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Performance and emissions of a modified small engine operated on producer gas

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ABSTRACT

Existing agricultural biomass may be upgraded converted to a gaseous fuel via a downdraft gasifier for spark ignition engines. In this work, a 0.6 L, naturally aspirated single cylinder compression ignition engine was converted into a spark ignition engine and coupled to a 5 kW dynamometer. The conventional swirl combustion chamber was replaced by a cavity chamber. The effect of variable compression ratios between 9.7 and 17:1, and engine speeds between 1000 and 2000 rpm and loads between 20% and 100% of engine performance were investigated in terms of engine torque, power output, thermal efficiency, specific fuel consumption and emissions. It was found that the modified engine was able to operate well with producer gas at higher compression ratios than with gasoline. The brake thermal efficiency was lower than the original diesel engine at 11.3%. Maximum brake power was observed to be 3.17 kW, and the best BSFC of 0.74 kg/kWh was achieved. Maximum brake thermal efficiency of 23.9% was obtained. The smoke density of the engine was lower than the diesel engine, however, CO emission was higher with similar HC emission.

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1. Introduction

Energy is important in driving economic growth. Depletion of conventional energy sources and escalating fuel prices are causing an energy crisis. A possible solution may be found with renewable energies such as biomass, solar, hydropower and wind energy. Biomass is especially abundant, environmentally friendly and is an attractive substitute to fossil fuels. Biomass can be converted to producer gas by gasification, and utilized for generation of power and heat [1,2]. It has the potential to be used to drive internal combustion engines, compared with other forms of energy. Producer gas engines were first introduced around 1914–18, but was used widely during the World War II. More than one million of vehicles used producer gas in Europe, North America and Australia [3]. The use of producer gas in internal combustion engines was seen again during the oil crisis of 1973. However, the use of producer gas to run internal combustion engines, so for, has not been very successful because the power is usually de-rated during the operation. A major cause of lower performance with producer gas is due to its low energy density, compared to gasoline, diesel or natural gas [3,4]. The engine performance may be improved by two methods. One may improve quality of the fuel by focusing on increasing the content of hydrogen and carbon monoxide. This may be achieved by improving gasifier design, combustion processes, characteristics of biomass and quality control systems [5]. Alternatively, engine modifications that improve the use of producer gas may be undertaken. Most previous works on producer gas engines were conducted at compression ratio (CR) of about 10, either adapted directly from spark ignited (SI) engines or modified compression ignited (CI) engines. Munoz et al. [6] carried out tests of a small SI engine with producer gas, at the originally low CR. The power was found to be reduced by 50%, compared to gasoline usage. Similar findings were reported by Ando et al. [7] and Shah et al. [8]. Dasappa et al. [9] experimented on a 100 kW SI engine with producer gas for over 1000 continuous hour at CR of 8.5. The power output was found to reduce by 45%, while the maximum overall efficiency was 18%. Low volumetric efficiency and low energy density of the combustible mixture may be the main causes. Tsiakmakis et al. [10] studied a small SI engine with CR of 10 fueled with producer gas mixed with propane. A loss in power output by about 10% was reported for 55:45 mixture of producer gas and propane. At CR of 10.5, Shivapuji and Dasappa [11] who investigated combustion characteristics of internal combustion engines operated on producer gas reported a de-rating of only about 19% for a 76 kW turbocharged SI engine. Raman and Ram [12] reported test results of producer gas on an SI engine,

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compared to natural gas operation at a CR of 12:1. The maximum overall efficiency was 21% at 85% of full load, while maximum power output was reduced by 12.4%.

For a 100% producer gas fueled SI engine, important modifications affecting engine performance would include changes to CR, spark ignition timing, air/fuel ratio and combustion chamber configuration [3,13–15]. Increasing CR was thought to give a lesser extent of power de-rating. A producer gas engine can operate at higher CR than a gasoline engine. The power output and thermal efficiency has been shown to rise by increasing the CR to those comparable to CI engine operation. However, limitation of knock still exists with producer gas operation [16]. Sridhar et al. [14,15] converted CI engines to operate as SI engines at CR of 11.5–17:1 with producer gas as fuel. For the large engine with CR = 12, power de-rating of 22–30% was reported. For the 24 kW engine with CR = 17, the overall efficiency achieved was reported to be 21%, with power output reduced by 17–19%. Homdoung et al. [17] modified a small agricultural CI engine into an SI engine with CR of 14. It was operated solely with producer gas, achieving a maximum brake thermal efficiency of about 19%.

Recent progress has been reported on producer gas utilization in SI engines with relatively high CR. However, there appeared to be a lack in research works regarding small engine development for producer gas. Therefore, the work was thought necessary to determine if a high CR small SI engine can operate well with producer gas. Thus, this work was interested in modifying a CI engine into an SI engine for producer gas with different CRs, comparable to diesel engine. Effect on its performance in terms of torque, power output, thermal efficiency, fuel consumption and emissions under varying loads and speeds was evaluated.

2. Methodology

2.1. Engine modification

In this experiment, a small agricultural CI engine was converted into SI engine and operated 100% on producer gas. The conventional engine was a small agricultural, diesel engine. It was an 8.2 kW, single cylinder, four strokes, indirect injection engine, 598 cc and CR of 21. (The detailed specifications of small producer gas engine and conventional diesel engine used in the experiment are shown in Table 1.) The modifications to the engine include changes to the combustion chamber, reduction of CR, mounting of ignition system in place of injector nozzle, and mounting of air–gas mixer.

The combustion chamber used for the producer gas engine had a cavity piston, adapted from the swirl chamber engine of the original diesel. The combustion chamber had a bowl in the piston and a flat cylinder head. This chamber was suitable for high CR and expected to provide high thermal efficiency. The symmetrical geometry of that chamber enabled minimum and near equal flame travel. Agitation was started by swirling the charge and completed by compression turbulence. CR was modulated to be in the range of 9.7–17. Variable CR was achieved by increasing the number of gaskets and extension in the range to 40–50 mm of a hollow in piston bowl. The cylinder head bolts and push rods were modified. Volumes of the cylinder head and piston head were measured using a hypodermic syringe with low viscosity oil.

Additional components of the spark ignition system consisted of a distributor, an ignition coil and spark plug. The spark ignition system selected was an electric ignition system, taken from a Mitsubishi 4G15 engine. The vacuum and centrifugal advances were disabled because the engine was run at a constant speed. Modification of the distributor was done by a magnet attached to the flywheel of the engine and a pick-up installed on the casing. When the magnet on flywheel rotated closed to the pick-up, a spark was initiated by a transistor and the ignition coil. Every revolutions of the engine provided a spark in combustion chamber. The spark ignition timing can be adjusted in a range of 0–60° TDC. For mounting of spark plug, the injector nozzle was removed. Auxiliary combustion chamber operated smoothly with new cylinder head. The gas mixer of the engine was of the venturi type. Air and producer gas was mixed before entering combustion chamber. The gas mixer was used to supply the suitable mixture of air and gas required for the engine, operating between 1000 and 2000 rpm and 25 mm of a throat diameter.

Table 1
Specifications of the small SI engine operated on producer gas and diesel engine.

	Modified engine	Original engine
Fuel	Producer gas	Diesel
Type	4 Stroke/naturally aspirated	4 Stroke/naturally aspirated
Bore × Stroke	92 × 90 mm	92 × 90 mm
Number of cylinder	Single cylinder	Single cylinder
Rated output	3.2 kW/1700 rpm	8.2 kW/1800 rpm
Rated speed	1900 rpm	2400 rpm
CR	9.7:1–17:1	21:1
Combustion chamber	Piston cavity	Swirl
Ignition system	Spark ignited	Compression ignited
Type of cooling	Water	Water
Loading device	Electrical generator	Electrical generator

2.2. Experiment apparatus and setup

Charcoal from longan tree was used. It is found in Northern Thailand and has a high calorific value, compared to another charcoals [18]. The average density of charcoal was about 250–300 kg/m^3 with 7% moisture content. The heating value was 28,000 kJ/kg. The producer gas used in this study was from a fixed bed downdraft gasifier run at atmospheric pressure. The gasification system consists of a gasifier, a gas cooler and gas cleaner, shown in Fig. 1. The capacity of the gasifier in term of charcoal consumption was between 5 and 6 kg/h and could generate producer gas in a range of 25–30 Nm^3/h. The gas cooler was a heat exchanger installed in a 100 L water tank. Cooling was conducted between cold water and hot producer gas. The gas cleaner included a cyclone, a water scrubber kit, a moisture separator, a biomass filter, a fabric filter and a paper filter. The water scrubber kit was a venturi scrubber and a pack bed scrubber installed over the tar box remover. The closed-loop water treatment plant used a 335 W water pump. The producer gas composition was determined using Shimadzu GC-8A gas chromatography. The composition of the gas feed on the test engine was of CO 30.5 ± 2%, H_2 8.5 ± 2%, CH_4, 0.35%, CO_2 4.8 ± 1%, and O_2, 6.3 ± 0:5%, and balance nitrogen. The mean calorific value of the producer gas was 4.64 MJ/Nm^3. The tar and particulate matter measurements were carried out at the entrance of the engine. They were found to be lower than 50 mg/Nm^3. Charcoal consumption was measured by an electronic weighing balance. During experiments, the gasifier was filled with charcoal every 2.5 h. The measurement of producer gas flow rates was conducted using Lutron YK-80 flow meters before entering the engine.

The engine torque was measured by a dynamometer set and monitored by a display panel. The electrical loads were from ten 100 W bulbs with ten 500 W heaters. F609 Chauvin Arnoux watt meter was used. Emissions from the SI engine were tested using Koeng KEG 200 gas analyzer with Heshbon HBN 1500B to measured CO, HC and smoke density and as a comparison, with the original diesel engine, before modification. The diesel consumption was measured using JZA electronic-weighing scale gravimetric fuel

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