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Performance and emissions of a supercharged dual-fuel engine fueled by hydrogen-rich coke oven gas

Murari Mohon Roy [a,b,*], Eiji Tomita [b], Nobuyuki Kawahara [b], Yuji Harada [b], Atsushi Sakane [c]

[a] Rajshahi University of Engineering & Technology, JSPS Research Fellow, Okayama University, Tsushima-Naka 3, Okayama 700-8530, Japan
[b] Department of Mechanical Engineering, Okayama University, Tsushima-Naka 3, Okayama 700-8530, Japan
[c] Mitsui Engineering and Shipbuilding Co. Ltd., Japan

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ABSTRACT

This study investigated the engine performance and emissions of a supercharged dual-fuel engine fueled by hydrogen-rich coke oven gas and ignited by a pilot amount of diesel fuel. The engine was tested for use as a cogeneration engine, so power output while maintaining a reasonable thermal efficiency was important. Experiments were carried out at a constant pilot injection pressure and pilot quantity for different fuel-air equivalence ratios and at various injection timings without and with exhaust gas recirculation (EGR). The experimental strategy was to optimize the injection timing to maximize engine power at different fuel-air equivalence ratios without knocking and within the limit of the maximum cylinder pressure. The engine was tested first without EGR condition up to the maximum possible fuel-air equivalence ratio of 0.65. A maximum indicated mean effective pressure (IMEP) of 1425 kPa and a thermal efficiency of 39% were obtained. However, the nitrogen oxides (NOx) emissions were high. A simulated EGR up to 50% was then performed to obtain lower NOx emissions. The maximum reduction of NOx was 60% or more maintaining the similar levels of IMEP and thermal efficiency. Two-stage combustion was obtained; this is an indicator of maximum power output conditions and a precursor of knocking combustion.

1. Introduction

The use of alternative fuels in engines has been the focus of much attention because of increasing concerns about environmental protection and the shortage of crude oil. Producer gas and hydrogen (H_2) are two potential alternative fuels. Hydrogen engines have many attractive features, but they tend to suffer from premature ignition, especially under high load conditions [1–3]. Premature ignition is a much greater problem in hydrogen fueled engines than in other internal combustion (IC) engines, because of hydrogen's lower ignition energy, wider flammability range and shorter quenching distance. This problem is less severe in producer gas engines although producer gas contains about 12-20% hydrogen [4]. Several gas engines fueled by producer gas have been developed recently [5–15]. Most of them have a spark ignition (SI) combustion system [5–13]. Ref. [5] gave a detailed account of efforts made in evolving robust engine governing mechanism

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[*] *Corresponding author*. Department of Mechanical Engineering, Okayama University, Tsushima-Naka 3, Okayama 700-8530, Japan. Tel.: +81 86 251 8049; fax: +81 86 251 8266.

E-mail address: mmroy5767@yahoo.com (M.M. Roy).

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Nomenclature

°ATDC	degrees after top dead centre
°BTDC	degrees before top dead centre
°CA	degrees of crank angle
$(COV)_{imep}$	coefficient of variance in indicated mean effective pressure
EGR	exhaust gas recirculation
η_i	indicated thermal efficiency
IMEP	indicated mean effective pressure
MBT	minimum advanced injection timing for maximum IMEP
MFB	mass fraction burned
Φ	fuel-air equivalence ratio
R. O. H. R.	rate of heat release

(for maintaining engine speed and output frequency) under variable load operation for dedicated producer gas engine and its performance under field conditions. Results showed that the PID (proportional integrative and derivative) controller provides best control of engine speed (rpm), and was capable of maintaining the output frequencies and voltages within allowable narrow limits with fluctuating/oscillating load conditions. In Ref. [6], combustion characteristics of typical biomass gas assuming the wood chip pyrolysis gas, whose lower heating value was about 1/6 of the city gas in Japan, were investigated. Engine control system for biomass gas was also examined. It was confirmed that simulated biomass gas could achieve high thermal efficiency and stable combustion for wide range of equivalence ratio without knocking and at low emissions. About 2000 hours of gas engine operation with producer gas from biomass as fuel was conducted on the gasification combined heat and power (CHP) demonstration and research plant [7]. Two different control approaches were applied and investigated: one where the flow rate of the producer gas was fixed and the engine operates with varying excess of air due to variation in gas composition, and a second where the excess of air in the exhaust gas was fixed and the flow rate of produced gas from the gasifier was varied. It was seen that the optimal control approach regarding the gasifier operation resulted in engine operation with significant variation of the NOx emissions. Measurements of the emission of polycyclic aromatic hydrocarbons (PAH) showed that there were no detectable PAH in exhaust gas from the engine when it was operated on producer gas. The emissions of aldehydes were measured to be significantly lower for producer gas operation than for natural gas. Ref. [8] experimentally investigated the combustion characteristics of low-energy density gases (about 4.2 MJ/Nm^3) in order to develop engine generators for waste gasification and power generation systems. Two simulated low-energy density gases, obtained from one-step high temperature gasification (hydrogen-rich) and two-step pyrolysis/reforming gasification (methane-rich), as well as natural gas, were tested in a small SI engine. Compared to the natural gas driven engine, the hydrogen-rich low-energy density gas driven engine showed similar thermal efficiency but with significantly lower NOx and HC emissions and wider equivalence ratio range for stable engine operation. On the other hand, the methane-rich low-energy density gas engine showed narrower equivalence ratio range for stable operation. The test results showed engine performance more depends on combustion characteristics than on the heating value of the fuel gas. For better engine performance, hydrogen-rich fuel gas was found desirable. Ref. [12] tested a 1.1-liter four-cylinder natural-aspirated SI engine in conjunction with a two-stage gasifier with a nominal thermal input of 100 kW. The fuel gas was produced from wood chips in order to get a carbon dioxide (CO_2) neutral fuel for combined heat and power production. The producer gas had a very low tar and particulate content and high hydrogen content. As the gasifier was operated with varying fuel properties, engine tests were made with different fuel gas compositions. The engine tests showed that producer gas has a power and efficiency advantage compared to natural gas when operating the engine at lean burn conditions. The engine was operated at fuel-air ratios varying from stoichiometric to extremely lean burn. This was done while maintaining a good efficiency and power output. It was shown that it is possible to operate the engine at a compression ratio of 16:1 without experiencing knocking. By using a fuel mixture of 50 vol.% producer gas and 50 vol.% natural gas the hydrocarbon (HC) emissions from the engine were reduced by up to 70% compared to natural gas.

However, SI engine is not suitable for this kind of fuel under high load conditions because of the difficulty in achieving stable combustion due to the fluctuation of the producer gas components. Producer gas has been used to run dual-fuel engines in some applications [14,15]; however, these are naturally aspirated engines. Ref. [14] summarized the work conducted using biomass-derived producer gas in reciprocating internal combustion engines. The producer gas for the experimental work was derived from the well-established open top, re-burn, down draft gasification system, which was proven to generate consistent quality, ultraclean producer gas. The paper discussed the actual emission measurements in terms of NOx and carbon monoxide (CO) on a dual-fuel engine using high-speed diesel and producer gas fuel. It was found that the NOx levels are lower compared to operations with pure diesel fuel on account of lower peak flame temperature, whereas the CO levels were higher due to combustion inefficiencies. The experimental study was carried out on a diesel engine dual-fueled by wood-pyrolysis gas and biodiesel fuel [15]. Wood-pyrolysis gas was simulated by a low-calorie mixed gas (LCG), which consists of hydrogen, methane and inert gas. Effects of LCG/biodiesel ratio, biodiesel injection timing, and gas fuel composition were examined. Obtained results showed that under a constant torque condition, an increase in gas fuel consumption causes a decrease in a brake thermal efficiency due to a decrease in combustion efficiency and specific heat ratio. Also, NOx emission in exhaust gas was decreased by increase in gas fuel consumption under the low-load condition, while it showed no change under the relatively high-load condition. In addition, an early injection of biodiesel was effective to reduce CO emission due to increase in combustion pressure and temperature.