

EXPERIMENT OF PEAT GASIFICATION IN PLASMA REACTOR

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Gasification of solid and low quality fuel from the economic point is not a new idea or a new technology. Industrial applications for the production of energy gas from coal dates back to the beginning of the nineteenth century, whilst the construction of several large industrial plants for producing the electricity from coal and heavy oil fractions have been launched in the United States and Europe in the last 40 years.

The aim of this contribution is to verify the assessment of utilizable synthesis gas at high-temperature thermal treatment of the selected fuel commodity in terms of the energy recovery system in the cogeneration unit. An experiment was performed in 80 kVA plasma reactor with a dependent electric arc and hollow graphite electrode where the nitrogen N_2 was used to generate plasma arc.

Key words: plasma gasification, peat mass, synthesis gas.

Ekspériment uplinjavanja treseta u plazma reaktoru. Uplinjavanje krutog i nisko kvalitetnog goriva s ekonomskog stajališta nije nova ideja ili neka nove tehnologija. Industrijska primjena proizvodnje energetskog plina iz ugljena datira od početka devetnaestog stoljeća, dok je izgradnja nekoliko velikih industrijskih postrojenja za proizvodnju električne energije iz ugljena i teških frakcija nafte pokrenuta u Sjedinjenim Državama i u Europi u posljednjih 40 godina.

Doprinos ovog rada sastoji se u provjeri procjene iskoristivosti sintetiziranog plina na visokim temperaturama termičke obrade odabranog tržišnog goriva promatrano u sustavu obnavljanja energije u kogeneracijskoj jedinici. Pokus je proveden u 80 kVA plazma reaktoru sa zavisnim električnim lukom i šupljom grafitnom elektrodom pri čemu je dušik (N_2) korišten za stvaranje luka plazme.

Ključne riječi: uplinjavanje plazmom, tresetna masa, sintetizirani plin.

INTRODUCTION

Since 1980 the applied research in plasma gasification has led to the major advances in the understanding of basic phenomena included in the gasification process and to a renewed interest in the area of the use of thermal plasma in various material processes, as well as in the waste management. Several studies have been carried out to determine the suitability and effectiveness of using the thermal plasma process for the gasification of carbonaceous

materials to produce high-quality synthesis gas (hydrogen + carbon monoxide + hydrocarbon fraction).

The experiments in this field were conducted in a wide variety of types of plasma reactors. In general plasma reactors can be divided into two groups, according to the method for generating a plasma arc:

- generation of the plasma arc is directly implemented in the reaction chamber of the reactor (the

cathode electrode is placed at the top of the gasification chamber and the anode is formed by the electrically conductive melted metal located at the bottom of the reactor),

- the plasma arc generator is used (plasma torch), in which the plasma arc burns in the chamber of the plasma torch. Through the plasma torch nozzles plasma arc is directed into the plasma reaction chamber [1-4].

Depending on the type of reactor and boundary conditions of the gasification process in many cases interesting results have been achieved. The experiments of gasification materials of organic origin (peat, biomass) are presented below.

Extensive research in the field of gasification of peat was carried out by several teams of researchers in Finland in late eighties of the twentieth century. The author collective (E. Kurkela at el) proposed a method of gasification of peat in Boineer updraft fixed-bed gasifier. In the experiment the peat pellets with 16 % moisture content

were used as a fuel. The fuel is fed into the upper part of the gasifier, from where it flows downwards through drying, pyrolysis, gasification and combustion zones. An analysis of dry synthesis gas has shown the following composition of the gases generating in gasification process: CO - (25-27%), H_2 - (13-15%), CH_4 - (2.4-2.8%), CO_2 - (8-10%), N_2 - (47-50%) [5].

Production of synthesis gas from woody mass by plasma arc generated by AC plasma torch was studied in the experiments conducted in the Institute of IEE RAS (Ph. G. Rutberg at. el.) [6]. Significant advances in the field of plasma gasification of biomass to generate high-quality and clean synthesis gas was achieved by Hrabovsky. The experiments were performed in plasma reactor by the plasma torch equipped with a dc arc stabilized by combination of argon flow and water vortex. For the highest feed rates the calorific value of produced synthesis gas was almost 2.5 times higher than the reactor power. More information about the involvement of the reactor and gasification of boundary conditions are given in the References 7.

MATERIALS

Peat is partially petrified (fossilized) plant substance, usually of dark brown colour. It is generated in insufficiently oxygenated wetlands where the speed of accumulation of plants into structures of wetland is faster than the decomposition processes. It is a complex material, a mixture of organic materials consisting of two dominant components, of lignite and cellulose.

Representation of the chemical elements concentrated in peat (*Ba, Ca, Cd, Co, Cr, Fe, La, Mn, Ni, Ti, Zn, Al, Be, Cu, Pb, Mg, Na*) is variable in dependence on the depth of the peat placement layer. Generally,

it can be stated that this is a highly porous material with a low density of about 200 kg.m^{-3} . It is used e.g. to remove pollutants from the wastewater without further pretreatment or for energy purposes.

The sorption ability of peat can be adversely affected by its characteristics, such as low mechanical strength, high affinity of peat to water, poor chemical stability or the tendency of decrease and increase of volume. The percentage representation of organic substances in dry mass represents the value over 50 %. Molecular structure of lignite, cellulose and cell structure itself are shown in Fig. 1 and Fig. 2 [8, 9].

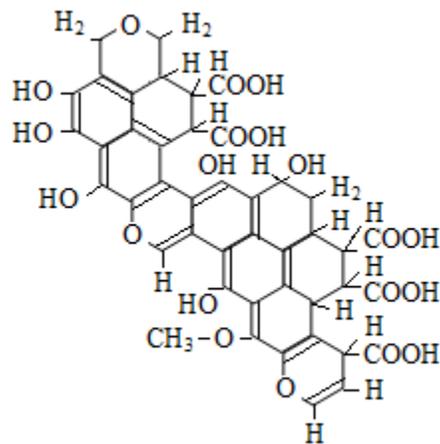


Figure 1. The cell structure of peat
Slika 1. Stanična struktura treseta

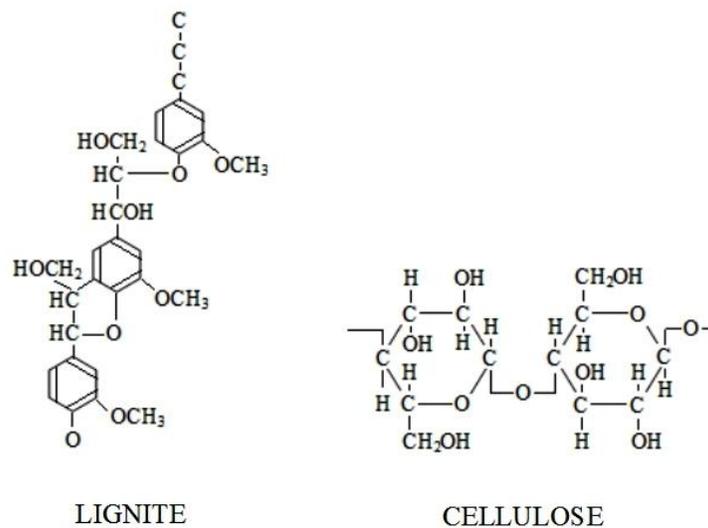


Figure 2. Molecular structure of lignite and cellulose
Slika 2. Molekulna struktura lignita i celuloze

On the basis of the species atoms representation in the molecular structure it is possible to presuppose a positive development of combustible gaseous components generation (H_2 , CO) in the

synthesis gas. The moisture contained in the fuel charge at gasification of peat can greatly contribute to the favorable ratio of C/O in the reaction chamber of the plasma reactor.

CHARACTERISTICS OF PLASMA DEVICES

Experimental gasification of peat was done in 80 kVA DC (direct current) plasma reactor with dependent electric arc with a hollow graphite electrode (reactor is industrially used for the treatment of electronic waste). The diagram of peat plasma gasification process is shown in Fig. 3.

The charge of the processed waste was ensured through the charging device (snail conveyor belt) to the reaction chamber of plasma devices with possibility of continuous charging of waste of grain size < 5 mm. The gasification process was conducted in a reduction vacuum

atmosphere, 0.05 to 0.1 kPa. The plasma arc is generated between an hollow graphite electrode placed centrally in the lid of the plasma reactor (cathode) and graphite crucible which forms the bottom of the reactor (anode).

The produced synthesis gas is drained through drain hole of synthesis gas, built in the lid of the reactor towards to the cyclone which makes the first stage of synthesis gas cleaning circuit. Tapping hole is placed in a graphite crucible near the bottom of the plasma reactor. The reactor envelope is cooled by air with the exception of the arch of the plasma reactor. [10, 11].

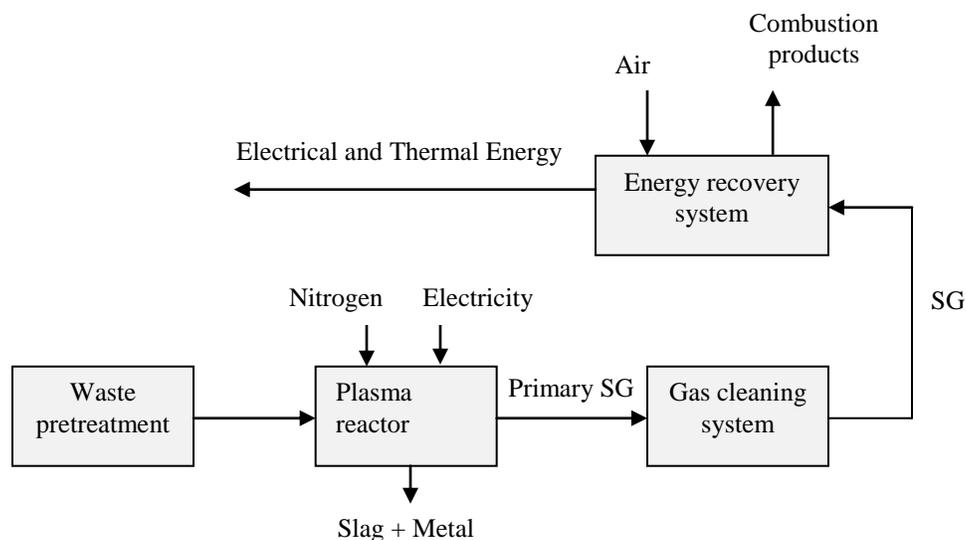


Figure 3. Diagram of peat plasma gasification process

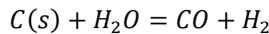
Slika 3. Dijagram procesa uplinjavanje treseta u plazma reaktoru

The main advantage of this type of reactor for the industrial use is the possibility for the installing the high performance equipment. On the other hand, similar type systems can have several major disadvantages, such as low efficiency of electricity utilization due to the high energy consumption of the plasma arc generation process,

low efficiency of heat exchange between the arc and melt processed materials, contamination of the by-product by the variety of contamination produced in the gasification process (essential pollution of the gasification products by admixtures of the melt material), faster destruction of the electrodes, etc. [12].

THE BASIC CHEMICAL REACTIONS AND ENERGY BALANCE OF GASIFICATION

The following simplified chemical conversion formulas describe the basic gasification process



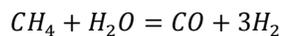
heterogeneous water gas shift reaction – endothermic,



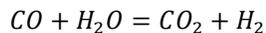
boudouard equilibrium – endothermic,



hydrogenating gasification – exothermic,



methane decomposition – endothermic,

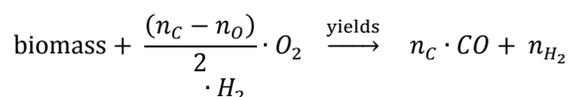


water gas shift reaction – exothermic [4, 12].

The maximum conversion efficiency of biomass to synthesis gas can be achieved if the carbon atoms of the prepared samples of biomass are oxidized to carbon monoxide in the plasma gasification process. This is achieved by adding oxygen, air, water vapor or carbon monoxide in the plasma chambers.

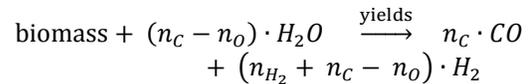
The maximum amount of oxygen in the reaction chamber should be moved to the level of the stoichiometric amount of oxygen needed for the realization of the chemical reactions [7].

Gasification of biomass with stoichiometric amount of *oxygen*

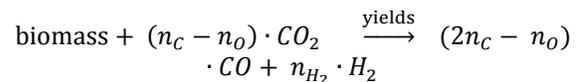


where n is a molar concentrations of the gas.

Gasification with stoichiometric amount of *steam*



Gasification with stoichiometric amount of *carbon monoxide*



where: $n_C = c/M_C$; $n_{H_2} = H/2M_H$; $n_O = o/M_O$ are the molar concentrations of carbon, hydrogen and oxygen in biomass [7].

During the plasma gasification process, various chemical reactions take place that are difficult to be reproduced in a simple equilibrium mode.

The simplified energy balance of the plasma gasification process can be described as follows:

$$\Delta Q_{\text{react}} = \eta \cdot W_{\text{torch}} - P_{\text{react}}(T_r) - Q_{\text{gas}}^{\text{out}}(T_r) - Q_{\text{sol}}^{\text{out}}(T_r)$$

ΔQ_{react} - power available for gasification,

η - efficiency,

W_{torch} - power of the torch,

P_{react} - power loss to the reactor wall,

$Q_{\text{gas}}^{\text{out}}$ - power loss carried out in the reactor by the produced gas,

$Q_{\text{sol}}^{\text{out}}$ - power loss carried out of the reactor by produced solids,

T_r - temperature in the reactor [12].

EXPERIMENT AND DISCUSION

Before the gasification process measurements in accordance with standards BS EN 14774-2 for determination of moisture content in the fuel were carried out.

The results showed that the moisture content in the analyzed type of peat was in area of 15 vol. % (Table 1).

Table 1. The result of the analyzed peat sample drying

Tablica 1. Rezultati sušenja uzoraka treseta

Identifications of the sample	Weight before drying (g)	Weight after drying (g)	Temperature of drying (°C)	Humidity (Vol. %)
RB-1	6,446	5,500	105 ± 2	14,676
RB-2	3,318	2,800	105 ± 2	15,612

The analyzed type of peat (origin Belarus) in the original condition showed grain size from 5 to 150 mm. Coarse-grained structure of the original sample did not meet the parameters corresponding to the

technical requirements of the charging device, so the fuel charge was adjusted by manual crushing to the grain size 0-5 mm. The pictures of the analyzed samples before and after reduction are shown in Fig. 4.



Figure 4. Samples of peat in the original state and after crushing

Slika 4. Uzorci treseta u izvornom stanju i nakon drobljenje

Total time of charging was 170 minutes at consumption of 14.5 kg of inlet peat (at steady sample charging of 5.12 kg·h⁻¹). Percentage volume of the three most

dominant components of generating synthesis gas in dependence on time is shown in Fig. 5.

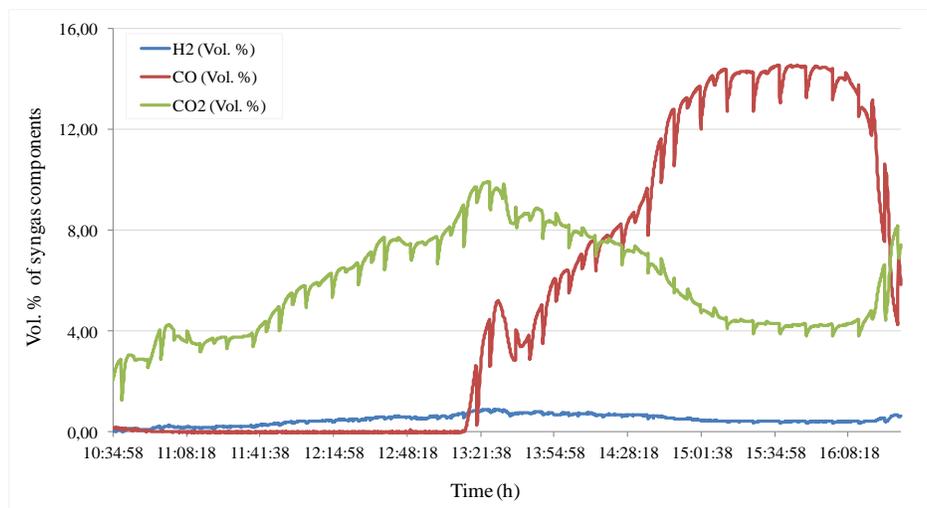


Figure 5. Development of selected components of synthesis gas generation

Slika 5. Tvorba odabranih komponenata sintetiziranog plina tijekom procesa generacije

Synthesis gas (a mixture of gases produced in the process of decomposition of the sample plus the nitrogen used in the plasma torch) when leaving the reaction zone of the plasma reactor went through the phases of cooling, cleaning, neutralization, and then it was burnt together with natural gas in cogeneration unit with a micro-turbine.

The average lower calorific value of the produced gas was set to 1.3 to 2.3 MJ·Nm⁻³ which corresponds to the energy

value from 0.36 to 0.64 kW·Nm⁻³ at the given conditions. Solid residues leaving the gasification process in the form of slag and entrained dust captured in the cyclone separator were subjected to a partial analysis of the matrix components as it is shown in Tab 2.

To protect the reactor graphite hearth (carbon bed on the bottom of the reactor - anode) to the reactor was added *NiFeCo* alloy weighing 28 kg (56% *Ni*, 36% *Fe*, 6% *Co* and 2% *Cu*).

Table 2. Results of the analysis of slag and fly ash

Tablica 2. Rezultati analize troske i lebdećeg pepela

Slag		Fly ash	
Chemical compounds	%	Chemical compounds	%
<i>Al₂O₃</i>	38,55	<i>Al₂O₃</i>	9,45
<i>SiO₂</i>	20,58	<i>SiO₂</i>	9,48
<i>CaO</i>	17,91	<i>CaO</i>	12,65
<i>MgO</i>	1,53	<i>Cu</i>	1,49
<i>Fe celk.</i>	1,16	<i>Fe</i>	7,94
<i>Ni</i>	0,29	<i>Ni</i>	6,13
<i>La</i>	4,85	<i>Na</i>	0,58
Loss by annealed and other non-detected compounds	15,13	<i>K</i>	1,32
--	--	<i>C</i>	3,61
--	--	Loss by annealed and other non-detected compounds	47,35

The experiment of the gasification of peat samples was performed in a plasma reactor, which is industrially used for the treatment of electronic waste. Therefore, the composition of the collected slag, tapping after the experiment is to some extent influenced by slag residual from the previous experiments and by the elements released from the lining of the reactor. Weight of the tapping slag was at about 6 kg without the addition of slag additive forms. Substantial part of the slag comes from the previous treatment of the electronic waste. Fly ash quantities in the cyclone ranged at about 15 % of the charge (2.2 kg).

The content of the carbon in fly ash, determined by chemical analysis, predicts a limited conversion of carbon content into carbon monoxide in the gasification process of peat. The high content of *Fe* and *Ni* in fly ash comes from residual ballast, which is being formed during the industrial treatment of electronic waste. This residual ballast is released from the walls of the reactor. The concentration of carbon dioxide and hydrogen in synthesis gas greatly affects the calorific value and future use of this gas.

The average lower calorific value of the produced gas was set to 1.3 to 2.3 MJ·Nm⁻³ which corresponds to the energy value from 0.36 to 0.64 kW·Nm⁻³ at the given conditions. The calorific value of produced synthesis gas (the components

being created by the chemical reactions + nitrogen) is influenced by the amount of nitrogen injected into the reactor. Except nitrogen being injected for generating of the plasma arc in the synthesis presence of nitrogen can also be created by the secondary plasma reactor, which is being systematically integrated by the reactor used in the experiment. Sampling point for synthesis gas samples generated in a gasification process is located in the place in the system of plasma technology where resulting synthesis gas can be mixed with the by-source of nitrogen from secondary plasma reactor due to the common outlet of the synthesis gas entering the combustion unit.

Taking as a base the data present in various world publications, we can say that higher percentage of combustible components (*CO* and *H₂*) in the synthesis gas at the gasification of waste biomass and peat can be predicted by applying of different mode of plasma reactor operation.

The applied type of plasma burner affects the parameters of the plasma column significantly and the type of operational atmosphere of reactor (inert, oxidizing) takes share in ratio of gaseous and solid products leaving the plasma gasification process. More economical operation of the gasification can be achieved firstly by adopting of the reactor construction for the gasification of biomass.

CONCLUSION

Taking into account the results obtained from peat gasification in reduction atmosphere of the selected type of experimental reactor at the above defined conditions of gasification, it is evident that gasification is not economically profitable. Low percentage of combustible components of synthesis gas (*H₂* and *CO*) and high content of nitrogen, used for generation of the plasma column of volume of 8.5 to 10

Nl·min⁻¹, take significant share in low average value of lower calorific value of the obtained gaseous medium which is in range of 1.3 to 2.3 MJ·Nm⁻³ in this case.

The transformation of the solid waste into the gaseous fuel in the process of gasification is an alternative way for energy recovery of some, from the financial point of view, of little profitability fuel sources. The important parameter for producing thermal

and electric power is fuel energy of the resource. Solid fuels can be utilized by direct combustion or by conversion of unprofitable solid fuel in the gasification process into the form of gaseous or liquid fuel, whose transport to the place of use is far simpler.

Gasification of biomass waste and solid fossil fuels with low calorific value

(peat, lignite, low-quality brown coal, municipal solid waste) opens up new options in the area of utilization of these resources and raises the question of viable and economically efficient ways of combustion of synthesis gas in cogeneration units to generate electricity and heat.

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