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Performance of an Internal Combustion Engine Operating on Landfill Gas and the Effect of Syngas Addition

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ABSTRACT: The performance of a four-stroke Honda GC160E spark ignition (SI) internal combustion (IC) engine operating on landfill gas (LFG) was investigated, as well as the impact of H_2 and CO (syngas) addition on emissions and engine efficiency. Tests were performed for engine loads from 0.2 to 0.8 kW over a range of CO_2 to CH_4 ratios (0−0.50). In addition, variation across both the syngas content (up to 15%) and the ratio of H_2 to CO in the syngas (H_2/CO = 0.5, 1, and 2) were tested. Catalytic testing provided reactor data on the amount of syngas and H_2/CO ratios that can be obtained by autothermally reforming LFG. The emissions obtained from the test engine fueled with the simulated LFG were found to be comparable to emissions from commercial LFG to energy (LFGTE) systems currently deployed. Syngas addition was found to not only significantly reduce CO, unburned hydrocarbon (UHC), and NO_x emissions but also improve brake efficiency of the engine. CO emissions were reduced from 802 to 214 ppm for a 5% syngas addition and to 230 and 247 ppm for 10 and 15% syngas addition, respectively. UHC emissions were reduced from 113 ppm to approximately 12 ppm for all amounts of syngas addition. Syngas addition decreased NO_x from 100 to 62 ppm for 5% syngas and 71 and 76 ppm for 10 and 15% syngas, respectively. Finally, the brake efficiency increased by approximately 10% with the addition of 5% syngas.

1. INTRODUCTION

Landfills are the second largest source of anthropogenic methane emissions in the United States. Landfill gas (LFG) is generated from anaerobic bacterial decomposition of organic waste materials in municipal solid waste (MSW) landfills, typically consisting of about 50−55% CH_4, 40−45% CO_2, and other trace gases. Because methane is a potent greenhouse gas, current regulations require methane emissions from MSW landfills to be captured. LFG to energy (LFGTE) projects capture 60−90% of the methane emitted from a MSW landfill and use it primarily for electricity generation in internal combustion engines or turbines, or in direct-use projects.[1] An LFGTE project utilizing methane from a landfill reduces atmospheric CH_4 emissions and also displaces fossil fuels that would otherwise have been used. There are currently 519 operational LFGTE projects in the United States supplying 13 billion kWh of electricity and 100 billion cubic feet of LFG to direct-use projects annually.[2] The displaced CO_2 emissions also provide the opportunity to sell greenhouse gas credits, improving the economic feasibility of the LFGTE project.

The difficulty in using LFG for energy is that it is plagued by low and fluctuating energy content resulting in lack of flame stability, deteriorating fuel efficiency, and increased CO, unburned hydrocarbon (UHC), and NO_x emissions. To mitigate these emissions, there are many conventional postcombustion cleanup methods. However, many of these methods result in reduced power output due to pressure drop increases and could potentially add significant expense. Typically, emission waivers are required before LFGTE projects can be permitted.[3]

Due to the low energy content of LFG, most engines need to be modified considerably to accept it as a fuel source.[4,5] There have been many studies investigating the use of landfill gas or CH_4−CO_2 mixtures in spark ignition (SI) engines.[6−10] These studies showed that the presence of CO_2 in inlet fuel mixtures not only deteriorated engine efficiency but also increased pollutant emissions, compared to methane or natural gas fueling. Furthermore, often fuel conditioning is necessary due to variability in LFG composition. If the methane content drops, the addition of a secondary fuel is necessary to ensure continuous and stable combustion. The resulting economic considerations arising from the cost of upgrading fuel, the additional expense of using specialized power generators, postcombustion emission cleanup, and permitting costs have prevented widespread use of LFG. In view of these factors LFG is commonly flared, converting the CH_4 to CO_2 without efficiently utilizing the energy in the LFG.

One method of increasing the reactivity of LFG and therefore reducing engine emissions is to add hydrogen to the fuel stream. Akansu et al. have done an extensive review of prior work on the injection of H_2 into natural gas fuel streams to reduce emissions and improve internal combustion (IC) engine efficiency.[11] In general, UHC and CO emissions decrease with increasing H_2 due to the high reactivity and flame speed of H_2. The effect of H_2 injection on NO_x emissions varies by study and combustion system. This discrepancy can be attributed to an increase in flame temperature with H_2 injection at a given equivalence ratio, resulting in more thermal NO_x. However, H_2 also enables operation at lean conditions, resulting in lower in-cylinder temperatures and therefore a NO_x reduction. Furthermore,

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