

Investigation into the Selection of an Appropriate Piston Head Geometry for a Spark Ignition Engine Equipped Direct-Fuel Injector

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ABSTRACT

Constructors of gasoline engines are faced with higher and higher requirements as regards to ecological issues and an increase in engine efficiency at a simultaneous decrease in fuel consumption. Satisfaction of these requirements is possible by the recognition of the phenomena occurring inside the engine cylinder, the choice of suitable optimal parameters of the fuel injection process, and the determination of the geometrical shapes of the combustion chamber and the piston head. The aim of the study was to simulate flow in Direct-Injection Fuel engine with different geometrical shapes of piston head. The method of design piston head shapes was referring to existing motorcycle Demak single cylinder 200cc piston size using Solidwork and ANSYS softwarse. The parameter was shallow and deep bowl design on piston head. In term of fuel distribution throughout the combustion chamber, second model that having deeper bowl shows a better fuel distribution than first model as it manages to direct flow the fuel injected towards the location of spark plug. Therefore, second model is chosen as the best model among the two models as it can create a richer mixture around the spark plug.

Keywords:

Direct-Injection, CFD simulation, Piston Head Geometry, Stratification Combustion, Spark-Ignition.

1. INTRODUCTION

The GDI engines are proven to be more advantageous as compared to any other conventional SI engines. The two combustion modes that are homogeneous combustion mode and stratified combustion mode introduced in the GDI engines help to improve the accuracy of Air-Fuel, AF ratio during dynamics and decrease the fuel consumption and CO₂ emission [1-3]. With the injector installed inside the combustion chamber and its non-throttle

operation the engine can achieved higher power output.

Aside from the in-cylinder direct injection, GDI engine has another special feature that is the unique piston top surface shape of the GDI engine. The piston top surface shape plays an important role of determining the behavior of the air-fuel mixture inside the combustion chamber. Commonly, the piston surface of GDI engine is equipped with a piston bowl and the bowl design is mostly determined by its bowl radius, bowl depth, bowl width, bowl location relative to the spark plug [4-5].



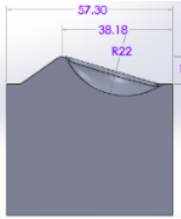
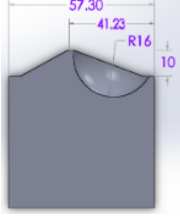
The piston top surface is designed in such way that it will be compatible for both homogeneous combustion mode and also the stratified combustion mode. For the homogeneous combustion mode, the piston top surface plays the role to create a homogeneous mixture of the fuel and air before the combustion. Whereas, for stratification combustion mode, the piston top surface has the responsibility to form a stratified-charge rich fuel cloud around the spark plug [6-7].

2. METHODOLOGY

2.1 Building Models

For this study, a total of two models were built with each of the models is having different types of parameters. The parameters to be varied in this project are mainly focused on the bowl's radius and the bowl's position on the piston top (Table 1). The models were built based on common GDI engine's piston design by using Solidworks software. In term of the piston design measurement, it is adjusted so that the piston will be compatible with the Demak engine with respect of the piston's bore and stroke.

Table 1: Piston design model

Model	Model 1	Model 2
Design		
Measurement		

2.2 Creating flow volume

After combining the piston with the cylinder head, a cavity exist inside the combustion chamber. For the simulation purpose, the cavity inside the combustion chamber has to be replaced with a flow volume first (Figure 1). The flow volume serves as the flow path of the mixture inside the combustion chamber. The flow volume can be created by using the Combine feature in Solidworks software.

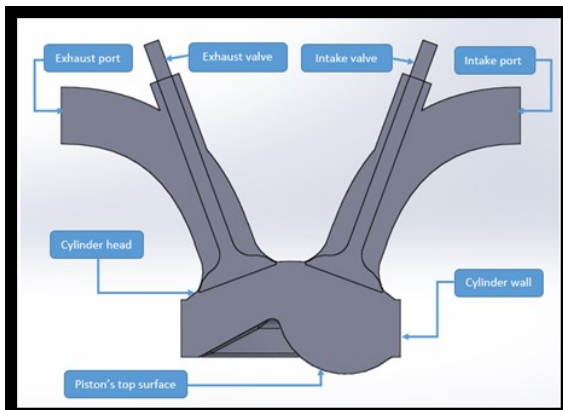


Figure 1: Flow volume and the required parts for the flow volume

2.3 Setting up IC Engine Properties

The engine properties are defined in the ICE properties after IC engine analysis has been selected from the analysis systems toolbox. In the ICE properties, input data such as the simulation type should be included. There are three types of simulation provided for the ICE engine simulation which are cold flow simulation, port flow simulation and combustion simulation. Out of the three simulation types, the combustion simulation is chosen for the simulation type of this project since spray injection has to be included in the study. Basic engine properties such as the engine's connecting rod length, crank radius, engine speed, minimum valves lift and the valves lift profile should also be defined (Table 2).

Table 2: Basic engine properties

No.	Property	Value
1.	Simulation type	Combustion simulation
2.	Combustion simulation type	Full cycle engine
3.	Connecting rod length	90 mm
4.	Crank radius	30 mm
5.	Engine speed	2000 RPM
6.	Minimum valves lift	0.2 mm

2.4 Decomposing geometry

The flow volume generated is imported to the Ansys Fluent software. The first step before the simulation process is carried out is to decompose the model geometry. When a model is decomposed, the model imported will be divided into smaller volumes where these volumes are compulsory as the mesh requirement in the meshing process. For that, the geometry of the model has to be designed in such way that each small volume can be generated during the geometry decomposition.

Before decomposing the model, some parts of the model need to be defined first such as the inlet, outlet, intake valve, exhaust valve, intake seat and exhaust seat. Since the scope of the study is focused on the fuel injection during the compression stroke, the model is decomposed at 644° CA just before the fuel is injected in the combustion chamber during the compression stroke.

2.5 Meshing

Once the model has been decomposed, meshing process is done. Mesh will be generated individually based on the small volumes of the model geometry created when the model is decomposed. For the analysis, dynamic mesh is conducted.

2.6 ICE Solver setting

ICE solver setting is divided into several parts where in each part, some settings are required for the model. Basically, the ICE solver setting is configured to set the relevant input data required for the simulation. Some example of the input data (Figure 2) are the engine type, fuel type, fuel injection, boundary conditions of the analysis and the type of result required at the end of the simulation (Table 3 & 4).

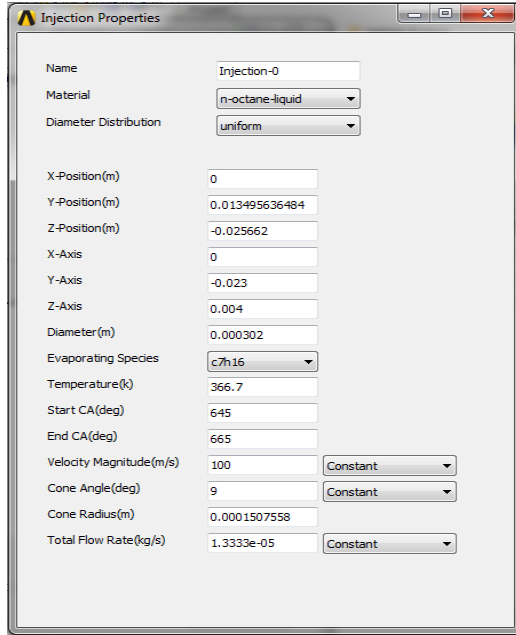


Figure 2: Data input for injection setting [8]

Table 3: Temperature of the combustion chamber wall [8]

Part	Zone	Boundary condition
Head	cyl-head, invalve1-ch, and exvalve1-ch	485 K
Piston	piston	485 K
Liner	cyl-tri	500 K
Exhaust valve	exvalve1-ib, exvalve1-ob, and exvalve1-stem	777 K
Exhaust port	exvalve1-port and exvalve1-seat	485 K
Intake valve	invalve1-ib, invalve1-ob, and invalve1-stem	400 K
Intake port	invalve1-port and invalve1-seat,	313 K

Table 4: Temperature and pressure of the mixture inside combustion chamber [8]

Part	Zone	Pressure	Temperature
Exhaust port	fluid-exvalve1-port, fluid-exvalve1-vlayer, fluid-exvalve1-ib	0.5 MPa	1070 K
Inlet port	fluid-invalve1-port, fluid-invalve1-vlayer, fluid-invalve1-ib	0 Pa	313 K
Chamber	fluid-ch	1 MPa	1070 K

2.7 Running the simulation

Ansys Fluent will set the relevant number of time-steps and iterations to be calculated for the simulation process to complete. For every one iteration, 30 time-steps are calculated. As an optional choice, to decrease the amount of time consumed in the simulation, the continuity of the calculation is increased to 0.1 and the number of time-step is increased to 1. The total iteration required for the simulation to complete is 3280

iterations where each of the iteration takes a maximum of 50 time-steps. Once every setting is done, the last step is to calculate the simulation. The simulation process can take days to complete depends on the number of iterations provided.

3.0 RESULT AND DISCUSSION

3.1 Swirl ratio

As depicted in Figure 3, Model 1 shows the highest swirl intensity compare to Model 2. This is because Model 2 has higher surface area compare to Model 1 due to its larger piston bowl radius and also the depth of the piston bowl which is deeper than Model 2. This high surface area is creating a high friction to the mixture flow when it comes in contact with the cylinder wall especially at the piston bowl region which in turn resisting the swirl motion inside the combustion chamber of Model 2.

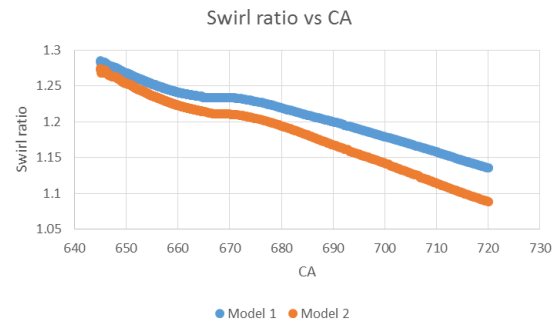


Figure 3: Swirl ratio generated in the combustion chamber of model 1 and model 2

3.2 Tumble ratio

The tumble ratio generated in combustion chamber of all the models tested starts with a negative value and continuously decreasing. However, the negative value does not indicate that the tumble intensity is decreasing but it indicates the direction of the tumble motion of the mixture which is being directed to the exhaust side of the combustion chamber. The figure shows that the intensity of the tumble motion is increasing in a certain direction along the increasing of CA.

The tumble intensity of Model 1 is higher than Model 2 (Figure 4). The major factor that contributes to the turbulent intensity is the piston bowl design where with the right design the piston bowl can help to promote the tumble motion. The right piston bowl design also can help to determine the direction of the mixture throughout the combustion chamber.

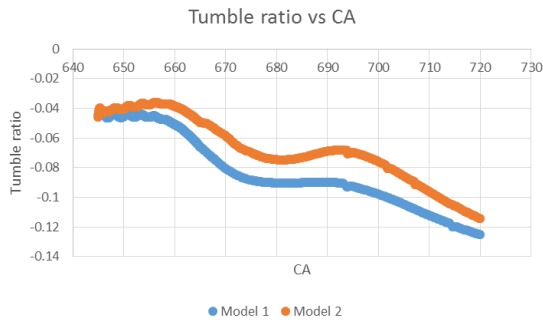


Figure 4: Tumble ratio generated inside the combustion chamber of the Model 1 and Model 2

3.3 Total Kinetic Energy (TKE)

The TKE of Model 2 is the highest among the two models (Figure 5). Due to deeper bowl depth and curvier piston bowl, the piston bowl of Model 2 tends to create vortices with much higher speed than speed of vortices created by piston bowl of Model 1 during the compression stroke. These high speed vortices, in time are colliding against each other to create high turbulent intensity inside the combustion chamber.

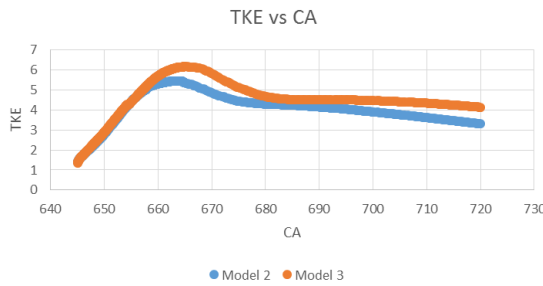


Figure 5: Graph of mass-average of turbulent kinetic energy (TKE) of the two models vs the crank angle

3.4 Pressure

The pressure generated inside the combustion chamber of Model 1 is slightly higher than the pressure in Model 2 (Figure 6). This slight difference is mainly due to the different of compression ratio for both model which is caused by different parameters of the piston models that have different bowl radius and bowl position. Model 1 has a compression ratio of 9 whereby the compression ratio for model 2 is 8.5. The bowl radius is affecting the clearance volume, V_c of both models and thus the compression ratio.

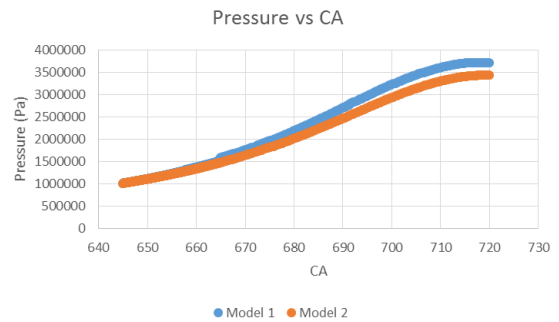


Figure 6: Generated pressure in combustion chamber of Model 1 and Model 2

3.5 Fuel particle traces

Model 1 fails to create rich mixture around the spark plug which is the most important requirement for stratified combustion (Figure 7). Furthermore, this piston design will end up to increase the fuel consumption and produces much lower power output due to unevenly fuel distribution.

For Model 2, when fuel is injected, it travels along the curve part of the piston bowl and in the end it is directed to the center of the combustion chamber where the spark plug is located (Figure 8). This behavior is preferable for stratified combustion since the fuel injected will form a rich mixture around the spark plug. However, there is also a portion of the fuel is being directed back to the intake side. Because of this, the consumption of fuel during combustion cannot be optimized.

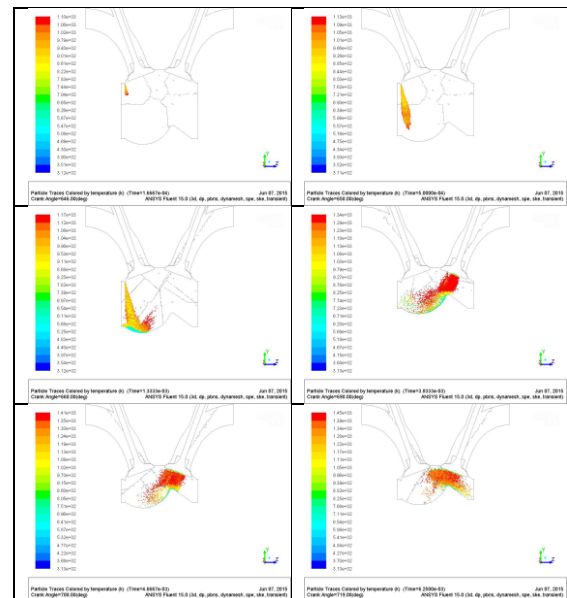


Figure 7: Fuel particle traces of Model 1

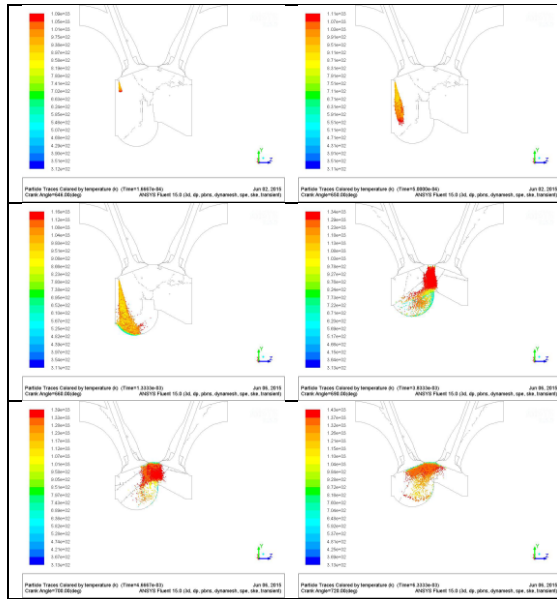


Figure 8: Fuel particle traces of Model 2

4. CONCLUSION

Based on the results obtained from the simulation, both models have their own advantages and disadvantages. For Model 1, the result indicates that it has higher swirl and tumble intensity compare to Model 2 whereas Model 2 has higher TKE value than Model 1. However, the result of swirl ratio, tumble ratio and TKE does not really show a significant difference between the two models. For the fuel distribution throughout the combustion chamber, Model 2 is better than Model 1 since the piston bowl of Model 2 directs the fuel axially towards the center of the combustion chamber where the spark plug is located. This behavior of model 2 design that have deeper bowl is much preferable for stratified combustion mode.

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