Study on Combustion Processes of a Premixed Charge Compression Ignition (PCCI) Engine Fueled with DME/Diesel

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Abstract. A dimethyl ether (DME) pre-mixing system was installed on a 2105 diesel engine for realizing pre-mixed charge compression ignition combustion mode. Combustion processes of a PCCI engine fueled with DME/diesel under various DME pre-mixing ratios were investigated in this paper. The results showed that the heat release process showed three stages with port induction of DME. As the DME pre-mixing ratio (PR) increased, the peak value of cylinder temperature and pressure raised and the corresponding crank angles advanced. The start of combustion (SOC) moved forward obviously and the duration of combustion extended; the peak value of the pressure rise rate reduced first and then raised. The results in this paper provided a reference for the combustion process optimization of DME/diesel PCCI engine.

1. Introduction
Under the policies of energy saving and emission reduction, automotive engines with higher efficiency and lower emission are required. Many studies on new combustion modes and clean alternative fuels have been investigated in order to ameliorate the performance and economy of the engine. PCCI combustion mode attracted wide attention because of its low emission and high efficiency [1, 2]. The formation of premixed gas in PCCI mode is a key problem. In this paper, dimethyl ether was selected as pre-mixed fuel due to its high cetane number (>55) and oxygen content (34.8%). Furthermore, DME has a good combustion performance in diesel engines because of its molecular structure (no C-C bonds), which can achieve smokeless combustion [3, 4]. Meanwhile, DME can be mixed with air to form homogeneous charge under normal pressure and temperature. In this study, DME pre-mixed with air in the intake pipe and then entered to the combustion chamber. Diesel fuel was injected to the combustion chamber directly thus PCCI combustion of DME/diesel was realized.

PCCI engines exhibited different heat release and combustion processes compared with traditional compression ignition engine [5, 6]. HCCI combustion occurred after premixed fuel entered into the cylinder. The heat release amount of HCCI combustion was determined by the quantity of premixed DME fuel, and then the combustion processes of PCCI engine were affected. In this study, the combustion processes of a DME/diesel PCCI engine under different DME premixing ratios were studied.

2. Experimental apparatus and methods
A naturally aspirated, four-stroke 2105 diesel engine was applied in this paper. The main technical parameters of the testing engine were shown in Table 1. In order to realize PCCI mode, a DME intake port premixed system was installed. In order to improve the uniformity of DME and air mixture, DME...
was heated by a constant temperature device (the temperature was maintained at about 50 °C) before DME entered into the intake port. The diesel injection timing was kept at 10 °CA (crank angle) before top dead center.

Table 1. Technical parameters of the testing diesel engine.

| Parameter          | Numerical value |
|--------------------|-----------------|
| Bore×Stroke        | 105×120 / mm    |
| Displacement       | 2.08 / L        |
| Compression ratio  | 17              |
| Rated power        | 21.9 / kW       |
| Injection pressure | 19 / MPa        |
| Injection timing   | 10/ °CA BTDC    |

Figure 1 showed a schematic layout of the testing setup. Kistler 7061 water-cooled piezoelectric crystal sensor was used to connect Kistler 7061B charge amplifier to obtain in-cylinder combustion pressure. Due to the cyclic variations, 100 consecutive cycles cylinder pressure data were collected under every condition. The pressure data was averaged and smoothed for analysis and calculation. Diesel was commercial 0° diesel oil and DME was high purity industrial DME.

The experiments were conducted at the conditions of n=1700 r•min⁻¹, 33% load and n=1700 r•min⁻¹, 66% load. DME premixing ratio (PR) was the ratio of energy consumption of DME to the total energy consumption of DME and diesel. The DME PRs of 0%, 10%, 20%, 30%, and 40% were selected in this study.

3. Results and discussion

3.1. Cylinder pressure analysis

Figure 2 showed the cylinder pressure under various DME PRs. It can be seen that with an increase in DME premixing ratio, the peak value of cylinder pressure raised gradually, and the phase of the peak value of the cylinder pressure moved forward: at 33% load, the maximum cylinder pressure increased from 4.99 MPa (under pure diesel condition) to 5.79 MPa (under PR=40% condition), and the corresponding phase advanced from 10.2 °CA after top dead center to 6.2 °CA after top dead center; at 66% load, the maximum in-cylinder pressure increased from 5.59 MPa (under pure diesel condition) to 6.78 MPa (under PR=40% condition), and the corresponding phase advanced from 11 °CA after top dead center to 8.2 °CA after top dead center. HCCI combustion of the pre-mixed DME occurred before the combustion of the diesel fuel because DME has a high cetane number (>55), which led to a higher temperature and pressure in the combustion chamber. Therefore, ignition delay time of diesel was shortened, and the corresponding phase of maximum cylinder pressure
advanced. As DME HCCI combustion occurred in the compression stroke, the heat release during this period leaded to a higher cylinder pressure.

![Cylinder Pressure vs Crank Angle](image1)

**Figure 2.** Variations of cylinder pressure under different DME PRs.

3.2. In-cylinder temperature analysis

Figure 3 showed the variations of mean cylinder temperature under various DME PRs.

![Cylinder Temperature vs Crank Angle](image2)

**Figure 3.** Variations of mean cylinder temperature under various DME PRs.

It was observed from figure 3 that as the DME PR raised, the maximum temperature in the combustion chamber increased gradually, and the crank angle of maximum cylinder temperature moved forward: at 33% load, the maximum in-cylinder temperature increased from 1490 K (under pure diesel condition) to 1569 K (under PR=40% condition), and the corresponding phase advanced from 20.4 °CA ATDC to 15.2 °CA ATDC; at 66% load, the maximum cylinder temperature increased from 1821 K (under pure diesel condition) to 1955 K (under PR=40% condition), and the corresponding phase advanced from 23.2 ° crank angle ATDC to 18 ° crank angle ATDC. The HCCI combustion of pre-mixed DME lead to a higher temperature and pressure in the combustion chamber, thus the direct injection diesel fuel mixed with air more adequately before ignition and the combustion was more sufficient, which leaded to a higher combustion temperature. In addition, the interval between the diesel diffusion combustion and the HCCI combustion of the pre-mixed DME was shortened, so the corresponding phase of maximum in-cylinder temperature moved forward.

3.3. Heat release rate analysis

Figure 4 showed the heat release rate of the PCCI engine under various DME PRs. It was seen that DME/diesel PCCI engine presented a completely different heat release process from traditional compression ignition engine. PCCI engine exhibited a three-stage heat release behavior: at low DME premixing ratio (PR=10%, 20%), DME high-temperature reaction combined with premixed
The combustion of the diesel fuel and the heat release process showed 3 stages, DME low-temperature reaction, diesel premixed combustion and diesel diffusion combustion; at high DME PRs (PR=30%, 40%), the quantity of premixed mixture of DME and air enhanced, thus the heat release increased in DME HTR stage, the heat release process showed three stages of DME LTR, DME HTR, and diesel diffusion combustion (premixed combustion of the diesel combined with HTR of the DME).

As the DME PR increased, the amount of DME increased but the amount of diesel decreased. Therefore, the maximum HRR in DME HCCI stage raised and the maximum HRR in diesel premixed and diffusion combustion stage decreased. The phase of the maximum HRR in DME LTR was kept at 24 °CA BTDC. The timing of the DME LTR was affected by the in-cylinder temperature [7]. The corresponding phase of the peak values of HRRs in diesel diffusion combustion stage and DME HTR stage advanced because the fuel ignition delay reduced and the start of combustion moved forward as the quantity of DME increased.

Figure 4. Heat release rate of the PCCI engine under various DME PRs.

### 3.4. Combustion duration analysis

In this paper, the CA of 5% accumulate heat release was named SOC, and the interval between 10% and 90% accumulate heat release was named combustion duration. Figure 5 showed the combustion duration under various DME PRs. It was seen that the SOC advanced gradually with the increase of DME PR. The heat release raised in HCCI combustion of DME because the amount of DME raised with the increase of DME PR, resulting in an advanced SOC. As the DME PR increased, diesel diffusive combustion advanced too, but the advanced extent of end of combustion was obviously less than that of start of combustion, thus the combustion duration was extended.

Figure 5. Variations of combustion duration under different premixing ratios.

### 3.5. Pressure rise rate analysis

Figure 6 showed the pressure rise rate of the PCCI engine under various DME PRs. It was seen from figure 6 that there were three maximum pressure rise rates for PCCI engine, which were caused...
by DME LTR, DME HTR and the diesel combustion. With an increase in the DME PR, the first maximum pressure rise rate in DME LTR stage appeared at almost the same phase (at about 24 °CA BTDC), but raised in value. The maximum pressure rise rate in DME HTR stage raised and the phase of this peak moved forward. The maximum pressure rise rate in diesel combustion stage reduced and the phase of this peak moved forward. The maximum PRR was used to indicate the combustion roughness of the diesel engine[8]. It can be observed that as the DME PR increased, the maximum PRR reduced first and then raised. That was to say, premixed DME could reduce the PRR and control the peak value of the PRR below 0.5 MPa•°CA⁻¹. However, at high DME premixing ratio (PR=30%, 40%), the peak value of the PRR increased. Therefore, the DME premixing ratio should be controlled at the range of 20%~30%.

Figure 6. Variations of pressure rise rate under different premixing ratios.

4. Conclusions
(1) As the DME PR increased, the maximum pressure and temperature in the combustion chamber raised, and the phase of the maximum pressure and temperature in the combustion chamber moved forward.

(2) The heat release of the DME/diesel PCCI engine was composed of three stages. As the DME PR raised, the maximum HRR in DME HCCI combustion stage raised, but the maximum HRR in diesel diffusion combustion reduced. The phase of the peak value of the HRR was almost kept constant in DME LTR stage, but moved forward in DME HTR stage and diesel combustion stage.

(3) As the DME PR increased, the SOC moved forward and the combustion duration extended. The maximum PRR reduced first and then raised, DME premixing ratio should be controlled at the range of 20%~30%.

5. Acknowledgments
This study was supported by Natural Science Basic Research Plan of Shaanxi Province (2020JQ-475).

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