A Cluster Nozzle Concept with high injection pressures for DI Diesel Engine

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A combination of high pressure injection and small orifices will be one of strategies to achieve the lean combustion. But the small orifice tends to increase soot under high load conditions because of short spray tip penetration. For this reason, a cluster concept was proposed in this study. The difference of the cluster nozzle is that the cluster has several groups of orifices; each group consists of two small orifices which are very close to each other and have included-angle. The cluster nozzle was investigated with different injection pressure under part load conditions and high load conditions in a single cylinder Diesel engine and it was compared with a reference nozzle. Among the experimental results, the clusters tend to make higher smoke than the reference nozzle under conventional injection timing because the spray from the cluster with a shorter spray tip penetration loses momentum near the piston bowl. But the clusters have improved smoke emissions with higher injection pressures. With the increase of injection pressure, the clusters have a potential to reduce, to some extent, the adverse effects on spatial distribution of spray due to better fuel atomization and evaporation.

Introduction

One possibility to realize the desired decrease in orifice diameter and increase in orifice number is to abandon the equispaced design and to cluster the orifices. Nishida et al. [1] and Gao et al. [2] study group-hole nozzles, as they call them, consisting of two sprays with an included angle of -10 to 10°. For converging sprays (negative included angle), spray penetration behavior was found to be similar to the corresponding conventional nozzle. For the diverging nozzles (positive included angle), a reduction in the penetration of the spray tip is found. Zhang et al. [3, 4] investigated the spray-wall interaction of sprays from group-hole nozzles. They found better atomization characteristics and asymmetries in the impinging spray on the wall when comparing the group-hole nozzles to conventional ones. Different studies have suggested advantages of cluster nozzles in engines under part-load conditions with convergent configurations being more advantageous than the divergent ones [5, 6]. Gao et al. [7] have shown advantage of divergent cluster nozzles over conventional ones in terms of soot formation through soot luminosity measurements in an optical engine. As no such advantage in terms of soot emissions in engines has been observed in other studies, it seems that the sprays from cluster nozzles have deficits in terms of soot oxidation.

The cluster with included angle of 10° having orifices in a plane perpendicular to the injector axis was designed with the same spray-cone angle as the reference injector (158°) for better targeting. The Cluster in Fig. 1 was named according to their geometry. The first part denotes total number of orifices (14). The two numbers separated by a slash denote te sprayh cone angle formed by the orifices in different orifice circles (158/158). The two orifices of a cluster were separated by 0.6mm.

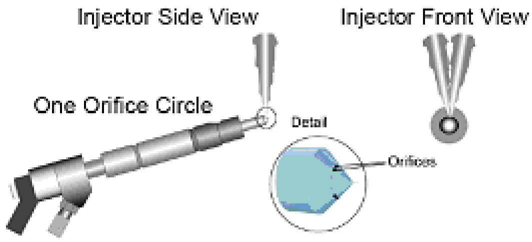

Fig. 1: The cluster nozzle configuration

Experimental setup

The engine experiments are performed on a 0.8 liter single-cylinder engine (16:1 compression ratio) with a swirl ratio of 1.5 based on a V-8 Duramax-engine from General Motors. Piezo injectors (CRI 3.3) were used for the experiments.

Test point	**TP1**	**TP2**
Speed [rpm]	1400	1400
Rail Pressure [bar]	500 - 900	1200 & 1500
IMEP [bar]	4.5	10.5
Start of Pulse [aTDC]	-30 ~ -3 (step 3deg)	-10 ~ 4 (step 2deg)
Boost Pressure [bar]	1.15	1.57
Boost Temp. [°C]	55	57
Temp. Oil & Coolant [°C]	90	90
EI Nox(EGR) [g/kg of fuel]	4	4.5

Table 1: The engine operating conditions

The cluster 14x158/158 and the reference nozzle were separately tested under low-load and high-load condition at 1400 rpm. Injection duration was varied to maintain the IMEP, while NO_x was

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maintained at constant levels for different sets of experiments by varying EGR (Exhaust Gas Recirculation). Injection rate measurements were carried out for all the nozzles to determine the actual injected mass for the test points. The table 1 shows the engine operating conditions.

Result and discussion

Fig. 2 shows the pressure curves, heat releases and cumulative heat releases of reference nozzle and Cluster 14x158/158 for -12° CA aTDC SOI with 900bar rail pressure for TP1. Ignition delay in the case of the cluster nozzle is generally shorter than that in the case of the reference nozzle. The rate of heat release is also higher for the cluster nozzle. The combustion period is shortened. It seems that the cluster has better fuel atomization, fuel evaporation, and air entrainment with smaller orifices.

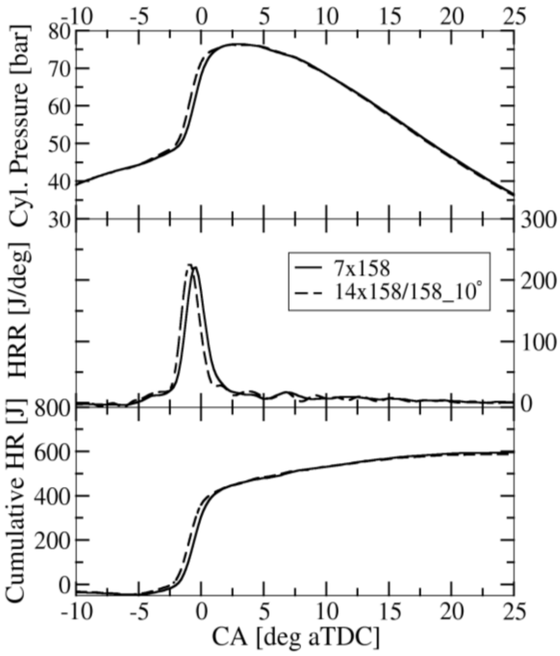

Fig. 2: Pressure curves and heat release for TP1: 1400rpm, 900bar rail pressure, -12° CA aTDC SOI, 4.5bar IMEP, 4g/kg_fuel NOx.

In Premixed charge compression ignition (PCCI), fuel is injected very early to produce a premixed fuel-air charge before ignition. It requires a large amount of cooled EGR to delay the ignition timing, which lowers the combustion temperature. The results are discussed for an early injection timing of -27°CA aTDC with 600bar rail pressure for different EGR rates under TP1. The results for smoke, HC and fuel consumption are shown in Fig.3. The cluster having small orifices is regarded as a promising approach to lower fuel consumption because the sprays from clusters have a greater mass of entrained ambient gas and more mass of fuel vapor compared to the reference nozzle. The BSFC (brake specific fuel consumption) of the cluster is lower than the reference nozzle. In PCCI condition, hydrocarbon (HC) and carbon monoxide (CO) emissions are of major concern, because HC and CO emissions are usually higher when the combustion temperature is low. The cluster shows an improvement for HC, because the reference nozzle with long spray tip penetration causes more fuel in proximity of the cylinder liner and combustion chamber walls, where flame quenching occurs. Lower soot emissions for the lower oxygen concentration conditions, which have substantially lower flame temperatures, suggest that NOx and soot can potentially be simultaneously reduced with small orifices and exhaust gas recirculation. The BSFC, HC and smoke levels stay pretty much the same with different NOx levels. It seems that a change in NOx, which is achieved by a change in EGR, has no effect on BSFC, HC and smoke, which is different from what is seen with conventional injection timings. There are two strong effects with the increase of already high EGR for early injection strategy. The first effect is dilution of oxygen with high EGR, which has a negative effect for BSFC, HC and smoke emissions and the second one is a longer ignition delay with higher EGR (ignition closer to TDC), which has a positive effect for them. Because of these effects the tradeoffs of BSFC, HC and smoke with NOx were reduced for early injection timings under part load conditions.

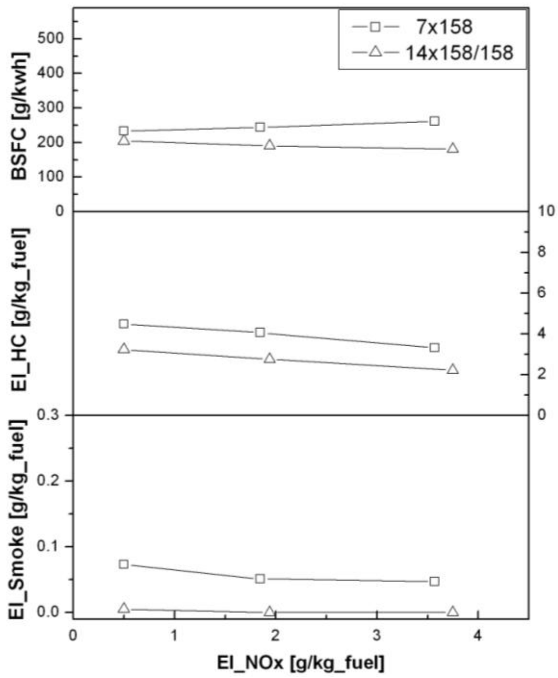

Fig. 3: BSFC, HC and Smoke with different EGR for TP1: 1400rpm, 600bar rail pressure, -27° CA aTDC SOI.

Cluster 14x158/158_10° was also used to investigate effects of rail pressure and was compared with the reference nozzle. The results for rail pressure variation under TP1 are shown in Fig.4. The graph on the top shows smoke emission for different rail pressures at an SOI of -5° CA aTDC. The graphs at the center and bottom show smoke for different SOI with 600bar and 900bar rail pressure respectively. All the results are for TP1 with NOx emission index of 4. The cluster shows higher smoke than the reference nozzle under conventional injection timing for TP1 because the spray from a cluster with a shorter spray tip penetration loses momentum near the piston bowl. But the cluster shows improved smoke emission with higher injection pressures. With the increase of injection pressure, the cluster shows a potential to reduce, to some extent, the adverse effects on spatial distribution of spray due to better fuel atomization and evaporation. A combination of high pressure injection and clusters with small orifices could be one of the alternative hardware to achieve lean combustion. Clusters with high pressure injection have improved fuel consumption and emissions as better fuel atomization and evaporation are achieved, while holding momentum near piston bowl and maintaining the penetration of the spray. The results for rail pressure variation under TP2 are also shown in Fig.5. The graph shows smoke of different SOI with 1200bar and 1500bar rail pressure respectively. The cluster shows higher smoke than the reference nozzle with 1200bar rail pressure but the cluster with the increase of injection pressure show similar smoke to the reference nozzle.

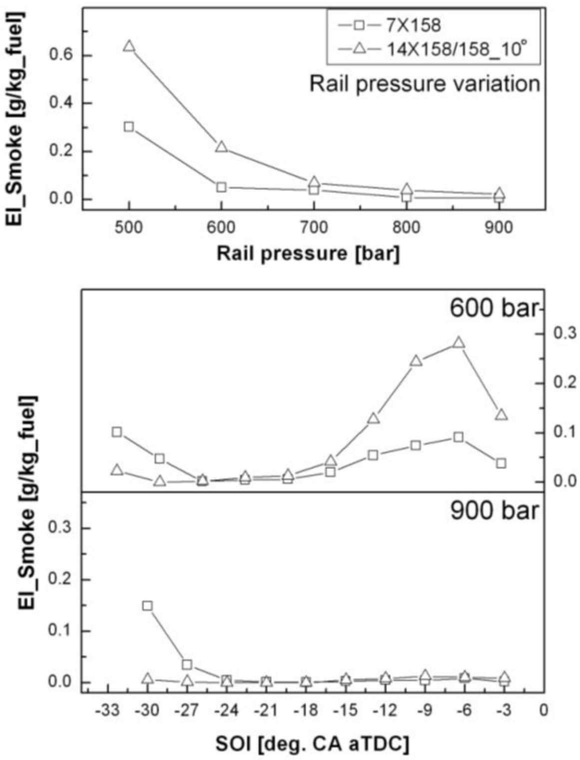

Fig. 4: Smoke with different rail pressures for TP1: 1400rpm, 4.5bar IMEP, 4g/kg_fuel NOx. Top: Rail pressure variation for -5° CA aTDC SOI, Center and Bottom: SOI variation for 600bar and 900bar rail pressure

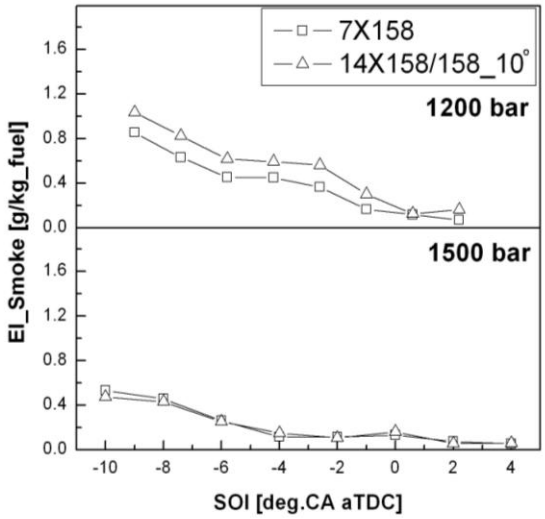

Fig. 5: Smoke with different rail pressures for TP2: 1400rpm, 10.5bar IMEP, 4.5g/kg_fuel NOx

Conclusion

A combination of high pressure injection and multi-hole nozzle with small orifices could be one of the alternative hardware configurations to achieve lean combustion. Ignition delay of the cluster nozzles is shorter and the initial rate of heat release and the maximum rate of heat release of diffusion combustion are higher than the conventional nozzle. The cluster has low smoke level with high injection pressures, despite the experiments being performed with a wide piston bowl without optimized swirl level.

Acknowledgments

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