Development of Swirl Generator in Intake Manifold to Increase Engine Performance Port Injection Gasoline Engine

Beny Cahyono[1,*], Taufik Fajar Nugroho[2], Mardji[3] and Rosli Abu Bakar[4]

[1]Department of Marine Engineering, Sepuluh Nopember Institut Technology Of Surabaya, Surabaya, Indonesia

[2]Department of Marine Engineering, Sepuluh Nopember Institut Technology Of Surabaya, Surabaya, Indonesia

[3]Department of Mechanical engineering, State University Of Malang , Malang, Indonesia

[4]Department of Mechanical Engineering, University Malaysia Pahang, Pahang, Malaysia

[*]*Corresponding author's email: cak_beny@yahoo.com*

ABSTRACT— ***The developments for future vehicles are how to reduce fuel consumption, pollutant emission while maintaining high level of engine performance. To deal with those issues, fuel system has been taken great concerns by scientists for a long period of time. As we know, Port Fuel Injection system (PFI) and Gasoline Direct Injection system (GDI) are popular techniques which are being used on commercial vehicles. This paper presents the possible improvement of engine performance by applying swirl generator at port injection gasoline engine. Adding swirl generators to the intake manifold aims to make the airflow more turbulent. The turbulent flow will increase the swirl flow in the combustion chamber. The mixture of fuel with air will also improve. Given these drawbacks, the study analyses the effect of adding a swirl generator to the intake manifold on engine performance, fuel consumption, and emissions produced.***

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

Keywords— port injection gasoline engine, engine performance, swirl flow.

---

1. INTRODUCTION

The main function of an air intake system is to supply the engine with clean air with correct mount for the required air to burn in the manifold chamber. The intake system of an engine has three main functions. Its first and usually most identifiable function is to provide a method of filtering the air and to ensure that the engines receive clean air free of debris. Two other characteristics that are important to the engineers designing the intake system are its flow and acoustic performance. The flow efficiency of the intake system has a direct impact on the power of the engine that is able to deliver. The acoustic performance is important because government regulations dictate the maximum air mass flow level that vehicles can make during a pass-by test. The speed of air generated by the intake system can be a significant contributor to this pass-by filter and separated flow. It may be noted that since the loss pressure from the intake duct towards an atmosphere, this paper assumes the inlet is at the intake manifold and air filter duct, and the outlet is at an atmosphere or environmental pressure (Das & Prasad 2008).

To increase the performance of the engine using ethanol fuel, the best airflow at the intake manifold is required for the combustion. A good intake manifold design allows for a better process of mixing air with fuel. This section will discuss the effect of adding swirl generators to the intake manifold to airflow in a cylinder. Testing is done by using steady state condition. The intake manifold used in the capture of experiments performed on the engine is also used here.
Swirl is usually defined as organized rotation of charge about the cylinder axis; swirl is created by bringing the intake flow into a cylinder with an initial angular momentum. Some decay in swirl occurs due to friction during the engine cycle. Intake-generated swirl usually persists through the compression, combustion, and expansion processes. In engine designs with bowl in piston combustion chambers, the rotational set up during intake is substantially modified during compression. Swirl is used in diesel and stratified charge engine concepts to promote more rapid mixing between the inducted air charge and the injected fuel. Swirl is also used to speed up the combustion process in spark ignition engines.
The second broad approach is to generate swirl within the port, about the valve axis, prior to the flow entering the cylinder, two examples of such helical ports. Usually, with helical ports, a higher flow discharge coefficient at equivalent levels of swirl is obtained, since the whole periphery of the valve open area can be fully utilized, a higher volumetric efficiency results. Furthermore, helical ports are less sensitive to displacement position. In this research, to increase the swirl in the combustion chamber a swirl generator is added to the intake manifold. These modifications will increase the swirl in addition to existing in the combustion chamber, which will even affect the airflow. To determine that effect, this research is done with steady state flow experiment on the flow branch.

2. METHODOLOGY

Research will be done at Mitsubishi 4G92 port-injection four-cylinder gasoline engine, for specification listed in tables 1 and for engine is shown in figure 1. Experiment was conducted in the laboratory on pekan campus of mechanical faculty. To get the data engine power and fuel consumption, engine couple with eddy current dynamometer. Fuel consumption can be measured using the measuring glass and stop watch. This experiment will be done using three different fuels, gasoline, ethanol 10%, and ethanol 20%, which in the run in with 2000 rpm up to 5000 rpm with the increase of 500. Experiment is done with the use of wide open throttle.

Fig 1. Engine and eddy current dynamometer

Table 1. Engine specification

ENGINE PARAMETER	Value
Bore (mm)	81
Stroke (mm)	77.5
Displacement (cm^3)	1.597
Number of cylinder	4
Connecting rod length (mm)	118.1
Max. intake valve open (mm)	7.095
Max. exh. valve open (mm)	7.095
Intake valve open	14^0
Close	58^0
Exhaust valve open	52^0
Close	16^0

Swirl Meter for Flow Bench Testing Cylinder Heads for Intake Air Motion

For years, engine builders have seen heads which flow great on the bench get beat on the dyno and the track by heads with less flow. Obviously there is more to investigate in cylinder heads than just great flow numbers.

Figure 2 Swirl meter apparatus

The swirl meter has been refined steadily with the addition of a three-position switch. At the top position, the display updates every half (0.5) second. In the middle position, the display averages and updates every 5 or 10 seconds. Held in the bottom position, the swirl meter shows the maximum, minimum and average for the 5- or 10-second period. This is useful to assess the stability of the swirl.

Design of Swirl Generator

This research aims to determine the influence of the Swirl generator on the air flow and Swirl pattern testing is done on the third type of swirl generator, which are the concave, flat bottom, and symmetrical, as shown in the picture below. In addition is To attach and to know the influence of angle of water flow and Swirl done by turning angle from the angle generator attach both concave, flat bottom, and the symmetrical. As in the analysis of angle is the angle of 0 degrees, 5 degrees and 10 degrees. This can create a matrix as in Table 2.

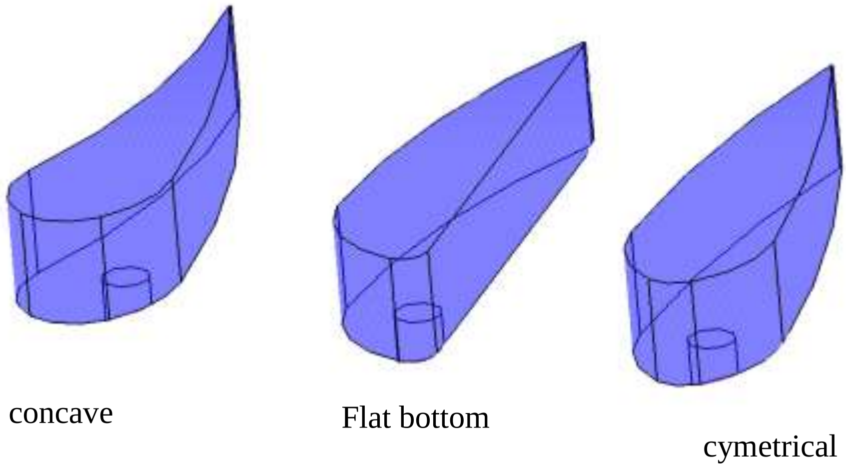


Figure.3. Design of swirl generator

Table 2 Type of swirl generator an angle of attach

Type of Swirl Generator	Degree of angle of attack		
Symmetrical	0	5	10
Flat bottom	0	5	10
Concave	0	5	10

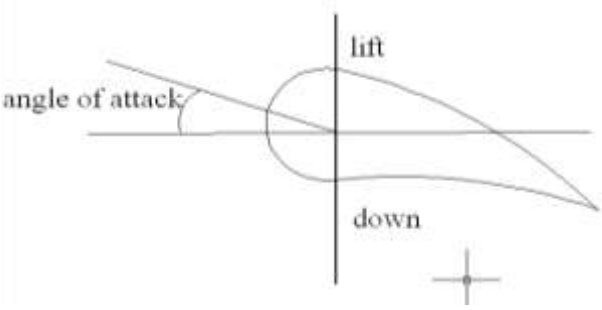


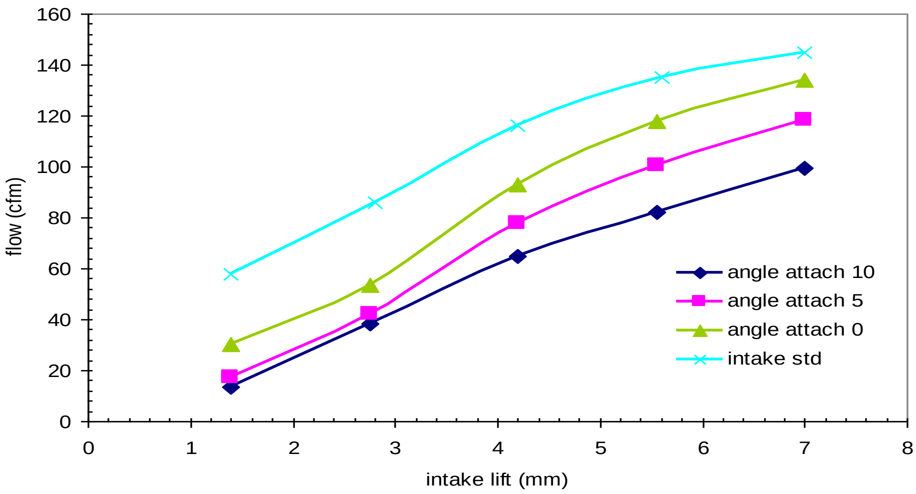
Figure 4. Direction of the angle of attack

3. RESULT AND DISCUSSION

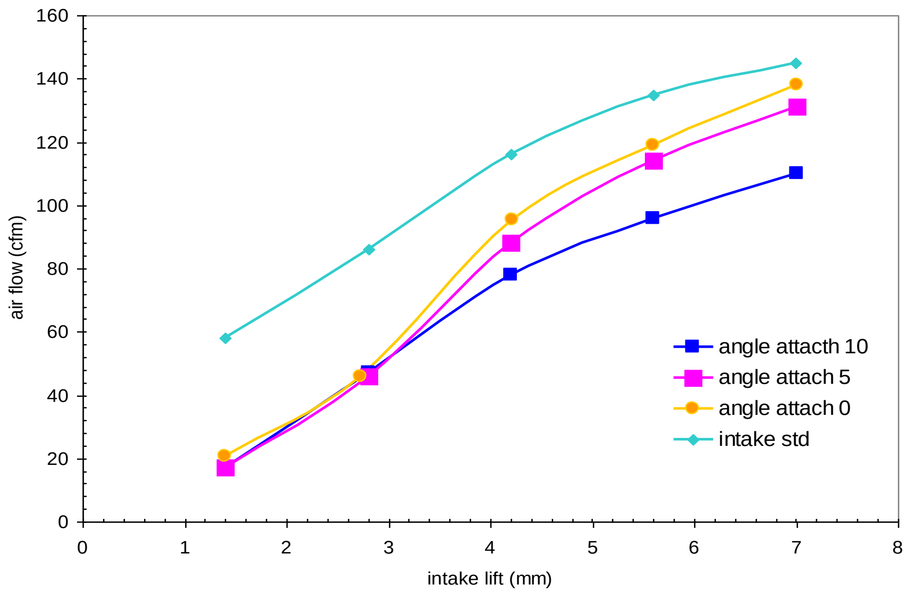
Effect of Swirl Generator Intake Manifold

Effect of Angle of Attacked to Airflow

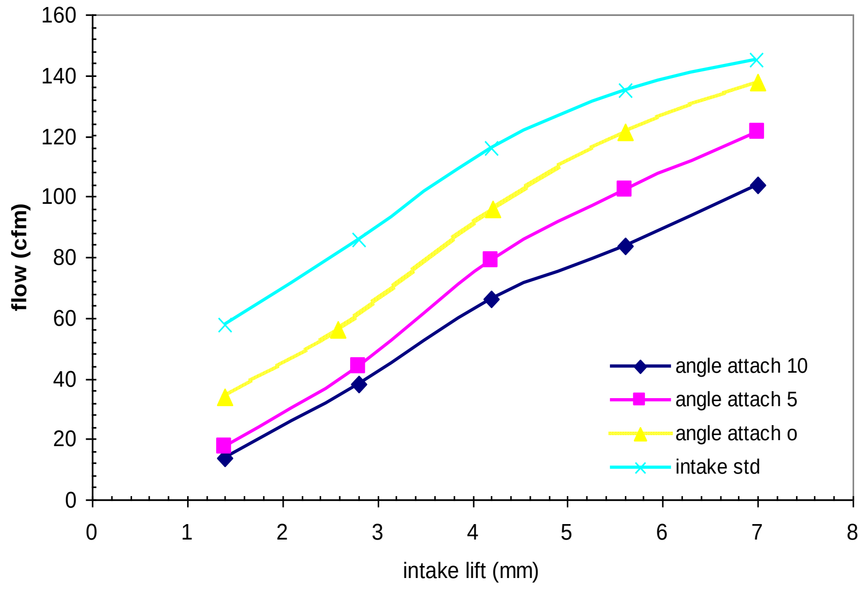
Results of the research on steady flow show the influence of angle attacked to air flow; large angle attack showed a decrease in airflow into the combustion chamber. Increased angle attacks will increase restriction in the intake manifold. Thus, the air flow rate has to be restrained. It applies to all types of swirl generators that are in use.



(a)Flat bottom swirl generator



(b)Concave swirl generator



(c)Symmetrical swirl generator

Figure 5**.** Effect of angle of attack swirl generator at air flow

Figure 5. Shows the effect of adding an angle attack to the airflow into the combustion chamber. The use of three different types of swirl generators and added angle attack greatly affects the amount of air allowed into the combustion chamber. In the three types of swirl generators used, attack angle difference has a profound influence on the amount of air that enters the combustion chamber. At angle attack with 0 degree, swirl generator symmetrical has a smaller resistance. It occurs because as the angle attack 0 degrees the airflow in the intake manifold symmetrical form will create a more aerodynamic flow. For the type of flat bottom, the air through the swirl generator will change the pressure and velocity differences between sides with the others. This event will form a turbulent flow at the rear of a swirl generator. The concave has a more aerodynamic shape than the flat bottom. Therefore, a concave shape to a lower angle attack might result in higher resistance.

The airflow on the concave type had a lower resistance compared with other types. The differences of shape in the swirl generator greatly affect the type of flow and the swirl in the intake manifold. With a flat bottom, increasing the angle will attack greater restriction compared with other types of swirl generators (Figure 6).

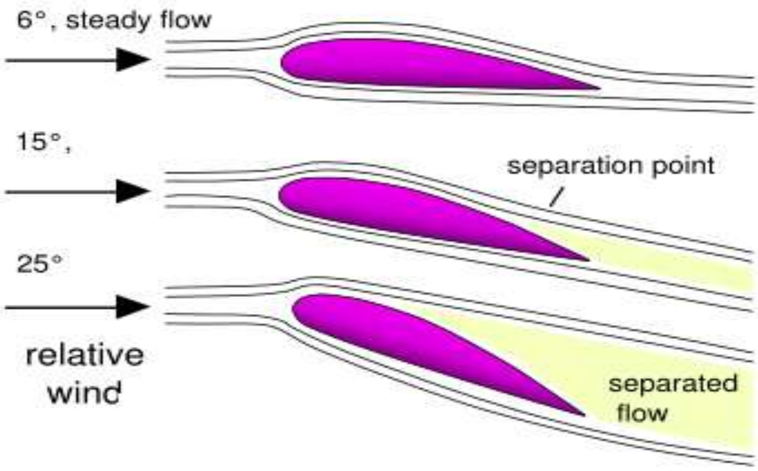


Figure.6: Air flow pattern in rear shape with different angle of attack.

The use of the swirl generator will change the shape of the flow around it. Pressure above the foil will come through an increase in velocity; however, pressure will decrease. Contrary to above of foil, pressures under the foil will increase, whereas speed of flow will decrease. Given these differences, the form of the flow behind the foil will be different from those in front of the foil. The addition of a swirl generator in the form of foil on the back of the foil, the resulting flow will have more turbulence. Turbulence that occurs behind the foil will be higher if the angle attacked the foil on the increase.

Increased angle attack at the swirl generator causes the difference in pressure and flow velocity around the foil to be significantly changed. This condition will result in separation of flow behind the foil. Given this separation, the airflow will have more turbulence. The turbulence flow behind the foil resulted in a higher drag higher drag causes greater restriction of the airflow. Thus, the additional angle attack of the swirl generator reduced airflow in the combustion chamber.

Effect Of Swirl Generator On Brake Torque

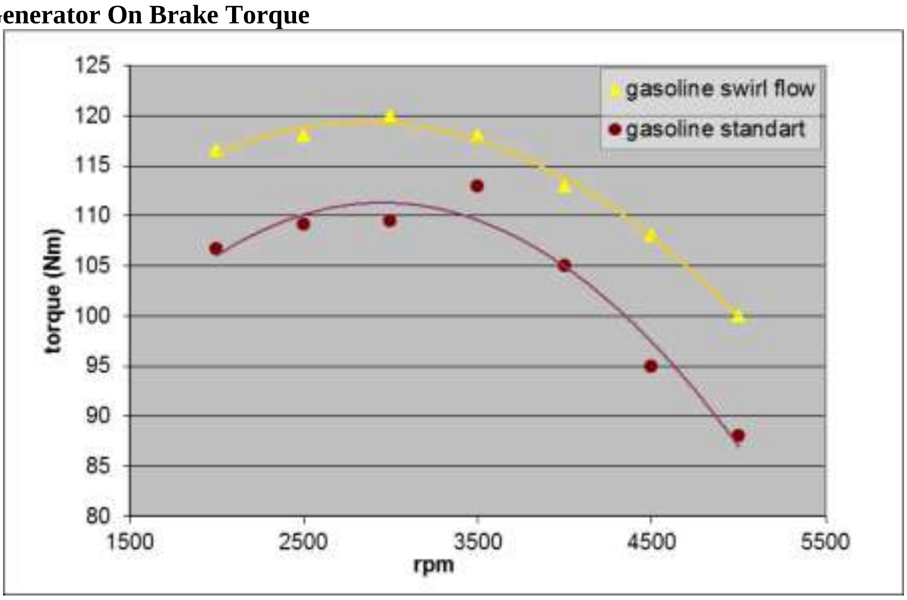


Figure 7. Effect of swirl generators intake manifold to engine torque

Figure above depict the effect of a swirl generator intake manifold on engine torque, The torque is generated by the engines with the standard intake manifold and swirl generator intake manifold at full load and wide open throttle. The engine with a swirl generator intake manifold has a greater torque and better BSFC.

Error! Reference source not found.. 7 showed that the swirl generator intake manifold, produces greater torque. Increases in engine torque are caused by swirl flow and air–fuel ratio. The process of combustion with swirl and turbulence intensity on the mass fraction burned, burn rate, and burn duration. High swirl flow increases burn duration. Swirl flow has an important effect on the engine combustion. According to the increased and maximum value of burn rate increased (Yamaguchi,et al. 1986), this occurs because burn durations of rich mixture are faster than lean mixtures. The flame speed seems to reach its maximum at a slightly rich mixture and falls off on the other side (Stephen 2000). At low values, lambda releases with air–fuel ratio, and the combustion process is both fast and stable; thus, the swirl ratio has only a small impact on burn duration. Furthermore, with higher swirl ratios, most of fuel is distributed near spark plug. Thus, it can be concluded that a higher swirl ratio will have the best stratification and shorter burn duration.

Effect of Swirl Generator on Engine Power

In addition to affecting the generated torque, use of intake manifold swirl generators have a significant effect on the power generated by the engine. At Wide Open Throttle, the power generated by the engine experienced a greater increase in comparison with low speed and at high speed, as shown in figure 7. By operating the engine at the Wide Open Throttle or at high speed, the velocity of air passing through the swirl generator will be higher in comparison with Half Open Throttle. These occur as a result of variation of the air velocity into the combustion chamber; the swirl generated will be higher. Despite the swirl generator, the air resistance increases, but with a swirl of higher engine power it can be improved.

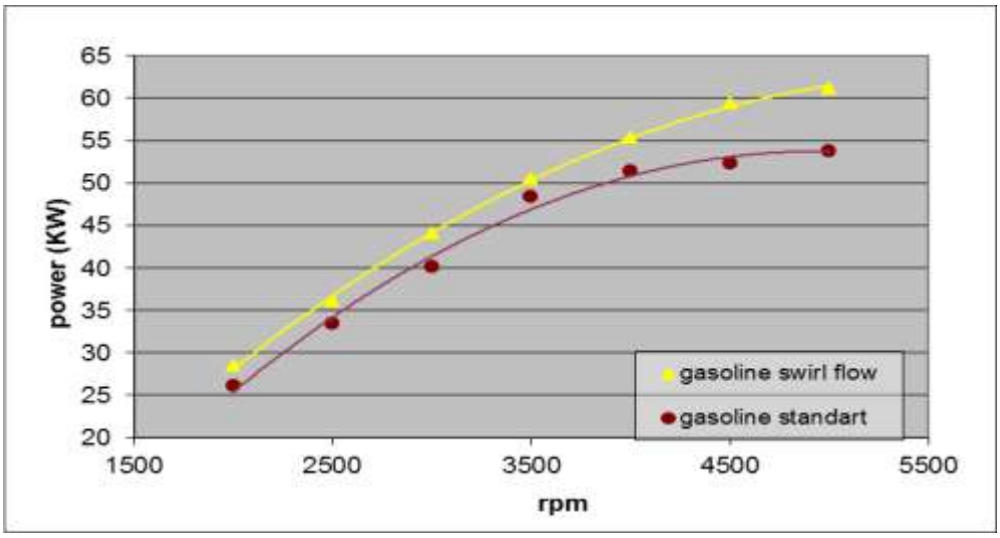


figure 8. Effect of swirl generators at intake manifold to engine power

Error! Reference source not found. illustrates the change of power generated by the engine's swirl generator intake manifold. At low speed, engine power is increases by 9.1% to 12.6% on average; at high speed, engine power increases more significantly by 11% to 13%. The highest increase in the gasoline fuel occurs at an engine speed of 4,500 RPM. Increased engine power and torque in the swirl generator intake manifold is caused by two conditions: the airflow entering into the combustion chamber and the swirl number. The increase is a result of the effect of mixture stratification combined with swirl motion. A faster burning rate occurs with higher oxygen concentration, which indicates more complete combustion.

Effect Swirl Generator Intake Manifold on Fuel Consumption

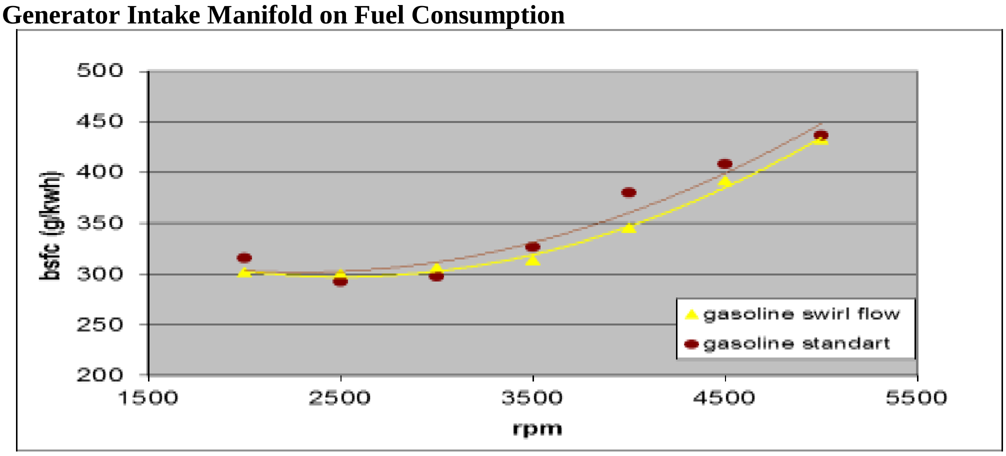


Figure 9. Effect of swirl generators to specific fuel consumption

The BSFC is one of the most important parameters of engine performance. It is a measurement of an engine's efficiency. However, combustion stability increased along with the air–fuel ratio, lengthening the burn duration; large cycle-by-cycle variation caused the BSFC to increase. The swirl generator intake manifold with high swirl charge motion has clearly reduced fuel consumption at Wide Open Throttle and with a high-speed engine.

Increasing swirl flow in the combustion chamber using swirl generator intake manifold resulting combustion process becomes faster. **Error! Reference source not found.**9. shows the swirl generator intake manifold causes engine fuel consumption with gasoline.

Error! Reference source not found. illustrates the differences in fuel consumption at Wide Open Throttle and the low speed and high speed. At low-speed conditions with a swirl generator, the fuel consumption did not change significantly. Fuel consumption decreased with increasing engine speed. This is evident when the engine speed is above 3,000 RPM, resulting in greatly reduced fuel consumption.

At high speed or at With Open Throttle, the addition of a swirl generator has an enormous influence on fuel consumption. Basically, WOT at high speed and fuel mixture in the combustion chamber is better. Furthermore, the addition of a swirl generator in the intake manifold causes airflow into the combustion chamber to be more turbulent. Increasing swirl in the combustion chamber will increase the mixing process of air and fuel; thus, the fuel mixture will be more homogeneous

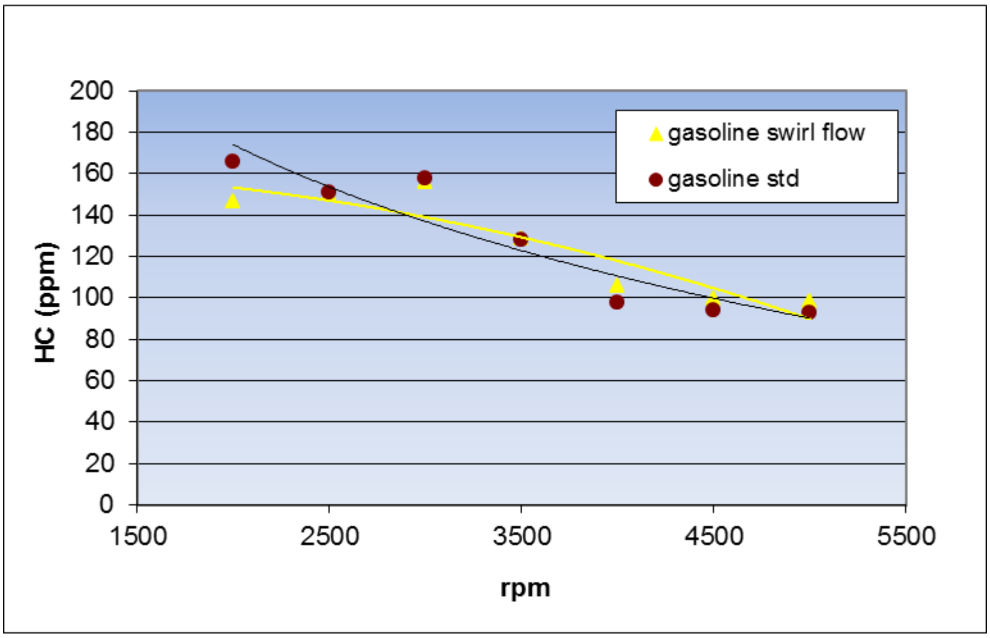


Figure 10. Effect of swirl generators to HC emission at different speed

Figure above illustrates the HC measurement, which is derived from experiments with the standard intake manifold and intake manifold swirl generator. Using a swirl generator in the intake manifold in general produces higher emissions in UHC, CO, and CO2 compared with a standard intake manifold. But at the Wide Open Throttle, the use of the intake swirl generator only increased HC slightly.

The swirl flow is higher, and the rapid combustion process becomes a factor in increasing HC. HC is basically a significant amount when comparing the quenching layer and crevice. Given the more turbulent flow in the intake process, a significant amount of fuel is held in the walls of the combustion chamber. Thus, at the time of disposal processes, that a significant amount of HC exhaust gas will travel through the channel. Of the three types of fuel used in this study, the intake manifold with a swirl generator increased in HC, as shown in figure 10.

The use of the swirl generator on the intake manifold enriches the fuel mixture, as shown in figure 10., where a good engine performance will have a designed air–fuel ratio near the stoichiometric value closer to 15. In addition, a rich air mixture causing a combustion process will produce larger HCs. At high speed and full load, the combustion process will be more perfect with a swirl generator, as the intake manifold reduces the amount of air entering the combustion chamber.

Lean air–fuel ratio excursions can even occur during transient period of operation. However, as the air–fuel ratio increases above the stoichiometric value, the speed and repeatability of combustion deteriorates. Poor combustion is one source of engine HC emissions. It is well known that as the air–fuel ratio of an engine increases above a certain value, the engine HC emission increased rapidly. This is attributed to decreased flame speeds that result in lower peak cycle pressures and, eventually, flame quenching. (Heywood, 1988).

Furthermore, improved combustion and operation with leaner mixtures may also reduce HC emissions from the engine. Two methods are commonly suggested for faster burning. The first is to generate a more turbulent charge motion via the use of intake flow restrictions or combustion chambers with large ‘‘squish’’ regions (Lucas & Brunt, 1982). The second is to increase the flame front area by minimizing the contact between the flame and chamber walls. It requires using a more compact (small surface-to-volume ratio) combustion chamber and moving the spark plug electrodes toward the chamber centre (Poulos & Heywood, 1983).

4. CONCLUSION

This investigation deals the development of the intake manifold with a swirl generator to increase engine performance. The research proceeded with the development of the intake manifold with a swirl generator to get a form that is more turbulent flow in the combustion chamber. The study next focused on the influence of the use of a swirl generator on engine performance. The research was done using a standard intake manifold and an intake with the addition of a swirl generator.

1. The addition of a swirl generator in the intake manifold will reduce the airflow into the combustion chamber; however, the swirl flow that is produced will be increased. The shape and angle of attack of the swirl generator have significant influence to the swirl flow and the amount of air that enters the combustion chamber.
2. The average engine torque increase from 10 until 13 %, in the case of Wide Open Throttle the engine torque increases by 9%.
3. But the emissions generated will be higher in the case of HC at Wide Open Throttle, increasing by 50%.

5. REFERENCES

1. Bayraktar, H. 2007. Theoretical investigation of flame propagation process in an SI engine running on gasoline-ethanol blends. *Renewable Energy*. **32**(5): 758-771.
2. Bogin Jr, G., Chen, J.-Y. and Dibble, R.W. 2009. The effects of intake pressure, fuel concentration, and bias voltage on the detection of ions in a Homogeneous Charge Compression Ignition (HCCI) engine. *Proceedings of the Combustion Institute*. **32**(2): 2877-2884.
3. Ceviz, M.A. 2007. Intake plenum volume and its influence on the engine performance, cyclic variability and emissions. *Energy Conversion and Management*. **48**(3): 961-966.
4. Ceviz, M.A. and AkIn, M. Design of a new SI engine intake manifold with variable length plenum. *Energy Conversion and Management*. **51**(11): 2239-2244.
5. El-Asrag, H., Lu, T., Law, C.K. and Menon, S. 2007. Simulation of soot formation in turbulent premixed flames. *Combustion and Flame*. **150**(1-2): 108-126.
6. Erdil, A., Kodal, A. and Aydin, K. 2002. Decomposition of Turbulent Velocity Fields in an SI Engine. *Flow, Turbulence and Combustion*. **68**(2): 91-110.
7. Guibert, P., Keromnes, A. and Legros, G. An Experimental Investigation of the Turbulence Effect on the Combustion Propagation in a Rapid Compression Machine. *Flow, Turbulence and Combustion*. **84**(1): 79-95.
8. Han, J.O. and Kim, S.S. 1992. Effects of swirl on high-speed combustion in a single-shot optical SI engine. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*. **206**(4): 237-247.
9. Haywood, J. B. 1988. Internal combustion engine fundamental. McGraw-Hill.
10. Hill, P.G. and Zhang, D. 1994. The effects of swirl and tumble on combustion in spark-ignition engines. *Progress in Energy and Combustion Science*. **20**(5): 373-429.
11. Joo, S., Chun, K. and Shin, Y. 2000. Swirl effect on the flame propagation at idle in a spark ignition engine. *Journal of Mechanical Science and Technology*. **14**(12): 1412-1420.
12. Lee, K., Bae, C. and Kang, K. 2007. The effects of tumble and swirl flows on flame propagation in a four-valve S.I. engine. *Applied Thermal Engineering*. **27**(11-12): 2122-2130.
13. Li, Y., Liu, S., Shi, S. and Xu, Z. 1998. The effect of in-cylinder tumble motion on combustion in a four-valve SI engine. *Kung Cheng Je Wu Li Hsueh Pao/Journal of Engineering Thermophysics*. **19**(1).
14. Lucas GG, Brunt MFJ. 1982. The effect of combustion chamber shape on the rate of combustion in a spark ignition engine. *SAE Paper* no. 820165:714–29.
15. Poulos SG, Heywood JB.1983. The effect of chamber geometry on spark-ignition engine combustion. *SAEPaper* no. 830334:1106–29
16. Yamaguchi, K., Yamamoto, H., Shiraishi, T. and Ohsuga, M. 1996. Influence of mixture preparation on HC emission of SI engine with high swirl ratio under cold conditions. *JSAE Review*. **17**(2): 107-112