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Performance of an Otto cycle engine using biogas as fuel

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Due to the rising price of petroleum, researches looking for alternative fuels are intensifying more and more. Brazil has a great availability of biogas from anaerobic digestion of waste in rural areas, of urban waste in landfills and of sewage treatment systems on urban centers. In this paper, an Otto cycle engine was evaluated on a dynamometer, fed with biogas, generating the characteristic curves of the engine for torque and power. First were made control tests, using the systems commercially available for these fuels, so they could serve as a comparative for the other tests. Next were made tests for the several combinations of ignition point, gas mixer and compression rate. By the analysis of the results, it can be concluded that the best power result for biogas was obtained when used compression rate 12.5:1, long gas mixer and spark advance 45°, because in these conditions, it was obtained the maximum power, superior to original biogas.

Key words: Energy, biomass, stationary engine, generator.

INTRODUCTION

Access to energy is an important base for human existence, essential for the satisfaction of the basic needs. But the global dependency from fossil fuels for energy generation and supplying of the ever growing demand, either on industrialized countries or also on developing ones, threatens the environmental stability of the Earth (Ortiz, 2003), and gathers and transforms natural substances and converts them into raw material for this process, always under the direction of the sun. The process of anaerobic digestion, made in a bio digester installed on a rural property, besides reducing organic charges and generating bio fertilizer, also produces biogas, which is a fuel mix basically composed by methane and carbon dioxide. Biogas can be used as an alternative fuel in internal combustion engines connected to energy generators installed on rural areas (Ortiz, 2003). Gas engines work according to the principles of gasoline and diesel oil engines, needing only a few changes on the feeding system, ignition and also on the volumetric compression ratio.

In Brazil there are companies that produce and commercialize generating groups for biogas utilization, and it is known that some of them, despite promoting the engine feeding with gas, refer the nominal performance to gasoline. The main target of this work was to analyze the performance of an Otto cycle engine, using biogas as an alternative fuel. The specific goals were to analyze the influence on torque and power curves of the variables: spark advance, compression ratio and the shape of the air/fuel mixer. The results of the tests leaded to a bigger

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Table 1. Typical composition of biogas.

Gas	Symbol	% in biogas
Methane	CH_4	50 to 80
Carbon dioxide	CO_2	20 to 40
Hydrogen	H_2	1 to 3
Azote	N_2	0.5 to 3
Sulphydryl and others	H_2S, CO, NH_3, O_2	1 to 5

Source: CCE (2000).

knowledge of the influence of these variables over the performance of the engine, bringing some suggestions for adaptations of already existent engines as a way to increase their power.

Literature review

Biogas

In accordance with (Almeida et al., 2002), biogas contains, on average, 55 to 65% methane, 25 to 30% carbon dioxide and trace hydrogen sulfide gas. For (Mialhe, 1980) "methane" is obtained by anaerobic fermentation of manure, by hay and vegetable waste. Methane, the main component of biogas, has no smell, color or taste, but the other gases present have a smell similar to rotten eggs. Biogas consists of a mixture of gases whose type and percentage vary according to the characteristics of the type of waste and the working conditions of the digestion process (BARREIRA, 1993; Santos, 2000). Table 1 shows typical composition of the biogas.

Otto cycle engines fed with gas

Gas engines work according to the principles of compression and spark ignition engines (Zareh, 1998). In fact, some gas engines are diesel or gasoline engines, adapted to work with gas. Conversion consists in some modifications on the feeding and ignition systems, and also on the compression ratio. A spark ignition gas engine has a smaller volumetric efficiency than the equivalent gasoline engine, because the addition of gas reduces the volume of aspired air. But the smaller volumetric efficiency is, usually, compensated by the fact that gas engines can work with compression ratios, 12 to 13:1, higher than those allowed by gasoline. This is possible because the antiknock power of the gas is connected to the number of methane, which means that the bigger the amount of methane, the bigger it is the resistance to detonation. From the making on a Honda engine 270 cm^3 (Munoz et al., 2000), fed with raw biogas and with the same ignition advance and compression ratio used for gasoline, the torque and power curves decreased around 50%. Huang and Crookes (1998) simulated biogas by injecting methane and carbon dioxide in different proportions in an Otto cycle engine. The amount of gas was defined respecting the proportions obtained with the bio digesters. They defined the best compression ratio as 13:1 for all the mixtures. For a 15:1 compression ratio and some bio gas compositions, there was knocking. According to Cañavate and Baader (1988), compression ratio should not exceed 12:1, because the composition of biogas is not constant, and it can lead to knocking in some conditions. But spark ignition have to be advanced, because the burn velocity of biogas is slower.

MATERIALS AND METHODS

The engine used on the research was a national volkswagen, model Ap 1.8 L, which equips several automobile lines of this company. It was acquired on a dealership and maintains the entire original configuration for the comparison with gasoline (control test). Although, the objective of this work is to determine the performance of an Otto cycle engine fed with biogas, it also used natural gas as a reference parameter, because with biogas purification processes can be achieved characteristics very similar to the ones of natural gas. The experiment was made on the internal combustion engine lab of the Technology Center from Santa Maria's Federal University. The internal combustion engine lab is one of the oldest of the Technology Center and is used by the professional subjects of the Mechanical Engineering course. The engine was connected to a JM Motorpower 800 V hydraulic absorption dynamometer. Its maximum absorption capacity is 476.6 kW (648 hp) for a maximum rotation of 9999 rpm and a maximum torque of 51 daN.m (52 m.kgf). The hydraulic brake has an analogical torque indicator connected to a load cell. The engine speed is given by a digital tachometer (magnetic pick-up) of 0 to 9999 rpm. The engine was directly connected to the axis of the hydraulic turbine (rotor) of the dynamometer through a system composed by two driveshaft universal joints to prevent any misalignments during the test.

To determine the power correction factors, according to the regulations NBR 5484, a dry bulb temperatures (dbt) and humid bulb temperatures (hbt) of atmospheric air, technically named "continuous flux psychrometer", was used. This psychrometer is a lab device, especially built according to the recommendations of ASHRAE, and that has been usually used in experimentations which involve the determination of atmospheric conditions. For the specific consumption of the fuels (biogas and natural gas), a flux anemometer was used, installed on a pvc pipe. This anemometer gave the velocity of the gas, for later calculation of the outputs.

Table 2. The parameters analyzed.

Natural gas vehicle	Simulated biogas
C_1 – short venturi	B_1 – short venturi B_2 – long venturi
T_1 – compression ratioe 1 (original – 8.5:1)	T_1 – compression ratioe 1 (original – 8.5:1)
T_2 – compression ratioe 2 (12.5:1)	T_2 - compression ratioe 2 (12.5:1)
P_1 – spark advance 40° Apms	P_1 – Spark advance 40° Apms
P_2 – spark advance 45° Apms	P_2 – Spark advance 45° Apms
P_3 – spark advance 50° Apms	P_3 – Spark advance 50° Apms

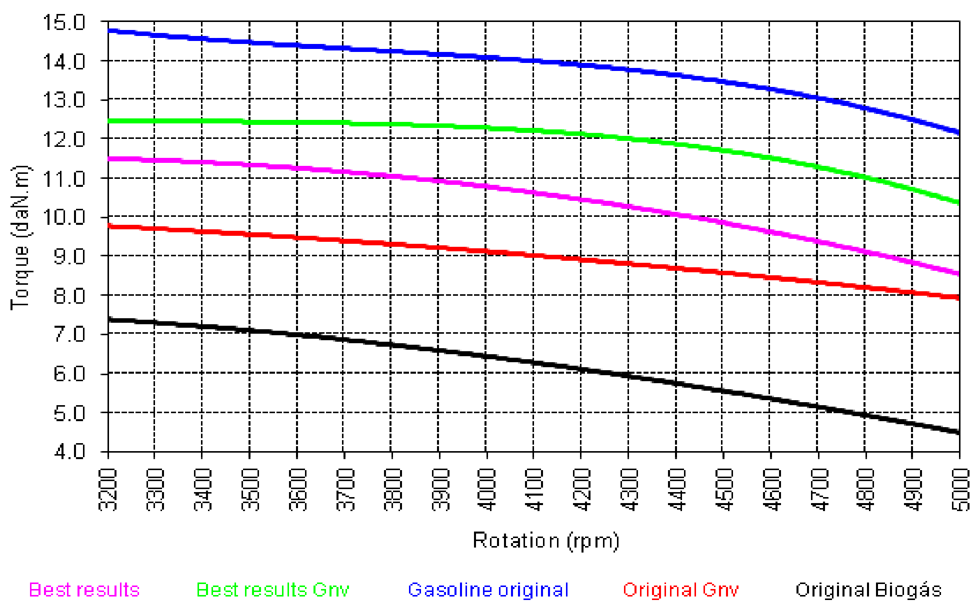

Figure 1. Variation of engine torque on the original conditions and after conversion.

The variables were defined by using what was already available in the market and also by searching for other schools and other researchers. Some technical visits to companies that worked with natural gas, among them being Petrobrás, also were made. Table 2 shows the parameters analyzed in the engine. For each set up were made 3 repetitions, with variations every 50 rpm, between 3200 and 5000 rpm; this interval was defined having as criterion the generation of curves that included the maximum torque and maximum power speed.

RESULTS AND DISCUSSION

Figures 1 and 2 show the torque and engine power curves on the condition 'original biogas', 'original gasoline', and 'original natural gas vehicle (NGV)', versus the best results of biogas and NGV. It was observed a gain of torque and engine power using a compression rate of 12.5:1 (T2), long gas mixer (B2) and spark advance 45° (P2). As NGV presents higher methane content than biogas, the results were better. The use of carbon dioxide absorption systems from biogas may contribute to obtain an alternative fuel similar to NGV. It was observed that the converted engine with biogas can produce a maximum power above 45 kW, with this being able to be connected to a 35 kVA generator so obtaining a self-sufficient electrical power rural property. The engine can also be connected directly to a pump for farming irrigation.

Conclusions

The highest engine power with biogas was obtained with a compression ratio of 12.5:1, long gas mixer and 45° spark advance, because on these conditions a maximum power 100% above original biogas was reached. The gain with the utilization of NGV in replacement of biogas can get to 15% at 3600 rpm engine speed, where the generator gives electrical power. The spark advance and

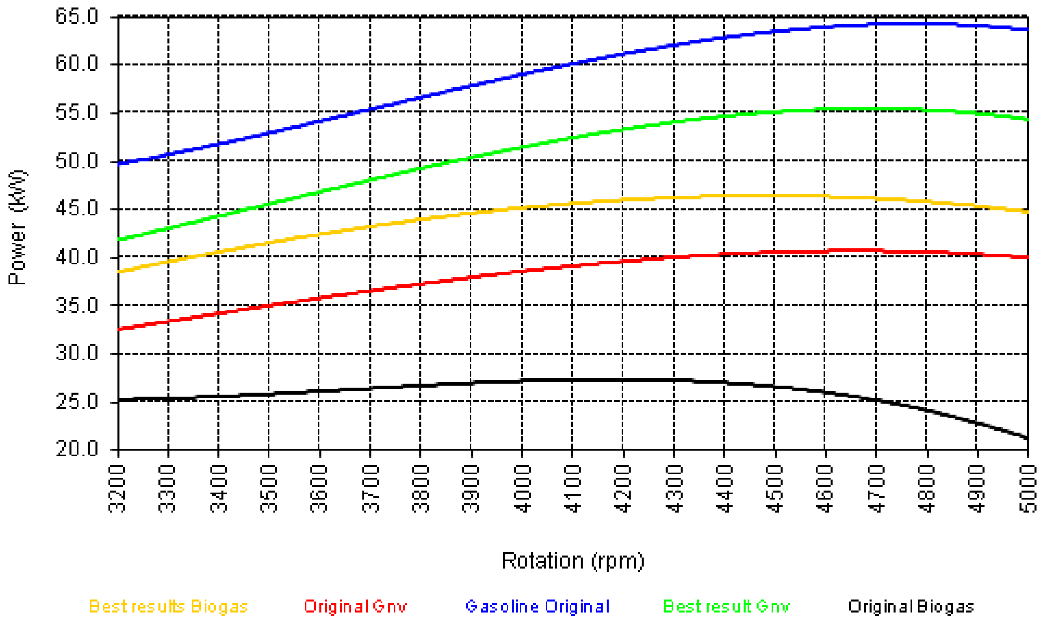

Figure 2. Variation of engine power on the original conditions and after conversion.

compression ratio with the best results for biogas are also the same used with NGV.

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