Fuel formulation and mixing strategy for rate of heat release control with PCCI combustion

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Introduction

Premixed charge compression ignition (PCCI) is one of the most promising combustion strategies for internal combustion engines in the future, since PCCI combustion is able to realize very low soot and nitric oxide emissions. PCCI is a low temperature combustion (LTC) strategy, which combines the efficiency of a Diesel and the low particulate emission of an Otto engine.

To achieve low emissions of NO_x and particulate matter (PM) the combustion should be decoupled from the injection of the fuel to avoid a spray that burns predominantly in diffusion mode. This decoupling makes the combustion process difficult to control. When allowing a certain degree of stratification in the cylinder, control over the combustion process by injection timing is partly restored.

Although premixed, the air-fuel mixture is not completely homogeneous, as in a homogeneous charge compression ignition (HCCI) engine. By premixing the charge, combustion in both HCCI and PCCI is dominated by chemical kinetics [1] instead of fuel/air mixing. The temperature and concentration gradients present in the charge when using the PCCI combustion strategy (charge stratification) slow down combustion because the mixture will not ignite everywhere at once.

The lower rate of heat release extends the operating range from low load to medium or even full load. Temperature stratification has the highest influence on the rate of heat release and pressure rise rate and extends the high-load operating limit [2].

A classification of PCCI combustion concepts is given in figure 1. In this figure the pressure inside the engine is plotted as a function of time and different classes of PCCI injection timing are shown. Port fuel injection is only applied for gasoline fueled PCCI engines and takes place before bottom dead center (BDC). For early direct injection (DI) PCCI combustion, collision of injected fuel spray against the cylinder liner, so-called wall-wetting, is one of the main hurdles to overcome.

In this project we are focussing on injecting towards the end of the early DI regime, around 30 CAD BTDC. The objective of this project is to investigate the influence of charge stratification on PCCI combustion to reduce the heat release rate and extend the operating range. This will be investigated by measuring velocities, concentrations and temperatures both in an optical engine and in a constant volume high pressure cell.

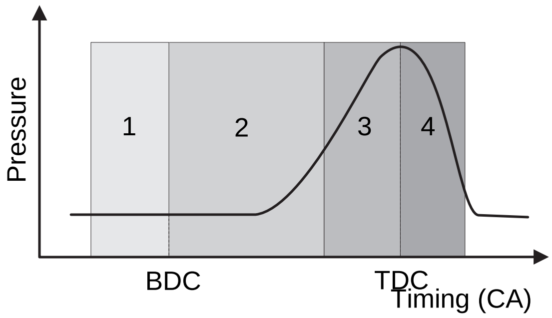

Figure 1: Engine cycle with pressure peak at top dead center (TDC). PCCI concepts classification by injection timing range. 1=port fuel injection, before bottom dead center (BDC), 2= early DI, 3=conventional diesel combustion, 4=late DI

Materials

In this project two setups are used to investigate stratification phenomena. A high pressure cell is used to investigate spray injection in a high temperature and pressure environment and an optical engine is used to investigate stratification under running engine conditions. The engine test setup consists of a one cylinder optically accessible heavy duty engine, based on a Ricardo Proteus test engine and a DAF MX NA cylinder head, driven by an electrical motor. A cross-section of the setup is shown in figure 2. The piston is elongated and the upper part of the liner and piston bottom are both made of sapphire. Via a mirror, positioned under 45 degrees, optical access to the combustion chamber is obtained. The hydraulic cylinder can be lowered, allowing easy access to the combustion chamber. The engine specifications in Table 1 show fixed valve timings and variable compression ratios (CR). The compression ratio can be changed quickly between measurements by positioning the cylinder head on a different height, thereby changing the volume at TDC.

The Eindhoven high pressure cell setup (EHPC) can be seen in figure 3. Its core is a cubically shaped combustion chamber produced through spark erosion inside a stainless steel cube. The holes on each side of the combustion chamber can be fitted either with a window or with a similarly shaped metal plug. Engine conditions towards the

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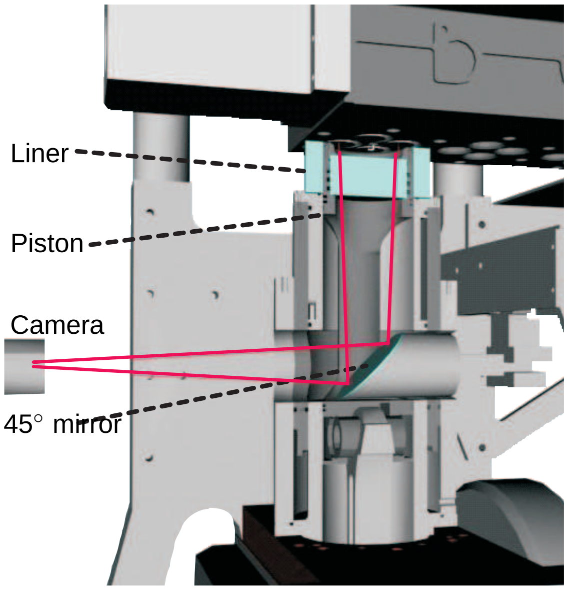

Figure 2: Cross section of the optical accessible one cylinder engine

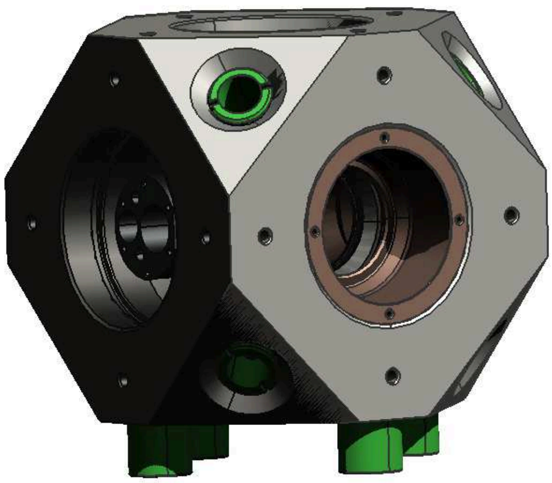

Figure 3: Eindhoven High pressure Cell

Table 1: Engine specifications

Bore	130 mm
Stroke	156 mm
Connecting rod length	270 mm
Displacement volume	2.07 L
Compression ratio	9.5 - 14
IVO	715 CAD
IVC	190 CAD
EVO	500 CAD
EVC	10 CAD
Swirl ratio	0.5
Piston bowl	Flat

Table 2: Methodology

Engine speed	1200 rpm
Fueling	Fixed injected energy Variable timing Single and double injections
Compression ratio	fixed
Boost pressure	fixed
Intake temperature	fixed
Swirl ratio	0.5
Nozzle geometry	fixed
Piston bowl geometry	flat

end of the compression stroke are simulated by burning a lean pre-charge of gaseous fuel, and the walls of the cell are heated up electrically to simulate realistic wall temperatures and prevent water condensation on the windows. This is the so-called pre-combustion technique. Once the desired conditions are reached the diesel fuel spray is injected. To determine the right moment of injection, the decay of average pressure at a certain condition is recorded.

Methodology

Stratification control will in practice have to rely on sophisticated injection strategies. The main focus point of this research is the use of (multiple) direct injections as a method to create stratification. For this project some restrictions are applied on the amount of engine operating points, summarized in table 2.

Outlook

A first elaborate set of PIV (Particle Image Velocimetry) measurements has been performed recently, with crank angle resolution obtained from ensemble averaging of single shot measurements [3]. Time-resolved PIV measurements are in progress, to obtain a data set for comparison with CFD results. The engine will be modified further to apply PCCI combustion by implementing more flexible fuel injection equipment.

Tracer PLIF will be used to measure temperature and concentrations gradients (which is now being prepared at Radboud University of Nijmegen [4], possibly combined with a phosphoresce technique for temperature gradient detection. The phosphoresce technique is developed in cooperation with Lund institute of Technology.

Acknowledgements

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