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Full Length Article

The effect of the CO_2 ratio in biogas on the vibration and performance of a spark ignited engine

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ABSTRACT

Being a renewable fuel, biogas can be produced either through anaerobic digestion from animal manure, inedible seed residue, food waste, agricultural waste, domestic waste and sewage sludge or through thermochemical processes. Along with thermal applications, by means of combustion inside an engine, biogas can produce both mechanical and electric energy. Depending on the inertia forces of the active parts and the characteristics of the in-cylinder combustion of the engine, vibration can be quite a big problem because it leads to rapid breakdown of engine parts, noisy operation and decreased performance and power output. The CO_2 in biogas is an important compound that affects its lower heating value (LHV), burning characteristics and exhaust emissions. There are a limited number of studies in the literature on the effect of biogas CO_2 content on engine vibration.

In the present study, a four-cylinder diesel engine was modified to operate with a spark plug and used to detect the effect of the biogas CO_2 content on the vibration of the engine. The experiments were carried out with biogas containing 13% and 49% CO_2 at 1.5–9 kW with 1.5 kW load increments at a steady 1500 rpm speed. The amplitude of the engine vibration at all three axes increased as the CO_2 ratio in the biogas and the engine load increased. On the other hand, by decreasing the CO_2 ratio and increasing the engine load, cylinder pressure increased and brake specific fuel consumption decreased. The highest amplitude of engine vibration for all loads was observed at the lateral axis.

1. Introduction

Dwindling oil reserves and decreasing exhaust emission limits are forcing researchers to conduct studies on renewable energy resources to replace oil. In this context, in the future the European Union plans to use biomass resources to produce at least 25% of their bioenergy [1]. Biogas contains a high amount of CH_4 and can be purified from most of its contaminants at low cost. Its range of flammability is broad so it can easily be used to make up a homogeneous mixture with air for better ignition. For these reasons, among others, biogas is an important renewable energy source [2].

The combustion of gas fuels produces lower amounts of exhaust emissions compared to gasoline and diesel fuels [3]. Gas fuels can be used in both spark- and compression-ignited (CI) engines [4]. Biogas is a renewable gas fuel that is produced through anaerobic digestion from animal manure, inedible seed residue, food waste, agricultural waste, domestic waste and sewage sludge, or through thermochemical processes [5–8]. Volumetric percentages of biogas content are about 50–70% CH_4, 25–50% CO_2, 0.3–3% N_2, 1–5% H_2 and a very low percentage of H_2S. The H_2S, CO_2 and N_2 in biogas do not take part in the combustion process and reduce the lower heating value (LHV), burning ratio and flame speed, and this in turn leads to increased ignition delay and mean combustion time. In addition, H_2S causes engine parts to corrode and shortens the lifetime of the engine [4,9,10]. The CO_2 ratio is the most effective parameter on the LHV value of the biogas. For this reason, decreasing the CO_2 ratio of the biogas increases the flame speed and LHV value.

Crookes, in his experiments with simulated biogas, determined that knockless operation was possible with a compression ratio of between 11:1 and 13:1 [11]. The high compression ratio of biogas engines reduces the power loss by increasing the thermal efficiency. Over-increasing the compression ratio raises the knock tendency and the emissions of nitrogen oxide (NO_x) and hydrocarbon (HC). Biogas has a high auto-ignition temperature which increases the resistance to knock [9,12]. This is a significant advantage of spark-ignited biogas engines.

It is impossible to use the biogas directly in traditional diesel

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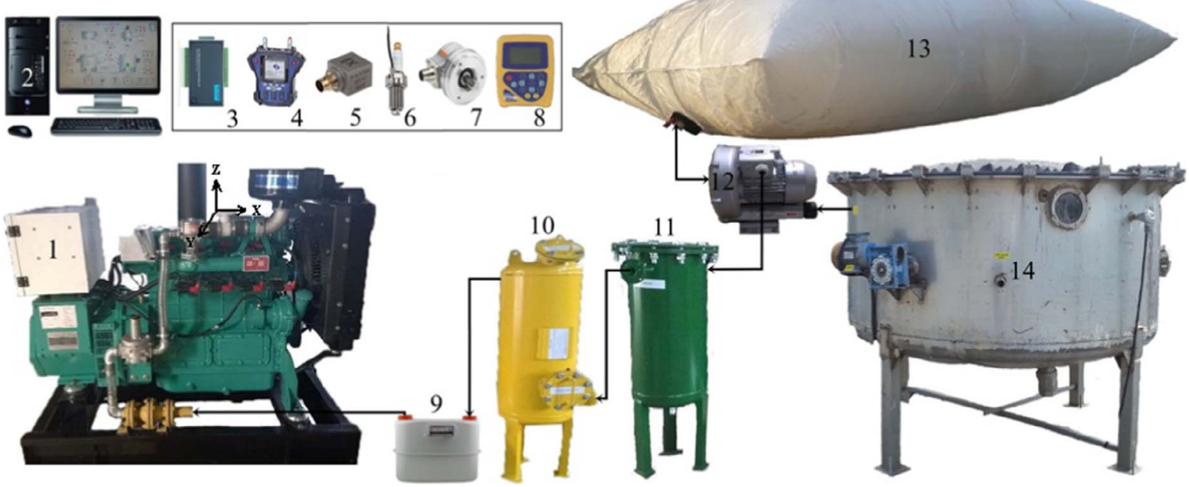

Fig. 1. Schematic view of the experimental setup.

engines because of its low cetane index. However, it can be used in diesel engines with a guide fuel which has a high cetane index. Moreover, because biogas has a high ignition temperature, it can be used in spark-ignited engines having high compression ratios [13]. In other words, a diesel engine can be converted to a spark ignited biogas engine with a high compression ratio by replacing its injectors with spark plugs and modifying the pistons [12,14,15].

A number of studies have been carried out dealing with the effects of biogas on ignition, engine performance and emissions. In a study by Barik and Murugan, biogas produced through anaerobic digestion was tested at four different flow rates (0.3, 0.6, 0.9 and 1.2 kg/h) in a diesel engine that worked in double-fuel mode. The best engine performance and the lowest emission values were measured at a 0.9 kg/h flow rate [1]. Porpatham et al. studied the effect of CO_2 ratio on the performance, emissions and combustion of a spark-ignited engine with a 13:1 compression ratio by using biogas containing 41%, 30% and 20% CO_2 at a steady 1500 rpm engine speed. It was confirmed that a low ratio of CO_2 increases the pressure by increasing the flame speed, and thereby increasing the thermal efficiency and the power of the engine [6]. Byun and Park reported that the CO_2 in biogas reduced the combustion-end temperature, cylinder pressure, heat release rate and flame speed. It has been reported that ignition is delayed and slows down when the CO_2 ratio exceeds 50% [16]. Jeong et al. studied the effects of H_2 addition to biogas on the combustion pressure and exhaust emissions of a spark-ignition engine depending on the excess air ratio. They reported that flame speed, efficiency, maximum indicated pressure and NO_x emissions were increased by the H_2 ratio in the biogas [17]. Alisaraei and Asl added ethanol to pure diesel fuel by 2, 4, 6, 8, 10, and 12% and tested it in a six-cylinder CI engine at full load and 1600, 1700, 1800, 1900 and 2000 rpm engine speeds. They then evaluated the torque, brake thermal efficiency (BTE), combustion, and vibration levels. Compared to pure diesel fuel, the 6% ethanol blend fuel increased the torque and power of the engine by an average of 3.8%, while engine vibration increased by 7.75%. In-cylinder pressure rise caused knocking in the engine [18].

Celebi et al. produced biodiesel from *Pongamia pinnata* and tung oils in order to evaluate the effect of using hydrogen with high viscosity liquid fuels. They investigated the effect of giving hydrogen through the intake manifold on the brake specific fuel consumption (BSFC) and total vibration. Adding hydrogen through the intake manifold improved the fuel economy and decreased the total vibration acceleration of the engine [19].

Patel et al. examined three different test fuels (Karanja biodiesel, 20% (v/v) Karanja-biodiesel blend and baseline mineral diesel) in a CI engine for noise, vibration, combustion, and spray characteristics. The Karanja-biodiesel blend was found to produce the highest vibration (in the direction of the piston). Compared to the other fuels, the highest external engine noise measured by microphone was observed with the Karanja biodiesel. Along with the load increase, lateral and vertical vibration levels increased for all fuel types [20].

The literature review above shows that there are still only a limited number of studies on the effects on engine vibration of CO_2 in biogas produced by co-fermentation from wastes. In this study, the spark-ignited engine of a biogas generator was operated on biogas containing 13% and 49% CO_2 at 1500 rpm and at different load levels. The effects of the engine load on the indicated pressure, BSFC and engine vibration were investigated experimentally for the biogas fuels containing both CO_2 ratios.

2. Material and methods

The biogas used in this study was produced by co-fermentation of poultry manure, whey and bovine manure (35% water, 17% whey, 40% bovine manure and 8% poultry manure). A load of 150 kg/day of this raw material, 12% of which being dry matter, was conveyed to two fermenters (3 m^3 each) and decomposed in an air-free atmosphere to produce biogas (Fig. 1).

This biogas was then purified from H_2S and CO_2 via desulfurization and a washing tower, respectively. After these procedures, the CO_2 content of the biogas was adjusted to 13% and 49% by passing it through a water separator unit. The biogas composition was determined by using a portable biogas analyzer (Geotech GA2000). The gaseous flow rate consumed by the engine was measured using a hooded-type gas flowmeter (Meter Italia MG16). Cylinder pressure was measured by the spark plug coupled with a pressure sensor (Oprand Auto PSI-TC) capable of measuring a 0–200 bar pressure range. An encoder (Kubler,