistant may come from surface roughness, cross section area, or anything that can slowing down the movement of the gas.

The second research relates the cross-section of the pipe with the power produced. While the third research claimed that the length of the pipe influence of the behaviors of the fluid. So, it proved that area and the length affect the flow of the gasses which influence the losses developed in the pipe.

Pumping loss can be considered as pressure loss. Low pressure loss means low pumping loss which influenced by better flow of the gasses. By maintained the diameter of the pipe, the variation of result can be obtained from difference length. It can be examine by referred it with Reynolds number.

2.2 Reynolds Number

The flow of gasses in the pipe can be considered as internal flow which a pipe is completely filled with a fluid. Laminar flow is characterized by smooth streamlines and highly ordered motion while turbulent flow is characterized by velocity fluctuations and highly disordered motion. Those conditions can be determined by Reynolds number.
From Fluid Mechanics text book [2006], it state that

$$\mathrm{Re} = \frac{V_{avg} D}{\nu} = \frac{\rho V_{avg} D}{\mu} \qquad (1)$$

Where	V_{avg}	=	average flow velocity (ft/s)
	D	=	diameter of the pipe (ft)
	ν	=	kinematics viscosity of the fluid (ft^2/s)
	ρ	=	fluid density (lbm/ft^3)

If

Re $\leq$ 2300	laminar flow
2300 $\leq$ Re $\leq$ 4000	transitional flow
Re $\geq$ 4000	turbulent flow

In exhaust pipe, the gasses wave travel at very high speed and it tend to form turbulent flow. By knowing the Re number, the pressure loss and power required can be calculated. Both the characteristic can be expressed as:

Pressure loss, $$\Delta P_L = f \frac{L}{D} \frac{\rho V^2}{2} \tag{2}$$

Power Required, $$\dot{W} = \dot{V} \Delta P \tag{3}$$

Where

f	=	friction factor
L	=	length (ft`)
$\dot{V}$	=	flow rate (ft/s)

f can be found from Moody chart or by using Colebrook equation when the relative roughness of the pipe, $\frac{\varepsilon}{D}$ is known.

Colebrook equation

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right) \quad \text{(for turbulent flow)} \tag{4}$$

An approximate explicit relation which was given by S.E. Haaland

$$\frac{1}{\sqrt{f}} \cong -1.8\log\left[\frac{6.9}{\mathrm{Re}} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right] \tag{5}$$

In this project, the variable D will be constant but the length; L will be varied because the interest of this project is to see the difference of fluid flow characteristic in variable pipe length. Even though the variation of the length used is not very large, but there are some differences in flow pattern for different length of the pipe.

2.3 Theoretical Background of Exhaust System

2.3.1 Exhaust Flow

Exhaust gasses is hot and it is better to keep it as hot as possible for as long as possible through the exhaust pipe. The purpose is to reduce the backpressure and increase gas velocity. It is because cold air is denser that hot air. Dense air is heavy, so the piston needs to push harder to move out the gas which consumes more power from the engine.

The size of the pipe has an effect to the gas velocity. An extremely large exhaust pipe will cause a slow exhaust flow, which will in turn give the gas plenty of time to cool down. It also will decrease low end torque and will have a problem with ground clearance.

The length of the exhaust pipe also can influence the engine output. Especially in the header, the pipe must be equal in length so that there is no lag in the header. It is also the same for the exhaust pipe. Longer pipe will make more power at low rpm and vice versa.

2.3.2 Type of Exhaust System

There are two types of exhaust piping system. There are single exhaust system and dual exhaust system.

2.3.2.1 Single Exhaust System

Found in in-line engine. There is only one pipe that carries out the exhaust gasses from exhaust manifold to tail pipe. The arrangement of single exhaust system is shown in Figure 1.

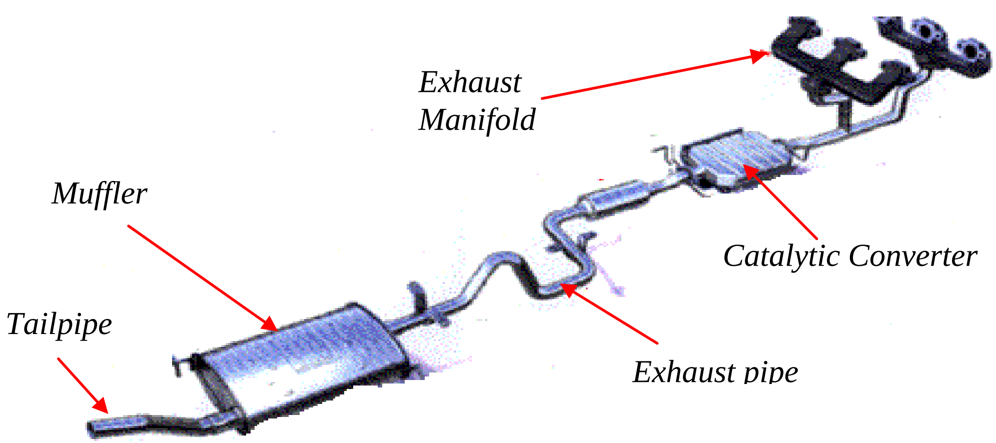


Figure 1: Single Exhaust System

2.3.2.2 Dual Exhaust System

Dual exhaust system was normally found in V-types engine. It mean that it has an exhaust manifold on each side of the engine, 2 catalytic converters and 2 intermediates mufflers, but only one rear muffler. But, there are also cases where this type of exhaust system is provided with two separate mufflers.

The other type is the exhaust pipe is connected to each manifold flange, and these two pipes are connected into a single pipe under the rear of the engine which normally referred as “Y” pipe. Then, it will be connected to the pipe which will joint it to the catalytic converter, muffler and the tailpipe. Figure 2 show the example of the dual exhaust systems.

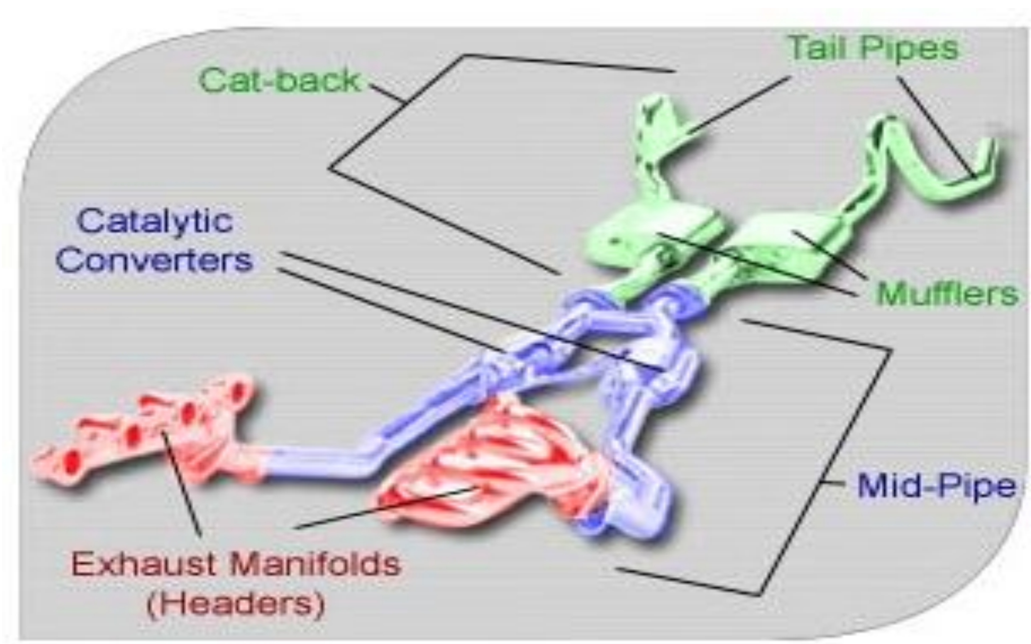


Figure 2: Dual Exhaust System

2.3.3 Arrangement of Exhaust System

There are two types of exhaust arrangement that normally used for four cylinder engine. They are 4-2-1 and 4-1 arrangement. 4-2-1 mean the gasses flow from 4 tubes to 2 tubes and to 1 tube before it goes to the rest of exhaust components. 4-2-1 is better for road or street driving because it gives good all-round power, with no special power peaks or dips. The 4-1 is more suitable for high performance or racing purpose because the system give the best power at high revolution but at the expenses of low end power.

2.3.4 Component of Exhaust System

The main components of the exhaust system are exhaust manifold, catalytic converter, and muffler. The entire components are connected to each other by exhaust pipe.

2.3.4.1 Exhaust Manifold

Manifold is an assembly designed to collect the exhaust gas from the cylinder into the exhaust pipe. Exhaust manifolds are usually made of cast iron which is able to resist the high exhaust temperature. It can also be fabricated from stainless steel which is much lighter than the cast iron.

Figure 3: Exhaust manifold

2.3.4.2 Exhaust Pipe

The piping that connects all the individual components of the exhaust system is called exhaust pipe. Exhaust pipe serves as a connector between exhaust manifold, catalytic converter, and muffler. Exhaust pipes may be made from stainless steel or titanium.

Its purpose is to route exhaust gas away from the engine, through the catalytic converter and muffler and out the rear of the vehicle. Even though it is just a circular tube, but the length and cross-section of the pipes, as well as the type of junction used, influence the vehicle's performance characteristics and sound behavior.

Figure 4: Exhaust pipe

2.3.4.3 Catalytic Converter

The catalytic converter or ‘cat’ serves as an exhaust-gas cleaning device for spark ignition (SI) engines. It is mounted as close as possible to the engine so that it can quickly reach its operating temperature and therefore be effective in urban driving. It uses *catalyst* to convert harmful compounds (hydrocarbon, carbon monoxide, and nitrogen oxides) in the gasses into harmless compounds.

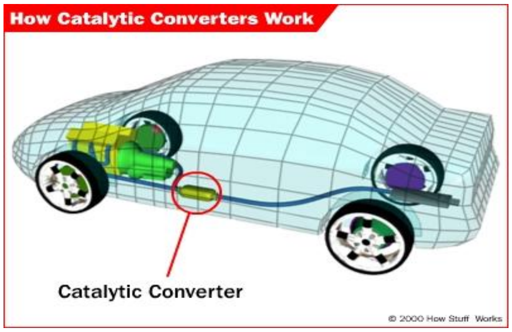


Figure 5: Catalytic Converter

2.3.4.4 Muffler

Muffler also referred as a resonators or a silencer. Its function is to reduce the amount of noise emitted by the machine. A muffler contains perforated pipes, baffle, and resonance chambers which are designed to break up the pulsating effect of the exhaust gasses. It typically installed along the exhaust pipe to reduce the exhaust noise.

There are three types of muffler:

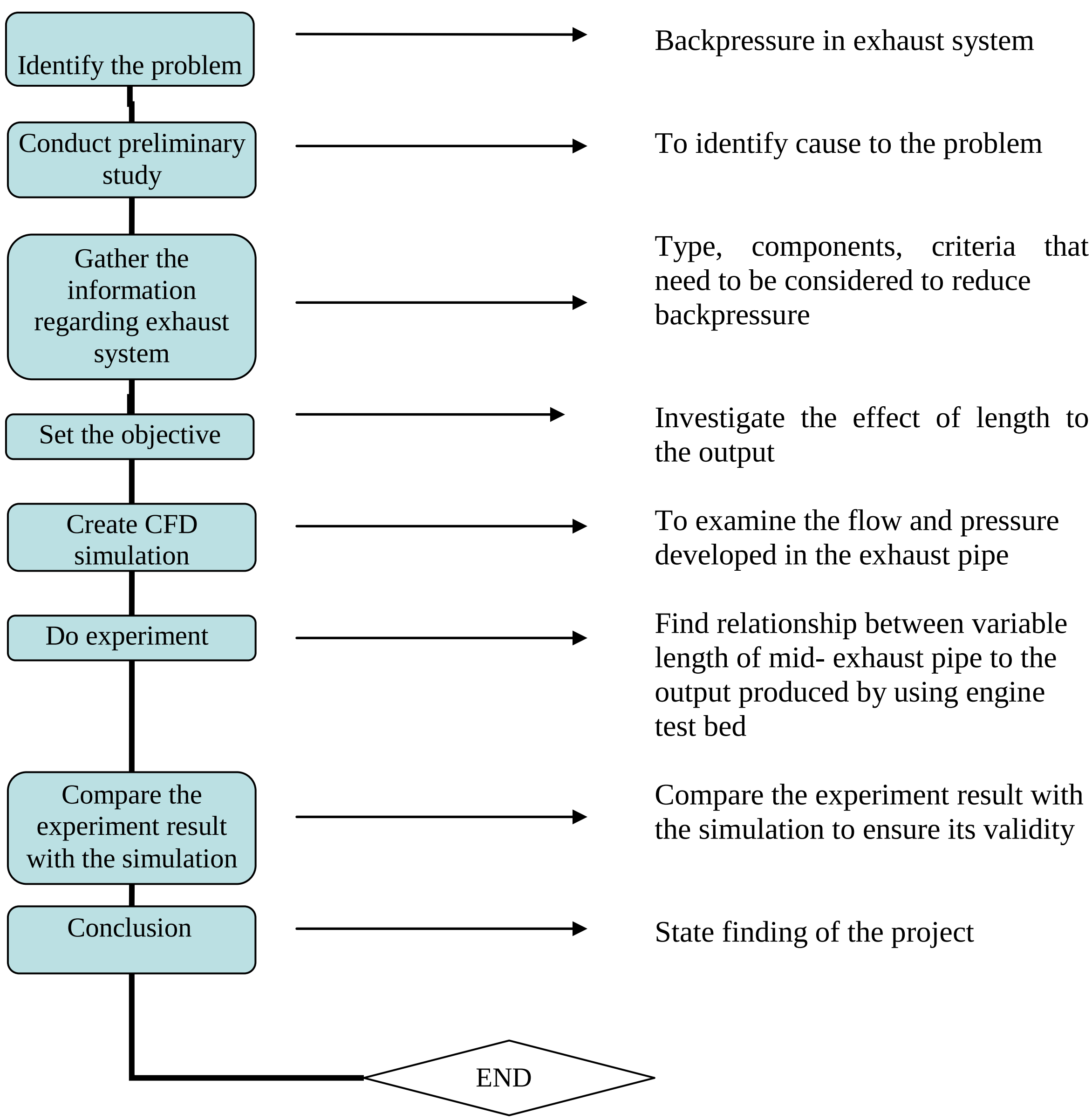
1) Absorption mufflers - the simplest type
2) Restriction mufflers - the least expensive to manufacture
3) Reflection mufflers - the most sophisticated type

Figure 6: Muffler

CHAPTER THREE

METHODOLOGY

3.1 Procedure Identification



3.2 CFD Simulation

CFD simulation is used to examine the flow pattern and pressure developed in the exhaust pipe. ANSYS software will be used to create the simulation. The analyses will use two-dimensional (2-D) with FLOTRAN element FLUID141. The assumptions used are the velocity profile at the inlet is uniformed, zero velocity condition at the inlet in the direction normal to the inlet flow, no-slip condition all along the walls, and zero relative pressure at the outlet are applied. The gasses are considered incompressible and all the gasses properties along the pipe are considered constant.

Even though the pipe is circular, but it will be represented as rectangle in 2 Dimension from the side view. By doing that, the flow pattern and pressure developed can be observed along the pipe. The scope of study is just some portion of the mid-pipe of the system but it can be considered to represent the entire system and the properties of the fluid are considered constant along the pipe.

3.3 Laboratory Experiments

From the previous research, they claim that the length will affect the power released by the engine. Hence, this project will focus more on the length of the exhaust pipe to examine whether it contribute to the extra power gain or not. So, the experiment will show what length of the exhaust pipe which can boost high horsepower at certain engine speed.

The objective of the experiments is to find the relationship between pipe lengths with the power produced by the engine. The interests of the experiments are the performance characteristic of the engine.

The exhaust system that will be used is the system which is design for diesel engine test bed. First, the data will be taken by using the original pipe length of the system. After that, the experiment will be continued by changing the length of mid-exhaust pipe to see the variation of the power generated.

3.3.1 Experimental Methodology

The desired data from the experiment is the performance characteristics such as Brake Horsepower, torque, Brake Mean Effective Pressure, and specific fuel consumption.

Experimental Procedure

1. Engine test bed is set up
2. Run Auto Test 4 Software on the computer provided
3. Engine will be let to warm up for at least 5 minutes to get better and accurate reading.
4. In Manual_Intereption taskbar(AutoTest4), engine speed is set to 1000 rpm
5. The engine will be left to run for 5 minutes. All the data obtained from the Auto Test will be recorded.
6. Then, the engine speed will be increased by 1000 rpm
7. Step 5 and 6 will be repeated until the engine speed reach 4000 rpm
8. After the data at 4000 rpm has been taken, the engine will be slowly ramped down to 1000rpm.
9. The experiment will be repeated by using different length of the exhaust pipe
10. The collected data will be analyzed to see the effect to the engine output

3.3.2 Equipment Required

In order to examine the result of various pipe length to the power produced, the experiments was conducted by using Diesel Engine Test Bed. The equipment is 4 cylinder engines with cubic capacity of 1753.

The engine was fuelled by pure diesel. Its exhaust system consists of catalytic converter, muffler, and 2.5 inch pipe diameter with overall length of 12.8 m.

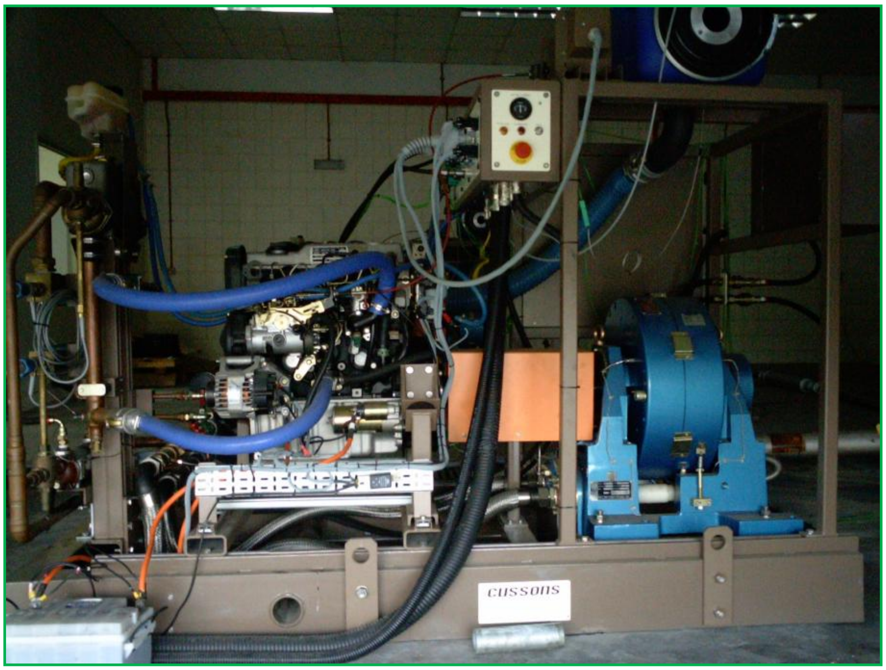


Figure 7: Diesel Engine Test Bed

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Experimental Work

Experiment was carried out to observe the relationship between exhaust pipe lengths to the engine performance. The experiment has been conducted by using three different lengths of the exhaust pipe. The experimental results proved that the length of the pipe influences the performance characteristic of the engine.

The first experiment was done by using original exhaust pipe length. Then, the experiment was repeated by using 35.7% and 55.7% of original exhaust length which is 5.67 meters and 8.24 meters long.

Figure 8 below show the schematic diagram of the original exhaust system for the diesel engine test bed. The following figures below are not to scale.

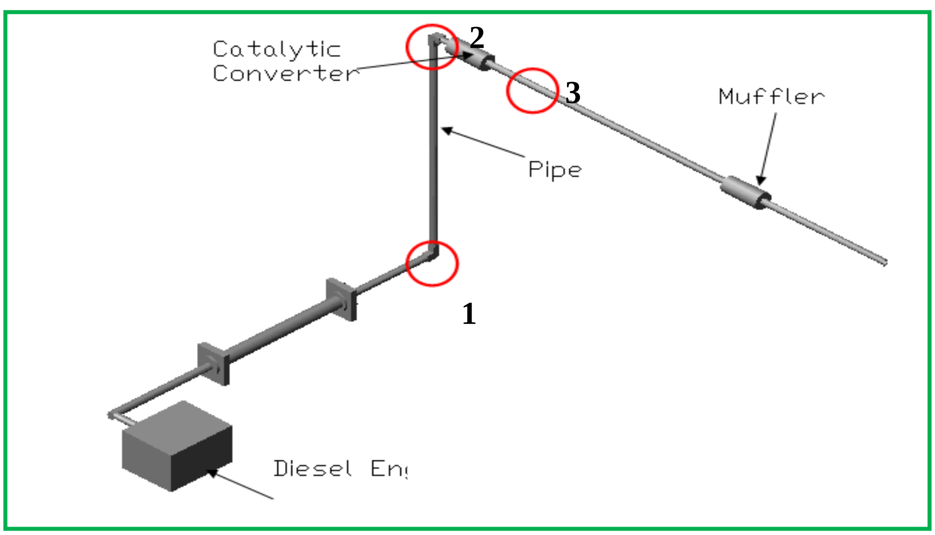


Figure 8: Schematic Diagram of Diesel Engine Test Bed exhausts system (12.8 m)

The red circle indicated by 1 to 3 is the joint of the pipe which can be unfastening to shorter the exhaust pipe. Due to some limitation, the pipe can only be opened at joint number 1. The schematic diagram for 5.67 m and 8.24 m are shown in Figure 9 and Figure 10 below.

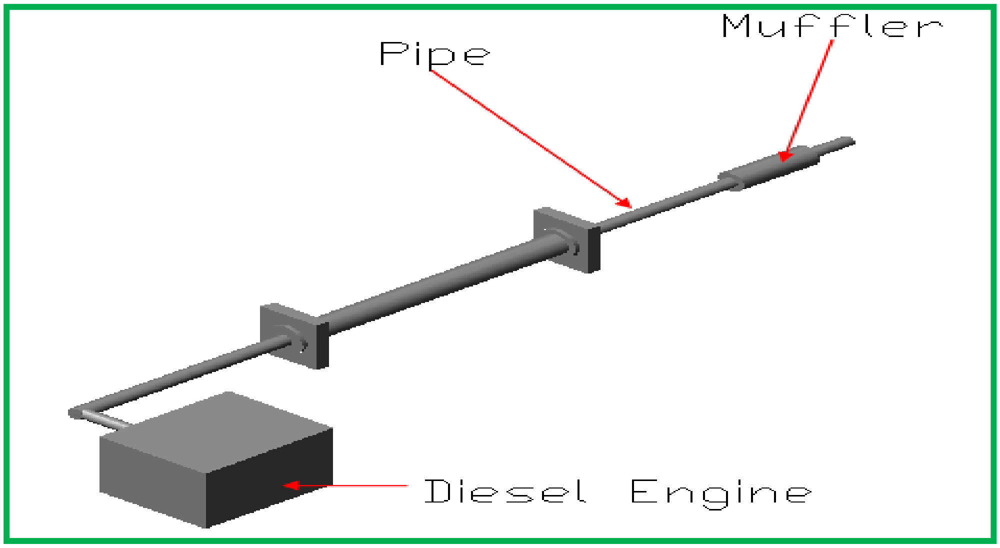


Figure 9: Schematic Diagram for 5.67 m

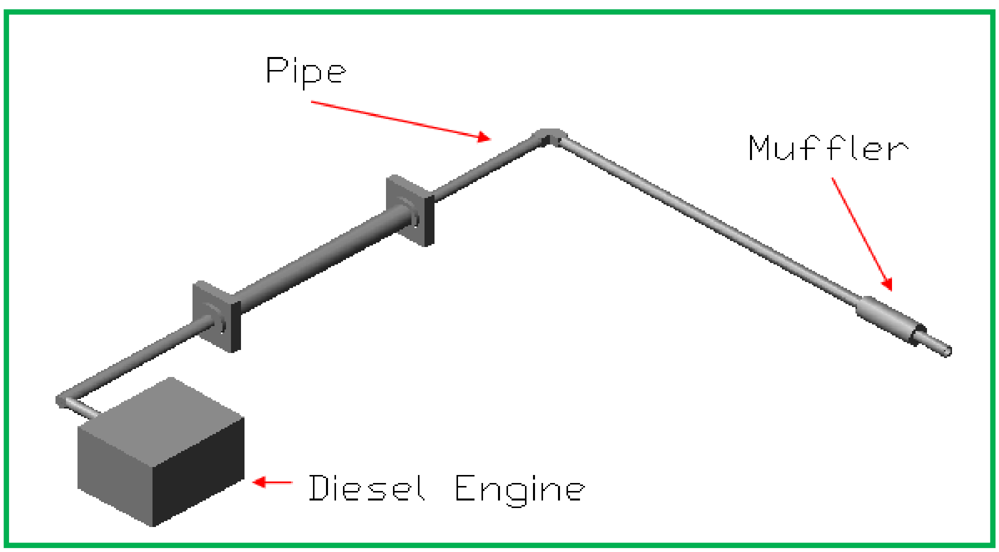


Figure 10: Schematic Diagram for 8.24 m

The original muffler of the system is fixed to the laboratory wall, so the external muffler of the straight flow type was used in 5.67 m and 8.24 m pipe system to reduce the sound produced when the engine was running. It was assumed that the result by using the external muffler was the same with the original muffler.

From the result, it could be seen that different lengths give different output value. The result has shown that shorter exhaust pipe give higher engine performance.

4.2 Experimental Data

The experiment was running by using pure diesel as a fuel. It is conducted in two phase which is with 50% throttle opening and 100% throttle opening. In 100% throttle opening, the throttle was set to maximum level so that the engine would run to the highest possible level that it could achieve.

50% throttle opening can be considered like driving in normal condition or daily driving while 100% throttle opening is like pressing the pedal to its maximum level or until it reach the bottom of the car floor.

The performance characteristics studied are the torque, brake horsepower (bhp), break mean effective pressure (BMEP) and specific fuel consumption (SFC).

The results for the experiment are shown at the next page.

Table 1: Experimental Result for 50% throttle opening

Rpm	Torque (Nm)			BHP (hp)			BMEP (bar)			Sfc (g / kWh)		
	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng
1000	68	67	66	9.5	9.5	9.3	4.87	4.85	4.76	306.2	313.7	316.3
2000	68	67	65	19.1	18.6	18.2	4.88	4.78	4.65	285.8	274.5	291.7
3000	46	45	40	19.2	19.0	16.6	3.29	3.25	2.85	297.7	298.6	359.4
4000	30	30	18	16.8	16.6	10.2	2.16	2.14	1.31	413.2	417.6	668.3

Indicator:

1st Length = 5.67 m

2nd Length = 8.24 m

Original Length = 12.8 m

Table 2: Experimental result for 100% throttle opening

Rpm	**Torque (Nm)**			**BHP (hp)**			**BMEP (bar)**			**Sfc (g / kWh)**		
	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng	1st Lng	2nd Lng	Ori Lng
1000	71	70	70	9.9	9.8	9.7	5.06	5.02	4.98	317.8	311.4	314.1
2000	86	83	83	24.2	23.2	23.2	6.20	5.94	5.95	302.5	309.9	299.3
3000	88	84	79	36.7	35.2	33.2	6.29	6.03	5.68	303.8	318.8	335.2
4000	80	75	68	44.4	41.6	38	5.70	5.34	4.88	321.3	346.2	374.7

Indicator:

1st Length	=	5.67 m
2nd Length	=	8.24 m
Original Length	=	12.8 m

4.2.1 Result of Torque

Torque is part of the basic specification of an engine. It is a measurement of the engine ability to do work. The power output of the engine is expressed as its torque multiplied by its rotational speed of the axis. The results of the torque with respect to the engine speed are shown below.

Table 3: Tabulated data for torque with respect to engine speed

rpm	50% throttle opening			100% throttle opening		
	5.67 m	8.24 m	12.8 m	5.67 m	8.24 m	12.8 m
1000	68	67	66	71	70	70
2000	68	67	65	86	83	83
3000	46	45	40	88	84	79
4000	30	30	18	80	75	68

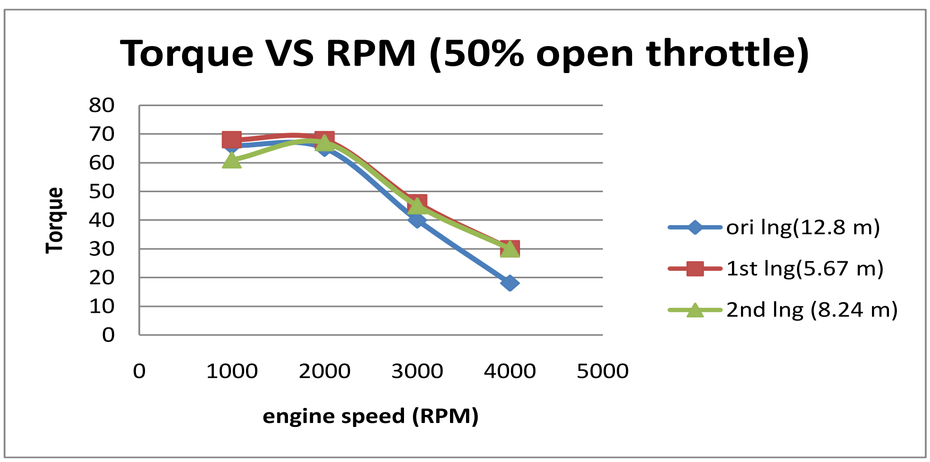


Figure 11: Graph of Torque vs engine speed (RPM) at 50% throttle

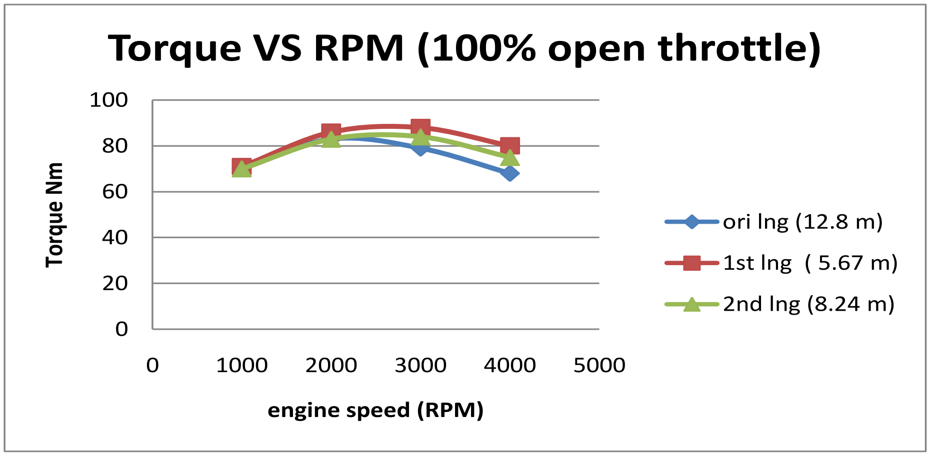


Figure 12: Graph of Torque vs engine speed at 100% throttle

From the graph, it could be seen that from 1000rpm idle speed, maximum torque would increase as the engine speed increase. The increment will reach a point where it reaches its maximum value, where there will be no more torque increase even the speed was increased.

After the maximum point, any increase of engine speed will reduce the maximum achievable torque value. That situation happened due to the friction. As speed increase, more energy will be required to overcome the friction generated to the rotation.

By referring to Figure 11, the highest torque of the engine was 68 Nm occurred at 2000 rpm and when the engine speed at 3000 rpm, the torque value reduces to 46 Nm and further speed increase would reduce the torque value. In Figure 12, the maximum torque is 88 Nm at 3000 rpm and it reduces to 80 Nm at 4000 rpm. Both values are achieved by 5.67 m exhaust pipe.

The result shown that shorter exhaust pipe give higher output compared to the output produced by the longer pipe. Engine speed at 2000 rpm for 50 % throttle opening and 3000 rpm for 100% throttle opening give higher torque value. There are theory that state the peak of the torque curve usually occurs somewhat below the overall power peak and it will never appear at higher rpm than the power peak.

4.2.2 Result of Brake Horsepower

Brake horsepower (bhp) is the measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump, and other auxiliary components. Thus the prefix "brake" refers to where the power is measured: at the engine's output shaft, as on an engine dynamometer and the measurement unit is horsepower (hp). Data for the brake horsepower was tabulated in the Table 4 below.

Table 4: Tabulated data for (bhp) with respect to engine speed

rpm	50% throttle opening			100% throttle opening		
	5.67 m	8.24 m	12.8 m	5.67 m	8.24 m	12.8 m
1000	9.5	9.5	9.3	9.9	9.8	9.7
2000	19.1	18.6	18.2	24.2	23.2	23.2
3000	19.2	19	16.6	36.7	35.2	33.2
4000	16.8	16.6	10.2	44.4	41.6	38

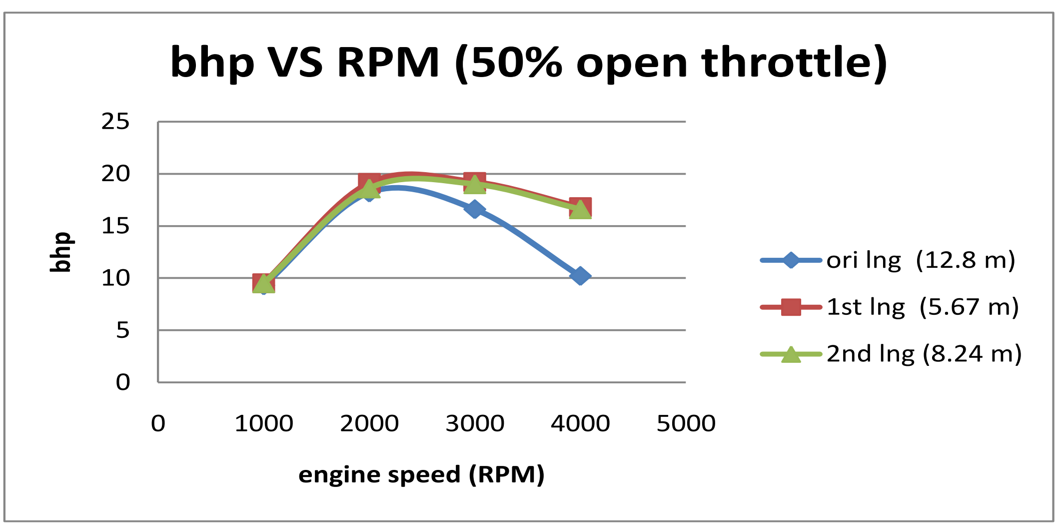


Figure 13: Graph of bhp vs engine speed at 50% throttle

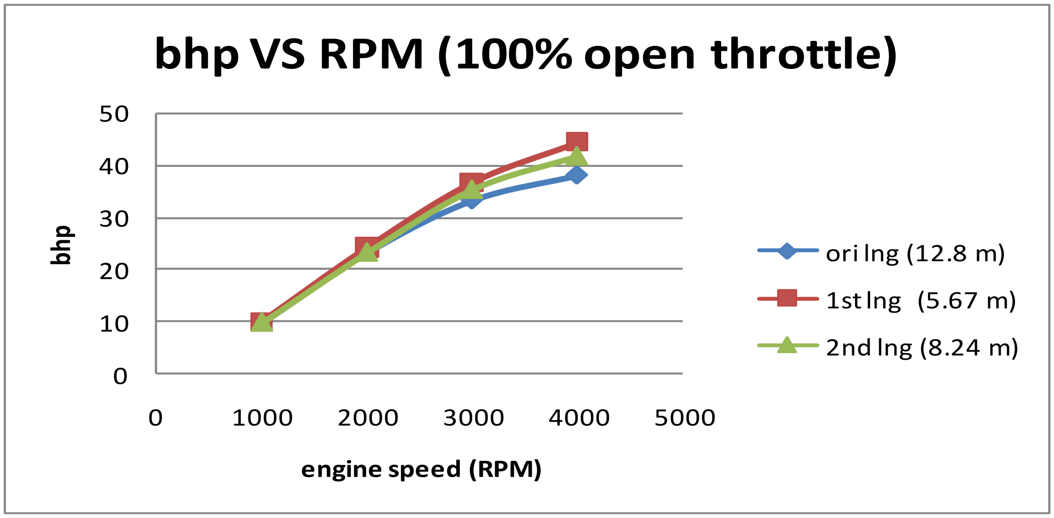


Figure 14: Graph of bhp vs engine speed at 100% throttle

In 50% throttle opening, the bhp value increase with the increasing of engine speed and reach its maximum value at 3000 rpm. However, the bhp value reduced as the engine speed reach 4000 rpm. The result for 5.67 m and 8.24 m is almost the same but for the 12.8 m exhaust pipe, there is slightly different value at 4000 rpm. The 12.8 m pipe gives the lowest value which is 10.2 hp.

In 100% throttle opening, the result for all the three exhaust pipe lengths are almost the same except at 4000 rpm. The graph of brake horsepower vs engine speed shown that the brake horsepower (bhp) is proportional with the engine speed. The maximum bhp values are form at 4000 rpm and 5.67 m exhaust pipe gives the highest value which is 44.4 bhp.

From the graph, there are no significant of bhp for those pipe length at 1000 and 2000 rpm. The bhp value for 5.67 m and 8.24 m exhaust pipe for both throttling condition also was almost the same. It was a difference condition for the 12.8 m exhaust pipe. Its result follow the other at the beginning but the gap become wider when the engine speed approach 4000 rpm especially in 50% throttle opening.

4.2.3 Result of Specific Fuel Consumption

Specific fuel consumption (SFC) is frequently used as an alternative criterion of performance. It is used as a measurement of the fuel consumed by the engine design with respect to thrust output. The SFC is represented in g/kWh unit.

Low value of SFC is desirable as it use less fuel to produce work. SFC is lower when the engine is in high volumetric efficiency. However, length of the exhaust pipe also play an important role in the engine efficiency as it was related to the power required to push the gases along the pipe. Table 5 below show the specific fuel consumption for 3 different exhaust pipe length studied.

Table 5: Tabulated data for (SFC) with respect to engine speed

rpm	50% throttle opening			100% throttle opening		
	5.67 m	8.24 m	12.8 m	5.67 m	8.24 m	12.8 m
1000	306.2	313.7	316.3	317.8	311.4	314.1
2000	258.8	274.5	291.7	302.5	309.9	299.3
3000	297.7	298.6	359.4	303.8	318.8	335.2
4000	413.2	417.6	668.3	321.3	346.2	374.7

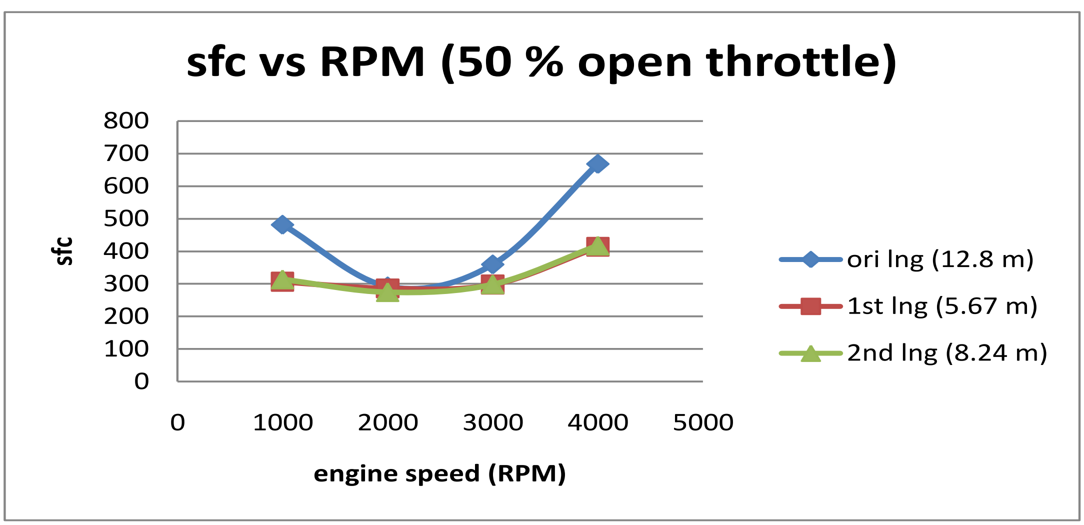


Figure 15: Graph of specific fuel consumption vs engine speed (50% open throttle)

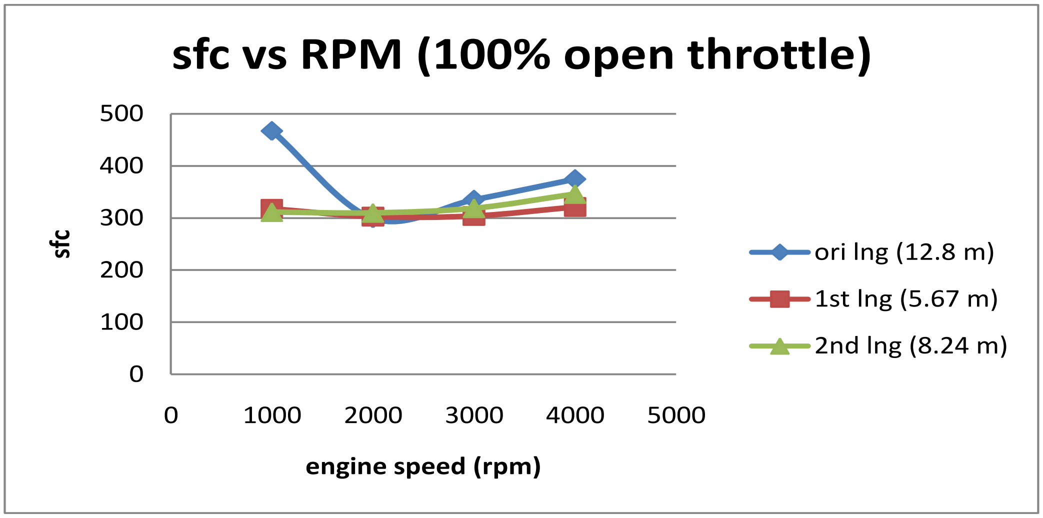


Figure 16: Graph of specific fuel consumption vs engine speed (100% open throttle)

Based on the gathered data, a graph is produced to visualize the relationship of fuel consumption with respect to engine speed. The graph shown the fuel consumption by the shorter exhaust pipe length is less than the fuel consumption by the original exhaust pipe system. The SFC decrease as the engine speed at 2000 rpm but increase back with the increment of engine speed.

It requires a lot fuel at 1000 rpm but decrease to the minimum at 2000 rpm before increase again till 4000 rpm. By relate it with the result of torque, it shown that higher torque value would produce lower SFC value. Higher SFC value represent that the engine consume more gram of fuel to give unit power output.

The SFC is higher at 1000 rpm because there is increased time for the heat of combustion to escape through the walls of the cylinders and so not do useful work. At higher engine speeds, the frictional loses of the engine rise alarmingly and so the energy of combustion is again being wasted, this time in heating the oil.

There reason that SFC is lowest at ‘middle’ rpm which is 2000 rpm is because the engine is tuned to develop best cylinder filling at middle revs, the engine’s breathing is at highest efficiency at these speeds.

From the result, it had shown that the SFC for the original length was so high at 1000 rpm. It should be more or less similar with the value for the other length because at that rpm, the engine is at idle state and no work is done yet.

So, the flow of the gas inside the pipe is not very turbulence, hence it was not have great impact to the pressure loss or the power required by the piston.

That situation occurred might due to the warming up session by the engine. It is because the first experiment was started with the original exhaust system. Much fuel is required to put the engine from cold state to its normal operational condition.

The second and third pipe length experiments were carried out after the engine is in operational mode. It means that the engine is already in suitable temperature to operate.

4.2.4 Result of Brake Mean Effective Pressure

Mean Effective Pressure (MEP) is an abstraction of the pressure exerted into the combustion chamber of an internal combustion engine. Mean Effective Pressure is defined as the average pressure that the gas exerts on the piston(s) through one complete operating cycle of the engine. ‘Brake’ MEP for denoting dynamometer testing.

BMEP do not indicate an actual cylinder pressure. It is simply an effective comparison tool between different engines. It measures the efficiency of the conversion from the indicated mean effective pressure in the cylinder to the output shaft and the level of pressure attained in an engine. Higher value of BMEP would indicate higher performance of the engine.

Data gathered for Brake Mean Effective Pressure are shown in Table 6 and the result was visualized in Figure 17 and Figure 18.

Table 6: Tabulate data for BMEP with respect to engine speed

rpm	50% throttle opening			100% throttle opening		
	5.67 m	8.24 m	12.8 m	5.67 m	8.24 m	12.8 m
1000	4.87	4.85	4.76	5.06	5.02	4.98
2000	4.88	4.78	4.65	6.20	5.94	5.95
3000	3.29	3.25	2.85	6.29	6.03	5.68
4000	2.16	2.14	1.31	5.70	5.34	4.88

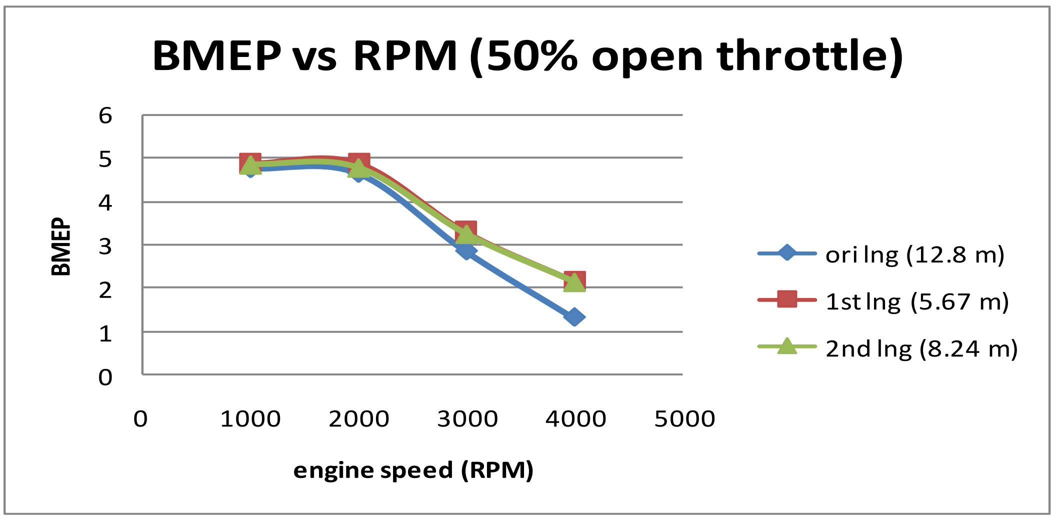


Figure 17: Graph of BMEP vs engine speed at (50% open throttle)

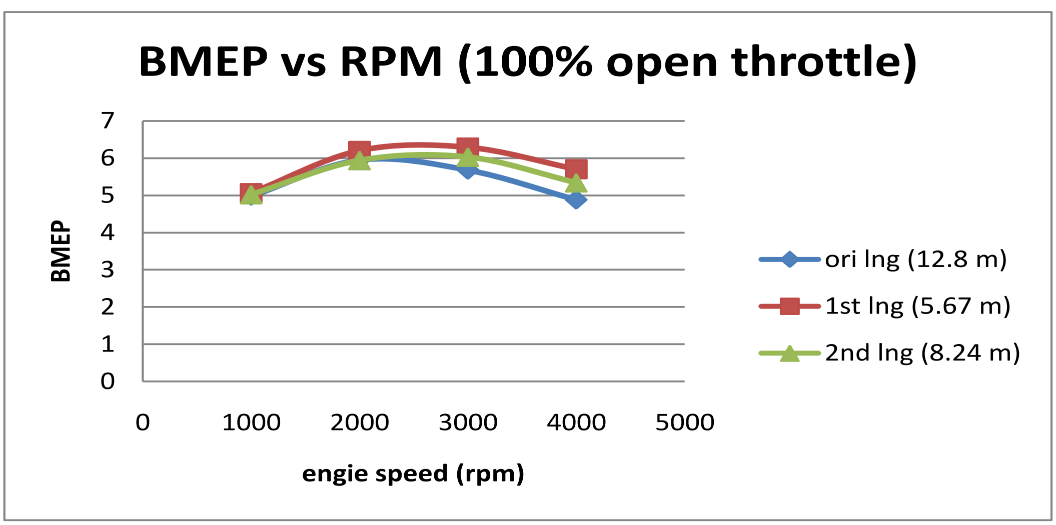


Figure 18: Graph of BMEP vs engine speed at (100% open throttle)

The result for BMEP is quite similar with the result for the torque. From the graph, it shown that the highest BMEP value which is 4.88 at 2000 rpm for 50% throttle opening and 6.29 at 3000 rpm for 100% throttle opening. Both results are achieved by using 5.67 m exhaust pipe.

For 50% throttle opening, the BMEP value is reduced from 4.88 to 3.29 at 3000 rpm and 2.16 at 4000 rpm. For 100% throttle opening, the BMEP value only decrease after 3000 rpm. The value increases from 5.06 at 1000 rpm to 6.29 at 3000 rpm and decrease to 5.7 when engine speeds reached 4000 rpm. It makes the result look like parabolic curve.

Both of the graph (50% and 100% throttle opening) shown that the BMEP decrease with the increasing of pipe length. The longest exhaust pipe has the lowest value of BMEP. The BMEP is higher at 2000 rpm but decrease when the engine speed becomes 4000 rpm especially in 50% throttle opening.

BMEP become lower when the engine speed increase because its efficiency was lowered by more friction and air viscosity. Longer pipe will have more friction, so it make the longer pipe has the lowest BMEP value at 4000 rpm.

4.3 ANSYS Simulation Result

The purpose of ANSYS simulation is to view what was happened in the pipe. It also gives clear picture about the pressure developed and flow pattern of the fluid in the pipe. The analyses of two-dimensional (2-D) with FLOTRAN element FLUID141 was used. The assumption used is the velocity profile at the inlet is uniformed, zero velocity condition at the inlet in the direction normal to the inlet flow, no-slip condition all along the walls, and zero relative pressure at the outlet are applied. The gasses are considered incompressible and all the gasses properties along the pipe are considered constant. The figures and graph below shown the result of the pressure developed in the pipe.

Red Color – High pressure area

Figure 19: Pressure development in pipe

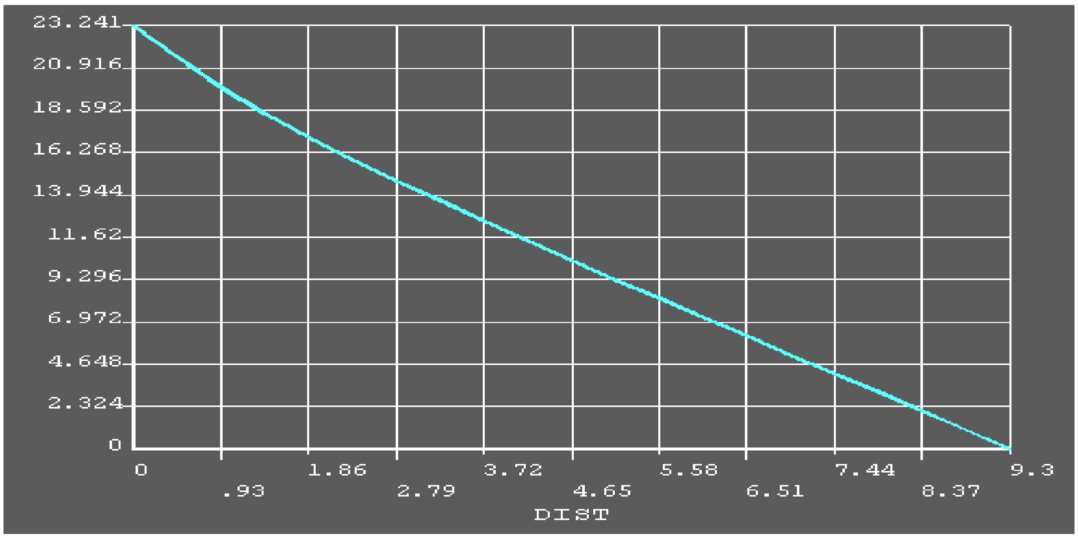


Figure 20: Graph of Pressure vs distance traveled (5.67m)

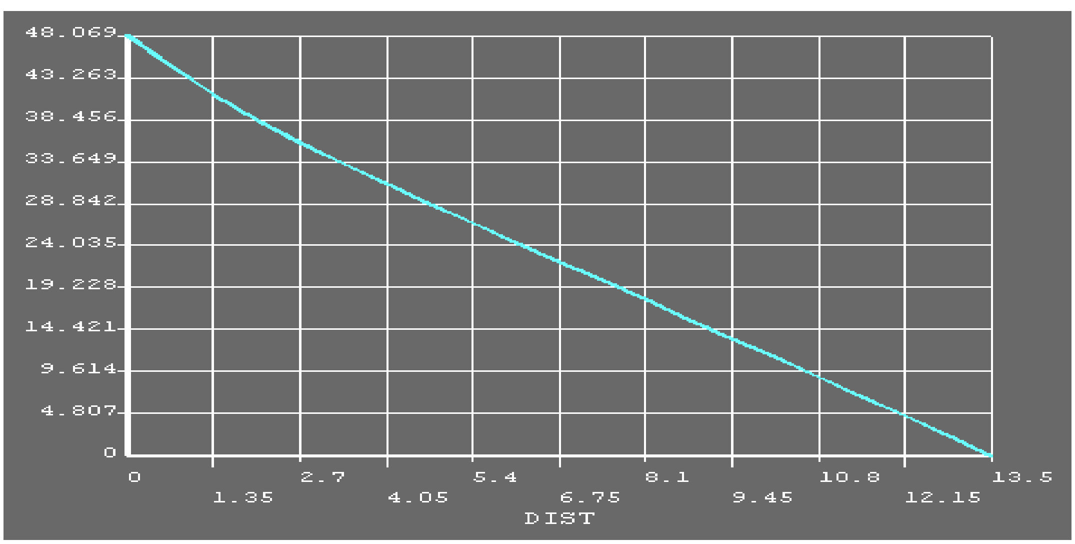


Figure 21: Graph of Pressure vs distance travel (8.24 m)

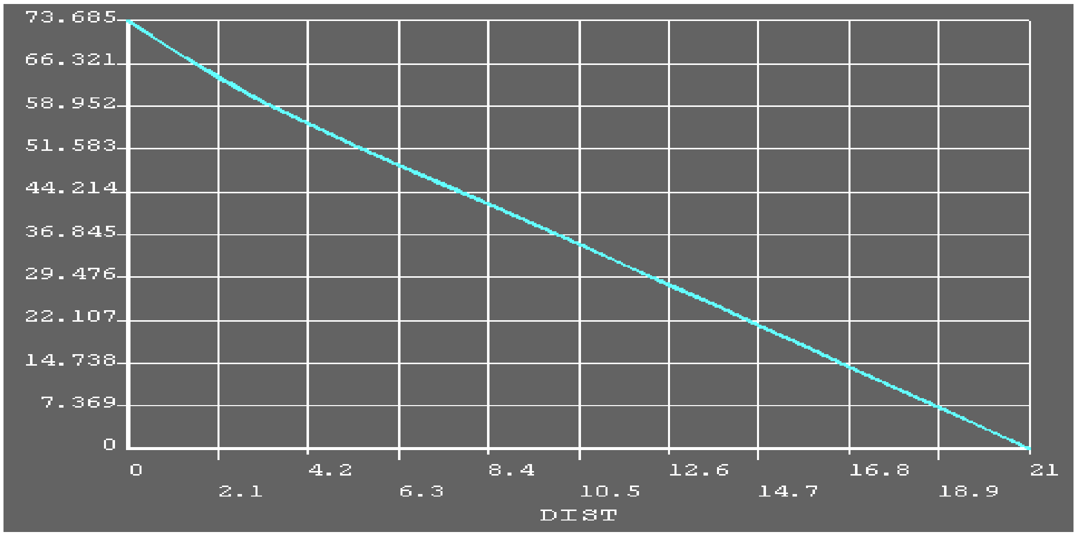


Figure 22: Graph of Pressure vs distance travel (12.8 m)

The exhaust pipe diameter is 2.5 in along the pipe. So, the pipe was represented as a straight long pipe. The pressure development for by all the three length was almost the same as shown in the Figure 19. The pressure is high at the entrance and it is decreasing as it moves toward the outlet. Due to the limitation, the scale of the exhaust pipe is 1:24.

The red color represents high pressure area. Red color appeared at the entrance of the pipe because it is near to the exhaust manifold. The exhaust gases which accumulated in the exhaust manifold will flow toward the exhaust pipe. High pressure was developed because there are huge amount of gases but small area of the exhaust pipe.

Red color in the pressure profile exists almost along the pipe. As the gases move toward the end of the pipe, the flow become less turbulence and the pressure was decreasing. Shorter pipe has less red area compared to the longer pipe. It is because shorter pipe has less resistance as well as the power required to push out the gases also is lower.
Not much difference can be seen in term of pressure developed in all the three length. It may due to the geometry of the pipe which is just circular pipe. But in the experimental result, it had shown clearly that shorter exhaust pipe length has the highest output in

term of torque, brake horsepower, and brake mean effective pressure. Beside that, shorter pipe also require less fuel to operate than the longer ones.

4.4 Reynolds Number Application

In order to find the pressure loss created in the pipe, Table 7 and Table 8 was created to show the data obtained based on the gas properties at 2000 rpm and 3000 rpm. This engine speed range is chosen because it is where the engine gives the highest value of engine performance.

Calculation below is the sample of Reynolds Number application to find the pressure loss in the exhaust pipe. The data is based on the gas properties at 2000 rpm for 5.67 m exhaust pipe which is taken from the experimental result for 50% throttle opening.

Pipe diameter	=	2.5 in	= 0.2083 ft
Pipe length	=	5.67 m	= 18.6 ft
Cross section area of pipe	=	$\frac{\pi D^2}{4}$	
	=	$\frac{\pi (0.2083)^2}{4}$	
	=	0.0341 ft^2	
Engine capacity	=	1753 cc	
Engine speed	=	2000 rpm	

Gas properties at 2000 rpm

Temperature	=	307.2 ^oC	=698.36 ^oF

For the efficiency, 0.85 is used for natural aspirated engine and the value of C is 2 for four cycle engine.

In order to find the exhaust flow rate, substitute all the data into the equation of

$$\text{Exhaust flow rate} = \frac{\begin{pmatrix} engine \\ displacement \end{pmatrix}(rpm)\begin{pmatrix} engine \\ efficiency \end{pmatrix}(temp. + 460)}{C(941670)}$$

$$= \frac{(1753)(2000)(0.85)(698.36 + 460)}{2(941670)}$$

$$= 1832.754 \ \text{ft}^3/\text{m}$$

$$= \underline{30.545 \ \text{ft}^3/\text{s}}$$

The above formula was proposed by Western Filter Co. (2005). Then, for the flow velocity, the equation below is used

Exhaust gas velocity = exhaust flow rate (ft^3/sec) / pipe inlet area (ft^2)

= (30.545 ft^3/s) / (0.0341 ft^2)

= <u>895.77 ft/s</u>

From Table A-9E in Fluid Mechanics text book [2006], the properties of gases at 698.36 ^{o}F was as follow:

Density = 0.0341 lbm/ft^3 and Kinematic viscosity = 0.000623 ft^2/s

By using the Eq. 1, the Reynolds Number is

$$\text{Re} = \frac{V_{avg}D}{\nu} = \frac{(895.77 \ ft/s)(0.2083 \ ft)}{6.23x10^{-3} \ ft^2/s} \qquad = 2.99 \text{ x } 10^5$$

Calculated Re is greater than 4000, therefore the flow is turbulence.

The relative roughness of the pipe is

$$\frac{\varepsilon}{D} = \frac{0.000007\ ft}{0.2083\ ft} = 3.36x10^{-5}$$

By referring to the figure 8-27 in Fluid Mechanics text book [2006], the estimate friction factor was 0.01229 and this value was applied to all the pipe length.

Then, pressure loss can be calculated by using Eq. 2,

Pressure loss, ΔP_L

$$= f\,\frac{L}{D}\frac{\rho V^2}{2}$$

$$= (0.01229)\left[\frac{(18.6\,ft)(0.0341 lbm/\,ft^3)(895.77\,ft/s)^2}{2(0.2083\,ft)}\right]\left[\frac{1lbf}{32.2lbm.ft/s^2}\right]$$

ΔP_L = <u>466.27 lbf/ft^2</u>

By knowing the value of pressure loss, ΔP_L the power required can be calculated by using the equation of $\dot{W} = \dot{V}\,\Delta P$ (4)

Power required, $\dot{W}$ = (30.55 ft^3/s) (466.27 lbf/ft^2) ($\frac{1W}{0.737 lbf.ft/s}$)

= 19327.75 W

= <u>19.3 kW</u>

Power required in hp = (19.3 kW)$\left(\frac{1hp}{0.7457\,kW}\right)$ = <u>25.88 hp</u>

The overall calculation results are shown in Table 7 and Table 8. All the gases properties are based on 50% throttle opening experimental result.

Table 7: Reynolds Number application at 2000 rpm

	18.6 ft (5.67 m)	**27.03 ft (8.24 m)**	**41.99 ft (12.8 m)**
Temperature (F)	698.36	723.92	732.38
Flow rate (ft^3/s)	30.55	31.22	31.44
Flow velocity (ft/s)	895.77	915.85	922.39
Kinematic viscosity (ft^2/s)	0.000623	0.000644	0.000652
Density (lbm/ft^3)	0.0342	0.0336	0.0333
Reynolds Number	2.99×10^5	2.96×10^5	2.95×10^5
Pressure loss (lbf/ft^2)	466.27	697.19	702.34
Power required (kW)	19.3	29.5	30.0
Power required (hp)	25.88	39.6	40.2

Table 8: Reynolds Number application at 3000 rpm

	18.6 ft (5.67 m)	**27.03 ft (8.24 m)**	**41.99 ft (12.8 m)**
Temperature (F)	647.42	675.14	704.12
Flow rate (ft^3/s)	43.80	44.90	46.05
Flow velocity (ft/s)	1285.01	1317.17	1350.80
Kinematic viscosity (ft^2/s)	0.000577	0.000601	0.000626
Density (lbm/ft^3)	0.036	0.0350	0.0341
Reynolds Number	4.6×10^5	4.56×10^5	4.5×10^5
Pressure loss (lbf/ft^2)	1010.28	1504.43	1540.98
Power required (kW)	60	91.7	96.3
Power required (hp)	80.5	122.9	129.1

From Table 7 and Table 8, it has shown that the pressure losses are proportional to the pipe length. As the length increase, the pressure loss increase as well. The power obtained in Table 7 and Table 8 is different from the power generated in the experiment.

In the calculation, it was assumed that the gases properties along the pipe are constant. The Reynolds Number obtained also was very big which is greater than 4000. It was indicated that the turbulence flow existed in the pipe.

The power in experimental results is the net power generated by the engine, but in Table 7 and Table 8 is the power required to overcome the pressure losses or frictional losses in the pipe. It has shown that the difference of power required between 5.67 m pipe and 8.24 m pipe was very big. It might due to the shape of the exhaust path flow between both of them. In 5.67m piping system, the flow of the gases is just in straight flow but in 8.24 m piping system, there are bend in the exhaust gas flow.

The bend in the pipe also can affect the output of the engine. In the experimental result, it shown that the result for 5.67 m and 8.24 m pipe is quite similar. There is not much difference in term of value of the engine performance. The graph is almost similar especially in 50% throttle opening. The factor that differentiates their value is the bend. The bend in 8.24 m pipe cause the gas to slow down, hence the engine need more energy to push out the gas. As the result, the power generated becomes lesser.

The length actually did not adversely affect the performance result. It is because the length difference between those three lengths is not very big. Not much increment of power if those three lengths are just in straight pipe. The performance result for original length was the lowest because there is vertical path flow and also two bend exist in the pipe. That kind of exhaust flow actually create wider gap in term of performance result between original lengths with the others. As the number of bend increase, the performance characteristics become lower.

The results in the Table 7 and Table 8 are not the exact value. The calculation above was just the estimate value to find pressure loss. It is not easy to determine the exhaust velocity in the pipe because there are a lot of things that need to be put in consideration such as friction between the piston and the cylinder. The pressure at the exhaust manifold also always changing and the combustion process occur very fast in short period of time. However, it should give some information to estimate the pressure loss in the pipe.

From the calculation results and the experimental results, it proves that when the pressure loss is low which mean low backpressure, the higher the performance characteristic will be obtained. For example, the pressure loss in 5.67 m pipe is lower than 8.24 m pipe. As the result, the torque generated by using 5.67 m pipe was higher than the torque obtained with 8.24 m exhaust pipe.

From the ANSYS point of view, shorter pipe which has low backpressure or pressure loss will have smaller area of red color which indicates high pressure area. When the resistance lesser, the gasses can flow easily. Hence, high pressure area is reduced.

4.5 Experimental Error

Through out the experiment there are some errors occur which affect the result of the experiment. The possible errors are as follow:

4.5.1 Human Error

This type of error might happen during the installation of external muffler when shorter exhaust pipe is used. The joint might not very tight which can allow exhaust gas to escape. Even though the gap at the joint is not very wide, but it might affect the output data. The other place where human error might occur was when adjusted the throttle opening percentage.

The engine needs to be put in idle condition before the experiment could be run. In order to avoid strain to the engine, the throttle needs to be opened bit by bit. The user needs to put the value in the space provided with the 10% increment to drive the engine to 100% throttle opening and vice versa when the engine need to be turned off. If the value inserted is not compatible with the current engine condition, let say from 10% throttle opening and the user just put the value of 50 in order to reach 50% throttle opening, it will cause strain to the engine and the data gathered might not very accurate.

4.5.2 Instrumental Error

The engine will not be able to generate stable output every time because the engine speed is not in steady phase. It is always changing so the data is not very precise. If the process is repeated several times, the data will not be the same but the difference is quite small. So, the data collected is still acceptable.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

The output of the exhaust system depends on the length of the pipe. By proper choice of the length of the exhaust pipe, the performance of internal combustion engines can be increased. The longer the pipe, the higher the resistance will be. The resistance may be due to the surface roughness of the pipe and also the friction occurred between the moving fluids with the pipe wall. Higher resistance will increase the pressure loss. Pressure loss is a pressure required to overcome the resistance in the pipe.

The calculation had shown that the shorter pipe length give less pressure loss as well as the power required to overcome the loss occurred in the pipe. It also proved by the experiment that shorter exhausts pipe length gives better performance output compared to the longer exhaust pipe. Beside that, the fuel consumption also is less for shorter exhaust pipe due to the less resistance encounter.

In the real world, shorter exhaust pipe is not necessarily better because it depend on what output that we want. Different length will give different high performance data at different engine speed (rpm) value. But, if it is properly tuned, it will increase the engine performance while decrease the fuel usage.

Gasses path flow and number of bend exist in the pipe also influenced the engine output. From the result, it clearly shown that the result for original length (12.8 m) is lower from the others in term of performance characteristic. Besides has one vertical exhaust flow, it also has two bend in its exhaust path flow.

The result for 5.67 m and 8.24 m are almost the same. Even though the 8.24 m pipe was longer than 5.67 m pipe, but the difference is not contributed much to the output. The factor that makes the performance result of 8.24m pipe lower than the 5.67 m pipe was due to the present of bend in its exhaust path flow.

The bend actually slow down the movement of the gas and create high pressure at the bend which increase the resistance in the pipe. This condition increase the formation of backpressure, so more energy is required from the engine to overcome that problem. As the result, the net power or final output of the engine become lesser.

The result might not very accurate due to the error existence. Limitation of the available exhaust pipe length also gives disadvantage to the result gathered. Although the experiment and simulation result did not show much different in term of the result, but it proves that exhaust pipe length have an impact to the power generated.

As for the conclusion, both length and bend influence the engine performance characteristic. The bend give greater impact to the engine performance compared to the pipe length. The more bend exist in exhaust pipe, the lower the engine output will be.

For the recommendation, further study can be perform to get better understanding about the effect of the exhaust pipe length to the engine performance. Effect of exhaust diameter to the engine performance has been studied by many people but it is difference for the exhaust pipe length.

To get better result of the effect of exhaust pipe length, the further experiment can be conducted by using more exhaust pipe length. Let say 5 or 7 difference of length to get better results. Besides that, experiment by using different capacity engine might be help in determining the best possible exhaust pipe length to the specific engine capacity.

The other recommendation is by using different shape of exhaust flow instead of using just straight exhaust flow. For example is using exhaust pipe which in form of ‘Y’ shape or ‘S’ shape. It is because straight flow is not always the best. By using different exhaust path flow, the suitable exhaust piping shape for specific engine capacity can be determined.

The purpose of using different exhaust path flow actually is to examine the relationship between the bend and the engine output. The angle of bend in ‘Y’ shape exhaust should be difference with the angle in ‘S’ shape or from other shape. So, the results from the experiment might tell how much the bend affect the engine output.

The experiment also can be run by applying small scale of rpm increment. It mean that the user increase the engine speed with the 100 rpm or 200 rpm increment. The result that will be obtained will be more accurate.

Even though the exhaust system is just a simple system, but it also can help to boost more power from the engine. According to Mr. Shahrom Wahid, the owner of the Service and Exhaust Center in Kuala Lumpur, properly tune exhaust can give extra power by recover power loss from the engine. Beside help the car to accelerate faster and have higher top speed, it also can contribute to fuel saving.

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APPENDICES

APPENDIX 1 : Experimental data from AutoTest 4

1.1 Experimental data taken from Auto Test 4 for 5.67 m

1.2 Experimental data taken from Auto Test 4for 8.24 m

1.3 Experimental data taken from Auto Test 4for 12.8 m

APPENDIX 2 : Specification of Diesel Engine Test Bed

APPENDIX 3 : Summary of Previous Research