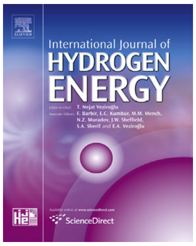
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 9897–9906

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/he



H_2 effects on diesel combustion and emissions with an LPL-EGR system

Youngsoo Cho, Soonho Song, Kwang Min Chun[*]

Graduate School, Department of Mechanical Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 16 March 2013
Received in revised form
22 May 2013
Accepted 26 May 2013
Available online 25 June 2013

Keywords:
Hydrogen
Low pressure loop EGR
Diesel engine combustion
NOx
PM

ABSTRACT

In this study, we examined H_2 effects on the combustion and emissions of a diesel engine with low-pressure loop (LPL) exhaust gas recirculation (EGR). We converted a 2.2-L four-cylinder direct-injection diesel engine satisfying Euro5 for H_2 supply. An LPL-EGR system replaced the high-pressure loop (HPL) EGR system. For all tests, the brake mean effective pressure (BMEP) was kept at 4 bar and the EGR ratio was varied from 9 to 42%. The H_2 energy percentage was varied from 0 to 7.4% independently to evaluate the H_2 effects and EGR effects separately. The heat release rate was calculated from the measured cylinder pressure. We found that substitution of H_2 for diesel fuel made the premixed burn fraction larger, and reduced the nitrous oxide (NOx) and particulate matter (PM) emissions simultaneously. For example, the NOx emissions were reduced by 36% for an EGR of 42% and an H_2 percentage of 7.4%. PM emissions were reduced by 18% for an EGR of 35% and an H_2 percentage of 7.4% compared with diesel fuel only cases.

1. Introduction

Due to stricter regulations and concerns over global warming and human health problems, many researchers have focused on the development of various eco-friendly technologies to reduce CO_2, particulate matter (PM), and nitrous oxide (NOx) emissions from vehicles. Recently, there has been greater interest among consumers for diesel vehicles since their lower pumping losses and higher compression ratios provide better fuel efficiency. However, due to their lean operation conditions and diffusion combustion, diesel vehicles emit more NOx and PM than gasoline vehicles.

Many studies have attempted to reduce NOx and PM emissions. Several technologies are available to reduce PM and meet current regulations, including diesel particulate filters (DPFs), catalyzed DPFs (CDPFs), and diesel oxidation catalysts (DOCs). Lean NOx traps (LNTs), hydrocarbon selective catalytic reduction (HC-SCR), and urea-SCR have been developed to reduce NOx. To satisfy Euro6 legislation, heavy duty diesel vehicles use urea-SCR; LNTs are used on light duty diesel vehicles. These after-treatment technologies efficiently reduce PM and NOx emissions; however, they significantly increase the cost of the vehicle due to equipment expenses.

Unlike after-treatment technologies that reduce PM and NOx in the exhaust pipe after the combustion process, various advanced combustion technologies and pre-treatment technologies have been developed to reduce PM and NOx emissions without supplementary equipment such as DPFs, LNTs, or SCRs. Exhaust gas recirculation (EGR) is one of the pre-treatment technologies for reducing NOx. EGR lowers the temperature of the cylinder, taking advantage of the difference in the specific heats of the exhaust emissions and fresh air [1].

Advanced combustion technologies have been developed to reduce PM and NOx during the combustion process in a cylinder. A representative of advanced combustion technologies is homogeneous charge compression ignition (HCCI).

---

[*] *Corresponding author*. Tel.: +82 2 2123 2819; fax: +82 2 393 5740.
E-mail address: kmchun@yonsei.ac.kr (K.M. Chun).

0360-3199/$ – see front matter Copyright © 2013, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijhydene.2013.05.143

Nomenclature

EGR:	exhaust gas recirculation
HPL:	high pressure loop
IMEP:	indicated mean effective pressure
LPL:	low pressure loop
HCCI:	homogeneous charge compression ignition
LTC:	low temperature combustion
ECU:	engine control unit
H_2:	hydrogen
O_2:	oxygen
NO*x*:	nitrogen oxide
PM:	particulate matter
DOC:	diesel oxidation catalyst
sLPM:	standard liters per minute
BMEP:	brake mean effective pressure
FMEP:	friction mean effective pressure
CA:	crank angle
DPF:	diesel particulate filter
LNT:	lean NO*x* trap
SCR:	selective catalytic reduction
TDC:	top dead center
ATDC:	after top dead center
MB:	mass burn fraction
MB10:	10% mass burn fraction
θ_{MB10}:	crank angle of MB10

There is a trade-off between PM and NO*x* emissions for conventional diesel engines. However, HCCI can reduce PM and NO*x* simultaneously because the air–fuel mixture is homogeneous, and the combustion temperature is lower than that of conventional diesel engines [2,3]. To realize low-temperature combustion (LTC), such as HCCI, various technologies such as PREDIC, UNIBUS, and MK have been developed [4–6]. However, serious problems remain for HCCI, including combustion phasing and limited operating range [7,8]. First, HCCI cannot control the start of combustion in the traditional manner, such as by initiating fuel injection or firing a spark plug, because the chemical properties of the reactants dominate the reaction at low temperatures. Second, there is a limited operating range because engine failure could occur due to the high rate of pressure rise during the combustion process. Therefore, HCCI technologies cannot be applied over the entire operating range of engines.

Many studies have been performed to optimize internal combustion engines using H_2, due to its low ignition energy, high diffusivity, and fast flame-propagation speeds. Researchers have studied the effects of an H_2 additive on the combustion and emissions of gasoline engines. Andrea et al. [9] reported that H_2 improved the coefficient of variation (COV) of the indicated mean effective pressure (IMEP), and decreased the burn duration under lean conditions ($\phi < 0.85$). Ji et al. [10–12] reported that the H_2 effects on the combustion and emissions as the load conditions varied. The addition of H_2 to a gasoline engine increased the thermal efficiency under lean and low load conditions and reduced HC and CO emissions under lean conditions.

Fuel and H_2 are distributed homogeneously in a cylinder of a gasoline engine; the combustible mixture in the cylinder ignites instantaneously and forcibly by spark-plug ignition. H_2 additive can increase the flame speed of a gasoline engine because the gasoline fuel and H_2 are ignited simultaneously by the spark plug. However, in a diesel engine, the diesel fuel is injected into a cylinder along with air and H_2, which are distributed homogeneously throughout the engine. The diesel engine ignites spontaneously without ignition equipment. Thus, the effects of H_2 on diesel engines can differ significantly from those on gasoline engines. Despite this, there have been very few studies that discuss the effects of H_2 on the combustion and emissions of diesel engines [13–15].

Shin et al. [16,17] studied the effects of H_2 additive on the combustion and NO*x* emissions of a diesel engine under constant fuel injection. They held the amount of diesel fuel constant while increasing the amount of H_2 additive. The engine power increased with the amount of the H_2 additive. Thus, the thermal efficiency of the diesel engine improved due to the higher IMEP with a similar friction mean effective pressure (FMEP). The NO*x* emissions decreased under these conditions, because the main combustion duration increased. However, Shin's studies did not deal with the independent effects of H_2 on diesel engine combustion and NO*x* emissions, because the brake mean effective pressure (BMEP) and surrounding temperature of the cylinder also changed with the addition of H_2. The temperature elevation, in particular, affected not only the combustion, but also NO*x* formation [18].

In this study, we investigated the effects of H_2 on the combustion and emissions of diesel engines under constant BMEP conditions. The engine power was kept constant with respect to the H_2 supplied to the engine by adjusting the quantity of injected diesel fuel. This allowed investigation of the effects of H_2 without influencing the engine power or temperature. We also investigated the effects of H_2 on the PM that was emitted from the diesel engine. In this case, a four-cylinder 2.2-L direct-injection diesel engine, satisfying Euro5 legislation, was converted for H_2 feed and with low-pressure loop (LPL) exhaust gas recirculation (EGR). The cylinder pressure and emissions were measured to evaluate the H_2 effects on the combustion, and on the NO*x* and PM emissions, as the H_2 energy ratio changed for various EGR ratios.

2. Experiment

2.1. *Experiment setup*

Fig. 1 shows a schematic diagram of the experimental setup, which consisted of a diesel engine, a dynamometer, an LPL-EGR system, a thermodenuder, a scanning mobility particle sizer (SMPS), and equipment that measured the pressure, temperature, air flow rate, H_2 flow rate, and exhaust/intake gas composition.

A four-cylinder 2.2-L R-engine made by Hyundai Motor Company was used in this study. This engine satisfied Euro5