EVALUATION OF USAGE BROWN GAS GENERATOR FOR AIDED ADMISSION OF DIESEL ENGINE WITH FERMENTATIVE BIOGAS AND PRODUCER GAS

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Abstract

Due to the ending stocks of fossil fuels, as well as instability of the political situation in the world, especially in countries that are major crude oil suppliers, governments of countries poor in the resources are forced to seek alternative sources of energy.

Currently, the most common fuel for admission of internal combustion engines is oil. As a result of the continuous increasement of fuels prices and legislation imposing decrease of toxic exhaust gasses emissions tends to expansion the power base of the automotive industry through the introduction of alternative fuels. One of them is fuels derived from renewable energy sources. These include gaseous fuels like biogas, hydrogen, and its mixtures.

The presented paper includes description of Brown gas generator and verification of the desirability of enrichment in hydrogen and oxygen gaseous fuels used to supply internal combustion engines. The connection scheme of Brown gas generator for the engine is also presented.

Division of alternative fuels used to power internal combustion engines, diagram of connection generator to the engine when the gas is feed to inlet manifold, Diagram of power supply system of gas generator, are also presented in the paper.

Keywords: *fermentative biogas, producer gas, gaseous renewable fuels, Brown gas, electrolysis.*

1. Introduction

In the modern world it is virtually impossible to imagine living without electricity or a car. Throughout the last decades, societies have become dependent on fossil fuels, which enable the use of modern facilities. Yet, constant growth of the Earth's population and quick and continuous technological development diminish natural resources and degrade the natural environment, which in turn forces people to seek alternative energy sources. Data referring the consumption of chosen energy resources are presented in Tab. 1.

Tab. 1. Consumption of selected energy carriers in Poland in years 2008-2009 [1]

Energy carrier \ Year		2008	2009
Gasoline	[thousand tonnes]	4416	4242
Diesel oli	[thousand tonnes]	10441	10810
Oven gas	[mln m^3]	4168	3049
Natural gas	[mln m^3]	808	774

In Europe and all over the world, new political agendas originate to define possible solutions to the problem of environmental pollution. Part of the ideas aim at limiting the use of fossil fuels and increasing the use of alternative ones. Research in alternative fuels use focuses primarily on gaseous and liquid. The greatest emphasis is put on the fuels whose resources are considerable or renewable. Alternative fuels which can fuel engines are presented in Fig. 1.

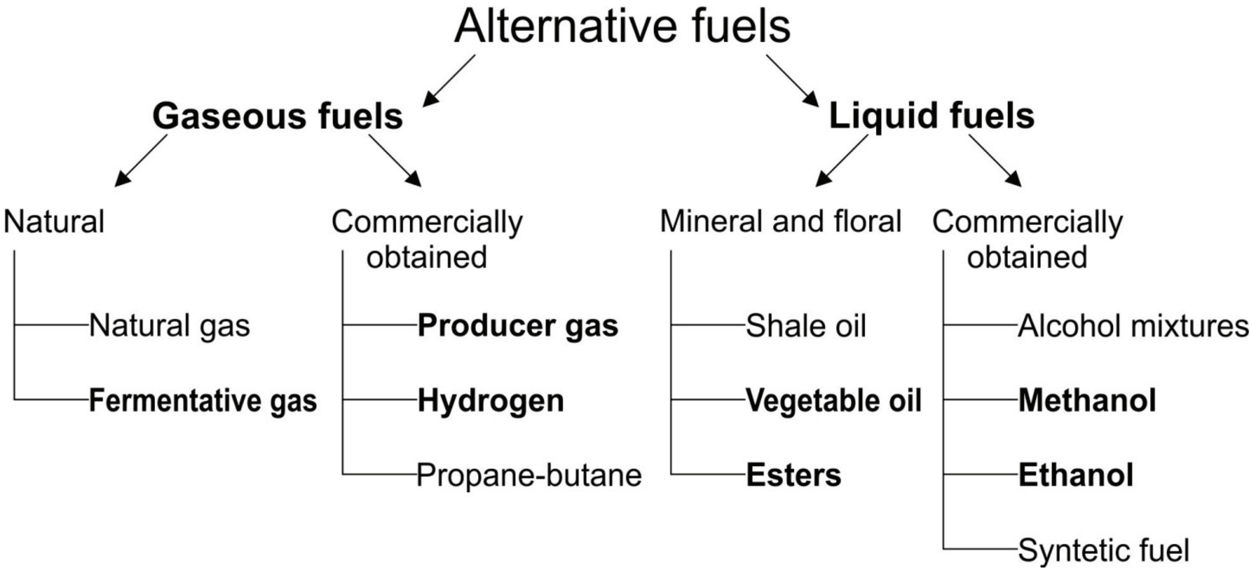

Fig. 1. Division of alternative fuels used to power internal combustion engines [2]

When it comes to alternative fuels, special attention should be paid to the renewable ones. Both gaseous and liquid biofuels - due to a wide range of production methods, their properties and benefits – present a big commercial potential. The most important liquid biofuels feature bioethanol (produced from sugar plants and grains, and used as a substitute for petrol) and biodiesel (produced mainly from plant oils, used instead of crude oil) [3]. Liquid biofuels can be used both as pure substances (B100) as well as additives to traditional fuels (B20). Gaseous biofuels are used to propel I.C. engines; depending on their properties, they can be stored as gases, compressed to 20 MPa, or in its liquefied form – at 1.5 MPa. The main gaseous biofuels include:

- Biogas – composed mainly of methane and carbon dioxide, and retrieved in the process of anaerobic fermentation of biomass. According to the way it is produced, we differentiate between:
  - landfill gas, a product of fermentation in landfills,
  - sewage sediments gas, which is produced as a result of anaerobic fermentation of sewage slime,
  - agricultural gas, retrieved from biomass from plantations of energetic plants and remainders of plant production, or animal excrements,
  - biogas from butchery, brewery and remaining food production waste.
- Generator gas – which is produced when solid fuels undergo a series of thermo-chemical reactions in order to produce a gaseous fuel. Thanks to the processes of pyrolysis, gasification and part-oxidation, a solid fuel gives gas, with carbon monoxide and hydrogen as its main combustible components. The product of such conversion is called a generator gas, and the process – gasification (oxygen pyrolysis). The process is conducted in 1000°C in a machine called a gas generator (gasifier). Generator gas is a general term, which defines the production process of gas fuel, whose name depends on its application, a production method and substances which were substrates. The following kinds of generator gas are distinguished [4]:
  - coal gas – derived from hard coal heated in 1000°C in the absence of oxygen,
  - water gas – derived as a result of gasifying coal, when steam is the gasification facto,
  - wood gas – produced as a result of gasifying wood.

2. Gaseous fuels – an opportunity to propel diesel engines

The diesel engine is nowadays the most frequently used unit, when it comes to transportation or stationary applications, because of its high effectiveness, low oil consumption and high torque generated at low RPM. The technology of the engine is constantly developing, which leads to a more and more effective use of energy in the process of oil combustion, and subsequently results in better performance at lower oil consumption. Although the diesel engine is highly effective, it emits a lot of contaminants into the environment. Exhaust fumes of C.I. engines constitute a serious problem since they contain a lot of toxic substances (nitrogen oxide, sulfur oxide, hydrocarbons, and particle matter - PM). Minimizing the adverse impact of diesel engines on the environment poses a problem which is very much in focus. Solutions sought by developing various technologies and ideas, part of which propose reduction of fossil fuels consumption by increasing usage of alternative fuels.

Basis research conducted the use of C.I. engines, shown that fuelling these units with gaseous fuels poses many obstacles. Because of low compression and the way of ignition (which is difficult to achieve for gaseous fuels) is being initiated, fuelling C.I. engines with gaseous fuels is hardly possible. Moreover, the composition of the fuelling mixture has also an impact on the parameters of engine at work, such as:

- knocking
- mixture combustion temperature in the cylinder
- maximum pressure of mixture combustion,
- velocity of pressure increase in the cylinder,
- torque [5, 6, 7],

and not taking the above into consideration hinders the engine work or even can lead to its failure.

In order to use a gaseous fuel in diesel engines, it is necessary to introduce certain construction changes in the engine and adapt the following parameters:

- the percentage of gaseous fuel and pilot does in the total load delivered to the cylinder,
- the amount of gaseous mixture delivered to the engine,
- the amount of heat which should be absorbed from the engine to prevent overheating,
- the pressure of pilot dose injection,
- timing of combustion initiation, by setting the pilot dose injection start [6].

Changes in the construction of C.I. engines can be introduced in two ways. The first one relies on a considerable modification of the engine by its total reconstruction (demounting injection apparatus, modifying the construction of the piston head and bottom, and subsequent mounting of the gas injector and ignition system (control system and spark plugs). Then the engine works as if it was SI engine, and additionally it is impossible to come back to the previous fuel (mono-fuel system). The second way is to leave the injector, which provides a constant amount of diesel oil independently of the current power load, which is called a pilot dose of oil which fuelled the engine before. It is necessary to mount an extra gas injector and gas control system. While combusting the pilot dose triggers the air-gas mixture combustion (dual-fuel system) [4].

The dual-fuel systems for C.I. engines use direct or indirect injection into the gaseous fuel combustion chamber. Combustion in these systems is performed in two ways. In the first method, the main dose of gaseous mixture is first injected into the intake manifold with the use of an extra gas injector. In the manifold, gas mixes with air and then it is delivered as a mixture to the cylinder. In the cylinder, the mixture is compressed and then the pilot dose of oil is injected, which as a result of self-ignition combusts and ignites the air-gas mixture. The second way relies on a two-way injector. In this solution, there is only air in the cylinder during the compression stroke. At the end of the compression stroke there comes the pilot dose of oil, which as a result of self-combustion combusts and ignites the main dose of gas which is injected subsequently to the pilot dose. In both systems, the dose of oil is essential, since the self-combustion temperature of oil (330–350 °C) is much lower than the self-combustion temperature of gaseous mixture (680°C for biogas) [8].

The research done so far into dual-fuel systems for diesel engines has suggested that the bigger the load is, the lower the percentage of gas in air-gas mixture should be, as too big a proportion of gas results in negative phenomena in subsequent cycles of the engine's work. They can be eliminated by increasing the amount of the delivered oil or by postponing the start of injection of the oil dose which initiates combustion [9].

Nowadays, four kinds of gaseous fuels are applied in diesel engines in everyday practice. These are: LPG, natural gas, generator gas and biogas.

3. Additives in gaseous fuels

Additives are used in gaseous fuels which fuel diesel engines in order to better fuels properties by enriching them with gas of qualities and quantity positively influencing the whole process of fuel combustion in the engine. The trend to use alternative gaseous fuels is becoming more and more visible, and due to the fact that biofuels are often produced with non-standard methods, their properties are not always optimal as engine fuel, if their quality is not increased in appropriate processes [10]. Thus a growing interest in using enriched gaseous fuels can be observed. Because of its price, hydrogen seems to be the best additive in this aspect. It shows the highest energy-to-weight ratio among the known hydrocarbon gaseous fuels and has favourable physical and chemical properties as regards combustion. As a result of doping with hydrogen, the calorific value of gaseous mixtures used in engines grows in line with the correlation (1) calorific value of gaseous mixture W_u depends on the calorific value of its component gas W_i and its percentage in the mixture U_i.

$$W_u = \sum_{i=1}^{n} W_i \cdot U_i. \qquad (1)$$

Moreover, hydrogen combustion does not increase the contents of carbon dioxide and other toxic compounds in exhaust fumes and it is possible to dope up to 20% of hydrogen in the mixture with no need to modify the engine. Doping with hydrogen in quantities which do not require modification does not increase the explosion threat of fuel mixture [11]. Yet, hydrogen has some disadvantages. A lot of energy is necessary to produce it and it is highly reactive and has low density, which means it is difficult to store. Having considered its properties, it can be assumed that doping with hydrogen seems to be a very effective way to better the qualities of such gaseous biofuels as gas derived from biomass by fermentation or generator gas, especially produced with non-standard methods.

4. The HHO technology

As far as doping gaseous fuels with hydrogen is concerned, an additive such as Brown's gas – HHO gas - is an interesting solution. Brown's gas is derived in the electrolysis of water. As a result, water is split into atoms of hydrogen and oxygen, which constitute homogenous mixture, i.e. Brown's gas. It is possible to fuel I.C. engines solely with HHO gas. Yet, considering its limited production, as well as a lot of energy needed to split water, it seems reasonable to use HHO gas to dope gaseous fuel. The technology of generating HHO gas is called 'production on demand' – it means that gas is generated in such a quantity as is needed to currently dope the main fuel fuelling the engine, and hydrogen is not stored. Gas production starts as the engine is ignited and finishes as it is switched off. It is a benefit of this technology that gas is not stored anywhere, which minimizes the threat of explosion. It would be too dangerous to store the gas since it carries high energies and easily and violently combusts producing a lot of energy. In this production method, the whole gas which is derived is delivered to the intake manifold of the engine, mixing there with air, and 'pure' HHO gas is present only in the hose connecting the manifold and the generator. The combustion reaction of hydrogen-air mixture is presented by equation (2), [12].

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \;\Delta H = -241.826 \frac{kJ}{mol(H_2O)}. \tag{2}$$

Water (steam) is a combustion product when HHO gas combusts in the cylinder of the engine. It positively influences processes in the engine in many ways. Water absorbs heat from exhaust fumes, with change of state and volume. Thus, exhaust fumes from the cylinder are colder and steam increases the engine's efficiency. Additionally, steam from the cylinder probably enables pyrolysis - gasification of PM form the pilot dose combustion. The fact that it does not require any modifications of the engine is yet another advantage of HHO technology. Brown's gas may be added to the container with the gas which fuels the engine, or to the intake manifold. When the second way is chosen, anti-explosive fuse has to be mounted on the connection, so that the flame will not reach the generator and is not able to destroy it when the mixture combusts in the hose. The scheme of connecting the generator to the engine when gas is delivered to the intake manifold is shown in Fig. 2.

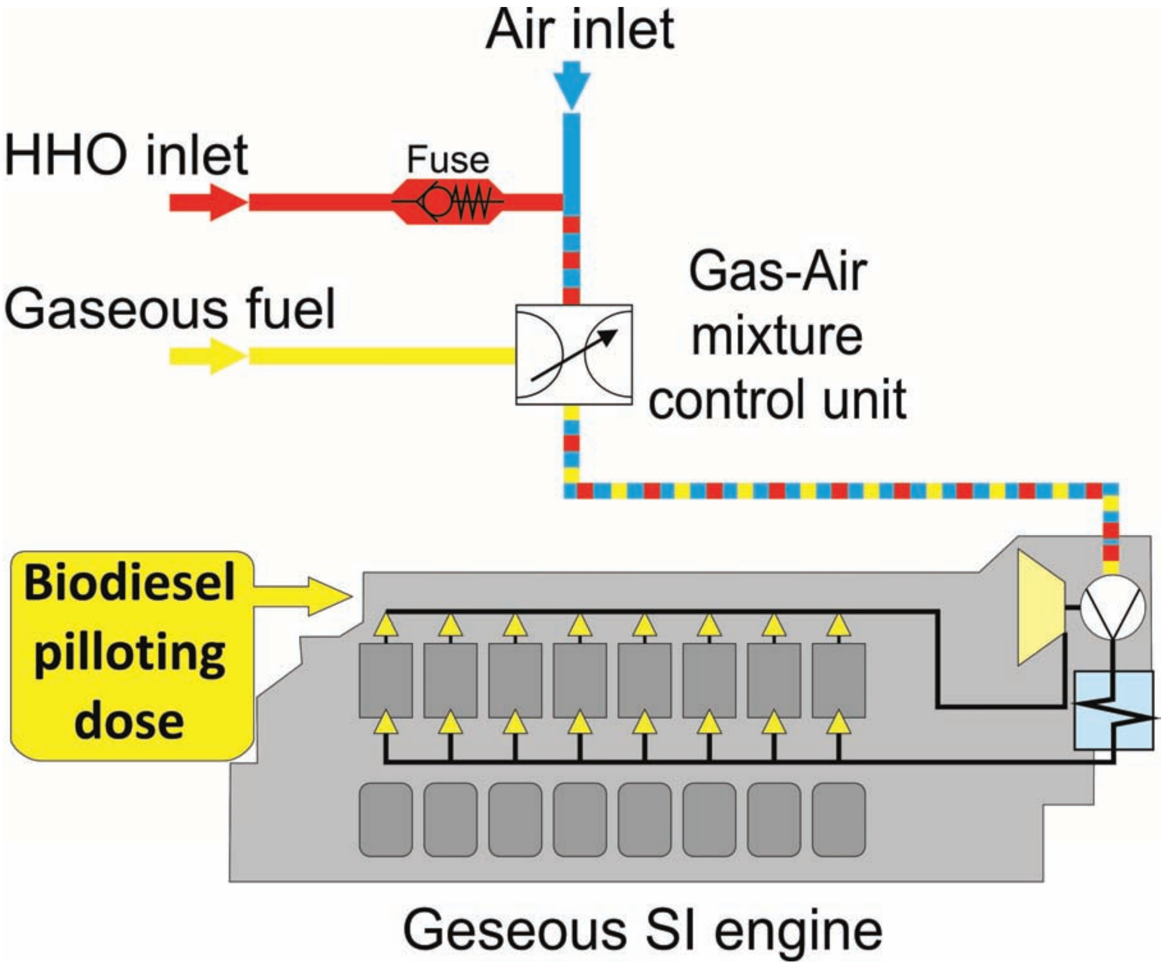

Fig. 2. Diagram of connection generator to the engine when the gas is feed to inlet manifold

5. The HHO generator

The Brown's gas generator is presented in Fig. 3 and 4. Its shell is made of 10 mm thick transparent acrylic glass plates, which facilitates observing processes which take place inside the generator and the degree of degradation or perhaps also corrosion of electrodes. Electrodes are made from 9 stainless chromium-nickel steel plates 316 type, 0.8 mm thick, separated by 2.5 mm each. In every plate there are 3 openings so that gas and electrolyte can flow freely. Two external plates constitute negative electrodes, and the middle plate is the positive electrode. Two spouts are attached to the shell, the lower one is connected with the electrolyte container (28% KOH in the water, w/w), the upper one is the outlet for the generator gas.

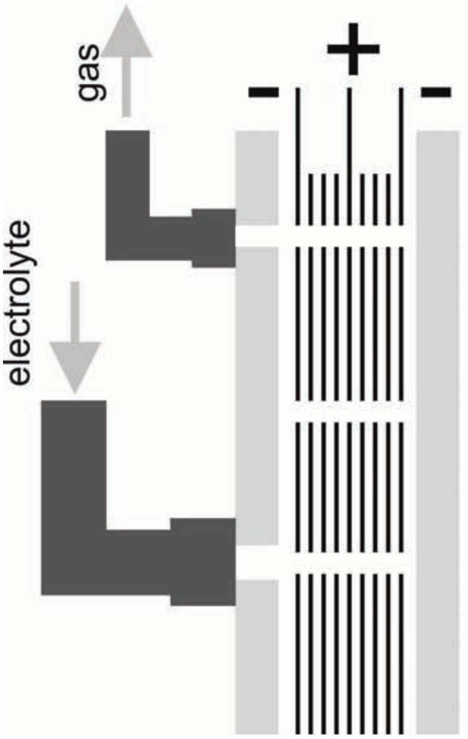

Fig. 3. Scheme of Brown gas generator

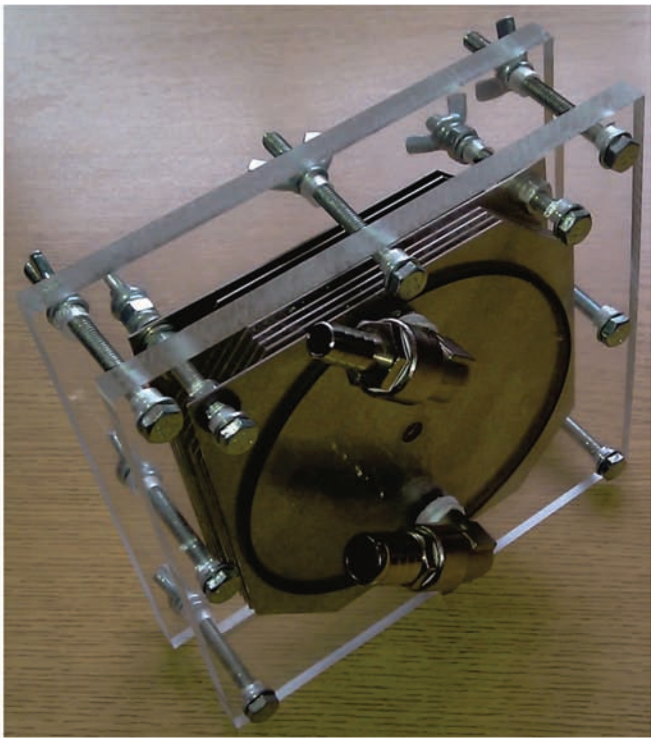

Fig. 4. Picture of Brown gas generator

According to [13], the optimal voltage on the electrode is 1.48V, while the amount of the produced gas depends on the current strength. After transforming the patters (3) – Clapeyron equation and (4) – the first Faraday's law, we arrive at the pattern for the volume of the produced gas for a single pair of plates – a cell (5).

$$p \cdot V = n \cdot R \cdot T, \tag{3}$$

$$Q = \frac{F \cdot m \cdot z}{M}, \tag{4}$$

$$V = \frac{R \cdot I \cdot T \cdot t}{F \cdot p \cdot z}, \tag{5}$$

where:
V - volume of gas [m3],
R - gas constant (≈8.314472$\left[\frac{\mathrm{J}}{\mathrm{mol \cdot K}}\right]$),
I - current [A],
T - temperature [K],
t - time [s],
F - Faraday constant (≈96485.34 $\left[\frac{\mathrm{C}}{\mathrm{mol}}\right]$),
p - ambient pressure [Pa],
z = number of excess electrons (2 for H2, 4 for O2).

According to (5), when connected to 14V voltage and 20A current strength in standard temperature and pressure conditions, the presented generator comprising 8 cells will produce

110 dm3 of gas per hour.

Pulse Width Modulator (PWM) helps to control the current strength in a precise way, thus it is possible to control the amount of electricity which is delivered to the generator. Controlling relies on regulating the duty cycle of electrical signal, i.e. changing the width of an impulse of constant amplitude. The scheme of connecting the gas generator to the power supply system is shown in Fig. 5.

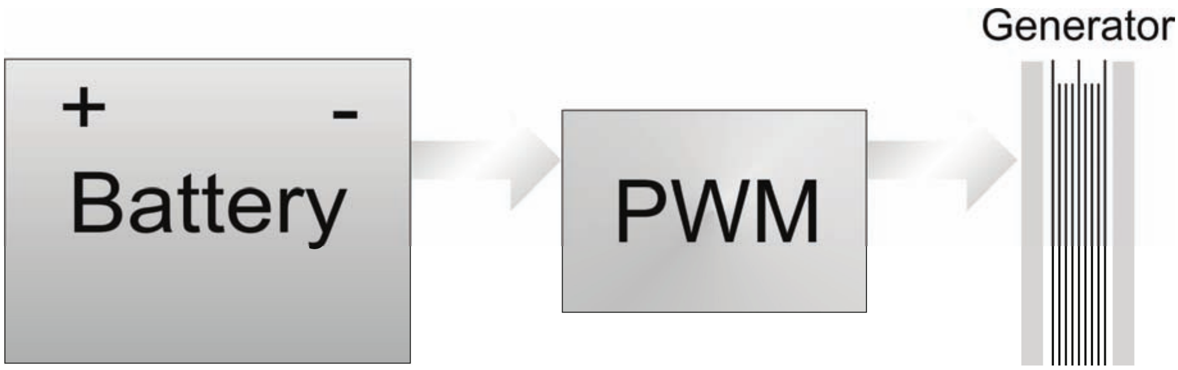

Fig. 5. Diagram of power supply system of gas generator

6. Conclusions

The HHO gas generator seems to be a really beneficial solution as a device producing gas for doping gaseous biofuels used to fuel C.I. engines. The power supply for the generator can be obtained from the system producing electrical energy which is connected to the engine and using currently produced excess of energy of the engine. A wide range of advantages of doping gaseous fuels with high-calorific mixture of gases, in line with (1), results in an increase of energy load carried by the fuel and in better properties of the combusted fuel mixture. Moreover, hydrogen and oxygen reaction produces water, which absorbs energy from exhaust fumes cooling them and increasing its own volume, which increases the efficiency of the engine and its durability. It is worth mentioning that while diesel oil (or biofuel) is combusted to ignite the mixture in the cylinder, PM are produced – not combusted particles of fuel, which are highly carcinogenic for living organisms. When they are affected by steam, which is an oxidant, they can undergo gasification, as it happens in fluidised bed gas generators in oxygen pyrolysis processes. Those suppositions have not been confirmed by research results yet, which leaves space for further development of this field of studies.

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