Applied Thermal Engineering 108 (2016) 1–10

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Exhaust emission characteristics of gaseous low-temperature biomass fuel in spark-ignition engine

Lei Chen [a], Peng Song [b,*], Wen Zeng [a], Jing Zhang [a], Chao Feng [a], Hongan Ma [a]

[a] Liaoning Key Laboratory of Advanced Measurement and Test Technology for Aviation Propulsion System, Shenyang Aerospace University, Shenyang 110136, Liaoning, China
[b] College of Electromechanical & Information Engineering, Dalian Nationalities University, Dalian 116605, China

HIGHLIGHTS

- Combustion and emission tests of bio-gas engine were carried out.
- The effect of fuel components on engine performance were comprehensive analyzed.
- The ideal operation has been obtained by using component-control methods of biogas.

ARTICLE INFO

Article history:
Received 20 April 2016
Revised 15 July 2016
Accepted 16 July 2016
Available online 18 July 2016

Keywords:
Bio-gas
Combustion
Emission
SI engine

ABSTRACT

This paper presents the results of research on the combustion and emission characteristics of synthetic bio-gas in a spark-ignition engine. The combustible gas components methane, hydrogen and carbon monoxide as well as the diluted gas component carbon dioxide are employed to simulate actual bio-gas which is produced through a low-temperature gasification technique. The effects of fuel components, equivalence ratio, fuel substitution and dilution on combustion and emission characteristics were investigated. The results show that CO_2 dilution gives little variation in brake thermal efficiency at a low dilution ratio, but there is clearly a reduction in brake thermal efficiency at a high dilution ratio. The NO_X emission of individual fuels also decreases with the dilution ratio because there is less input heat. However, a high CO_2 content also leads to deterioration in the stability of engine operation and a high CO emission level. The substitution of H_2 improves brake thermal efficiency and engine stability, which offsets the adverse effects, to a certain extent, of dilution with CO_2 dilution at a high dilution ratio. By utilizing a component-controlling strategy, it is possible to use bio-gas to obtain ideal engine operation gas with acceptable brake thermal efficiency and NO_X emissions.

1. Introduction

The production of biomass materials such as animal waste, straw and landfill resulting from animal husbandry, planting and daily human life has caused some environmental problems. For instance, surface or ground water contamination and air pollution problems with the release of the greenhouse gases CH_4, CO_2 and N_2O have become the main factors that restrict economic development [1–6].

The application of biomass processing techniques [7,8] has made it possible to transform these biomass materials into a gaseous mixture [9,10], which includes both combustible and incombustible gases. This has provided the opportunity to utilize these bio-gases to fuel prime movers such as internal combustion engines. Researchers have carried out actual experimental and numerical research on bio-gas engine operation in recent years.

Jung et al. [11] studied the performance and NOx (nitrogen oxides) emissions of a biogas-fueled turbocharged internal combustion engine by using a one-dimensional cycle simulation. The results show that the combustion behaviors were improved as the CH_4 content in the biogas increased. The brake power, brake thermal efficiency, and NOx emissions increased as either the CH_4 content or the boost pressure increased. The lean operation limit was extended up to a relative air/fuel ratio of 1.5 with various biogas compositions and up to a relative air/fuel ratio of 1.7 for the CH_4:CO_2 volume ratios of 65%:35% and 70%:30% without knocking. Park et al. [12] studied the effects of adding H_2 on the behavior of an engine with various excess air ratios and CH_4 concentrations in the biogas. It was found that adding H_2 improved the in-cylinder combustion characteristics while reducing the hydrocarbon emissions. Porpatham et al. [13] carried out tests to compare the

* Corresponding author.
E-mail address: 20143625@qq.com (P. Song).

http://dx.doi.org/10.1016/j.applthermaleng.2016.07.115
1359-4311/

Nomenclature

CO_2	carbon dioxide
NO_X	nitrogen oxide
CO	carbon monoxide
H_2	hydrogen
SI	spark ignition
CH_4	methane
DI	direct injection
HC	hydrocarbon
N_2	nitrogen
O_2	oxygen
H_2S	hydrogen sulfide
NO	nitric oxide
BTDC	before top dead center
DR	dilution ratio
SR	substitution ratio of H_2
CR	substitution ratio of CO
ϕ	total equivalence ratio of blended fuel
ϕ_{H_2}	equivalence ratio of H_2
ϕ_{CO}	equivalence ratio of CO
ϕ_{CH_4}	equivalence ratio of CH_4
LHV	lower heating value
BMEP	brake mean effective pressure
COV_{IMEP}	coefficient of variation of IMEP
CNG	compressed natural gas
WOT	wide open throttle
MBT	maximum brake torque

performance, emissions, and combustion characteristics of a biogas-fueled spark-ignition engine with different compression ratios. They reported an increase in the brake thermal efficiency and brake power when the compression ratio increased. They also found that when the compression ratio was above a critical value of 13:1, the brake thermal efficiency and brake power increased slightly. Damrongsak and Tippayawong [14] carried out experimental work to research the use of a small bio-gas engine to drive the automotive vapor-compression air-conditioning system on a small-size single-cylinder engine. The bio-gas produced by a continuously stirred reactor with a methane content of 72% by volume and lower heating value of 22.9 MJ/m^3 was employed in this work. It was reported that the bio-gas engine can be used to run the air-conditioning system with acceptable operation over a range of speeds and loads. The overall primary energy ratio of the modular refrigeration system driven by the biogas engine reached a maximum at approximately 1.0–1.2.

Table 1
Real gaseous component through low temperature gasification in this research.

Item	Unit	Flow rate/percentage (by volume)
H_2	%	35–50
CO	%	6–15
CH_4	%	2–8
CO_2	%	19–25
C_2+	%	0–0.8
Others (mainly N_2)	%	15–29

In addition, researchers have also committed to bio-gas research on dual-fuel engine operation. Nathan et al. [15] noted that due to the presence of CO_2, the use of bio-gas could result in low thermal efficiency of the engine. The biogas addition results in a decrease in the thermal efficiency at lower load conditions depending on the biogas quality, however, the fuel composition hardly affects the thermal efficiency at higher loads. Cacua et al. [16,17] employed commercial diesel and simulated biogas (with a typical composition of 60% CH_4 and 40% CO_2) in dual-fuel mode engine operation for a micro-trigeneration system. It is reported that the global energy efficiency of this system at the engine full load was 40% and 31% in diesel and dual mode, respectively, while these same efficiencies of this engine as originally used for single generation were 23% and 18%, respectively. A maximum diesel substitution level of 50% was achieved in dual mode. Barik and Murugan [18] used bio-gas as an alternative gaseous fuel in a DI diesel engine in the dual fuel mode. Diesel was used as an injected fuel and bio-gas which consisted of H_2, CH_4, CO, N_2, CO_2, O_2 and H_2S was inducted through the intake manifold at different flow rates. It is reported that the biogas inducted at a flow rate of 0.9 kg/h was found to give better performance and lower emissions, than those of the other flow rates. The ignition delay in the dual fuel operation is found to be longer than that of diesel throughout the load spectrum. The NO and smoke emissions in

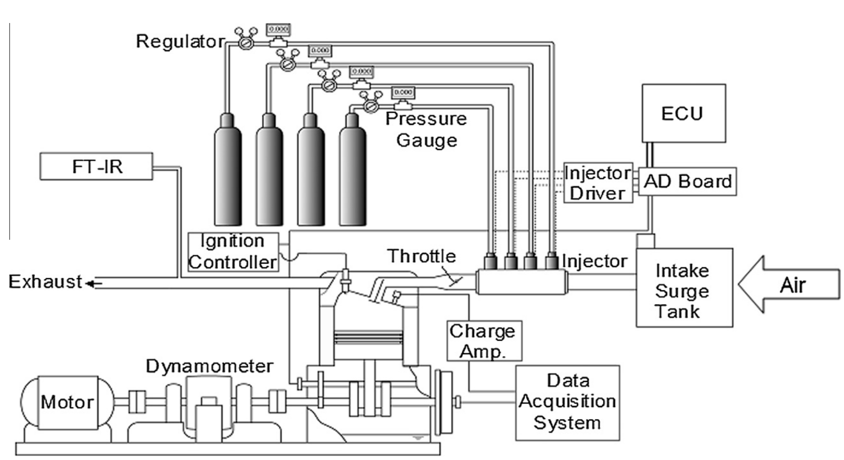

Fig. 1. Experiment schematic.