2nd International Seminar on Ocean and Coastal Engineering, Environment and Natural Disaster Management, ISOCEEN 2014

Air-fuel mixing and fuel flow velocity modeling of multi holes injector nozzle on CNG marine engine

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Abstract

This research deals with the computational modeling assessment of a new multi holes injector nozzle for a sequential port injection CNG engine. The objective of this paper was to investigate the characteristics of a new multi holes injector nozzle on CNG engine. The methodology of this research is using computational modeling of the fuel flow of the new injector nozzle was made using Cosmos FloWok. The investigation is focused in the characteristics of the fuel-air mixing and flow velocity on CNG engine effect using the new multi holes injector nozzle. The result of the computational modeling of the fuel flow of the new injector nozzle increased the spray distribution, fuel-air mixing and fuel flow velocity.

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Peer-review under responsibility of the Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember.

Keywords: CNG marine engine, fuel-air mixing, fuel velocity, multi holes injector nozzle, modelling;

1. Introduction

Fuel-air mixing and fuel flow velocity affected the performance of the Compressed Natural Gas (CNG) engine in terms of the power of the engine1,2,3,4. Better fuel-air mixing and fuel flow velocity can increase combustion in the engine. Then, the CNG fuel can be combusted completely, which can increase the engine’s power.

To determine the best fuel-air mixing and fuel flow velocity, several types of injection nozzle have been simulated in the SPI CNG engine model. In this research, the modelling and visualisation result was focused into multi holes injector nozzle. The intake air and injected CNG mixing modelling results were based on variations in injection timing
or valve lifts such as Semin and Bakar. The modelling results of the intake air and injected CNG fuel mixing of the new injectors are shown in isometric view, front view and top view. In the fuel-air mixing results, the blue colour is for air and the red colour is for CNG. In this research, the results of fuel flow velocity from the modelling focused on the combustion chamber area.

The injected CNG fuel and intake air mixing modelling results of the original nozzle injector is based on variations in injection timing. The original injector nozzle air-fuel mixing and fuel flow velocity was set as a reference for injected CNG and intake air mixing for the improvement of injector nozzles with multi-holes. The diameter of the original injector nozzle is 3.5 mm. In the SPI CNG engine, the fuel-air mixing of the original injector was the best if the CNG fuel is injected at 2 Bar and the intake air flow is at a pressure of 1 atm. Based on Czerwinski et al., the discussion focused on 2 bar of injected CNG fuel pressure and 1 atm of intake air flow pressure.

The flow of injected CNG fuel and intake air was differentiated by fixing the colour of the mixing flows. In the results, the injected CNG is in red and the intake air is in blue. By fixing the fluid colour, the flow of injected CNG fuel and intake air can be analysed in the fuel-air mixing. The fuel flow was differentiated by the fixing in valve lift. Without modification to the injector nozzle holes, injected CNG fuel is not mixed perfectly in the CNG engine combustion chamber.

The objective of this research is to simulate and analyse the CNG fuel-air mixing and fuel flow in the CNG engine combustion chamber using original injector and new multi holes injector nozzle.

2. Methodology

The modelling was run using Cosmos FloWork from SolidWork and the engine data is according to Semin et al. For the new injector nozzle hole diameter design and application in the SPI CNG engine model, the injector nozzle was replaced with the new injector nozzle holes in the SolidWork engine model. The modelling started to simulate the new injector fuel-air mixing effects with injection timing of 26.9 degrees BBDC, 43.7 degrees BBDC, 63.6 degrees BBDC and 77.5 degrees BBDC.

<table>
<thead>
<tr>
<th>Engine Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Bore (mm)</td>
<td>86.0</td>
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<tr>
<td>Stroke (mm)</td>
<td>70.0</td>
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<tr>
<td>Displacement (cc)</td>
<td>407.0</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>1</td>
</tr>
<tr>
<td>Connecting rod length (mm)</td>
<td>118.1</td>
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<tr>
<td>Piston pin offset (mm)</td>
<td>1.00</td>
</tr>
<tr>
<td>Max. intake &amp; exhaust valve open (mm)</td>
<td>7.095</td>
</tr>
</tbody>
</table>

Fig. 1. Sequential port injection CNG engine model

In this modelling, the specification of engine has shown in Table 1. The speed of the engine was set at 1800 rpm or 50% of the engine speed at maximum power. The air fuel ratio, temperature and pressure of the intake air in the intake manifold, injected gas from the injector and the combustion chamber as a boundary condition of engine model. The air-fuel ratio of the SPI CNG engine is ideally from 12.0 to 15.0. The air intake pressure at the intake manifold was set from a minimum of 0.87 Bar to maximum of 1.13 Bar. The intake air temperature in the intake manifold was
set from a minimum of 333.40 K to maximum of 364.58 K. The injector pressure was set from 1 Bar to 4 Bar and the temperature was set from 333 K to 335 K. In the SPI CNG engine, the pressure and temperature at 1800 rpm were set at 53.62 Bar and 3228.37 K, respectively.

According to Semin and R.A Bakar, the model of the SPI CNG engine is shown in Fig. 1. The model is based on an actual engine in terms of bore, stroke, and intake valve. The diameter of the bore is 86 mm and the length of the stroke is 70 mm. The model of new injector is shown in Fig. 2.

3. Result and Discussion

1.1. Fuel-air mixing

The modelling results of the original and new multi holes injector nozzle on fuel-air mixing are shown in Fig. 3–7. The modelling result shows the different types of flow of injected CNG and intake air mixing in every type of new multi holes injector nozzle. The result for intake air and injected CNG fuel mixing flow in the combustion chamber was analysed in different angles of view such as isometric view, front view and top view.
Fig. 4. Fuel-air mixing injected in 26.9 degree BBDC

Fig. 5. Fuel-air mixing injected in 43.7 degree BBDC
Fig. 6. Fuel-air mixing injected in 63.6 degree BBDC

Fig. 7. Fuel-air mixing injected in 77.5 degree BBDC
Fig. 3 shows fuel-air mixing of original injector in variation injection timing in isometric view, front view and top view of original injector nozzle hole. The top view shows the clearer of fuel-air mixing of the injected CNG and intake air of original injector in different injection timing. The best fuel-air mixing was found with injection timing of 26.9 degrees BBDC, since after injection timing is finished, the intake valve is closed and the fuel-air mix is used for combustion in the engine combustion chamber. The best fuel-air mixing occurs when the intake air and the CNG are spread evenly in the combustion chamber because the SPI CNG engine uses spark ignition. Complete fuel-air mixing leads to better engine combustion and higher engine power.

The injection timing 26.9 degree BBDC is the latest step of intake air and injected CNG. In this step the intake air velocity is high and the injected CNG is sprayed in combustion chamber wall spread evenly because effect of low valve lift and closured with intake valve. The increasing injection timing has decrease the injected CNG sprayed in combustion chamber wall and has increase the injected CNG in centre of combustion chamber. More centered injected CNG can be decrease the CNG combusted because the SPI CNG engine combustion burner is need the fuel-air mixing completely to make the combustion is in better condition and produce the higher engine performance. The phenomenon in injection timing 26.9 degree BBDC is better fuel-air mixing of CNG engine with burned in centre of piston bowl.

Fig. 4 - 7 shows the effect of new multi-hole injector nozzles on fuel-air mixing with injection timing of 26.9, 43.7, 63.6 and 77.5 degrees BBDC. With injection timing of 26.9 and 43.7 degrees BBDC, the new four-hole nozzle injector was better for fuel-air mixing. With injection timing of 63.6 degrees BBDC, the injector with three holes was better for fuel-air mixing. The even spread of CNG fuel spray in the combustion chamber led to better CNG combustion. Better combustion leads to better performance of the engine. For all of the new multi-hole injectors, better fuel-air mixing was seen with the injector with four holes with injection timing of 26.9 degrees BBDC. In this state, the air and fuel mixed and spread evenly. Fortunately, the better fuel-air mixing effect led to increased combustion in the CNG engine.

Theoretically, improved fuel-air mixing in the combustion chamber produces the best combustion. Better fuel-air mixing flow with the new injectors led more spread out fuel-air mixing in the combustion chamber. Some researchers, such as Baik, Jennings and Jeske, Hyun, Tanabe and Sato, have been reported that more holes in an injector leads to better fuel-air mixing in the combustion chamber, but in this study the injector with more holes did not yield better fuel-air mixing of injected CNG and intake air in the combustion chamber because more holes in the injector was associated with less penetration in the SPI CNG engine. Injection is indirect via intake pipe and the some of the injected CNG is blocked by intake valve.

Based on the results in Fig. 4 - 7, better fuel-air mixing was not seen with the five-hole injector, but rather with the four-hole injector. Since with the four-hole injector, the CNG was injected with more penetration, less CNG fuel was blocked by the intake valve and the CNG fuel could be mixed and spread evenly in the combustion chamber of the engine. The optimal fuel-air mixture should yield the required power output with the lowest fuel consumption that is consistent with smooth and reliable operation.

1.2. Fuel-air mixing

In this research, the results of fuel flow velocity from the simulations focused in the combustion chamber area. The fuel flow velocity in the combustion chamber affected the combustion and performance of the CNG engine. As the reference data, the original injector nozzle was been simulated using Cosmos FloWork to compare it with the new injector nozzles with multi-hole geometry design in terms of fuel velocity. Fig. 8 shows the average injected CNG fuel velocity of the original injection nozzle with variable injection timing.

Fig. 8 shows the fuel flow velocity of injected CNG fuel and intake air from the start of flow, fuel flow velocity in the valve stem area, on the cylinder wall and on the piston surface of the combustion chamber. Based on Fig. 8, decreasing intake valve lift or decreasing injection timing degree from BBDC increased the flow velocity of the injected gas fuel and intake air.

When the CNG fuel was injected with injection timing at a higher degree BBDC or when the intake valve lift was higher, the open area for intake air and CNG fuel in the combustion chamber is greater. The effect of the greater area was a decrease in the velocity of intake air and injected CNG fuel.
Fig. 8. Fuel flow velocity of the original injector

Fig. 9. Fuel velocity of new injector 2 holes

Fig. 10. Fuel velocity of new injector 3 holes
The injected CNG fuel flow velocity was higher than the intake air because the pressure at the start of flow of the injected fuel was higher than that of the intake air.

Fig. 9 - 12 shows the effect on injected CNG fuel flow velocity by the new multi holes injector nozzle. The investigation focused on new injectors with two, three, four and five-holed nozzles. The simulation was performed with variable injection timing at 77.5, 63.6, 43.7 and 26.9 degrees BBDC. In Fig. 9 - 12, at a distance from 0 to 0.02 metres of flow length, the gas fuel flows from the injection start to the valve stem area. At a distance from 0.02 to 0.034 metres of flow length, the gas fuel flow crosses the valve stem area. At a distance from 0.034 to 0.12 metres, the gas fuel flow reaches the walls and cylinder of the combustion chamber of the engine. At a distance from 0.12 to 0.18 metres, the gas fuel flow reaches the piston surface in the combustion chamber.

Fig. 9 - 12 shows the average injected fuel flow velocity profile of the new two, tree, four and five-holed nozzle injectors. The fuel flow velocity shows that the flow at injection start was similar, but the 4 holes is better for injection timing at 77.5, 63.6, 43.7 and 26.9 degrees BBDC. In the injection timing at 77.5 degrees BBDC, the velocity was lower than with the others. The highest flow velocity was found when the fuel flow crossed the intake valve stem into the cylinder; this was caused by less space in the area around the valve stem. After the fuel flow out of the valve stem, the fuel flow spread evenly over the wall and cylinder with non-uniform flow velocity to the piston surface and
the centre of the combustion chamber. The non-uniform flow was caused by the cross-fuel flow over the sides of the cylinder wall.

On the piston surface or the bottom of the combustion chamber, the fuel flow slowed down with injection timing of 77.5, 63.6 and 43.7 degrees BBDC and increased for injection timing of 26.9 degrees BBDC. The increasing fuel flow velocity with 26.9 degrees BBDC injection timing was caused by the intake valve opening, since during injection timing, the intake valve is slightly opened, and the result is increased fuel velocity. Fuel flow over the piston surface was more stable than over the other surface areas. The fuel-air mixing flow in this step was used in the pressure stroke of the engine from BDC to TDC.

2. Conclusion

Based on this research, trend in fuel–air mixing with injection timing of 77.5 degrees BBDC, the injector with two holes was better for fuel-air mixing. The improved spray flow was spread more evenly in the combustion chamber and the CNG fuel could flow into the combustion chamber as a rich mixture with intake air. In the fuel flow velocity profile of the new two, tree, four and five-holed nozzle injectors, the fuel flow velocity of 4 holes is better for injection timing at 77.5, 63.6, 43.7 and 26.9 degrees BBDC compare to the others new multi holes injector nozzle.

Acknowledgements

We would like to acknowledge to Institute of Research and Public Service, Institut Teknologi Sepuluh Nopember, Surabaya Indonesia for providing the grant to support of this project.

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