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Performance and emission characteristics of a vehicle fueled with enriched biogas and natural gases

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HIGHLIGHTS

- One enriched biogas and five natural gases were tested using a CNG vehicle.
- THC, CO, NO_x, and CO_2 were lower, but fuel economy was higher in ETC cycle.
- Toluene represented the highest proportion of the BTEX emissions in both cycles.
- Nanoparticle concentrations were lowest for M91 among six tested fuels.

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ABSTRACT

This study aimed to investigate the characteristics of exhaust emissions and the fuel economy of a compressed natural gas (CNG) vehicle fueled with biogas and natural gases. A large CNG vehicle currently used as a city bus in Korea was tested on a chassis dynamometer under the European Transient Cycle (ETC) and the National Institute of Environmental Research (NIER) 06 cycles. One CH_4-enriched biogas (97.6% CH_4) and 5 natural gases with different CH_4 contents (81.6–94.0% CH_4) were used as test fuels. Total hydrocarbons (THC), CO, NO_x and CO_2 emissions in the NIER 06 cycle were higher than those in the ETC cycle for all tested fuels, while the fuel economy in the NIER 06 cycle was 43.7–51.5% lower than that in the ETC cycle. Total VOC emissions increased with increasing CH_4 content in the fuel, with toluene being the highest proportion of the BTEX emissions in both the ETC cycle (72–80%) and the NIER 06 cycle (73–78%). Emissions of elemental/organic carbon exhibited a similar trend to that of nanoparticle emissions. Total organic carbon was mainly comprised of organic compounds at 97–99% (ETC cycle) and 95–99% (NIER 06 cycle). Polycyclic aromatic hydrocarbon emissions in the NIER 06 cycle were 133.3–577.8% higher than in the ETC cycle because of incomplete combustion and an increase in unburned fuel in the NIER 06 cycle, which is a low-speed driving mode. Nanoparticle number concentrations were lowest for M91 among the 6 tested fuels; the total number of particles in the NIER 06 cycle was 33.2–123.8% higher than in the ETC cycle.

1. Introduction

Climate change and environmental degradation are key issues facing the world today. In particular, global warming due to anthropogenic CO_2 emissions has become a substantial environmental challenge [1–3]. In response, renewable energy recovery and harvesting methods to achieve CO_2 emissions reductions have been extensively studied and adopted, including different types of cycles for heat and energy generation [4,5], renewable energy integration [6–11]. Various countries are endeavoring to develop alternative fuels that can reduce the emissions of greenhouse gases (GHGs) and other air pollutants. The European Union (EU) has set a target for reduction of GHG emissions of at least 35% by using biofuels rather than fossil fuels [12]. In addition, 10% of all fuels consumed in the transportation sector are mandated to be replaced with biofuels by 2020 [13]. In addition, EU policies include a goal of supplying 20% of European energy demand using renewable energy systems (RES) by 2020 [14].

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Nomenclature

ATD	automatic thermal desorber
BTEX	benzene, toluene, ethylbenzene, and xylene
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
CHP	combined heat and power
CLD	chemiluminescent detector
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DCU	dyno control unit
EEPS	Engine Exhaust Particle Sizer
ETC	European Transient Cycle
EU	European Union
GHG	greenhouse gas
HC	hydrocarbon
HFID	heated flame ionization detector
KGC	Korea Gas Corporation
NDIR	non dispersive infrared
NIER	National Institute of Environmental Research
NO_x	nitrogen oxides
PAH	polycyclic aromatic hydrocarbon
PEU	power exchange unit
RES	renewable energy systems
RTFO	Renewable Transport Fuel Obligation
THC	total hydrocarbon
TOC	total organic carbon
VOC	volatile organic compound

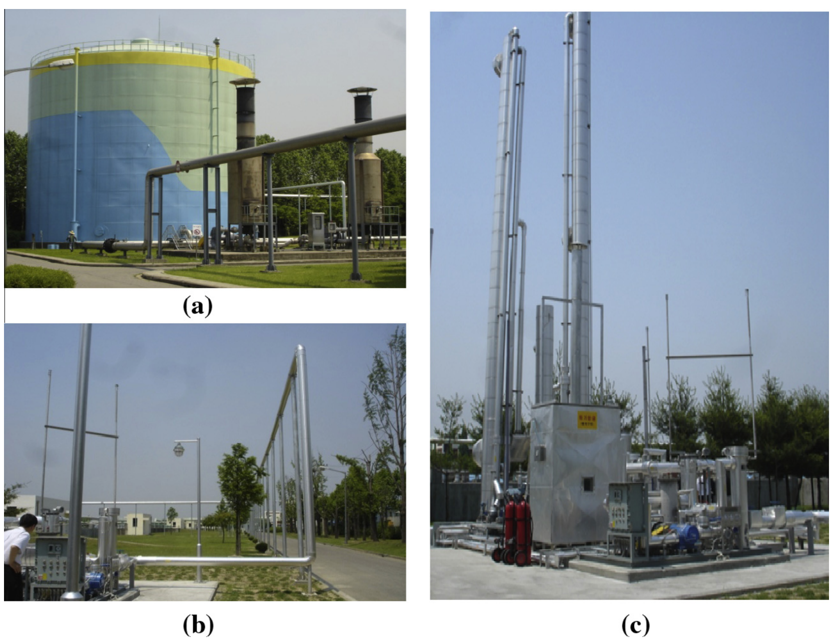

Fig. 1. Photograph of biogas production plant using sewage sludge. (a) Digestion storage; (b) biogas transport conduit; and (c) purification facility.

In 2007, the UK government established the Renewable Transport Fuel Obligation (RTFO) to enhance development of biofuels. The biofuel content targets were 3.25% in 2009/2010, 3.5% in 2010/2011, 4% in 2011/2012, and 5% in 2013/2014 [15]. In Sweden, biogas produced by local biogas plants is the most commonly used fuel for transportation [16]. Biogas production is an important strategic initiative in energy supply in China; 38.5 million household-scale digesters and 27,436 large- and medium-scale biogas plants had been built by the end of 2010 [17]. In Germany, the number of biogas plants increased nearly 10-fold during 1996–2008, and the electrical power supplied to the national grid from biogas plants experienced a 6-fold increase during 1999–2008 [18]. In Germany, biogas is mainly used for combined heat and power (CHP) and electricity generation and feeds into the national grid [18].

Biogas is obtained by anaerobic digestion from biomass or biodegradable organic wastes [1,19–20]. It is typically composed of CH_4 (40–75 vol.%) and CO_2 (15–60 vol.%) although its main composition varies depending on the digestion process and the type and composition of the raw materials [20–22]. Biogas can be used for production of electricity and heat [20,23] and in fuel reforming for hydrogen production. If properly upgraded, it can be a good alternative to petroleum for vehicle fuels [19–21]. There are many ways to upgrade biogas, including thermochemical

Table 1
Compositions of the biogas and natural gases used in this study.

Natural Gases	CH_4 contents (%)	Composition ratio (% mol/mol) C_2H_6	C_3H_8	N_2	Calorific value (kcal/Nm^3)
1	81.6 (M81)	11.0	6.8	–	11,200
2	85.7 (M85)	10.0	2.3	2.0	10,400
3	88.0 (M88)	12.0	–	–	10,400
4	91.0 (M91)	6.0	3.0	–	10,400
5	94.0 (M94)	–	6.0	–	10,400
Biogas	97.6 (M97)	–	–	–	9300