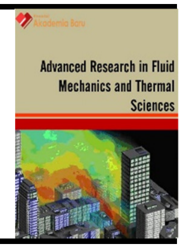
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 52, Issue 2 (2018) 198-204

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Numerical Simulation of Spark Ignition Engine with Pre Combustion Chamber (PCC)

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ARTICLE INFO

Article history:
Received 13 October 2018
Received in revised form 2 December 2018
Accepted 10 December 2018
Available online 12 December 2018

Keywords:
Pre-Combustion Chamber, SI Engine, Natural Gas, Cold Flow Simulation

ABSTRACT

In this paper, a numerical model of a spark ignition (SI) engine was developed to simulate the effect of pre-combustion chamber (PCC) on the dynamics flow inside the engine. Four concept designs of PCC were used in this simulation. The single cylinder SI engine model and PCC were generated by using CATIA V5 R21 software. The SI model is based on Loncin G200F (D) engine generator. After that, cold flow simulation is used to analyze each type of the PCC powered with natural gas fuel by ANSYS Fluent 16.0 simulation software. Each of the PCC simulation investigated by its flow behavior for the velocity vectors and turbulence kinetic energy (TKE). This PCC can give bigger effect to the engine performance by 10% - 15% using natural gas as the fuel source. The result revealed that PCC1 is the best concept design of pre-combustion chamber as it generates highest velocity vectors and TKE.

1. Introduction

It is widely known that fossil fuels (petrol and diesel) are non-renewable source and it reserves around the world are limited. Besides, the demand of hydrocarbon fuels source made the fossil fuel price increases. The emission from combustion of this fuels are harmful and become an issue for health and global climate change. As a result, many countries have strict regulations for limitation of exhaust gas emission from vehicles [1-3]. Compressed Natural Gas (CNG) was chosen as alternative fuel due to many reasons such as high-octane number which mean it can operate in high compression ratio engine [4]. Moreover, it has low carbon/hydrogen ratio. Hence, it emits smaller amount of CO_2 emission compared to any other hydrocarbon fuels [5]. Besides, the price of CNG is lower than fossil fuels.

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However, CNG has main problem which is it produced lower performance. Gaseous fuels are low in volumetric efficiency than liquid fuels [6]. Liquid fuels produce an evaporative cooling on intake charge during vaporization as they have latent heat of vaporization. In other hand, CNG does not have evaporative cooling due to physical properties of gas which is it vapor in ambient temperature. As result, the volumetric efficiency of gaseous fuels is low compare to liquid fuels [7]. CNG also has lower mixture density than liquid fuels. This cause the heat transfer rate of CNG become low because low density will produce low amount of burned fuel and also create less temperature during the ignition stage. This condition explained why the heat transfer rate of CNG is lower than liquid fuels [6].

The problems related to CNG engines have been concern nowadays. CNG fuel give a great deal as the alternative fuel for the future. Many researches on CNG engine have been conducted to enhance its performance. Tahir *et al.,* [6] and Gharehghani *et al.,* [8] reported power output of CNG lower that gasoline. One of the research is by adding or mixing hydrogen in the CNG. Hora and Agarwal [9] investigated the benefic potential of hydrogen enriched compressed natural gas (HCNG) in CNG engine. They found that HCNG increases power output, torque and lowering emissions. In addition, Wang *et al.,* [10] discovered hydrogen addition can increase the power output at large exhaust gas recirculation (EGR) operation.

One of the solutions to improve the performance of CNG is by using pre-combustion chamber (PCC). It mainly functions to create the turbulence for the air and fuel to be properly mixed. The steady rate of burned fuel in pre-combustion chamber creates a uniform increment of pressure in cylinder as it flows into combustion chamber [11-16].

Esfahanian *et al.,* [17] studied the engine concepts of both conventional Homogenous Charge Compression Ignition (HCCI) and Premixed Charged Compression Ignition (PCCI) with a pre-chamber using a multi-dimensional CFD modeling tool coupled with a chemical kinetics solver (AVL Fire-CHEMKIN) is utilized to simulate the performance and emissions of the engine. The results reveal that the PCCI case has the earliest start of combustion. It is also shown that in the ultra lean operating conditions (fuel equivalence ratio of 0.1) decreasing the intake temperature from 450 K results in an efficiency increment for the PCCI engine, while for the HCCI case this causes misfiring and more CO emission. Nevertheless, the PCCI engine has higher levels of NO emission compared to the HCCI cases [18].

This main objective of this research to model the problem related to the CNG which is it lower performance compared to fluid fuels. This research simulates cold flow simulation only. It means, the flow in the engine do not include reacting of the species and combustion. Besides, the simulation take place on the power stroke which is the flow will begin in the PCC and end in the engine cylinder.

2. Methodology

In this study, ANSYS Fluent is utilized to create the numerical model of the gasoline engine with pre-combustion chamber. The developed Computational Fluid Dynamics (CFD) model is utilized for cold flow simulations of four different PCC designs as the manipulated variables.Three dimensional (3D) solid geometry of a spark ignition (SI) engine with a single piston is first drawn using CATIA V5. The geometry dimension is based the real single cylinder generator engine namely Loncin G200F.

2.1 Design of Three-Dimensional (3D) Spark Ignition (SI) Engine and PCC Geometry

The engine and PCC as shown in Figure 1 and Figure 2 are draw using CATIA V5R21 software. The process making 3D geometry starts with estimation of all parts included the intake and exhaust valve, cylinder head, piston, and combustion chamber. This research included four difference types of PCC design, which will be installed to the drawn engine model.

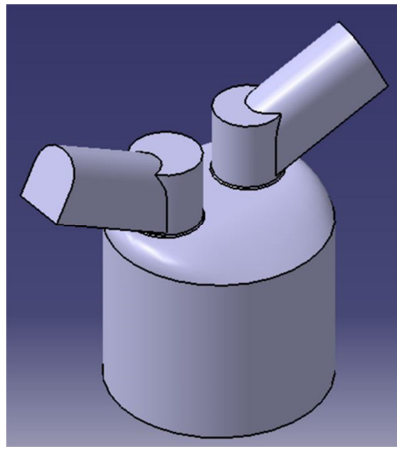
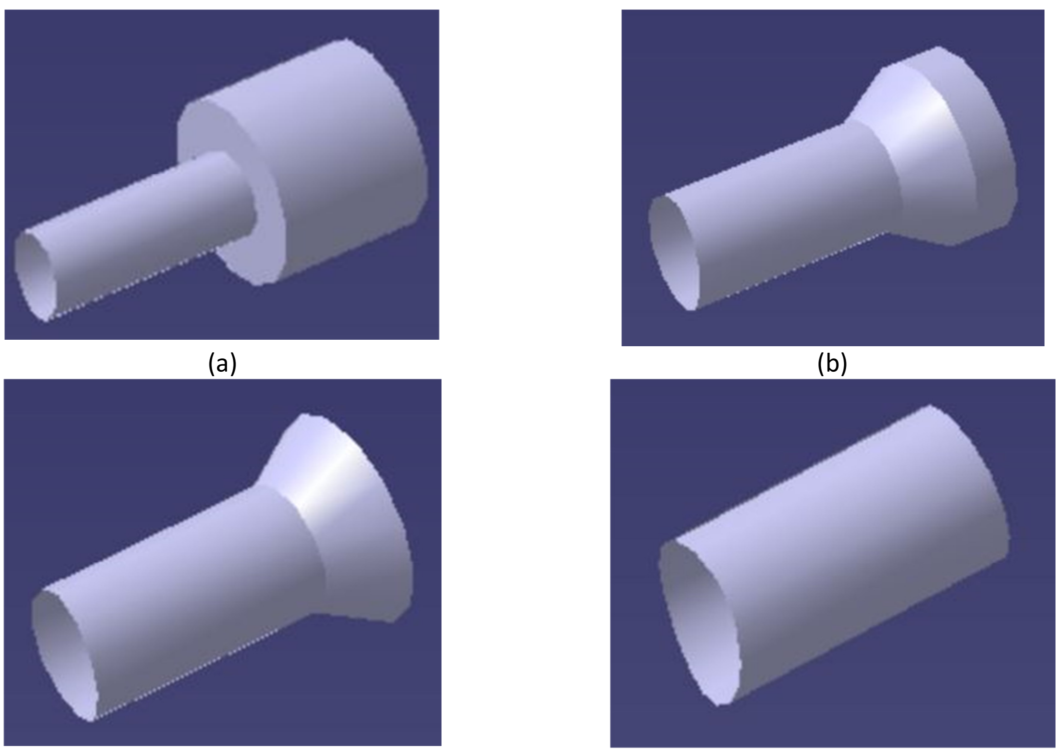


Fig. 1. Engine model generated using CATIA V5 R21



(a) (b) (c) (d)

Fig. 2. PCC design generated using CATIA V5 R21. (a) PCC1 (b) PCC2 (c) PCC3 and (d) PCC4

2.2 Meshing

Once the geometry model is completed, it is the imported into ANSYS Design Modeler for meshing process as shown in Figure 3. The model will be defined for the details of inlet face, outlet face, wall chamber and fluid.

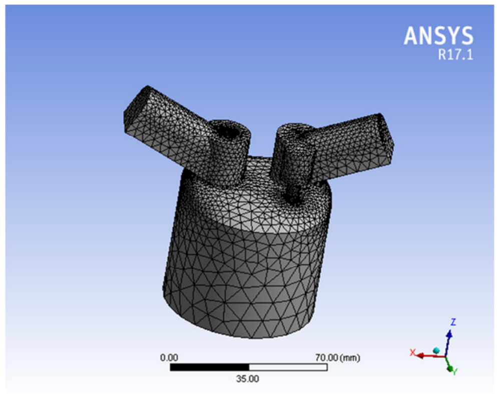


Fig. 3. Engine model meshing design

2.3 Boundary Condition

Boundary condition are essential step to run a simulation. There were five boundaries zone where the cells are grouped in. These boundaries are inlet, outlet, wall chamber, wall inlet and fluid zone. The boundary conditions for this study were set-up as stated in Table 1. This study was run under steady state simulation.

Table 1
Boundary Condition

Parameters	Conditions
Inlet pressure	101.3 kPa
Outlet Pressure	0 kPa
Methane-Air mixture Velocity	10 m/s
Methane-Air mixture Temperature	300 K
Hydraulic diameter	29 mm
Turbulence Intensity	5 %

2.4 Solver Setting

For the model boundary, the incompressible Navier-Stokes equations under k-ε two-equation was chosen as the turbulence model. This model independently calculates turbulent viscosity and a length scale using two equations related to the kinetic energy of the turbulence, k and the rate of dissipation, ε. The SIMPLE algorithm is utilized for the pressure-velocity coupling.

3. Results and Discussion

3.1 Velocity Vectors

Results were analysed from the cold flow of natural gas in four different designs of pre-combustion chamber. The results were presented in graphical views. Figure 4 shown the velocity vectors for PCC1, PCC2, PCC3 and PCC4 in Figure 4(a), Figure 4(b), Figure 4(c) and Figure 4(d) respectively. The velocity vectors of the flow at each of designs of pre-combustion chamber were analysed to determine the swirl pattern of the flow and also the maximum velocity vector of the flow.

Regarding to Figure 4, the maximum velocity vector of PCC1, PCC2, PCC3 and PCC4 are 91.89 m/s, 42.73 m/s, 43.69 m/s and 15.80 m/s respectively. It shows that PCC1 generates the highest maximum velocity vector. Although, the velocity vector of PCC1 decrease dramatically as it flows downward, it has highest minimum velocity vector which is 22.97 m/s. It is due to small outlet diameter of PCC1. Thus, PCC1 is best design of PCC based on the velocity vector profile. This velocity vector can show the fluid flow pattern in the engine.

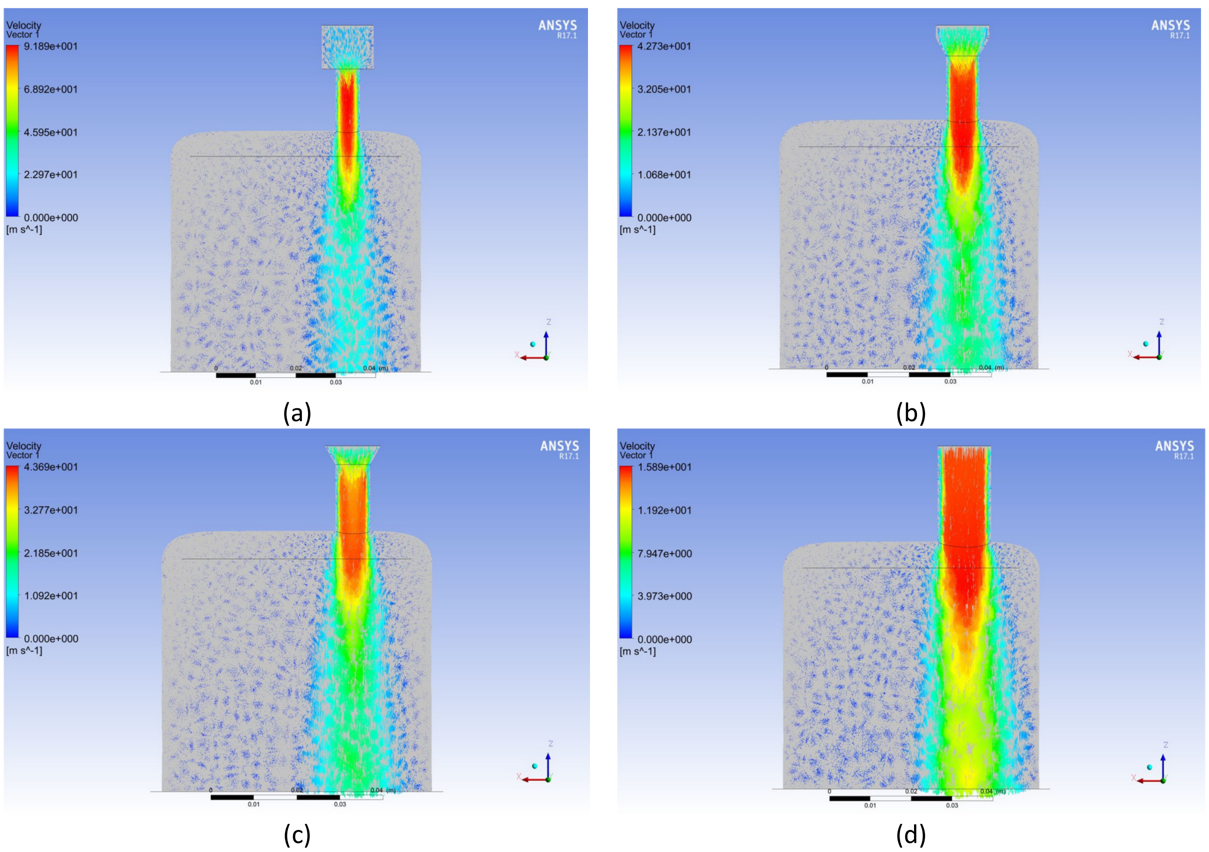


Fig. 4. Velocity vector of engine model with PCC. (a) PCC1 (b) PCC2 (c) PCC3 (d) PCC4

3.2 Turbulence Kinetic Energy (TKE)

From the results of kinetic rate of reaction shown in Figure 5, there are different place of flow propagation happened in different designs of PCC. The irregularity of flows is represented by turbulence and it is good for mixing of air and fuel and help to increase the combustion rates. By referring the Figure 5, the brightest color indicates higher value of Turbulence Kinetic Energy (TKE).

Figure 5 shown the velocity vectors for PCC1, PCC2, PCC3 and PCC4 in Figure 5(a), Figure 5(b), Figure 5(c) and Figure 5(d) respectively. The maximum TKE of PCC1, PCC2, PCC3 and PCC4 are 363.8 m^2/s^2, 24.27 m^2/s^2, 29.45 m^2/s^2 and 4.371 m^2/s^2 respectively. Hence, PCC1 has the highest maximum TKE compare to the others PCC. Besides, PCC1 also has highest minimum TKE which is 8.118×10^{-3} m^2/s^2 compare to PCC2, PCC3 and PCC4 which are 3.462×10^{-3} m^2/s^2, 3.264×10^{-3} m^2/s^2 and 1.106×10^{-3} m^2/s^2 respectively.

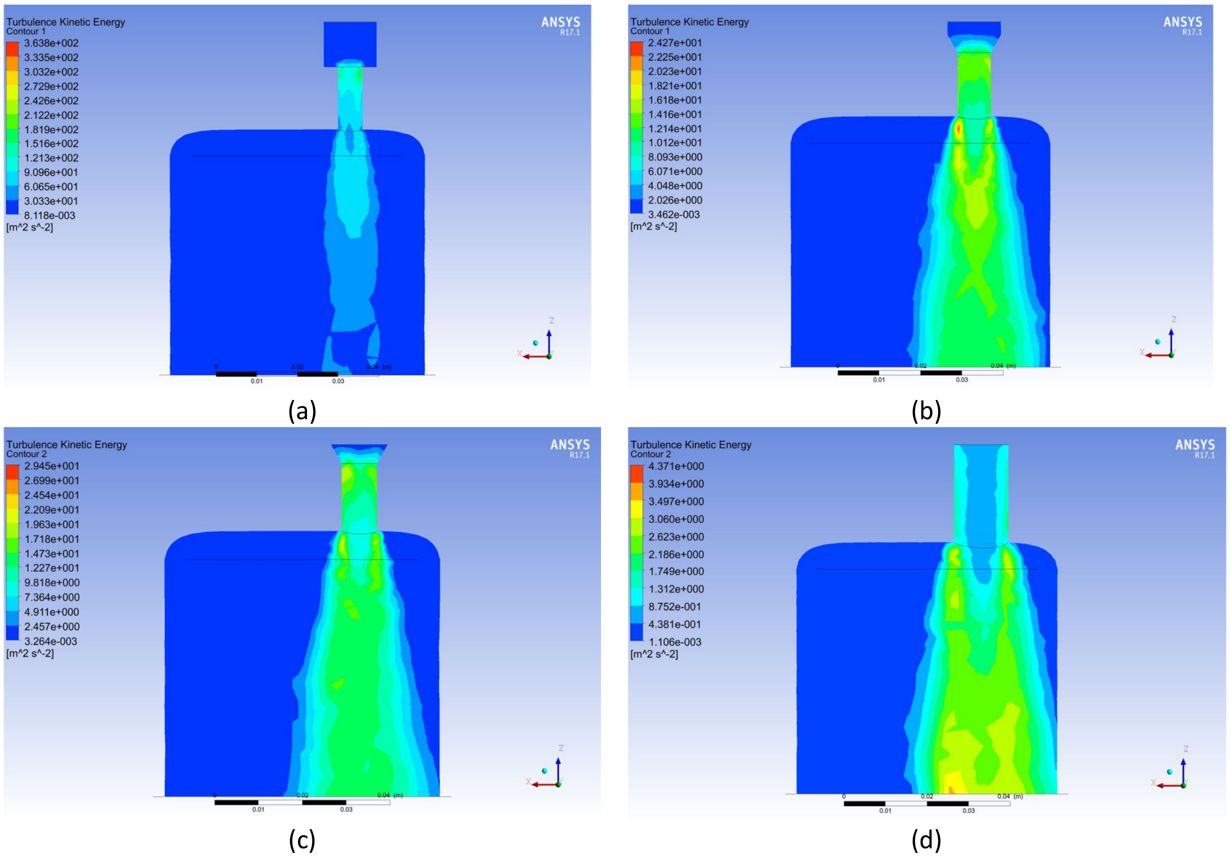


Fig. 5. Contour of Turbulence Kinetic Energy (TKE) of engine model with PCC. (a) PCC1 (b) PCC2 (c) PCC3 (d) PCC4

4. Conclusions

In this paper, the cold flow simulation was simulated using computational fluid dynamic (CFD) by ANSYS Fluent simulation software. The results were based on velocity vector and Turbulence Kinetic Energy. It can conclude that the PCC1 is the best design as it generates highest value of velocity vector and Turbulence Kinetic Energy (TKE). When the velocity vector is higher, the combustion process completed much more rapidly, resulting in greater engine efficiency. Besides, TKE can help to increase the combustion process rates.

Acknowledgment
The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for funding this research.

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