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Bibliographic Review

Use of biogas in internal combustion engines

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Abstract

The biogas from the anaerobic digestion of solid or liquid waste is an alternative energy source. Its composition is a mixture of gases in which methane and carbon dioxide are in higher proportions. The internal combustion engines are widely used because they can operate with different kinds of both liquid and gaseous fuels. So that biogas can be used as fuel, either in engines, gas turbines or microturbines, it is necessary to identify its flow, chemical composition and calorific value, parameters that determine the real potential to generate electricity.

Keywords: bioenergy, biofuels, engine, Otto cycle

Introduction

According to CORTEZ et al. (2008), currently in a lower intensity, most of the countries, either they are developed or not, are promoting actions so that the alternative renewable energies have significant participation in their energetic matrix. The motivation for this change in posture is the need of reduction on the use of oil derived products and, consequently, the energetic dependence of these countries in relation to the countries which export oil. Besides that, the reduction in the consumption of the oil derived sources of energy also reduces the emission of gases which promote the greenhouse effect. Thus, it is considered a renewable energy when the natural conditions enable its reposition in a short time horizon, the residual biomass (GOLDEMBERG and LUCON, 2008).

This way, we have as a good option - biogas -which can be burn for the generation of heat or passed in a set engine/generator for the generation of electricity. This study aims at developing a discussion about characteristics of engines which use this energetic source for its functioning using the information about the use of biogas in internal combustion engines, describing its functioning and efficiency, as well as the amount of biogas to be used.

Characterization and discussions

Biogas

Biogas was simply seen as a by-product, obtained from the anaerobic decomposition (without the presence of oxygen) of organic residues. However, the environmental crisis, the ratification of the Kyoto Protocol, the implementation of the CDM and the fast economical development of the last years, as well as the increasing elevation of the price of the conventional fuel, has made an increase in researches and investments in the production of energy from new alternative and economically attractive sources which enable the preservation of exhaustible natural resources (SALOMON, 2007).

The biogas which comes from the anaerobic digestion of solid or liquid residues is an alternative energy resource, and it contributes a lot in the solution of environmental problems, since it potentially reduces the impacts of the pollutant source. Its composition is a mixture of gases in which methane and carbon dioxide are in larger proportion. The energetic potential of biogas is in function of the amount of methane contained in the gas which determined its heating power. The content of methane ranges from 40 to 75% depending on the

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generating source. The amount of biogas product of the biodigestion corresponds only to 2.0 to 4.0% of the weight of the organic matter used in the process (CASTANÓN, 2002).

The presence of non combustible substances in biogas, as water and the carbon dioxide damages the process of burn, making it less efficient. These substances absorb part of the generated energy. Besides them, there is also the presence of sulphide acid (H_2S), which may cause the corrosion, reducing both the yield and the useful life of the thermal engine used. Most of the anaerobic digestives produce a biogas which contains between 0.3 to 2% of H_2S, observing also the presence of tracks of nitrogen and hydrogen (COELHO, 2006 A). For the author, it is important to emphasize that depending on the application, it is recommended the purification of the biogas removing the H_2S, CO_2, and the humidity. The most used practices are:

- Removal of humidity: It can be done with glycols, with silica gel, among others, depending on the final use of the gas it will be established the acceptable degree of humidity.

- Removal of Carbon Dioxide (CO_2): there is a variety of processes of removal of the CO_2 present in the natural gas used by petrochemical industries. Different mechanisms can separate some constituents of the gas, being noteworthy between them: the ones of physical and chemical absorption, adsorption in a continuous surface, separation by membranes, cryogenic separation and separation from chemical conversion (chemical reactions).

Internal Combustion Engines

The internal combustion engines are widely used since they can operate with different types of fuel, either liquid or gas. They are thermal machines in which the chemical energy of the fuel is transformed in mechanical work, and the flow of work consists in the products of the combustion of the air-fuel mixture, and the combustion chamber and the process of combustion itself are integrated to the general functioning of engine. They represent the most widespread technology among the thermal machines, due to its simplicity, robustness and high relation potency/weight, which makes that these conditioners are employed in large scale as elements of propulsion for the generation of continuous electricity, of back-up or peak charge and for activate bombs, compressors or any other type of stationary charge (SALOMON, 2007).

The combustion engines may be classified as of the type of EXTERNAL COMBUSTION, in which the flow of work is completely separated from the mixture air/fuel, and heat of the products of the combustion is transferred trough the walls of a reservoir or boiler, and of the INTERNAL COMBUSTION type, in which the flow of work consists in the products of the combustion of the mixture of air/fuel. One major advantage of the alternative engine with internal combustion, over the installation of other types of potency, consists in the absence of exchangers of heat in the circuit of the fluid of work, as the boiler and condenser of one steam installation.

The absence of these pieces not only leads to the mechanic simplification, but also eliminates the loss inherent to the process of transmission of heat trough a finite area exchanger. The alternative engine of internal combustion has another important main advantage over the steam installation or gas turbine, i.e.: all the pieces may work at temperatures below the maximum cyclic temperature. This detail enables the use of very high cyclic temperatures and makes high efficiency possible (RAHDE, 2006).

Engines of internal combustion moved by steam

Biogas is a gaseous fuel with a high energetic content similar to natural gas, composed, mainly, by hydrocarbons with short and linear chain. It can be used for the generation of electric, thermal or mechanical energy in a rural property, contributing for the reduction of production costs. In Brazil, the rural biodigestors have been used, mainly, for rural sanitation, having as by-products biogas and biofertilizer (ALMEIDA, 2006).

So that the biogas may be used as fuel, either in engines, steam turbines or microturbines, it is necessary to identify their flow, chemical composition and heat power, parameters which determine the real potential of generation of electric energy, besides enabling to dimension of the processes of pre-treatment of the biogas, as the removal of H_2S (hydrogen sulphide) and of the humidity, with aims at avoiding damages to the equipments of the installation and increasing its heating power (COELHO, 2006 A).

The proportion of each gas in the mixture depends on a series of parameters, as the type of digestor and the substrate (organic matter to be digested). At any rate, this mixture is essentially constructed by methane (CH_4) and carbon dioxide (CO_2), and its heating power is directly related to the amount of methane existent in the gas mixture. The formation of the biogas involves, basically, three stages, which are fermentation, acetogenesis and methanogenesis (COELHO, 2006 B).

Based on the results of works mentioned by the international literature as instance from ORTIZ-CAÑAVATE et al. (1981), BRANDINI et al. (1983), MITZLAFF (1988), among others who obtained good results from diesel engines operating with double fuel, SILVA (1995) developed a system of double fuel fed, using purified biogas (methane) as main fuel and diesel as pilot fuel, with aims at facilitating the use of biogas in automotive machines in the rural mean, most equipped with diesel engines, in which the production of biogas is favored by the availability of organic residues. The referred system is composed by a reducing and dosing valve of low pressure which has its mechanism of control of gas discharge, associated to the mechanism of acceleration of injector bomb. In this system, methane is mixture to the air admitted in the entrance of the collector and the ignition happens due to the pilot injection of diesel, and the engine is controlled by the charge of cylinder filling.

PERCORA (2006) compared the technologies commercially available concerning the conversion of energy according to what was demonstrated in table 1.

These authors emphasize that for the energetic conversion of biogas engines have higher efficiency. Steam turbines have higher global efficiency of conversion when operated in co-generation – heat and electricity.

SILVA (1995) underlines that internal combustion engines with lean burn (known as Lean Burn Engine) use the biogas directly, and do not need a sophisticated treatment of the fuel, only drying and filtering is enough. These engines have the inconvenience of being imported, with higher costs of investment and maintenance to Brazil; however they are widely used in Europe.

The generation of electric energy is made by the generator directly coupled with the engine. For large engine cycle Otto (imported), the investment cost of the system of biogas caption and energy generation is of approximately 1.200 U$/kW installed. The Rankine cycle is composed by boiler to generate vapor of high pressure and temperature, steam turbine, condenser and bombs. It is the oldest energy generation system and it is very much present with equipments and suppliers in Brazil, due to the sugar ethanol sector, which uses these equipments even for the self-production of electric energy.

The region of Sertãozinho, in the state of São Paulo, stands out as the center of these technologies, concentrating companies of engineering, chair and turbine manufacturers, among other equipments, with investment costs approximately 10% inferior to the cost of engines. In the cases of manure biogas, the technology is restricted to internal combustion engines of low size (50 a 100 kW), enough to supply farms with electric energy generation or even conditioning irrigation bombs. The manure processing machines are adapted with drains which capture the biogas and generate energy in small engines. Since they work with small amounts of manure (in relation to landfills), it is common the use of gasometers to store biogas when the demand for energy is not big. The equipments are mostly of national technology, using engines of adapted vehicles or even new ones, as it is the case of Mercedez Benz, which has a special line for biogas (ZALAUF, 2001).

Table 1. Comparisson of technology available for energy conversion (PERCORA, 2006)

	Gas engines	**Diesel engines: Biogas + Diesel**	**Gas turbines of Low – Medium Size**	**Microturbines (CAPSTONES)**
Potency	30kW – 20MW		500 kW – 150 MW	30 kW – 100 kW
Yield with biogas	30% to 34%	30% to 35%	20% to 30%	24% to 28%
Emissions of NOx	< 3000 ppm Engines with low emission: < 250 ppm	Mean of approximately 27 ppm	Mean aprox. 35 to 50 ppm	< 9 ppm
Obs:		Needs diesel with low content of “S”		

Methane is the useful compound of biogas as it can be used as fuel. Despite its high level of methane, biogas has some inherent problems. First, the critical point of biogas is very low. The critical point of a gaseous substance is the thermodynamic state in which the liquid and gas phases of a substance coexist in balance (PRICE and CHEREMISINOFF, 1981).

The critical point of methane is -82.5 °C and 46.7 bar. This means that biogas cannot be liquefied in a temperature above -82.5 degrees Celsius, which is a limitation in the use of biogas (CONSTANT and NAVEAU, 1989). Information about the critical point of temperature and pressure of some gases are presented in table 2.

Table 2. Critical point of several gases (CONSTANT and NAVEAU, 1989).

	H_2	N_2	NH_3	O_2	CH_4	CO_2	H_2S	C_3H_8	C_4H_{10}
Temperature (C°)	-239.9	-147.1	132.4	-118.57	-82.5	31	100.4	96.6	152
Pressure (Bar)	13.1	34.2	113.9	50.8	46.7	73.85	90.1	42.5	37.9

These authors also describe the energetic content of some gases as it was showed in table 3.

Table 3. Energetic content of the gases* (CONSTANT and NAVEAU,1989)

Fuel	MJ kg^{-1}	MJ m^{-3}
Methane	50.0	35.9
Purified biogas	45.0	32.3
Mean of the biogas	30.0	21.5
Butane	45.7	118.5
Propane	46.4	90.9
Methanol	19.9	15.0 10^3
Ethanol	26.9	21.4 10^3
Gas	45.1	33.3 10^3
Diesel	42.1	34.5 10^3

Basically, there are two basic ways to use methane biogas – (1) flame heat and (2) of internal combustion. For the heat of the open flame there are several easy applicative. Biogas may be simply burned, without any intention of generating heat or may use the flames for heating. Due to the potential of carbon dioxide and high levels of hydrogen sulphide, the gas should not be directly burned in a closed area.

The use of biogas in internal combustion engines is another viable option. There are two basic types of engines which should be executed with the biogas: those with Otto cycle and those with Diesel cycle (MARCHAIM, 1992).

The Otto cycle engine inflames the fuel with a spark-ignition and it generally uses volatile fuels, as gas. Theoretically, the Otto cycle engine must be more efficient than the Diesel cycle engine. Due to the fact that the comprehension rate inhibits the efficiency of the Otto cycle engine, a Diesel cycle engine is considered more efficient in the practice. The Diesel cycle engines inflame the fuel using the compression. In a correct combination of the pressure and temperature, the fuels would burn themselves. Therefore, the engine must be projected for the destined fuel, with the right temperature and pressure. The stoichiometric ratio air-fuel found in previous studies was 5.71 m^3 per m^3 of methane gas for the production of biogas of 60%. This relation should be followed for the complete combustion of biogas (CONSTANT and NAVEAU, 1989)

Concerning the ignition commanded by pure gas, it is considered that most of the Otto cycle engines which use gas, currently may be easily modified for the functioning with natural gas, propane, methane compressed. (EMCON ASSOCIATES, 1980).

The diesel engine may be modified to operate with biogas in two different ways: bi-fuel operation with ignition per injection of pilot fuel, and steam functioning only with ignition per spark (MIHIC, 2004).

For NAVEAU and CONSTANT (1989), there are two changes which should be done to guarantee the appropriate functioning of the change from gas to biogas. First, a carburetor gas should be installed, and next modified according to what was mentioned above to compensate the low speed of the flame to increase the consumption of air for the methane burn. Second, the spark plugs with high temperatures should be installed to combat the combustion of high temperature from methane.

The modifying of an Otto engine is relatively easy, since the engine is projected to work with a mixture air / fuel with ignition per spark. The basic modifying is the supply of air / gas mixer, instead of carburetor. The engine control is made from the variation of the supply mixture. An increase in the compression rate is desirable, and predicts an increase in the process from the thermo-dynamic point of view. Thus, lower specific consumption of fuel and higher potency may be expected. The change is permanent and prevents the use of the original fuel of the engine. The adjustment of the ignition point in relation to the low ignition speed of the biogas does not impose any specific problem – as a pattern of ignition, the system predicts adjustments in a sufficiently wide scale (MIHIC, 2004).

A second kind of engine which may use biogas is the dual modified Diesel Cycle engine. Due to the slow speed of methane combustion, engines with low speed, engines with diesel cycle are more propitious to the use of biogas (NAVEAU and CONSTANT (1989). These systems are projected to burn diesel oil, while they burn biogas. This gives a flexibility concerning the fuel and increases the efficiency of biogas burn. However, this system requires that the diesel fuel is added regularly and also a higher maintenance.

Due to the existence of one regulator in most of the diesel engines of automatic control of speed/potency may be done changing the quantity of injection of fuel in the diesel engines, so that the biogas does not flow out of control. The substitution of diesel by biogas is less substantial in the present case. There are certain limitations, the bi-fuel engine cannot work without the providence of diesel to the ignition, the jets of fuel injection may overheat when the flow of diesel fuel is reduced to 10% or 15% of the normal flow. For MIHIC (2004), the lower bi-fuel engines circulate extra diesel fuel trough the injector nozzle of fuel is affected, however, each project should be specific, due to the material and thermal charge of each engine and, therefore, it changes from case to case. A verifying of the injector nozzle after 500 hours of the operation in the double fuel is recommended.

The last type of engine which may be used with biogas is the diesel cycle engine modified for the use of pure gas. The main changes of the diesel engine include: the removal of the injectors, besides spark ignition, a carburetor gas and reduction in the compression rate (NAVEAU and CONSTANT (1989). Even if that is the most complicated way, it is possibly the most appropriated way to use with biogas.

This modification involves a main operation in the engine and the availability of certain pieces, which will have to be changes. These changes are: the removal of the injection pump, and of the injection nozzle, reduction of the compression rate for 10…12, assembly of one ignition system with distributor, ignition coil, spark ignition and electric feed (alternator) and one dispositive of mixture for the providence of a constant air / fuel mixture.

In any case, mechanic energy may be acquired by internal combustion engine. Since a generator system may be easily connected, this situation is ideal. One of the main advantages of a group generator of internal combustion is that it produces electricity at a constant level. The electricity is more easily used for different function and may be sold to companies of local energy generation (HERRINGSHAW, 2009).

Steam Otto engines, when modified from Otto engines using gas fuel, are found to produce less energy than in the version that uses gas. The reason is the reduction of the volumetric efficiency as a gas fuel occupies most part of the volume, the mixture is sucked to the engine of liquid fuel and displaces the air in conformity. The liquid fuel has energy higher in volume than the biogas (MIHIC, 2004).

A gas engine, especially when operated with biogas, with a great proportion of useless carbon dioxide, may suck a reduced amount of air only to enable space for the needed amount of fuel has. Since in Otto engines one relation of air excess $\lambda=1 \pm 0.1$ has to be maintained and the pipes of admission and the collectors are dimensioned to work with gas, using energy.

The rate of reduction of the power depends on the volumetric heat of the gas, for example, biogas with 70% CH_4 has a higher volumetric heating power of biogas, than with only 50% CH_4. The power of outcome of one engine is, therefore, higher in operation of gases with a high caloric value than in functioning in "weak" gases. Biogas (60% CH_4), with a heating power of Hu = 25 000 kJ / Nm ^{3} gamma as a medium and weak has causes the reduction of energy of approximately 20% (methane of purified natural gas 10% and GLP 5%). The main effect of the reduction of the power is that it needs to be well considered in the selection of the class of potency of an appropriated engine for a determined application with a demand of specified potency (MARCHAIM, 1992).

The engine potency and the speed control are made by a variation of the supply of the mixture air/ engine fuel. This is made by the work of a butterfly valve located between the real dispositive of mixture of admission of the engine. Closing the effects of the butterfly vale, there is a drop of pressure (bottleneck) in the mixture flow, through which the cylinder is filled with a mixture with low pressure, consequently with a lower amount of air/fuel in the mixture and in a base of mass and energy. As a result, the outcome of the power, the mean effective pressure and the reduction of the efficiency in the operation control.

The effect of the reduction of the efficiency is made in an increase of the specific consumption of fuel in the operation or partial charge. To compensate the effects mentioned above, the engines should be operated in medium speed, but with an opened accelerator. This requires an appropriate combination with the demands of speed and potency of the activated machine (MIHIC, 2004).

According to MUÑOS et al. (2000), in experiments performed with engine Honda 270 cm^3, fed with crude biogas and maintained the point of ignition and the rate of compression of the gas, and the curves of torque and potency had a decrease of 50% in relation to the original fuel. HUANGA and CROOKES (1998) simulated biogas injecting methane and carbon gas in different proportions in an Otto cycle engine. The amount of gas which was injected in the engine was defined respecting the proportions formed in the biodigestors. They defined as the best rate of compression 13:1 since it achieved all the mixtures. For a rate of 15:1 in some compositions, there was detonation.

According to CAÑAVATE and BAADER (1988), the rate of compression cannot exceed 12:1, since the composition of the biogas is not constant, and this may lead to the detonation in some moments. The point of ignition must be advances, since the speed of combustion of the biogas is slower.

According to SOUZA (2004), the higher potency of the Otto cycle engine used for the biogas was obtained when it was used the rate of compression 12.5:1, long mixer of gases and point of ignition advanced in 45º, since in these conditions it was obtained the maximum potency 100% superior to the original biogas. The gains with the use of CNG in substitution to biogas reached 15% in the rotation of 3600 rpm where the engine will generate electric energy. The point of ignition and the rate of compression with the best results obtained for biogas are also the same used with CNG.

Final considerations

The use of biogas in diesel engines, as in collecting fleets, besides reducing the consumption of diesel used in approximately 30%, which ends up causing economic and environmental gains for the place in which it is used.

In order to convert the chemical energy of the biogas in electric energy, it is necessary that the biogas produced presents composition and characteristics appropriated to the conversion technology applied. Biogas is a fuel with all the technical and economical conditions to be exploited in Brazil. Currently, it is inserted in the governmental program of incentive to the alternative energy sources (PROINFA), according to which the biogas is viable with a price of approximately R$ 170 / MWh and with the carbon credits (Kyoto protocol), essential to the investitures and for enable the projects.

So that biogas is used in its higher potency to the generation of electric energy, it is in general needed a few changes in Otto cycle or diesel cycle engines, which current exist in the market.

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