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A study of a GCI engine fueled with gasoline-biodiesel blends under pilot and main injection strategies

Yanuandri Putrasari[a], Ocktaeck LIM[b,*]

[a] Graduate School of Mechanical Engineering, University of Ulsan, San 29, Mugeo2-dong, Nam-gu, Ulsan 44610, South Korea
[b] School of Mechanical Engineering, University of Ulsan, San 29, Mugeo2-dong, Nam-gu, Ulsan 44610, South Korea

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ABSTRACT

A study was conducted to compare gasoline with the addition of 5% by volume of biodiesel (GB05) to 100% neat diesel using the multiple injection strategies in a gasoline compression ignition (GCI) engine. The engine was tested at 1200 rpm using 70 MPa of injection pressure and multiple injections, which consisted of a pilot injection at the 350-degree crank angle before top dead center (°C A BTDC) for approximately 1140 µs, followed by the main injection at 40 °C A BTDC for around 350 µs. The results show that low-temperature combustion can be achieved for GB05 with multiple injections at an in-cylinder temperature of approximately 1800 K. The heat release rates (HRR) for multiple injections of GB05 were lower than that for a single injection of 100% diesel. However, it is higher than those of multiple injections of 100% diesel and a single injection of GB05. Using multiple injections and increasing the temperatures of the intake, oil and engine coolant could result in improved combustion and engine efficiency. Multiple injections of GB05 showed decreased carbon monoxide (CO) emissions, which could be due to the pilot injection of GB05. The biodiesel content and using gasoline as a highly volatile fuel in GB05 showed the significant effect of lowering total hydrocarbon (THC) and CO emissions. However, nitrogen oxide (NOx) emissions from GB05 for both the multiple and single-injection modes seem to be higher than those of multiple injections of 100% diesel and even higher than those of a single injection of 100% diesel, which is due to the oxygen content in the GB05 fuel.

1. Introduction

Particulates matter (PM) and NOx are the problems of CI engines. These emissions can be contributors to air pollutant, which have serious environmental and health implications. The emission control technology such as after treatment systems are being developed, however, expensive, complicated and reduce the main advantage of CI engines. Moreover, limitations of vehicle emission regulations especially CI engine are getting to be more stringent in all over the world. Therefore, to develop engine combustion systems that offer high efficiency but low emissions motivate engine researchers to study the utilization of high volatile fuels, such as gasoline and alternative fuels, for CI engines. Biodiesel, which is made from various renewable resources, is known to be very suitable as a sustainable alternative fuel for CI engines [1,2]. Furthermore, biodiesel has proven to have prominent advantages in reducing engine soot emissions [3,4], because the presence of oxygen in the biodiesel plays a significant role in lowering soot formation during combustion [5].

CI engines are much more efficient than SI engines for several reasons. First, as the main reason, CI engines do not suffer from knocking at high loads and, hence, can have higher compression ratios compared to SI engines. Second, CI engines can run at part load by reducing the amount of fuel injected, rather than controlling the mass of air trapped in the cylinder. Third, in a CI engine, during the compression stroke, only air is compressed, rather than a mixture of fuel and air, which brings the performance closer to the ideal cycle efficiency. However, CI engines running on diesel fuel always produce high emissions, especially NOx and soot/smoke/particulate matter, which are difficult to control through subsequent treatments. In contrast with CI engines, SI engines running on gasoline fuel have lower engine

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Abbreviations: B, Biodiesel; B100, 100% biodiesel; BTDC, Before top dead center; CA, Crank angle; CA50, Combustion phasing (50% the heat release); CI, Compression ignition; COV, Coefficient of variability; D100, 100% diesel; G, Gasoline; GB, Gasoline-biodiesel; GB00, 100% gasoline; GB05, Blend of 95% gasoline and 5% biodiesel; GCI, Gasoline compression ignition; HC, Hydrocarbons; HCCI, Homogeneous charge compression ignition; HRR, Heat release rate; IMEP, Indicated mean effective pressure; IVC, Intake valve closure; IVO, Intake valve opening; kW, Kilowatt; MPa, Mega pascal; N2, Nitrogen gas; NOx, Nitrogen oxides; PCCI, Premixed charge compression ignition; PM, Particulate matter; PPRR, Peak pressure rise rate; RTD, Resistance temperature detector; SOHC, Single overhead cam; SOI, Start of injection; TDC, Top dead center; THC, Total hydrocarbons

* Corresponding author.
E-mail address: otlim@ulsan.ac.kr (O. LIM).

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efficiency, but also produce lower emissions, especially NOx and particulate matter. Based on these realities, a breakthrough combustion method is required to obtain high efficiency like a diesel engine, but produce lower emissions like a gasoline engine [6,7]. Recently, GCI is being considered as the most promising concept due to its high thermal efficiency and low emission characteristics [8–14]. Although homogeneous charge compression ignition (HCCI) and premixed charge compression ignition (PCCI) also offer attractive combustion phenomena under uniformly lean conditions, the complexity of auto-ignition controllability in HCCI and the fuel injection system in PCCI makes GCI more user-friendly [15–20].

Many researchers have been consistently working on GCI engines. Loeper [21] identified and quantified the effects of the variation of input parameters on overall engine operation. The input parameters include inlet temperature, inlet pressure, injection timing/duration, injection pressure, and engine speed. The results showed that input parameters could be manipulated efficiently to maintain low NOx emissions and proper combustion stability. According to Kodavasal et al., the start of injection (SOI) timing also has effects on the balance of combustion [22]. The most stable combustion for a GCI engine was obtained by simulation at excellent SOI timing for -30° after top dead center (ATDC) and ultimately misfired at SOI earlier than -42° ATDC. SOI has the very high possibility of solving the emission problem by reducing NOx and maintains the high efficiency of low-temperature combustion. However, more engine noise (instability) and more top emissions, especially CO and hydrocarbon (HC), will occur due to misfiring, knocking, and wet in-cylinder wall impingement. Also, some researchers have started using biodiesel blends in CI engines to increase the lubricity and oxygen content [23]. Adams [20] studied the effect of biodiesel-gasoline blends on GCI combustion using 5% and 10% biodiesel. The partially premixed, split-injection combustion strategy was applied in the study. Since it is well-known that initially supplying a high intake temperature is always difficult, the study focused on reducing the required intake temperature of GCI engines at the low load condition by blending biodiesel with gasoline. However, the critical property of biodiesel currently limiting its application to blends of 20% or less is its relatively poor low-temperature properties [23]. Conventional fuel containing a blend of 25% biodiesel was observed as the best-suited blend to apply to the engine without heating or any engine modifications [24]. The practice of using gasoline-biodiesel blends in a GCI engine and experimental tests of a combination with 20% by volume biodiesel in a GCI engine using single-injection mode has been studied previously [25]. However, the study was conducted without manipulating the initial conditions, so the intake air, oil, and coolant temperatures were merely maintained at a room temperature of approximately 25 °C. The results also seem to be not sufficiently satisfying, especially on the NOx emission results, which are much higher for the GCI engine using a blend of 20% biodiesel and 80% gasoline compared to the diesel engine.

Previous studies have presented detailed analysis and discussion of the combustion and emission characteristics of engines based on biodiesel blends and the initial conditions, especially the intake temperature. However, the combustion and emission characteristics of CI engines are also influenced by various other factors, such as fuel injection strategy. Various injection strategies can lead to discrepancies in characterizing engine combustion and emissions. Therefore, it is very important to describe the effect of injection fuel strategy, e.g., multiple injections, on the combustion and emissions of GCI engines fueled with gasoline-biodiesel blends. The multiple-injections strategy, which is comprised of a pilot and main injections applied directly to a cylinder engine [26], and the earlier split-port injection method, which is used to create fuel stratification combustion [10], was applied to successfully reduce NOx. The pilot and main injection strategies created a decreasing NOx profile that was attributed to the decreases in combustion pressure and temperature peaks along the combustion phasing generated by the progressively later combustion [27]. At medium engine loads and speed, the pilot-pilot-main injection strategy, which is optimized using the design of experiments, allows the NOx emissions to be decreased significantly and has led to higher mean combustion pressure, lower heat release rates, shorter ignition delays, and lower brake specific fuel consumption [28]. There is less experimental data characterizing the combustion and emissions of the GCI engine using the multiple-injection strategy with fossil gasoline and biodiesel blends, and the theory that discusses GCI with biodiesel utilization is less well-developed for the multiple-fuel injection strategy. Thus, experimental studies to identify the important fuel properties and quantify the effects of the pilot and main injection strategies on GCI engines using gasoline-biodiesel blends are essential for advancing the theory and contributions to successfully implement gasoline in CI engines and biofuel into the transportation sector.

The objective of this study was to determine the effects of various injection strategies, i.e., multiple-injection mode, which consists of a pilot and main injections, and single-injection mode, on the combustion and emissions of a GCI engine fueled with gasoline-biodiesel blends. To obtain a clear and comprehensive analysis of the effect of various injection strategy on combustion and emissions of GCI engine the same basic energy input of injected fuels was used for comparing the various parameters. The pilot and main injection modes for the gasoline-biodiesel blend were also combined with modification of several initial conditions, such as intake, oil, and coolant temperatures. The analysis of the combustion characteristics of cylinder pressure, heat release rate, combustion stability, ignition delay, and emission characteristics are discussed as the focus of this study.

2. Methodology

2.1. Fuel preparation

The main fuels utilized in this study were pure commercial gasoline (GB00) and neat diesel (D100) from a common fuel station and pure soya bean biodiesel (B100) from an industrial source in Korea. For complete information about soya bean vegetable oil, its chemical composition can be seen in Table 1 [29]. Biodiesel and gasoline were then mixed to make a gasoline-biodiesel blend. The concentration of biodiesel in the blends was 5% by volume, and the blend was referred to as GB05. The "G" stands for gasoline and "B" is for biodiesel, and the numeric value refers to the percentage content of biodiesel in the blend. The gasoline-biodiesel blend was prepared through a mixing/shaking process for approximately 2 to 10 min to obtain homogeneity. Because biodiesel and gasoline blends are known to have stability issues due to a large density difference, a macroscopic visualization test to explore the phase separation and crystalline colloids of the blends was performed in a previous study [30]. The fuel blending process in this study was performed immediately before the experiment was conducted to

Table 1
Chemical composition of soya bean vegetable oil [29].

Fatty Acid	System Name	Structure	Formula[a]	Composition (wt %)
Myristic	Tetradecanoic	14:0	$C_{14}H_{28}O_2$	0
Palmitic	Hexadecanoic	16:0	$C_{16}H_{32}O_2$	12
Stearic	Octadecanoic	18:0	$C_{18}H_{36}O_2$	3
Arachidic	Eicosanoic	20:0	$C_{20}H_{40}O_2$	0
Behenic	Docosanoic	22:0	$C_{22}H_{44}O_2$	0
Lignoceric	Tetracosanoic	24:0	$C_{24}H_{48}O_2$	0
Oleic	*cis*-9-Octadecenoic	18:1	$C_{18}H_{34}O_2$	23
Linoleic	*cis*-9,*cis*-12-Octadecadienoic	18:2	$C_{18}H_{32}O_2$	55
Linolenic	*cis*-9,*cis*-12, *cis*-15-Octadecatrienoic	18:3	$C_{18}H_{30}O_2$	6
Erucic	*cis*-13-Docosenoic	22:1	$C_{22}H_{42}O_2$	0

[a] xx:y indicates xx carbons in the fatty acid chain with y double bonds.