POSSIBILITIES OF SUPPLYING INTERNAL COMBUSTION ENGINES BY WOOD GAS

Andrzej Piętak, Kamil Duda, Natalia Chraplewska

University of Warmia and Mazury in Olsztyn
Faculty of Technical Sciences, Mechatronic Faculty
Słoneczna Street 46A, 10-710 Olsztyn, Poland
tel.: +48 89 5245101, fax: +48 89 5245150
e-mail:mechatronika@uwm.edu.pl

Abstract

The article presents possibilities of implementation gas, came by wood biomass gasification, to run on internal combustion engines powered normally by Diesel fuel.

Carbonization, gasification and burning effects were introduced. Main processes occurring during biomass gasification were shown. Basic chemical reactions characteristic to each stage were named. The differences in composition of received gas according to sort of biomass, gasification medium and type of generator were mentioned. In article were depicted way of modus operandi and structures of typical generators along with its advantages and disadvantages. Gas properties obtained by this method and its main parameters were presented. The advantages and disadvantages posed by the use of wood gas in internal combustion engines were described. Parameters of the gas that should be amended to allow the engine to be powered were listed. Also were shown ways of changing these parameters. Necessary engine modifications to be able to supply it with wood gas were presented.

The article finishes with conclusions and risks resulting from the use of this technology and also possible impact on the environment.

Keywords: *producer gas, wood gas, combustion, biomass gasification, environmental protection*

1. Introduction

Technology based on gasification of solid fuels in order to obtain combustible gas has been known for over 200 years. Coal gas (called also city or light gas) was commonly used in Europe in the 1840s. In Poland the first facility converting solid fuels to gas was opened in 1856. In 1884 it was first adapted for fuelling internal combustion engines in England.

During the Second World War, when liquid fuel stocks were reserved mainly for the army, the technology of solid fuel gasification became more common. As a result, there appeared appliances used for supplying vehicles with wood distillation gas. It was estimated that ca. 9 mln vehicles had been fuelled with this kind of gas by 1945 [1].

Gas obtained in this way can be classified as a second generation bio-fuel since it can be produced from various kinds of biomass, for instance wood industry waste (sawdust, broken planks), forest plantations (roots, branches), crops (straw, plant stems) or municipal waste.

At present, discussion is going on the issue of running out of mine resources, their effect on the Earth's atmosphere, energy consumption of highly developed countries as well as energy needs of developing ones. Ecological thinking has become a world-wide trend - it is meant to reduce crude oil and coal mining and to diversify energy sources. In Poland, it is also planned to guarantee energy independence and introduce "scattered" power industry based on building household-adjacent energy co-generating facilities producing electric energy for the needs of individual households and small industry. Such approach makes the ground for the development of technology of thermal decomposition of organic substances for energy purposes.

Producing gas from biomass can be cost-effective on condition that gasifying facility is located in a place securing big supplies of the material. According to G. W. Huber and B. E. Dale, the value of annual energy of available (waste) biomass is capable of satisfying the current world demand for energy (30 bln of oil barrels a year) [2].

Also legal regulations affect the development of biomass gasification technology. Directive 2003/96/WE of the European Union Council of 27th October 2003 imposes certain obligations aimed at intensifying the use of biomass from agricultural and forest products as well as forest and wood industry waste for the production of bio-fuels and at reducing the dependence of transport on diesel fuels and petrols and their suppliers through using alternative fuels.

2. Classification of gases and their properties

Since there are a number of terms related to thermal processes, it is essential to define particular notions.

- Carbonisation process – (degassing, oxygen-free pyrolysis) is based on decomposition of organic substances under the influence of temperature (250-900°C) with no oxygen access. The share of oxygen in the process is equal to the amount of molecular oxygen contained in substrates. The products of such process are char, gas containing various chemical products and tar substances.
- Combustion of solid fuels, which is a reaction that takes place between combustible material (fuel) and oxidizer excess. During the reaction light and energy are emitted. Combustion can be divided into several phases: heating and drying, degassing, oxidizing.
- Gasification of solid fuels (oxygen pyrolysis) is based on incomplete solid fuel oxidation to gas form. The product of such thermal-chemical processes is called “producer gas” and the process – “gasification” (oxygen pyrolysis). The process proceeds at about 1000°C in a device called gas-generator (gasifier).

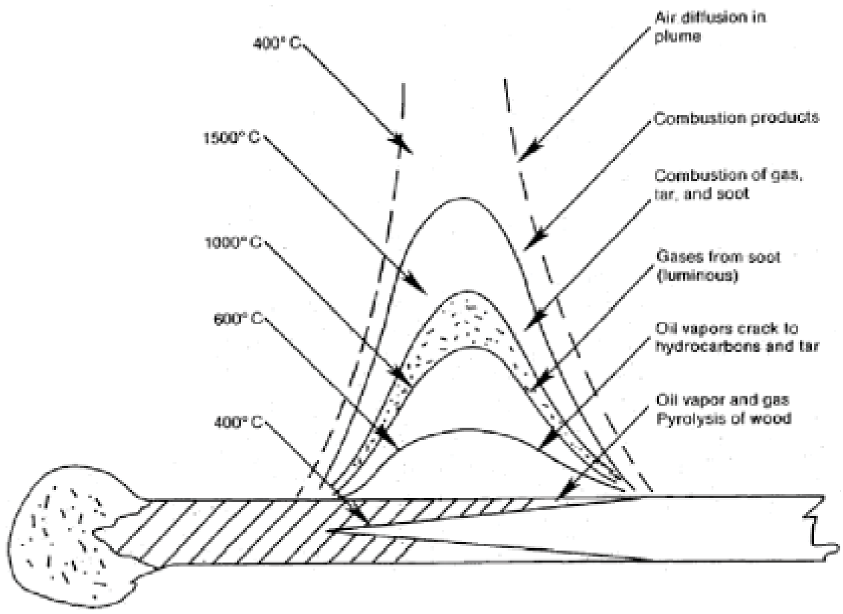

Fig. 1. Pyrolysis, gasification and combustion processes in flaming match [3]

Gas produced in the course of complete biomass combustion contains nitrogen (N_2), water steam (H_2O), carbon dioxide (CO_2) and oxygen excess (O_2). Combustion process in oxygen deficiency results in incomplete combustion the product of which is gas containing such combustible substances as carbon monoxide (CO), hydrogen (H_2), trace amounts of methane (CH_4), and also ballast such as nitrogen (N_2), water steam (H_2O) and carbon dioxide (CO_2), as well as solid (char) and liquid substances (tar).

Gas composition depends on many factors, among others on the kind of fuel that is gasified, process conditions, temperature in the furnace, gasifying factor, humidity of the fuel fed and others. Through change in parameters it is possible to steer the process. Table 1 shows the composition of gas obtained during coal oxidation depending on the oxidizer that was supplied during gasification and on its purpose, whereas Tab. 2 presents the composition of gas depending on the gasified fuel.

Tab. 1. Composition and destiny of coal gas depending on oxidant used during reaction [4]

Fuel	Oxidant	Composition of gas	Use of gas
Coal	Air	CO, H_2, N_2, CO_2	Combustible gas used for heating purposes
	Air and water vapor	Low caloric gas	Combustible gas used for heating purposes
		N_2, CO, H_2, CO_2, CH_4	
	Oxygen and water vapor	Synthesis gas	Gas to ammonia synthesis
		CO_2, N_2, H_2	
		City gas	Mains gas
		H_2, CH_4, CO, CO_2, N_2	
		Natural gas substitute	Mains gas
		CH_4, CO, CO_2	

Tab. 2. Composition of gas depending on kind of biomass and gasifier type [5]

Fuel	Gasifier type	Volume percentage					Calorific value MJ/m^3
		CO	H_2	CH_4	CO_2	N_2	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Charcoal	Updraft	30	19.7	-	3.6	46	5.98
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-60	5.00-5.86
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-1905	-	10-15	-	5.80
Pressed sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25

It is worth noticing that the substance with the highest share in gas composition is nitrogen (N_2), which is fed to the generator along with oxygen from air. Using pure oxygen or water steam as medium reduces nitrogen amount, and consequently, increases gas energy value. Yet, gasifying biomass in pure oxygen environment is not cost effective and economically justified.

3. Description of generator and technologies

Gasifying 1 kg of biomass takes about 1.5 m^3 of air (complete combustion of 1 kg of wood takes ca. 4.5 m^3 of air), from these components about 2.5 m^3 of gas can be produced. Since thermal-chemical process proceeding in the generator are endothermic, they require supplying external energy or part of the energy from the combustion process of gasifying fuel. In order to proceed the reaction itself takes 30-40% of substance which is supposed to be converted to energy and this is called convector efficiency [5]. Average conversion effectiveness is ca. 60-70% and can be calculated from the following formula [6]:

$$\eta = \frac{Calorific\ value\ of\ 1kg\ of\ gas}{Calorific\ value\ of\ 1kg\ of\ fuel}\,. \tag{1}$$

As the reaction between biomass and air proceeds in the generator, there are different kinds of its construction depending on the way of air supply and the way of flow of gases which are substrates and products of the process. Depending on the elements characteristic for each gas-generator type we can distinguish:

- Gas-generators with solid bed: downdraft, updraft,
- Gas-generators with fluidized bed: with circulation layer, with fluid bed,
- Indirect gasifiers: indirect gas reactors, indirect coke reactors.

Gas generators with solid bed are used in high power systems (> 10 MWt).

The characteristic feature of downdraft reactors is that air is supplied to them in the site of its narrowing, where supplied material is gasified and the produced gas is carried away in the lower part of the apparatus. This type of reactor has simple construction and low failure frequency. It is fed with material with humidity not higher that 20-30% and ash content below 1%. It guarantees a low level of tar in the produced gas [7].

In updraft reactors air is introduced in the lower part of the apparatus, and the produced gas is carried away in the upper part. Updraft reactors are capable of processing biomass with humidity of up to 50%. The advantage of this kind of reactor is high process efficiency. Its disadvantage is the fact that the produced gas contains high amount of tar [7].

Figure 2 shows a downdraft and updraft gasifier with solid bed.

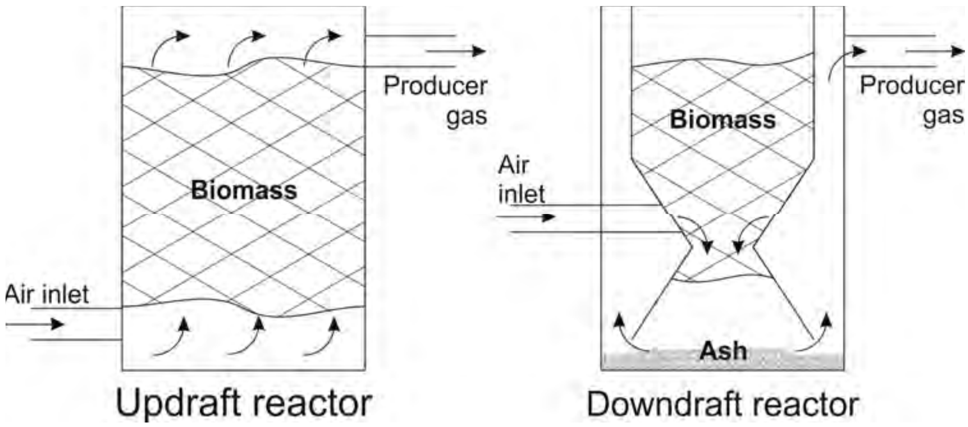

Fig.2. Scheme of updraft and down draft gasifier

Gas generators with fluid bed are designed for low power systems (below 10MWt). In the fluid reactor with circulation layer, gas production is based on the principle that air is supplied to the hot bed with solid fuel where it is mixed with the produced gas. The temperature of the gasified substance is kept stable. Due to strong mixing of gases in the bed the process is uniform – it is not possible to distinguish particular stages in it.

Reactors with fluid bed are characterized by the opposite flow direction of the gasifying agent and fall of raw material particles. Fluidized material bed is placed in the lower part of the apparatus; the produced gas along with ash and tar particles flows through the upper part [8].

4. Gas combustion theory

Practically, any organic substance can be gasified in laboratory conditions. Yet, economic justification, efficiency and reproducibility of the process reduce the group of available fuels. Another problem is the fact that there is no universal gasifier. In spite of a number of different gasifier kinds mentioned above, work parameters of each apparatus must be adjusted individually to specific conditions and specific fuel kind.

In the reactor there proceed four kinds of processes with chemical reactions characteristic for each phase:

- Drying, during which the energy from the reactions proceeding below this zone reaches the fuel and causes the contained water to evaporate at the temperature below 200°C.
- Pyrolysis, which takes place in the temperature range of 200-600°C and which causes release of volatile fractions from the fuel.
- Oxidation proceeding at the temperature of above 700°C. The processes result in oxidation of carbon and hydrogen contained in the fuel; there are formed carbon monoxide and dioxide (CO and CO_2) and water steam (H_2O). In spite of diversity of gasified solid fuels, apart from nitrogen only three other elements take part in the reaction: carbon, hydrogen and oxygen, and gasification process can be described with basic chemical reactions [5, 9, 10]:

$$C + O_2 = CO_2 + 401{,}9\ kJ/mol, \tag{2}$$

$$H + \frac{1}{2}O_2 = H_2O + 241{,}1\ kJ/mol. \tag{3}$$

  Energy excess produced as a result of these reactions is used for the other processes.
- Reduction, which proceeds during the passage of previously formed gases through incandescent carbon layer in which carbon dioxide CO_2 and steam water are reduced to carbon monoxide CO and hydrogen H_2. At this stage hydrogen, carbon monoxide and methane are produced, and it is the most significant stage of wood gas production, during which the following reactions proceed:
  - Boudouard’s reaction, also called generator gas reaction [4, 5, 10]:

$$\mathrm{C} + \mathrm{CO_2} = 2\mathrm{CO} - 164{,}9\ \mathrm{kJ/mol}. \tag{4}$$

  - Heterogenic reaction of water gas:

$$\mathrm{C} + \mathrm{H_2O} = \mathrm{CO} + \mathrm{H_2} - 122{,}6\ \mathrm{kJ/mol}. \tag{5}$$

  - Methane forming reaction:

$$C + 2H_2 = CH_4. \tag{6}$$

While arranging pyrolysis it is possible to satisfy the energy demand of endothermic reactions with exothermal ones which proceed simultaneously in the reactor or through supplying outside energy. Hence, there can be distinguished two kinds of processes:
- Autothermal – exothermic reactions which satisfy the energy demand of the remaining reactions,
- Alothermal – reactions in which the energy required in order to proceed is supplied from outside.

In practice, there are used auto-thermal processes based on gasifying solid fuel in the presence of oxygen solution and water steam. Figure 3 shows the schemes of reactors with particular process zones [11].

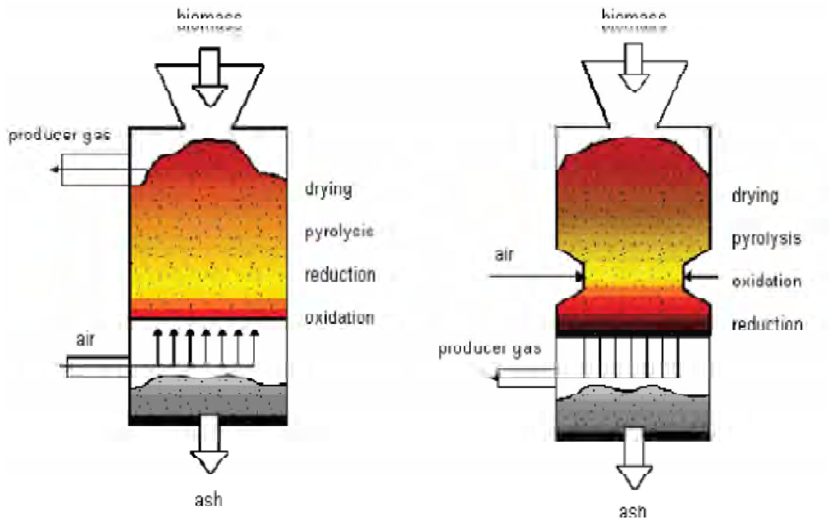

Fig. 3. Scheme of updraft and down draft gasifier with enhanced reaction zones

At this stage gas can only be used for burning to obtain energy. If it is produced to be used for engines, it has to be further processed, since it has too high temperature, too low density (energetic value) and contains too much impurities. The higher the purity and density of gas, the lower proneness to damage and higher efficiency of the engine fuelled with such gas.

Adjusting gas parameters for using it as engine fuel is done by:

- Gas cooling related processes.
  The temperature of gas leaving the generator ranges between 300 and 500°C. In order to cool gas heat exchangers, coolers and scrubbers are used. Gas cooling is done in order to increase its density, improve engine's energy balance and, in special cases, to prevent hot gas from entering delicate filters for gas purifying.
- Processes aimed at eliminating solid impurities from gas.
  In order to eliminate solid impurities presently there are used appliances for "dry" and "wet" gas purifying.
  - For "wet" purifying scrubbers are used. During this kind of purifying most impurities are removed from gas. Yet, they remain in the water, which also needs to be purified.
  - In the case of "dry" purifying, solid particles and ash are eliminated by means of passing gas through material with high contact surface with gas or through special devices in which dust falls to the device base as a result of changes in the pressure and speed of gas flow or centrifugal force action affecting it. For this purpose there are used dust extractors, cyclones, decanters, fabric filters and porous substances. Before, also small wood, cork or cone bits were applied.
- Processes related to eliminating tar and water steam.
  In order to achieve this, there are used reactors in which construction and course of proceeding reactions reduces the amount of the formed tar. Various tar-binding substances may be added to biomass. In some cases there are also used special apparatus elements whose function is catalytic conversion, mechanic purification (filtering, out dropping) as well as recirculating tar back to the reactor.

An example of a typical apparatus for preparing gas to supply exhaust gas engine is shown in Fig. 4.

Having undergone all the processes aimed at cooling and purifying gas from solid and liquid impurities the gas can be used as fuel in exhaust gas engines. It is best to supply it through an air filter in the engine inlet system; this will guarantee gas purity and facilitate thorough mixing of gas with air so that the gas-air mix is homogenous.

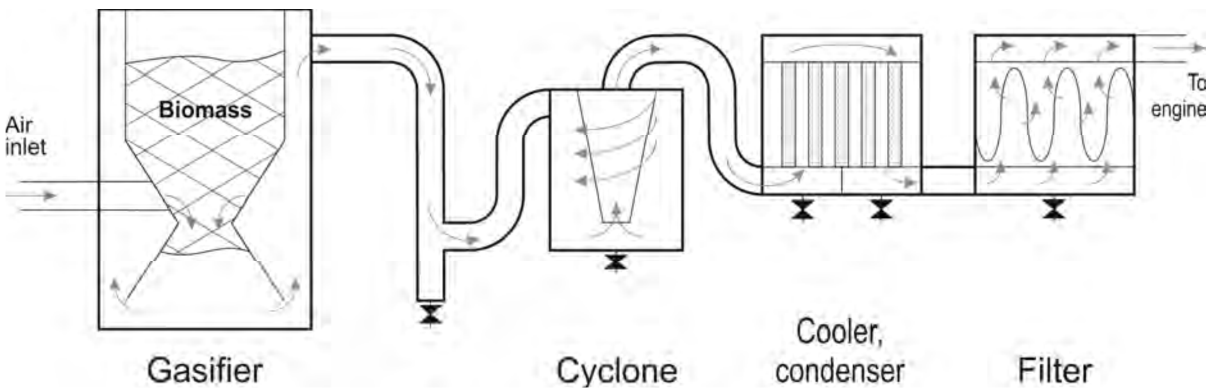

Fig. 4. Typical gas conditioning setup

5. Possibilities of applying gas in engines and gas properties

Any four-stroke internal combustion engine can be supplied with wood gas instead of petrol or diesel fuel. The best way of using gas obtained from solid fuel is supplying it to a stationary engine which is used for producing electric energy or for carrying out continuous work (e.g. operating a field watering pump, or moving a set of saws in lumberyard). It should be remembered that the size of the appliance for producing gas is relatively big so fitting one in a vehicle is problematic. However, during the war there were VW beetles with generators almost invisible under the bonnet only slightly more convex than normally [12].

In the case of petrol engines the matter of converting to wood gas fuelling poses no problems. Gas-air mix becomes compressed and next ignited with spark plug.

In compression ignition engines it is possible to supply gas fuel in two ways as this gas will not ignite only as a result of compression. One way is modifying engine by fitting an ignition system (steering system and plugs) and then the engine works on a principle similar to petrol engine. Previously, most engines adjusted to being fuelled with gasified biomass were modified like this. Such modification is not only costly but also irreversible: once the system is changed, it is not possible to return to fuelling the engine with diesel oil, bioester or DME. Another way of adjusting the engine to be supplied with gas is leaving diesel injectors which, irrespective of the current fuel demand for energy during engine work feed a constant amount of diesel with so called "piloting dose" with which the engine was supplied before. While getting ignited the piloting dose causes air-gas mix ignition. In such cases, the engine can be supplied with a mix of fuels and in the event of breakdown of any elements of gasifier or gas preparation system, it can be switched to be supplied with conventional fuel until the failure is mended. Such solution increases the system resistance to breakdowns and allows for momentary increase of engine power. Yet, it is related to the consumption of traditional fuel: such combustion accounts for maximum 30% of regular consumption of traditional fuel [13]. Presently, this kind of modification is applied most commonly.

The basic parameter characterising a given fuel is its energy value. One cubic meter of wood gas the value is 5-5.86 MJ, and for 1 l of diesel oil it is 35.7 MJ/l. Since 1 m^3 of gas is not equal to 1 l of fuel, the values should not be directly compared. In practice various sources report fuel consumption to range from 2.5 to 4 kg of wood per 1 litre of fuel used by engine before fitting the system [14]. Due to the fact that gas has lower energy value, its lowers engine power.

In the spark ignition engines power decreases by ca. 30%. Due to the fact that petrol has different combustion characteristics, ignition point angle should be modified by ca.30-40°; such modification ought to be made because the speed of flame spreading in gas-air mix is lower than that in petrol-air mix. From calculating the losses caused by producing gas $\eta \approx 68\%$ and engine efficiency $\eta \approx 25\%$, it follows that the overall system efficiency is $\eta \approx 10\text{-}13\%$, which means that from 1 kg of wood with input energy value of 19.6 MJ/kg we can obtain 0.55-0.75 kWh of mechanical power. Naturally, these values change depending on the level of generator load. For calculations, the average value of 0.7 kWh/kg is accepted [5].

In compression ignition engines, as was mentioned before, complete substitution of conventional fuel is not possible without significant alterations. Nevertheless, due to a higher compression ratio and maximum power generated at lower RPM it seems more justified to subject to modification Diesel engines. These engines usually work on poor fuel mix and are characterized by higher efficiency, thank to which their efficiency for gas fuelling is $\eta \approx 25\%$. 1 kWh of mechanic energy requires ca. 1 kg of wood and about 0.07 l of conventional fuel [5].

Engines fuelled with wood gas are used in many cases, starting from mobile installations fitted in vehicles: personal car engines, means of transport, heavy vehicles, agricultural machines, or even motorcycles with small gas generators, to stationary systems in which engines are used for producing electric and heat energy in co-generation as well as for fuelling various appliances which require mechanic energy for the needs of agriculture and industry or, briefly, wherever replacement of conventional fuels is economically justified and there is access to biomass from which gas can be produced. Wood gas will work best in installations with long daily work time, which results from the fact that starting an engine and reaching its full efficiency lasts about 20-30 min (that is how long gas generator takes to start).

References

[1] Breag, G. R., Chittende, A. E., *Producer Gas; Its Potential and Applications in Developing Countries*, Report No. G130, Tropical Products Institute, London, 1979.

[2] Huber, G. W., Dale, B. E., *Siana do pełna*, Świat Nauki, Sierpień 2009.

[3] Fantozzi, F., *Biomass Pyrolisys*, prezentacja BIOFUELS & BIOENERGY, Pyrolysis Part 1, 2008.

[4] Wandrasz, J. W., Wandrasz, A. J., *Paliwa formowane. Biopaliwa i paliwa z odpadów w procesach termicznych*, Warszawa, 2006.

[5] Rajvanshi, A. K., *Biomass Gasification*, www.nariphaltan.org/nari/pdf_files/gasbook.pdf, z dnia 20-06-2010.

[6] Kaupp, A., Gross, J. R., *Technical and economical Problems in the Gasification in the rice hulls* , Physical and Chemical properties, Energy in Agriculture, 1981-1983.

[7] Chmielniak, T., Żuromski, Z., *Zgazowanie biomasy w uk ładach małej mocy na p rzykładzie gazogeneratora firmy Zamer*.

[8] Bonder, L., Mirosz, M., *Przegląd technologii zgazowania biopaliw sta łych*, *INSTAL*, Vol. 11, 2007.

[9] Kozaczka, J., *Procesy zgazowania. Inżynierskie metody obliczeń*, Kraków 1994.

[10] Wielu Autorów, *BTG Biomass Gasification*, www.btgworld.com, Kwiecień 2008.

[11] Wielu Autorów, *Guideline for Safe and Eco-fr iendly Biomass Gasification*, The project is co-funded by the European Commission, www.gasification-guide.eu, Listopad 2009.

[12] www.drewnozamiastbenzyny.pl/gaz-drzewny-holzgas-faq, z dnia 20-06-2010.

[13] Piętak, A., Wierzbicki, S., Imiołek, M., Mikulski, M., *Dual-fuel feeding diesel engine behind assistance CNG with liquid dose piloting fuel renewable* , Journal of KONES Powertrain and Transport, Vol. 16, No. 3, 2009.

[14] www.drewnozamiastbenzyny.pl/gaz-drzewny-do-silnika, z dnia 20-06-2010.