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Investigation the Effect of Injector Nozzle Multi Holes Geometry on Fuel Spray Distribution Flow of CNG Engine based on Computational Modeling

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Abstract-To improve the CNG engine injector nozzle hole geometry and to understand the processes involved in fuel-air mixing and combustion is a challenge. Improvements the injector nozzle holes geometry can be improve the fuel spray distribution in the combustion chamber. This research has been improvements to the fuel spray distribution in the combustion chamber with proper new injector nozzle holes geometry to create turbulence, in addition to modifying the angle of CNG fuel spray. The modelling fuel spray distribution of the original injector nozzle compared to the new injector nozzle with multi-hole geometry in the CNG engine shown in this research. The conclusion of this modeling has been shown in this study that the new injector nozzle holes geometry can be increase the fuel spray distribution in the CNG engine cylinder.

Keywords: Computational Modeling, CNG Engine, Fuel Spray, Injection Timing, Injector Nozzle.

Introduction

Natural Gas (NG) has been found in various locations in oil and gas-bearing sand strata located at various depths below the earth's surface (Catania et al., 2004). CNG is NG in compressed form. It has been recognised as one of the most promising alternative fuels due to its substantial benefits compared to gasoline fuel and diesel fuel. These include lower fuel costs, cleaner exhaust gas emissions and higher octane number. Therefore, the number of engine vehicles powered by CNG is growing rapidly (Poulton, 1994; Pischinger, 2003). NG is safer than gasoline in many respects (Cho and He, 2007; Ganesan, 1999; Kowalewicz, 1984). The ignition temperature of NG is higher than gasoline fuel and diesel fuel. Additionally, NG is lighter than air and dissipates upward rapidly. Gasoline fuel and diesel fuel pool on the ground, thus increasing the danger of fire. NG is non-toxic and will not contaminate groundwater if spilled. Advanced CNG engines guarantee considerable advantages over conventional gasoline and diesel engines (Kato et al., 1999). However, research into applying NG as an alternative fuel in engines is an important activity, because liquid fossil fuels are limited and will become scarce and costly in the future (Catania, 2004; Sera, 2003). CNG has some advantages compared to gasoline and diesel when considering the environmental perspective. It is a cleaner fuel than either gasoline or diesel as far as emissions are concerned. CNG is considered to be an environmentally clean alternative to those fuels (Cho and He, 2007; Kato et al., 1999; Shashikantha and Parikh, 1999; Wayne et al., 1998). Another advantage of CNG as a fuel is its octane number, which is very good for spark ignition (SI) engines. CNG engines can be operated at higher compression ratios (Ganesan, 1999).

With the high compression ratio of a sequential port injection (SPI) CNG engine, the CNG fuel is injected using an injector. CNG engine injector nozzle hole geometry can be optimised with increased understanding of the fuel spray process which affects engine performance (Czerwinski et al., 2003). In any research, a prototype is developed after computational modelling to reduce the necessary cost, materials and time. To improve CNG engine injector nozzle hole geometry and to understand the processes involved in fuel-air mixing and combustion is a challenge. According to Mbarawa et al. (2001), Semin (2012), Semin et al. (2008-2014), this research has been improvements to the fuel spray distribution in the combustion chamber can be achieved with proper hole geometry to create turbulence, in addition to modifying the angle of CNG fuel spray.

Materials and Methodology

The methodology to develop this research is start from literature study, identification and problem statement, data collecting, data analyzing, application and verification.

The design and types of nozzles are shown in Table 1. First design of new injector was based on diameter of the nozzle holes (DH), the second design was based on the shape, angle or number of the inner nozzle holes (DN), the third design was based on the shape, angle or diffuser degree of the inner nozzle holes (DD) and the fourth design based on multi-hole nozzle (H).

Table 1: New injector nozzle types
(a). Multi-diameter nozzle holes

Type	Multi Diameter Holes Nozzle
1.0DH	Nozzle with diameter 1.0 mm
1.5DH	Nozzle with diameter 1.5 mm
2.0DH	Nozzle with diameter 2.0 mm
2.5DH	Nozzle with diameter 2.5 mm
3.0DH	Nozzle with diameter 3.0 mm

(b). Multi-degree nozzle holes

Type	Multi Degree Nozzle
10DN	10 degree nozzle
15DN	15 degree nozzle
20DN	20 degree nozzle
25DN	25 degree nozzle
30DN	30 degree nozzle

(c). Multi-degree diffuser holes

Type	Multi Degree Diffuser
10DD	Nozzle with 10 degree diffuser
15DD	Nozzle with 15 degree diffuser
20DD	Nozzle with 20 degree diffuser
25DD	Nozzle with 25 degree diffuser
30DD	Nozzle with 30 degree diffuser

(d). Multi-hole nozzles

Type	Multi Holes Nozzle
Original	1 hole nozzle with 3.5 mm diameter
2H	2 holes nozzle with 1.50 mm diameter
3H	3 holes nozzle with 1.35 mm diameter
4H	4 holes nozzle with 1.25 mm diameter
5H	5 holes nozzle with 1.00 mm diameter

The development of the new injector nozzle with multi-hole geometry for port injection-dedicated compressed NG (CNG) engine spark ignition is needed to improve engine model performance. Based on model performance, a number of physically diverse injector nozzles with multi-hole geometry will be designed, developed and manufactured.

This research focused on simulation modelling of the fuel spray distribution flow in the SPI CNG engine using original injector and new injector nozzle with multi-hole geometry. The simulations was run using Cosmos FloWork. The engine data is according to Semin et al. (2010).

This study focused on injected CNG fuel from the injector nozzle based on valve lift variations. The CNG fuel injection timing started at 26.9 degrees BBDC (1.78 mm intake valve lift), 43.7 degrees BBDC (3.55 mm intake valve lift), 63.6 degrees BBDC (5.33 mm intake valve lift) and 77.5 degrees BBDC (7.10 mm intake valve lift). The injection timing or valve lift variations were ideal for the simulation investigation. The position of injection timing is shown in Figure 4.10. The maximum power of the engine was 6.6 kW at 3600 rpm. For optimum performance and fuel consumption, the engine speed was set to 40%-60% of maximum speed at maximum power (Heywood, 1988; Stone, 1999). In this simulation, 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. (Zhao et al., 1995; Czerwinski et al., 1999). 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.

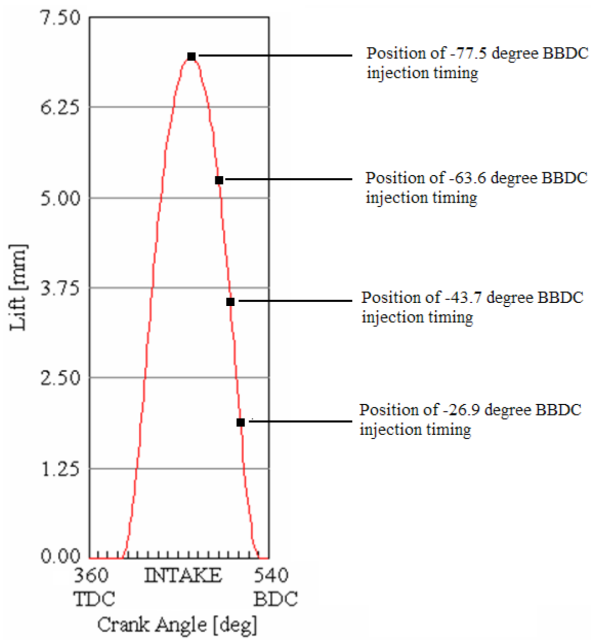

Fig. 1: Position of variations in injection timing points

Result and Discussion

In this modeling, the injected gas fuel flow is the fuel flow trend from the injector on the intake port to the combustion chamber of the engine. To determine the best injected gas fuel spray flow, several types of injector nozzle hole geometry were simulated in the SPI CNG engine model. The modelling fuel spray distribution of the original injector nozzle compared to the new injector nozzle with multi-hole geometry in the SPI CNG engine is shown in Fig. 2 - 5. The injected CNG fuel spray simulation results are shown with variations in injection timing.

Fig. 2 shows the new injectors with multi-diameter nozzle holes compared to the original nozzle injector spray distribution. The spray of the NG fuel from the injector to the combustion chamber of engine is shown in top view. The top view of the NG fuel spray gives a better view for analysing the fuel spray (Abraham, 1994).

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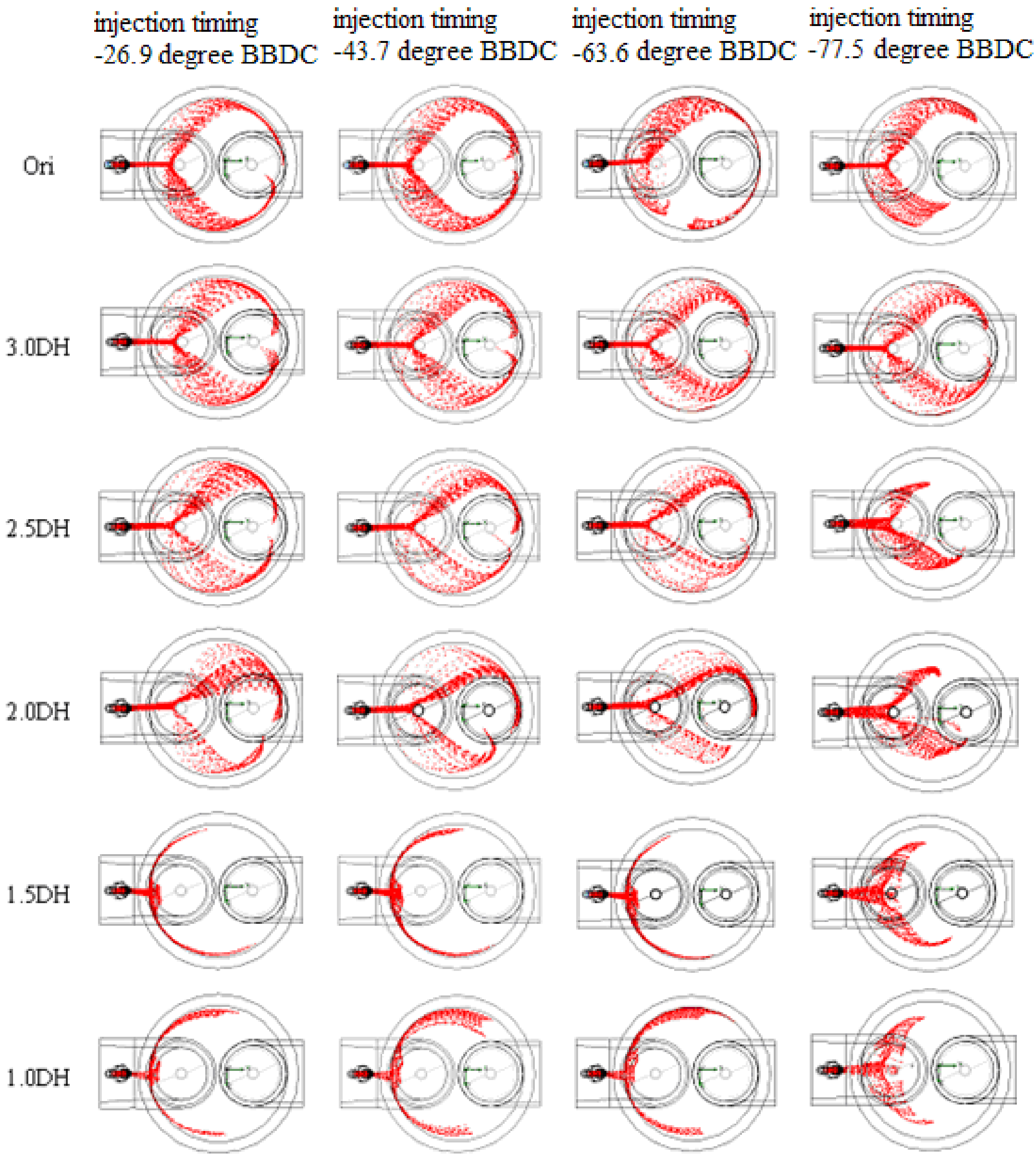

Fig. 2: Fuel spray distributions of new injector nozzles with multi-diameter holes

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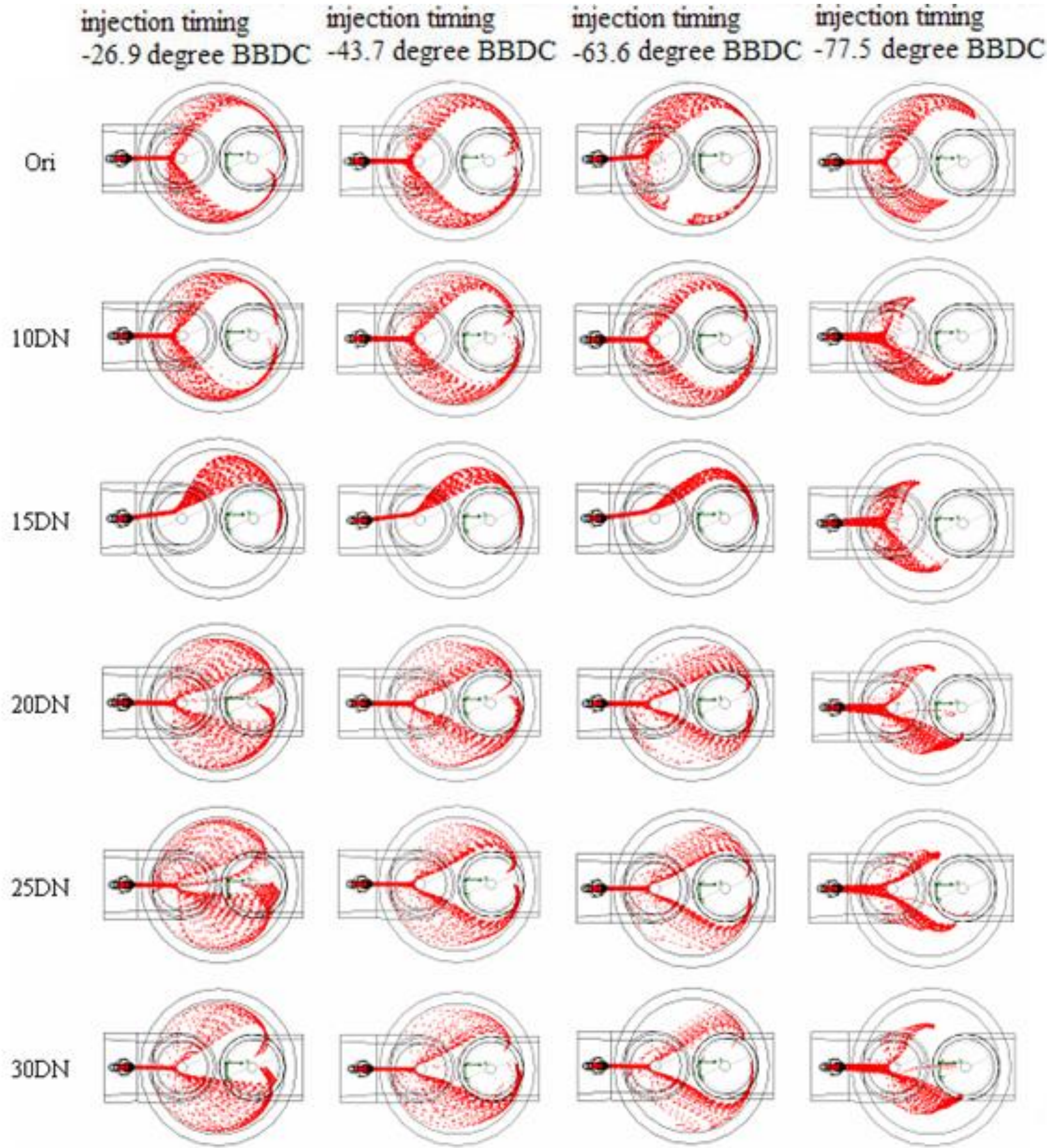

Fig. 3: Fuel spray distributions of new injectors with multi-degree nozzle holes

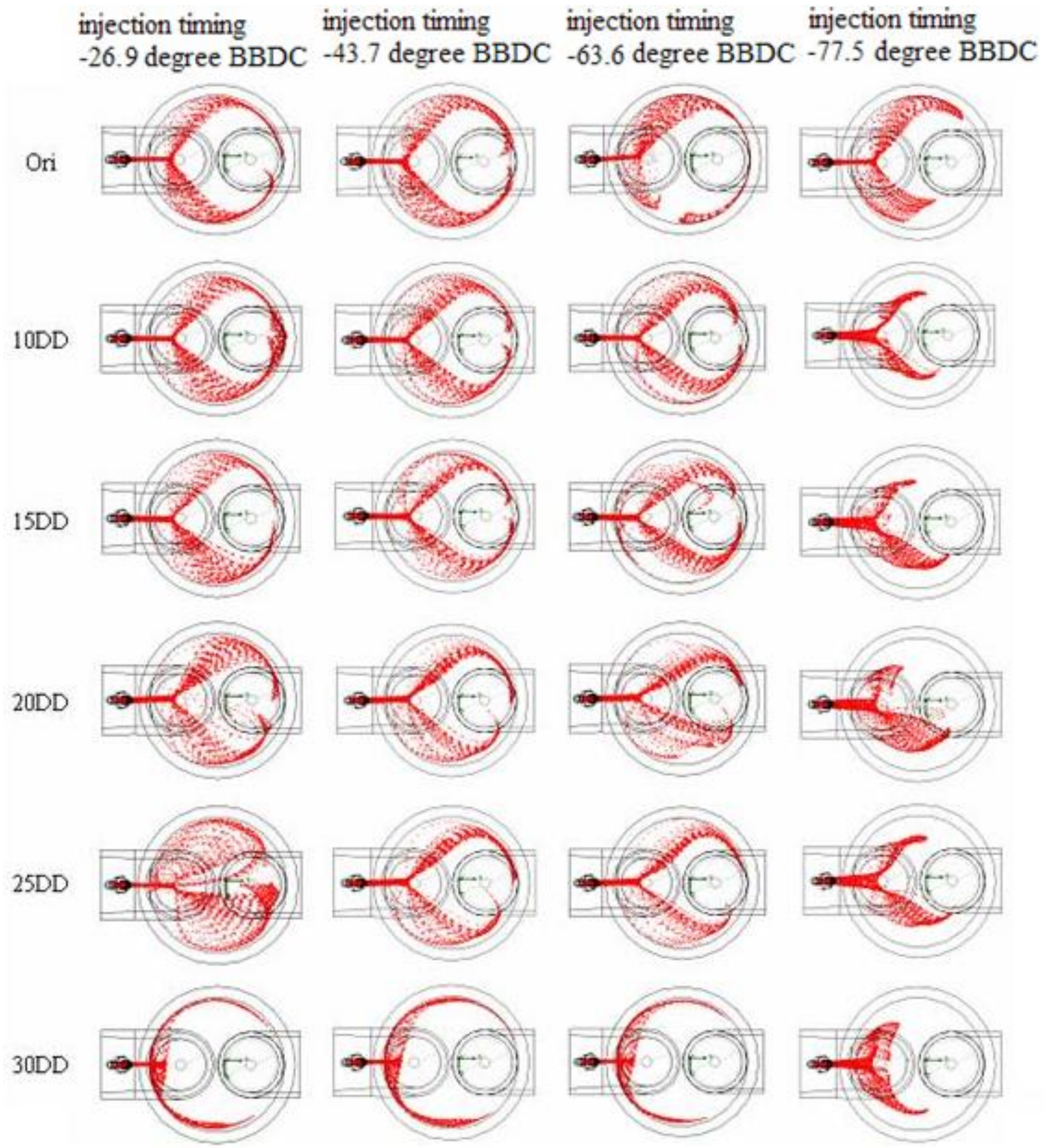

Fig. 4: Fuel spray distribution of new injectors with multi-degree diffuser nozzle holes

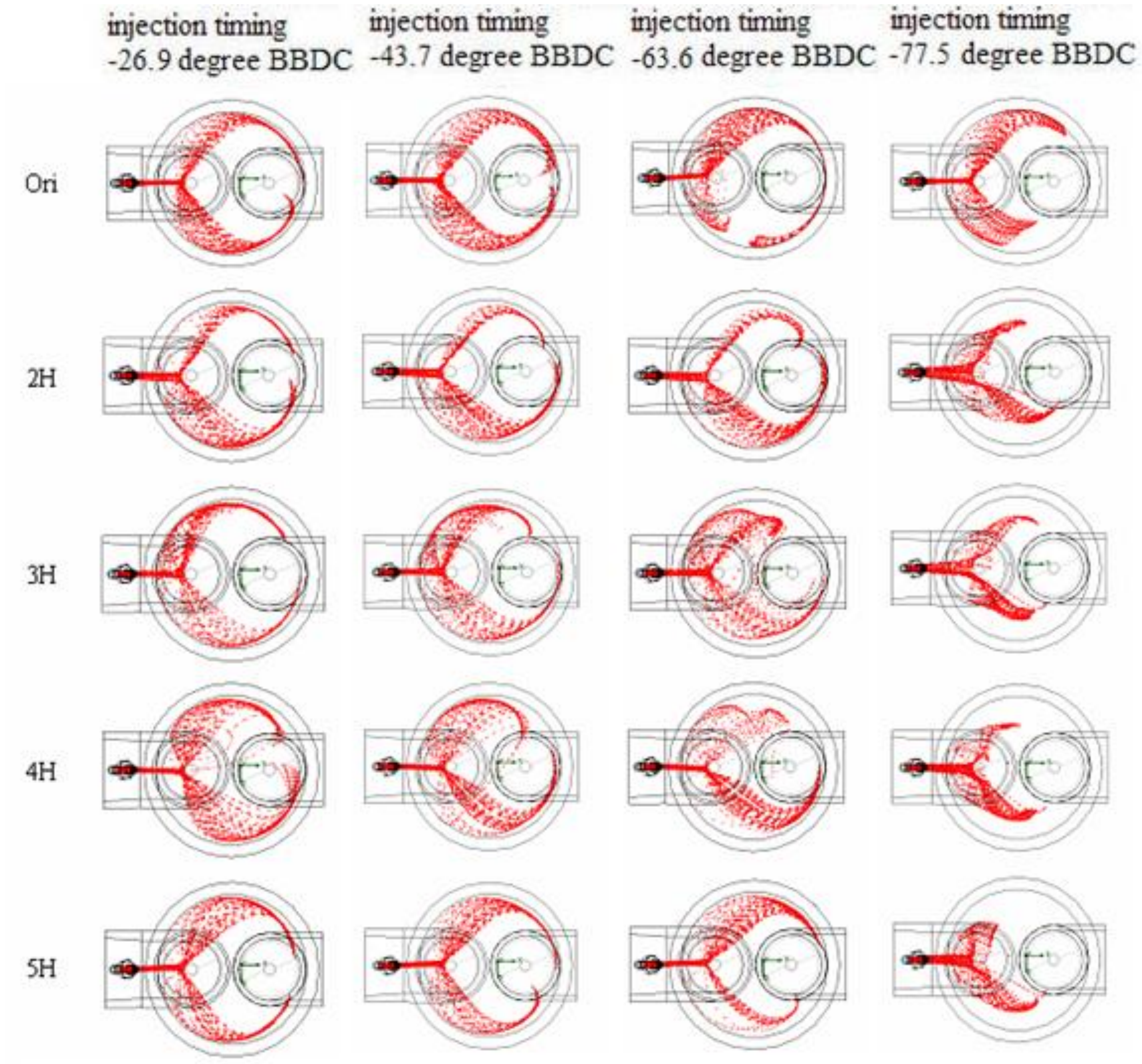

Fig. 5: Fuel spray distributions of new multi-hole injector nozzles

Fig. 2 shows that with the injection timing of 26.9 degrees BBDC, 43.7 degrees BBDC, 63.6 degrees BBDC and 77.5 degrees BBDC, the new injector with 3.0 mm diameter nozzle holes more thoroughly injected the CNG fuel spray compared to the original injector, the 2.5 mm diameter nozzle hole injector, the 2.0 mm diameter nozzle hole injector, the 1.5 mm diameter nozzle hole injector and the 1.0 mm diameter nozzle hole injector. The spray distribution of the 3.0 mm diameter nozzle hole injector resulted in more spraying around the engine combustion chamber. The 3.0 mm diameter hole nozzle injector was the best diameter for NG fuel in injection spraying. The 3.0 mm diameter hole nozzle injector was the ideal diameter with 26.9 degrees BBDC, 43.7 degrees BBDC, 63.6 degrees BBDC and 77.5 degrees BBDC injection timing. The CNG fuel was injected most widely and was spread more evenly than the others. The CNG fuel sprayed around the combustion chamber. With better spraying of CNG fuel in the combustion chamber of the engine, combustion in the engine is more complete and the CNG burns better than when spraying is deficient. This trend in spraying from the 3.0 mm diameter nozzle hole injector was for better engine combustion, as the fuel was spread evenly around the engine's combustion chamber; good combustion of CNG increases the engine's performance (Abraham, 1994; Brombacher, 1997).

Fig. 3 shows the spray pattern of the new injector with multi-degree nozzles compared to the original injector nozzle. With injection timing of 26.9 degrees BBDC, the 25 degree nozzle better injected the CNG fuel spray. With injection timing of 43.7 degrees BBDC and 63.6 degrees BBDC, the 10 degree nozzle better injected the CNG fuel spray. With injection timing of 77.5 degrees BBDC, the original injector nozzle showed the best trend in spray flow. Theoretically, more CNG fuel spray in the piston bowl in the combustion chamber produces better combustion (Heywood, 1988).

For all of the new injectors with multi-degree nozzles, the best CNG fuel spray distribution was with injection timing of 26.9 degrees BBDC and the 25 degree nozzle injector. With these modifications, the CNG fuel was sprayed evenly around the combustion chamber of the engine. The evenly spread fuel was very good for engine combustion, and better combustion resulted in better energy and performance.

Fig. 4 shows the spray distribution of the new multi-degree diffuser injectors compared to the original injector nozzle. With injection timing of 26.9 degrees BBDC, the 25 degree diffuser injector best injected the CNG fuel spray because the spray distribution was more spread evenly compared to the original injector, the 10 degree diameter diffuser injector, the 15 degree diameter diffuser injector, the 20 degree diameter diffuser injector and the 30 degree diameter diffuser injector.

The more evenly spread injected CNG in the combustion chamber is good for engine combustion. With injection timing of 43.7 degrees BBDC, 63.6 degrees BBDC and 77.5 degrees BBDC, the original injector best injected the CNG fuel spray because the spray of CNG was spread more evenly compared to the 10 degree diameter diffuser injector, the 15 degree diameter diffuser injector, the 20 degree diameter diffuser injector, the 25 degree diameter diffuser injector and the 30 degree diameter diffuser injector. Based on top view, the spray from the injector is spread evenly from the injector to the combustion chamber. The trend of evenly sprayed injected CNG is good for CNG engine combustion (Abraham, 1994 and Brombacher, 1997; Shiga et al., 2002). The fuel spray process has as a key element in engine performance. Good fuel spray leads to good engine performance (Suga et al., 2000).

Fig. 5 shows the spray distribution of the new multi-hole injector nozzles compared to the original injector nozzle. With injection timing of 26.9 degrees BBDC and 43.7 degrees BBDC, the four-hole nozzle injector better injected the CNG fuel spray. With injection timing of 63.6 degree BBDC, the three-hole injector better injected the CNG fuel spray. With injection timing of 77.5 degrees BBDC, the original injector better injected the CNG fuel spray. Better spray is spread more evenly in the combustion chamber and the CNG fuel can then flow into the combustion chamber in a rich mixture with intake air. The even spread of CNG in the combustion chamber leads to better CNG combustion, and better combustion means better performance of the engine (Suga et al., 2000).

Theoretically, more fuel spread in the piston centre or piston bowl in the combustion chamber produces the best combustion (Heywood, 1988). The better spray flow of the new injectors caused more spread of the fuel in the combustion chamber. Some researchers such as Baik (2001) and Hyun (1995) have reported that more holes in an injector will give more spray the in combustion chamber, but this relationship did not hold in this study as more holes in the injector resulted in less fuel penetration in this CNG engine is indirect injection via the intake pipe and the injected CNG flow is blocked by the intake valve

Conclusion

Based on this research, the trend in spraying from the 3.0 mm diameter nozzle hole, the 25 degree nozzle injector and the 4 holes injector are better than other in penetration, less fuel blocked by the intake valve and sprayed the fuel evenly in the combustion chamber.

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