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INVESTIGATION OF GUIDE VANE SWIRL AND TUMBLE DEVICE TO IMPROVE IN-CYLINDER AIR FLOW FOR COMPRESSION IGNITION ENGINE RUNNING WITH BIODIESEL

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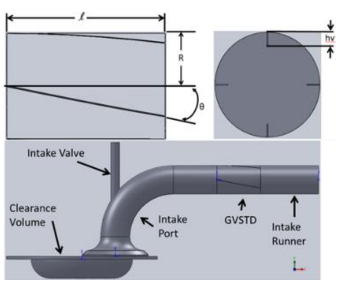
Graphical abstract



Abstract

Biodiesel is expected to become the main alternative fuel for transportation purposes in the coming future as a result of the recession of crude oil. The main advantage that makes biodiesel the first choice as a substitute for petroleum-based fuel is that biodiesel can be used in a compression ignition engine (CI) with minor modification. Unfortunately, with biodiesel, the engine experiences reductions in power and torque, and increases in fuel consumption and carbon deposits inside the combustion chamber mainly due to lower calorific value and heavier molecules present in the biodiesel. One of the solutions to minimize this problem is to increase the in-cylinder air motion and use this to break up the heavier molecules and mix these molecules with air. To achieve this, a high turbulent flow is required inside the cylinder. This paper presents the model of the Guide Vane Swirl and Tumble Device (GVSTD) to develop an organized in-cylinder turbulent flow. The basic model of GVSTD consists of simple fins imposed inside the intake system. Through computer simulations, the results of air flow characteristics are compared with a conventional intake system. The height of GVSTD vanes was varied at 25%, 50% and 75% of the intake runner radius. The results show that in-cylinder velocity, turbulence kinetic energy and absolute pressure at the start of the injection increase around 41%, 6% and 3%, respectively more than the ordinary system which is expected to improve the mixing of biodiesel and air resulting in better combustion.

Keywords: Guide Vane Swirl and Tumble Device (GVSTD), biodiesel, turbulence, in-cylinder flow

1.0 INTRODUCTION

In 2009, Sharma et al. [1] reported that the World Energy Forum predicted that petroleum-based fuel would be enough for another 10 decades only. This prediction can be true based on the recessions of crude oil started in the 1970s [2] and the current situation in petroleum industries where the fuel prices keep increasing every day. The people's awareness about environmental issues is also increasing pushing the government to increase the law regarding the production of emission gases [3, 4]. Based on these facts, the future fuel especially for automotive industries needs to be renewable and have a low emission profile [4].

One of the alternative fuels having these two characteristics is [5-7] biodiesel. Biodiesel was named after its source which comes from a biological compound and its properties which are matched with an ordinary diesel fuel (petroleum-based). Based on the name of biodiesel above, it clearly presents advantages as it is renewable and also can be used directly with minor adjustment to CI engines [8].

Biodiesel can be produced from various types of plants such as corn, cottonseed, peanut and palm oil [8, 9]. Out of these plants, palm oil is looking very promising for producing a better quality biodiesel. Sarin et al. [10] in their research concluded that a jatropha-palm biodiesel blend is an optimum mix for Asia. Reijnder [11] et al. called palm oil-based biodiesel from Malaysia 'environmentally friendly' and considered it as the cleaner biodiesel because it has no sulphur and nitrogen content. Thamsiriroj et al. [12] said that imported palm oil from Thailand provides higher gross and net energy compared to producing biodiesel from indigenous Irish rape seed in Ireland. Al-Widyan et al. [13] and Yu et al. [14] ran a CI engine using waste palm oil after repeated frying of food when it was not suitable to use for human consumption anymore. This evidence shows that Malaysia has high potential to produce a quality biodiesel from palm oil and to become the largest biofuel producer since Malaysia is the largest palm oil producer and exporter in the world [2].

However, overall results from testing the CI engine using biodiesel reported that the engine still produced less performance and increased some of the parameters of exhaust emissions (NOx, smoke opacity etc.) [4, 15], as compared to the standard diesel fuel. These problems actually come from the higher viscosity of pure biodiesel. That means the molecules of biodiesel are heavier making it less prone to evaporate and burn. Many techniques were used to solve this problem such as preheating the fuel to a certain temperature and blending it with ordinary diesel fuel to make its viscosity close enough to ordinary diesel [9, 14]. But it still does not solve the entire problem even though it shows an improvement.

Another method to improve this problem is to increase the in-cylinder air flow. The concept of improving in-cylinder air by using a guide vane is widely used for spark ignition (SI) or known as a petrol engine [16, 17]. Since the behaviors and properties of intake air flow for SI and CI engines are not very different hence it is believed that this technique can work on both engines [18, 19].

By having higher in-cylinder turbulence, the rotating air will break up the heavier molecules of the injected fuel and make it easy to mix with the air eventually improving the combustion and engine performance. Therefore, this project is investigating the effect of installing the Guide Vane Swirl and Tumble Device (GVSTD) in front of the intake port to generate an organized turbulence flow in CI engines.

2.0 METHODOLOGY

In order to investigate the potential of GVSTD to generate higher in-cylinder turbulence, a simulation model was developed because this method allows a better in-cylinder fluid dynamic analysis to be made as compared to an expensive experimental method.

The simulation model was drawn by using SolidWork 2010 (Figure 1) and the computational fluid dynamic (CFD) analysis was conducted using ANSYS-CFX 14.1. The basic engine simulation model was designed according to HINO 4OWD diesel-generator engine and the engine specification is tabulated in Table 1 The set-up of the internal engine CFD simulation was published by ANSYS INC. [20] and widely accepted and was referred to in this research to develop the engine simulation model. The mathematical models used to calculate the in-cylinder TKE, velocity and pressure are the preset equation in ANSYS-CFX [20] for ideal gas equation of state.

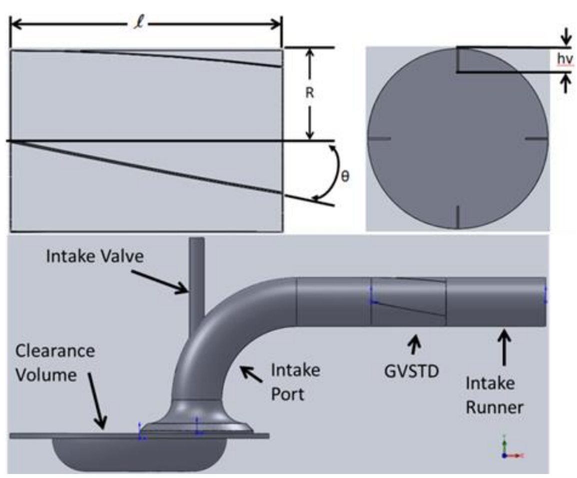


Figure 1 Basic drawing of GVSTD model

Referring to the patented designs of guide vanes published by various inventors and compromising the advantages and disadvantages of those designs to suit the CI engine, this project designed the GVSTD as its specification shown in Table 1 and illustrated in Figure 1.

This project was also interested to examine the effect of vanes of various heights on the air-flow characteristics. Three GVSTD models with height of the vanes set at 25%, 50% and 75% of the intake radius (R) were developed and simulated. All results of GVSTD models are compared with the base model and presented in the next section.

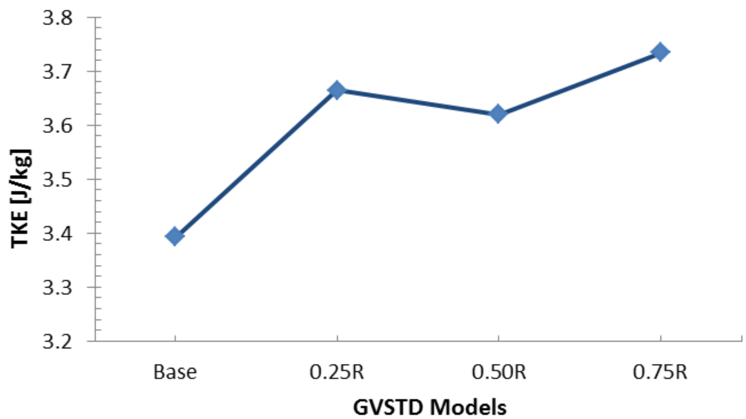


Figure 2 TKE at SOI versus GVSTD Models

3.0 RESULTS AND DISCUSSIONS

Referring to the CI combustion theory [21], the fuel is injected into the cylinder and mixed with the air for some time before auto-ignition occurs and burns the fuel to produce engine power. In order to improve the combustion efficiency, the atomization of the fuel needs to be improved allowing more air-fuel mixing to enhance the combustion.

As explained in the introduction, biodiesel has a problem of high viscosity, hence breaking up the fuel molecules is really important to solve the problem of the CI engine using biodiesel especially at the start of injection (SOI). Therefore this paper presents the results of turbulence kinetic energy (TKE), velocity and pressure at SOI to evaluate its characteristics to achieve the project objective.

When the fuel is injected into the cylinder, it will interact the air in turbulent form. The higher turbulence can break up more fuel molecules allowing more mixing and increasing the rate of combustion. Referring to Figure 2, higher TKE is developed by using GVSTD. This figure also shows that 0.75R which had the higher surface area of the vanes gave the highest TKE. Figure 3 shows the in-cylinder velocity at SOI for all models and it found that 0.50R gave the highest velocity. This higher velocity will help spread the fuel mixture from the injected fuel cone after it was broken up by TKE.

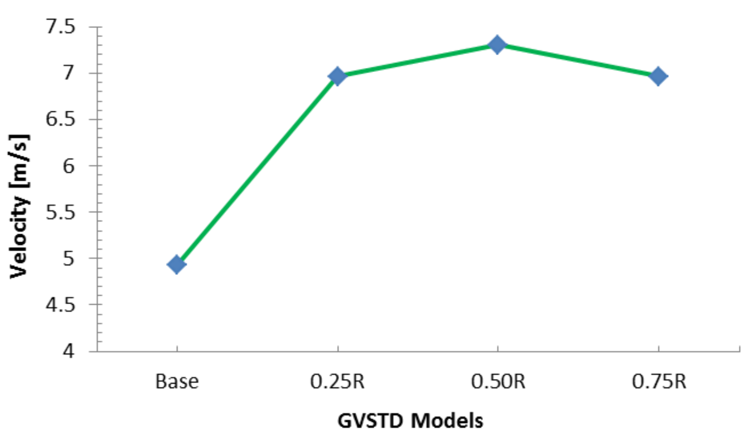


Figure 3 Velocity at SOI versus GVSTD Models

As for Figure 4, the highest in-cylinder pressure occurs at 0.25R. Higher in-cylinder pressure will increase the resistance of the injected fuel to penetrate inside the turbulent air. This situation will make the fuel spray wider than lower in-cylinder pressure eventually making a wider combustion area. A wider combustion area allows more fuel to be burnt resulting in higher combustion efficiency and reducing fuel consumption.

As for the selections of vanes height, this research acknowledge that 0.75R model with vane height of 0.75 times the radius of intake runner is the optimum one. This is due to highest in-cylinder TKE, and better in-cylinder velocity and pressure than the base model provided by this vane.

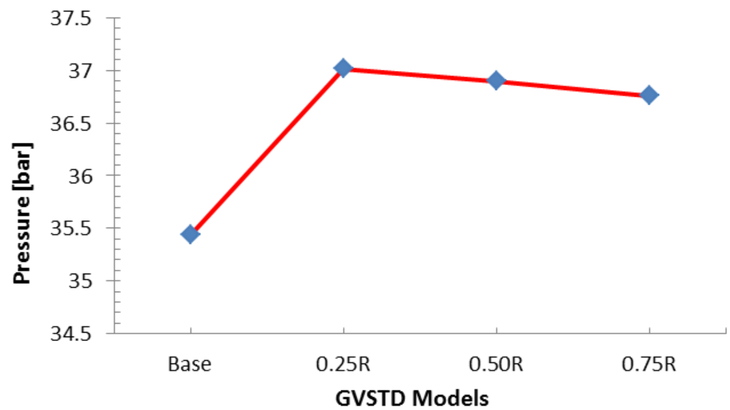


Figure 4 Pressure at SOI versus GVSTD Models

Table 1 Specification of the engine model and GVSTD

Engine Parameters		GVSTD	
Bore x Stroke	104 x 108 mm	Number of Vanes	4
Compression Ratio	17.9	Blades Twist Angle (θ)	35° Clockwise
Engine Speed	1500 rpm	Radius of Intake Runner (R)	10 mm
Start of Fuel Injection	14°	Length of the Vanes (l)	3 × R = 30 mm
		Height of the Vanes (hv)	0.25R = 2.5 mm
			0.50R = 5.0 mm
			0.75R = 7.5 mm

4.0 CONCLUSION

Based on the presented results, it can be concluded that GVSTD is a suitable candidate in improving the CI engine performance using biodiesel since in-cylinder TKE, velocity, and pressure at SOI are higher than the standard engine configuration. These parameters are expected to improve bulk turbulence to break up the heavier molecules of biodiesel and enhance the combustion, eventually, increasing engine performance. Based on the results presented above, this research found that 0.75R height model is the optimum height of the vane.

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