CONCEPT OF A MULTI-FUEL, LOW-POWER GENERATOR WITH A SELF-IGNITION, COMMON RAIL GAS ENGINE

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Abstract

An idea of using biomass for generating electricity and heat leads to new solutions for power generators, adapted to be supplied with gaseous and liquid biofuels. At present, there is a growing interest in low-power generators. This type of energy production is termed 'scattered energy generation'. It is expected that generating energy in small units situated close to energy consumers may bring about substantial benefits. It is assumed that in a scattered energy generation system, energy will be produced from local fuels, such as broadly understood biomass as a primary component for production of gaseous and liquid biofuels to power low-power energy generators. An adequate amount of biomass must be secured to ensure that biogas can be produced all year round. The easiest way to store highly efficient biomass is to ensile maize and rye as well as grass. The amounts of biogas obtained from these two types of silage are comparable. Using rye as a renewable energy source for production of either bioethanol or biogas is economically viable for at least two reasons: rye grows on poor class soils and rye cultivation technology can be reduced to just nitrogen fertilization. In conclusion, it seems reasonable to generate energy in Poland in scattered energy generation systems from crops grown for this purpose. Currently, gas-powered engines are being in several ways.

Keywords: *dual-fuel feeding, CNG, steering, renewable fuel*

1. Introduction

At present, there is a growing interest in low-power generators. This type of energy production is termed 'scattered energy generation' [1]. It is expected that generating energy in small units situated close to energy consumers may bring about substantial benefits. First of all, it will lower the costs of energy generation and transmission; it will also make consumers independent from a countrywide energy supplier. Such solutions will also improve the energy safety in risk situations and will help to utilize energy from renewable sources. It is assumed that in a scattered energy generation system, energy will be produced from local fuels, such as broadly understood biomass as a primary component for production of gaseous and liquid biofuels to power low-power energy generators.

The European Union Directive on promoting renewable energy (Directive 2009/28/EC of 23 April 2009) sets a tangible goal of reaching a 20% share of renewable energy to the total energy consumption in the EU countries by the year 2020. Considering these expectations, it is necessary to look for new technologies and methods of producing energy from renewable energy sources. Among potential solutions, there is production of biogas from agricultural produce or municipal waste to be used either to supply power generators or to run means of transport. A variety of waste products can be converted into biogas. However, the renewable raw materials which can be used in agricultural biogas plants are natural fertilizers (slurry, manure) and by-products (cereal crop waste, fodder waste) as well as crops grown or biogas. Romianiuk (after Matczuk) [5] concludes that with an average yield of particular energy crops, the amount of biogas produced is within 1,300 to 10,000 $m^3 ha^{-1}$ (Fig. 1). The crop that has the biggest potential for biogas production is sugar beet. However, this crop needs fertile, well-cultivated soil and high outlays on traditional cultivation technologies, which reach around 6,000 PLN ha^{-1} [2]. Another problem is that roots of the sugar beet are covered in soil, which then settles down on the bottom of a fermentation tank [8].

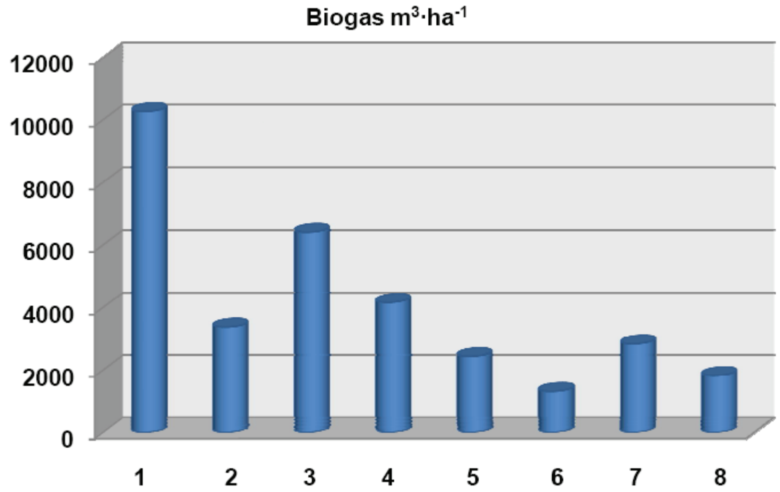

Fig. 1. Production of biogas from some crops,1-sugar beet roots, 2-sugar beet leaves, 3-maize, 4-alfalfa, 5-triticale, 6-oilseed rape, 7-sunflower, 8-rye

An adequate amount of biomass must be secured to ensure that biogas can be produced all year round. The easiest way to store highly efficient biomass is to ensile maize and rye as well as grass. The amounts of biogas obtained from these two types of silage are comparable (Tab. 1).

Tab. 1. Properties of some substrates for biogas production [6]

Raw material	Dry matter content		Biogas produced		CH_4 content
	d.m. [%]	o.d.m.[%]	m^3·t d.m.	m^3·t o.d.m.	[% vol.]
Maize silage	20-35	85-95	170-200	450-700	50-55
Grass silage	25-50	70-95	170-200	550-620	54-55
Rye silage	30-35	92-98	170-220	550-680	55

In Poland, most soils are acidic (66%) and over 30% of arable land belongs to light soils [3]. Rye is a crop that is highly tolerant to soil fertility and reaction. A new tendency in agriculture is to grow rye as a renewable source of energy, both as raw product for manufacture of bioethanol or for heat generation (straw incinerators). Kuś claims that at a yield of 2.44 t/ha it is possible to produce 854 l/ha of rye [4]. The Polish law imposes an obligation to purchase energy from renewable resources, as stated in the Energy Law. In compliance with the EU Directive 2003/20EC, the share of bioethanol in liquid fuels in Poland should have reached 9.21% in 2010. Using rye as a renewable energy source for production of either bioethanol or biogas (600 m^3 biogas from 1 ton of rye grain) is economically viable for at least two reasons: rye grows on poor class soils and rye cultivation technology can be reduced to just nitrogen fertilization [6]. In conclusion, it seems reasonable to generate energy in Poland in scattered energy generation systems from waste products and from crops grown for this purpose.

Using biomass for generation of electricity and heat forces us to look for new solutions in adapting of micro- and low-power generators to be powered with gaseous and liquid biofuels. At present, gaseous fuels (CNG, biogas, LPG) are mainly used to run spark ignition engines, as encouraged mainly by the properties of these fuels as engine fuel. Many research centres, both in Poland and abroad, are now engaged in intensive studies on using methane as fuel for self-ignition engines [10-13]. Such experiments are undertaken in order to take advantage of the greatest asset of self-ignition engines, such as its more superior general efficiency, and that of methane, namely low emission of toxic compounds.

2. Internal combustion engines supplied with gas

Currently, gas-powered engines are being in several ways [14-16]. The research conducted on using gaseous fuels to power combustion engines includes:

Spark ignition engines:

- studies on feeding engines with CNG, LNG and LPG,
- studies on feeding engines with biogas.

Self-ignition engines:

- feeding engines with CNG, LNG, LPG (dual-fuel feeding),
- feeding engines with biogas (via modification of an engine; change in the compression ratio, additional ignition unit),
- feeding engines with modified LPG and NG (using fuel additives enabling self-ignition).

Due to its properties, methane cannot be used as a fuel in self-ignition engines unless they are modernized. Methane will not start to burn in a self-ignition engine unless a certain dose of diesel oil initiating ignition is injected into the combustion chamber filled with a methane-oxygen mixture or else an electric spark is used to ignite the fuel. Some modifications are introduced so as to substitute the DO injection unit with a CNG feeding system equipped with spark ignition (change in a spark ignition engine). The diesel oil metering is altered, being now reduced to an ignition dose, and the feeding unit is adapted to supply gaseous fuel. There are also solutions in which a self-ignition engine is converted into a dual-fuel engine fed with CNG or petrol during the start-up phase. In a dual-fuel self-ignition engine, the fuel could be CNG, LPG or biogas used as the main dose and biogas as a dose initiating the ignition, the so-called pilot dose. At the same time, dual-fuel feeding of an engine can be achieved without any changes in the construction of the engine. Controlling the gas feeding dose in a dual-fuel self-ignition engine can be either quantitative (controlling the dose of a fuel) or qualitative (controlling the gas-oxygen mixture – a throttling valve). In a dual-fuel feeding system, it is important for the engine to run on one type of fuel depending on the character of its work. A dual-fuel self-ignition engine can be fed with gas or diesel oil or with diesel oil alone. A switch from one to another type of fuel should be smooth and should not require the engine to be stopped.

Noteworthy is the fact that studies on using gaseous fuels to feed self-ignition engines focus on adjusting an engine by fitting an additional ignition unit and depressing the compression ratio – however, changes in the construction of an engine will eliminate the main advantage of self-ignition engines that is their relatively high general efficiency. Such solutions are implemented primarily is immobile engines fed with gas from landfills or wastewater treatment plants.

3. A concept of a multi-fuel power generator with a self-ignition gas engine

Tests are carried out at the Department of Mechatronics of the University of Warmia and Mazury in Olsztyn to elaborate a gas supply system of a dual-fuel self-ignition engine. This article presents a concept of a power generator with a multi-fuel engine employed in a dual-fuel system with self ignition, which can be fed with gas and a pilot dose of diesel oil or liquid biofuel or with liquid fuel alone (Fig. 2).

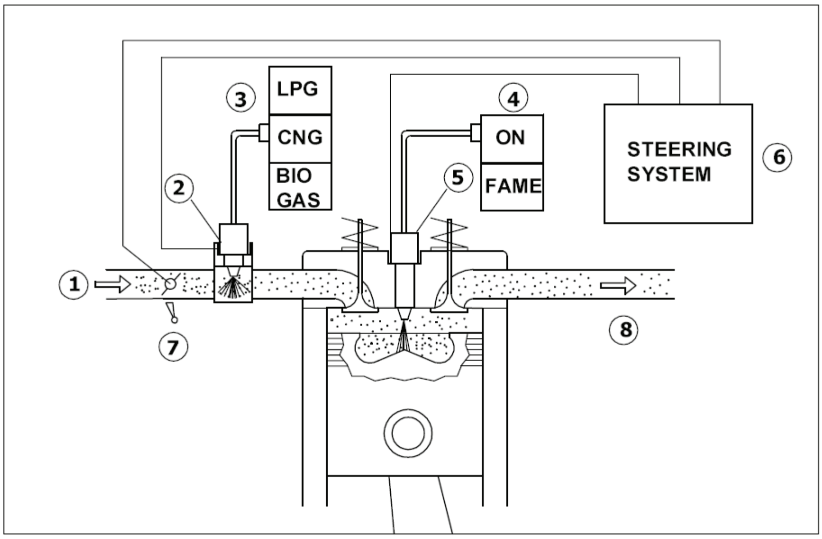

Fig. 2. A concept for multi-fuel supply of a self-ignition engine, 1 – air inlet canal, 2 – gas injector, 3 – gas supply system, 4 – liquid fuel supply system, 5 – liquid fuel injector, 6 – steering system, 7 – throttling valve, 8 – exhaust fume outlet

A multi-fuel self-ignition engine can run on CNG, LPG or biogas used as the main dose and diesel oil or rape fatty acid methyl ester (FAME) as a dose initiating ignition – the so-called pilot dose. A switch in the feeding fuel should be smooth and should not require us to stop the engine. A multi-fuel power generator with a self-ignition engine should be coupled with an electronic control system and a system for feeding the engine with gas and liquid fuel as the pilot and main doses. When running on liquid fuel, either diesel oil or FAME is fed, depending on the engine's load. In a dual-fuel system, the fuel unit supplies a small dose of liquid fuel – as a pilot dose, and a dose of gas which is adjusted by a controller according to the information from the sensors. In this solution, a self-ignition, gas-fed engine does not require any changes in its construction, but it is necessary to modernize the existing fuel feeding unit, to install additional gas installation and to interfere with the steering system. In order to attain the engine's work parameters comparable to the ones obtained in an engine fed with a constant supply of diesel oil, the liquid and gaseous fuel injection parameters, the size of the pilot dose and the volume of the main fuel dose should be adjusted according to the conditions in which the engine is working. The dual-fuel feeding system takes into account the steering of the liquid fuel pilot dose when the type of delivered fuel changes, e.g. lower combustion value of biogas, in order to maintain the constant energy demand in fuel.

The concept of a low-power power generator, presented in this paper, with a multi-fuel self-ignition engine fed in a dual-fuel system with gas and a pilot dose of liquid fuel or in a single-fuel system fed with liquid fuel can be used for creating and implementing new technologies employed for generating ecological and alternative energy in scattered energy generation systems. The results of the present study can be taken advantage of in:

agricultural and food processing – generating electric and heat energy from biogas obtained from fermentation of production waste, as well as using gaseous fuel to run a fleet of vehicles, having adapted the engines to run on gas

a) agricultural production – generating electricity and heat for farms' own needs and to gain additional income from selling the surplus production, to run agricultural machines – from gas obtained from own biogas production plants, from plant and animal fuels
b) furniture and wood processing industries – using production waste, generating electricity and heat, feeding engines in vehicles with gas produced from waste by-products obtained in the

furniture industry and from the biomass – in a broad sense of this term – produced in the wood processing industry

c) the civil engineering industry – using gas self-ignition engines in co-generation sets as eco-friendly, own sources of electric and heat energy, especially in farmsteads and industrial plants equipped with own gas generators

d) in transport – to run vehicles and machines, using gas self-ignition engines fuelled with natural gas or biogas.

4. Current research

The concept for an engine discussed in this paper is being tested at the Chair of Mechatronics, the University of Warmia and Mazury, using a FOGO power generator with a single-cylinder Hatz engine (table 2) coupled with a synchronous generator.

Tab. 2. Technical characteristics of a 1B40Hatz engine and a generator in the analyzed system

Technical parameters of the engine	
Type of the engine	HATZ, 1B 40, 4-stroke, air-cooled
Rated power	6.8 kW at 3,000 rpm
Number of cylinders	1
Swept capacity	462 cm^3
Compression rate	21
Fuel mixture production	Direct injection
Technical parameters of the generator	
Type of the generator	synchronous, brush
Rated power	5400 VA 3~

The Hatz engine is a single-cylinder, four-stroke, naturally aspirated, valve, piston internal combustion engine with a self-ignition system. Originally, the engine had been equipped with a pressure-controlled injector and a single-section, piston injection pump, run by a cam on the camshaft, which maintained the fuel injection pressure of 220 bars. The same cam also ran the inlet and outlet valves. The engine's working crankshaft's rotational speed was 3000 rpm. The engine was furnished with a centrifugal regulator, which ensured maintaining a constant rotational speed of the crankshaft at a load changeable within a set range, according to the nature of an energy receiver.

The original mechanic diesel oil delivery and metering system has been replaced with an original electronic fuel metering system including a high pressure diesel oil injection system and a gas injection system. For this aim, the engine was instrumented with such devices as a crankshaft's location and speed sensor, valve timing phase sensor, and temperature sensors, which provided signals (Fig. 4) necessary for the engine to work properly. The elaborated systems ensured external steering and selection of diesel oil and CNG injection parameters during dual-fuel or single-fuel feeding.

The engine was fuelled through a Common Rail fuel injection system equipped with a tank (Fig. 5a), and the original injector was replaced with an electromagnetic one (Fig. 5b). In the Common Rail system, it was possible to regulate the fuel pressure in the tank, and its value could be set externally. A knock combustion sensor was mounted on the cylinder head.

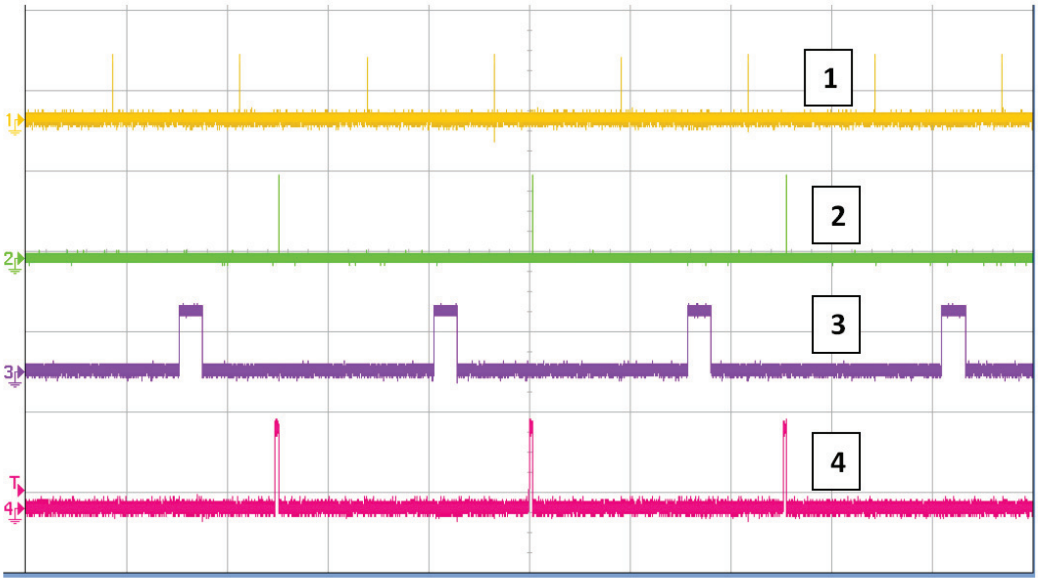

Fig. 4. Oscillogram of selected signals in the elaborated steering system for a HATZ 1B40 engine, presenting: 1 – signal from the crankshaft, 2 – signal of the location of a piston in TDC between the compression and work strokes, 3 – signal from the valve timing phase sensor, 4 – signal of the electromagnetic injector steering

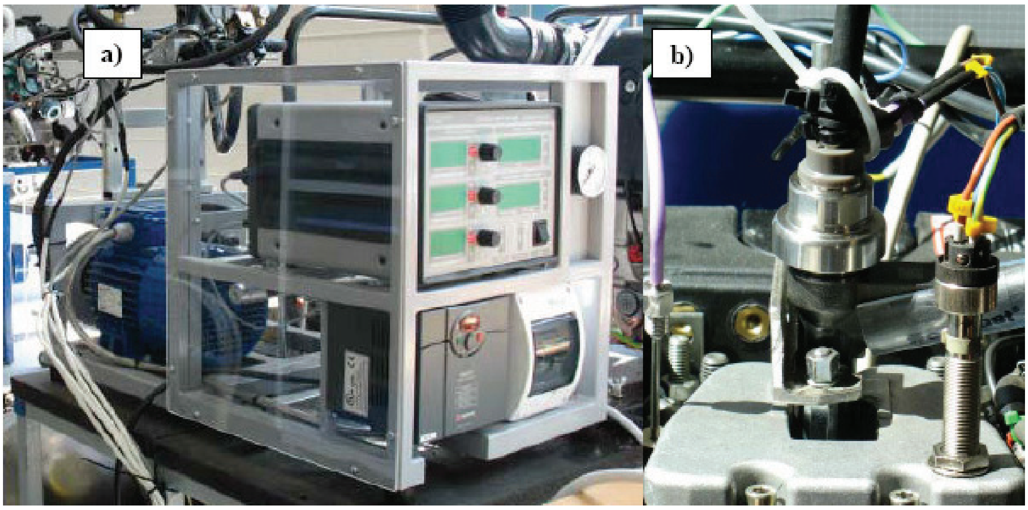

Fig. 5 (a) The applied laboratory diesel oil supply system of the engine (b) a view of the mounted electromagnetic injector

A gas installation was added to enable delivery of pressurized natural gas to the engine (Fig. 6a). Gas was delivered to the air sucked up by the engine through an injector mounted in the engine's inlet canal (Fig. 6b). Changing the type of fuel delivered to the engine was smooth. The engine could run on diesel oil alone, on diesel oil and CNG supplied in different ratios as the feeding dose, and with the minimum pilot doses of diesel oil, i.e. less than 5% per injection with gas as the main fuel.

The power generated by the tested engine was received by loading a three-phase generator with an electric receiver equipped with smooth regulation of power consumption. The research installation, as described above, enables us to determine regulation parameters for a self-ignition engine run on methane and a pilot dose of diesel oil within a preset range of loads, and to establish the optimum conditions for the engine system to work as a source of energy, provided:

- the minimum fuel consumption,
- the minimum toxicity of exhaust fumes,
- the maximum efficiency of the whole set.

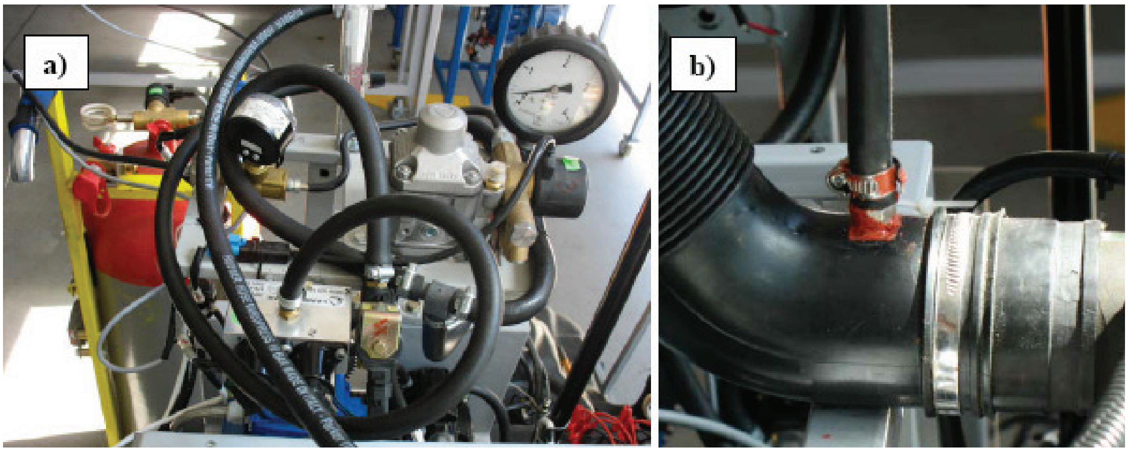

Fig. 6 (a) A laboratory CNG engine supply system, (b) a close-up of the gas injector mounted in the inlet canal

5. Conclusions

Biogas, liquid fuels and solid biomass are the sources of renewable energy used in Poland, and producing energy in a scattered energy generation system is considered to be an important issue in the country's energy production. The concept for an engine presented in this paper involves a multi-fuel power generator, run on renewable biogas or FAME as well as non-renewable fuels such as diesel oil, natural gas or LPG. The generator can work on liquid fuel alone or on low pilot doses of liquid fuel and main supply of gas. The generator's performance can be comparable to that of a traditional self-ignition engine but the costs of fuel are much lower. The idea presented in this paper is to use a gas self-ignition engine set up with a power generator as a primary ecological low-power source of electric energy for households and small business enterprises. However, for this aim to be achieved, we need to work out and make a system for gas and liquid fuel delivery as well as a system for the engine's control and to select the optimum parameters for the engine to work with a power generator. The research station, described above, enable us to work on a preliminary analysis of the current concept for a power generator coupled with a multi-fuel gas self-ignition engine. In this solution, the engine can be analyzed in a system consisting of a power generator supplied with two types of fuel; at the same time, we are able to conduct tests on the control system and combustion process in the engine fed gaseous fuels.

Our preliminary analysis indicates that it is possible to feed a low-power self-ignition engine in a power generator with LPG, CNG or biogas in a dual-fuel set with a diesel oil or liquid biofuel pilot dose. With adequate fuel delivery, metering and regulation systems, this engine can run on in a dual-fuel system or on diesel oil or biofuel alone, in a single-fuel system.

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