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An experimental and modeling study to investigate effects of different injection parameters on a direct injection HCCI combustion fueled with ethanol–gasoline fuel blends

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ABSTRACT

In this study, Stochastic Reactor Model (SRM) was used to simulate a direct injection homogenous charge compression ignition (DI-HCCI) engine fueled with ethanol–gasoline blends by two stage direct injection (TSDI) strategies. Performance of the DI-HCCI engine was examined at constant engine speed and high equivalence ratio conditions. TSDI strategies were applied during the intake stroke (first injections) and at the end of the compression stroke (second injections) by using different injection ratios (IR) of E10 and E20 blends. SRM results were compared and validated with the experimental results. Experimental and SRM results showed that the first injection variation does not have significant effect on controlling HCCI combustion while variation of the second injection timing and IR change peak pressure significantly. Therefore, this strategy can be used to control the HCCI combustion.

1. Introduction

HCCI has the potential to combine best properties of spark ignition (SI) and stratified charge compression ignition (CI) engines. This feature of HCCI provides important advantages such as higher thermal efficiency and lower NOx emissions compared to conventional SI and CI engines and makes HCCI an important alternative to conventional engines. Although HCCI have attractive specialties still there are important handicaps to apply in commercial applications such as effective control during the start of combustion, ignition delay and therefore extending the operation range.

HCCI combustion is a process of auto-ignition that is governed by the combustion phenomena. Even there is no single and effective control mechanism for HCCI combustion, there are two main mechanisms which plays an important role to control auto-ignition timing and heat release rate. These mechanisms are, time-temperature history and auto-ignition characteristic of fuel [1]. Some of the well-known auto-ignition control methods of the time-temperature history are variable compression ratio [2,3] and valve timing to adjust the level of internal EGR with negative valve overlap, external and cooled EGR [4–6], intake temperature [7–9], intake pressure [10,11], and DI timing [12,13]. When the intake valve closed, injection (single or double) timing in DI engines is the only way to control the temperature time history and fuel concentration [14]. Port fuel injection technique provides lower NOx and PM emissions while the power and the efficiency decrease for direct injection strategy in SI engines. Because this technique provides more time to prepare better air-fuel mixture to preserve high equivalence ratio and local temperature. Direct injection can be applied as a single or stratified strategies. TSDI strategies can be used to obtain higher volumetric efficiency and lower fuel consumption in the engines with

Abbreviations: °CA, Crank angle degree; CFD, Computational fluid dynamics; CI, Compression ignition; DI, Direct injection; EGR, Exhaust gas recirculation; GDI, Gasoline direct injection; HCCI, Homogenous charge compression ignition; IR, Injection ratio; NVO, Negative valve overlap; P_{inj}, Fuel injection pressure; P_{max}, Maximum cylinder gas pressure; PCI, Premixed compression ignition; PRF, Primary reference fuel; Q_{cyc}, Fuel quantity per cycle; SI, Spark ignition; SOI_1, Start of first injection; SOI_2, Start of second injection; SRM, Stochastic Reactor Model; TDC, Top dead center (before bTDC, after aTDC); TSDI, Two stage direct injection

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Table 1
Experimental engine properties.

Engine	Super Star 7716 Model Diesel Engine
Type	DI, natural aspirated, 4 stroke, water cooled
Cylinder number	1
Bore × Stroke (mm)	98.46 × 100
Compression ratio	17:1
Connecting rod (mm)	219
Engine Speed (rpm)	1100
Intake valve open (bTDC)	22
Intake valve close (aBDC)	60
Exhaust valve open (bBDC)	66
Exhaust valve close (aTDC)	16

high compression ratio [15,16]. Canakci and Reitz obtained significant reductions in PM and NOx emissions while increasing thermal efficiency by applying double injection strategy to a DI-HCCI engine fueled with gasoline [17]. Turner et al. studied with different ratio of bioethanol–gasoline blends by using single injection strategies at direct injection spark ignition (DISI) for a gasoline engine [18]. They obtained better combustion stability, increase in engine efficiency and peak cylinder gas pressure (Pmax), decrease in the changing coefficient indicated mean effective pressure for single injection and lower ethanol blends. Engine efficiency and combustion stability were increased when they were used the double injection strategy with IR (50–50%).

Fuels and fuel mixtures have significant effect on the combustion control in HCCI engines. Each fuel has different auto-ignition properties and these properties can be alter by using various fuel mixtures and additives [19]. Accordingly alcohols such as ethanol and methanol which have higher octane number can be used to control HCCI combustion.

Various studies can be found in the literature about Stochastic Reactor Model (SRM) application on engine combustion after Kraft et al. [20] were firstly applied the SRM approach for engine combustion to simulate HCCI engine. Although several studies done for engine combustion fueled with alternative fuels using SRM [21–24] there are limited investigation of TSDI or alcohol mixture application at HCCI engine by SRM approach. Su et al. [25,26] developed a new SRM-DI account for gas ex-change and compression–combustion–expansion in a direct injection HCCI engine and thus they were be able to model TSDI strategy in an HCCI engine with SRM approach. Also they insert a new wall-impingement sub-model to the SRM for DI thus they found that TSDI increases the combustion duration and thus enhances the HCCI operating range. Ahmedi et al. [27] simulated premixed compression ignition (PCI) using direct injection module of SRM. They simulated the PCI combustion with different fuel blends (*n*-heptane, PRF 84 and TRF 82, a toluene isooctane and *n*-heptane blend). Full cycle simulation for gasoline and ethanol fuels were studied by Battistoni et al. [28] for spark ignited engine using CFD modeling technique and detailed chemistry for full open cycle. They investigated ethanol and isooctane combustion behaviors under the optical engine test conditions.

It was seen from literature review that using TSDI technique and alcohol–gasoline fuel blends are effective parameters for controlling HCCI combustion phase and obtaining lower emissions. However, more simulation studies concerning the use of TSDI technique with alcohol–gasoline mixtures in DI-HCCI engines need to be done to understand better the combustion phenomena hiding in HCCI technique. In previous studies [29,30], effects of second injection timings on HCCI combustion for gasoline-alcohol blends were investigated experimentally while SRM analyses were performed only for gasoline fuel. E10 and E20 mixtures had been simulated in the current study to show the consistency of SRM strategy and chemical mechanism for different fuel mixtures. Furthermore, the effects of second injection timing was investigated to obtain deeper knowledge for HCCI combustion.

2. Experimental study

In this study, a single cylinder DI diesel engine was converted to DI-HCCI engine. Engine specifications are given in Table 1 and schematic diagram of the experimental setup is shown in Fig. 1. The engine is connected to a DC electrical dynamometer. K type thermocouples were

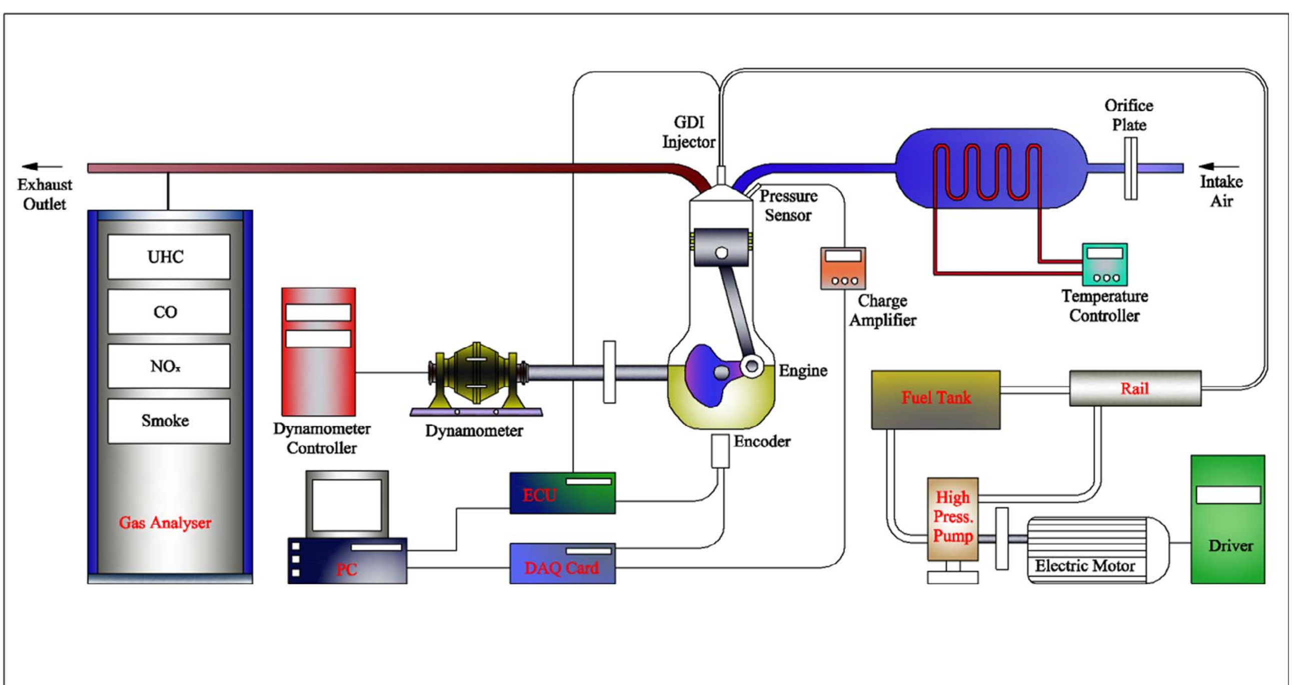

Fig. 1. Schematic diagram of the experimental setup.