BENEFITS OF HYDROGEN-RICH GAS (HRG) ON BIOMASS COMBUSTION PERFORMANCES

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Due to accelerated globalization, climate change and the increased costs of classical fuels, the notion of biomass is growing in recent years. Harnessing fuels as well as biofuels or hydrogen-rich gas (HRG) helps in a sustainable and environmentally friendly development of the energy sector. Although biofuels cover a vast field in terms of calorific value, maintaining a certain level of humidity is a real problem in practice. Thus, the primary combustion is difficult, and the combustion plants and their performances are restricted. Ideally, the humidity is recommended to be a maximum of 30%. Hydrogen-rich gas (HRG) is obtained from electrolysis, without the need to separate the two gaseous elements H_2 and O_2. Stoichiometric combustion is performed with oxygen from the gaseous fuel, the rest at the level of excess air being completed from the oxidizing medium. The experiments are carried out on pilot installations from University Politehnica of Bucharest and the advantages of co-combustion of solid biofuels with hydrogen-rich gas are highlighted. As a result, you want to increase the speed and combustion and decrease the CO emission. The limits of mass participation of avian waste mixed with biomass for co-combustion will be studied, with the highlighting of the influence of humidity and calorific value.

Keywords: Biofuels, HRG, co-combustion.

THE CONCEPT OF BIOFUEL

Today the concept of biomass encompasses the biodegradable part from a very wide range of fuels, industrial and agricultural waste such as: wood waste, agricultural, vegetable waste (fruit trees, vines), industrial and household waste, biogas, fermentation products, etc. (Bertrand *et al*., 2016). Energy crops are on the backsliding, especially due to relatively high costs, as well as resorting to fertilizers (Lazaroiu *et al*., 2020b).

The share of biofuels in the current energy balance is low, but a sharp development is expected mainly under the impetus of ecology. In our country, the production of energy from biofuels is about 2.1%. Biofuels may be used in a pure state or in a state of processing, in which case the notion of derived biofuel shall arise (Ubando *et al*., 2020).

From the category of derived biofuels, from solid ones, it is mentioned:

- Alcohol-type fuels (ethanol and methanol);
- Gaseous gas and pyrolysis gases;
- Biogas resulting from anaerobic fermentation.

The primary combustion of biofuels is, however, a difficult problem, starting from the very powering of combustion plants. Maintaining a certain level of humidity also restricts combustion technology as well as its performance.

If for wood biomass there are achievements, for the other categories of solid fuels, the researches have still remained at the initiation stage.

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ENERGY CHARACTERISTICS OF SOLID BIOFUELS AND COMBUSTION TECHNOLOGIES

Biofuels cover a very wide area for calorific value. But, the value of calorific power alone is not a sufficient indication for combustion processes. Elementary analysis is edifying analysis, it also leads to the value of calorific power. A simpler but sufficient analysis from the point of view of information is the technical analysis, which includes:

$$W_t^i + V^i + C_f^i + A^i = 100 \quad (1)$$

where:

W_t^i is the total humidity, in %

V^icoefficient of volatile materials, %

C_f^i fixed carbon, %

A^i ash (mineral mass), %

The index *i* indicates the fuel reference status.

Volatile materials allow the ignition process to be carried out. Fixed carbon is the carbon mass of organic carbon and also the main source of energy obtained by combustion.

The combustion process consists of three phases:

- Preparation for ignition (σ_p);
- Ignition and combustion of volatile substances (σ_v);
- Ignition and combustion of carbon (σ_c).

The size of the preparation time for ignition depends on the moisture and ash content, the sum of which is also called the ballast of fuel.

$$\sigma_p = f(W_t^i, A^i) \quad (2)$$

For solid biofuels with low humidity, the ash content is usually very low, the ignition time is less than 10% of the total combustion time $\sigma_a(\sigma_a = \sigma_p + \sigma_v + \sigma_c)$. But a high moisture content totally disrupts this balance.

Biofuels have a very high content of volatile substances, so ignition of fixed carbon (coke) is made easier.

Because combustion is controlled by the combustion of fixed carbon, the emission of carbon oxide will be high when the energy recovery of biofuels (Saxena *et al*., 2009; Lazaroiu *et al*., 2018a).

For direct combustion of solid biofuels, the solutions are (Lazaroiu and Mihaescu, 2021):

- For low power (below 1.2 MW) – layered combustion;
- For medium power (over 1.2 MW) – combustion in air current (similar to combustion sprayed for coal).

In both cases, the combustion of high ballast biofuels requires a heat input fuel (usually natural gas) to ease ignition, but also to reduce CO emission.

Replacing the natural gas used as a thermal support fuel with hydrogen brings advantages related to a much higher burning speed. Thus, the laminar rate of burning, *u*, of hydrogen compared to that of methane, at an excess of air λ = stoichiometric combustion, is 7 times higher (Methane 0.39 m/s; Hydrogen 2.96 m/s). The laminar burning rate, *u*, is expressed in m/s, and represents the speed at which the flame front advances, having the opposite direction with the direction of flow (Iordache and Chisaliga, 2022; Turner, 2004).

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The use of hydrogen instead of methane as a thermal support fuel has the advantage of releasing the point heat very quickly. In addition, the two gaseous fuels also have a similar value for the adjacent combustion temperature, having a value of around 2300°C. Rapid heat development allows the solid biofuel to be heated exactly in the areas necessary to ignite and complete the combustion, respectively.

Hydrogen-rich gas (HRG) is obtained from electrolysis, but does not include the separation of the two gaseous components H_2 and O_2. Stoichiometric combustion is performed with oxygen from the gaseous fuel, the rest at the level of excess air being completed from the oxidizing medium. It should be noted that the unit price of HRG is slightly lower than that of methane at the level of reporting to the heat released (Lazaroiu *et al*., 2018b; Saroj *et al*., 2020).

PRESENTATION OF THE CONCEPT OF TECHNOLOGY PROPOSED FOR THE COMBUSTION OF BIOFUEL IN A LAYER

The combustion of poultry waste depends on its calorific value which is influenced by its humidity. The poultry waste used in tests included the primary state of harvest with an average humidity of about 50%. This aspect involves an inhibition of the ignition process, especially for solid biomass a maximum humidity of 30% being usually required. The hydrogen-rich gas flame has a very high burning speed which allows for the correction of the negative thermo-physical aspects of ignition for humid raw poultry waste.

Experimental research was carried out on a pilot boiler located at UPB, this boiler is equipped with all the necessary facilities for experimental tests, allowing the determination of the flow rate of biofuel, HRG, thermal power output and polluting emissions (Lazaroiu *et al*., 2017; Aneke and Wang, 2016; Pîşă *et al*., 2016; Gejguš *et al*., 2016; Lazaroiu *et al*., 2020a).

During the experiments, a thermal power of 48 kW was achieved in the boiler, compared to the 55 kW nominal power.

The figure 1 shows the co-combustion scheme for wet poultry waste with hydrogen-rich gas (Lazaroiu *et al*., 2020c; Lazaroiu *et al*., 2021).

The combustion of avian waste responds to two objectives:

- Ecological (reduction of stored quantities);
- Heat generation (for poultry breeding halls).

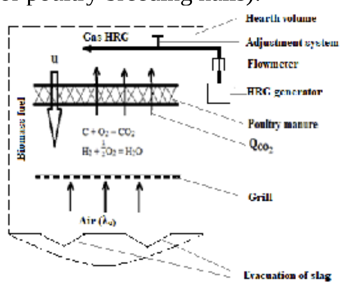

Figure 1. Co-combustion technology scheme using HRG

The validation tests will highlight the advantages of the new pilot demonstration installation.

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The use of co-combustion with hydrogen-rich gas will increase the mass share of avian waste above the previously determined values.

It is estimated that the maximum dose of HRG will be 40-50 liters for a quantity of 2-3 kg of avian waste-biomass mixture. The share of the thermal contribution of hydrogen in the above mentioned quantity is equivalent to an equivalent contribution of natural gas of 4-6%.

The energetic characteristics of the biofuel required the participation of hydrogen-rich gas to achieve an efficient combustion. The layered combustion of solid biofuels is under a strong influence of the density of the layer, the gaseous diffusion becoming much more permissive to a loosening of the layer.

Depending on the density of the solid fuel layer, combustion develops, according to two models shown in Figures 2 and 3.

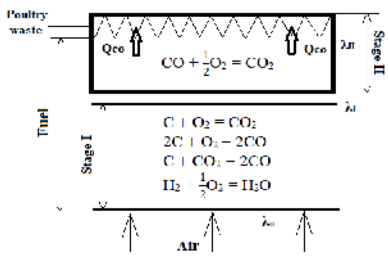

Figure 2. Scheme of the combustion model for a low porosity (high density) fix fuel bed, with two burning stages

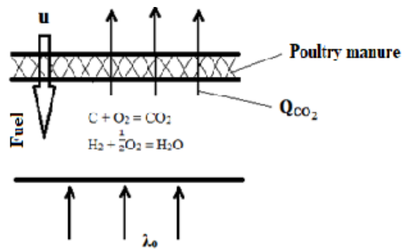

Figure 3. Scheme of the combustion model for a high porosity (low density) fix fuel bed

The burning rate will be influenced both by the quality of the waste biomass mixture (H_i^i, kJ/kg) and by the participation of hydrogen in co-combustion (% HRG).

Figure 4. Pilot plant, 55 kW boiler

Figure 4 shows the 55 kW pilot plant with the following furnace dimensions:

- length x width x height = 0.75 x 0.55 x 0.6 m;
- combustion volumetric space: 0.25 m^3;

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The dimensions of the fixed bars grate are:

- length: 0.52 m; width: 0.015 m; Space between bars: 0.015 m; Overall grill surface: 0.286 m^2; net surface of the grill: 0.19 m^2.

EXPERIMENTAL RESEARCH ON CO-COMBUSTION OF SOLID GAS BIOFUELS HRG, IN AIR CURRENT COMBUSTION TECHNOLOGY

This technology, as presented in Chapter 2, allows the combustion of biofuel particles with a diameter not exceeding 30 mm in air and flue gas suspension [9, 10].

The injection of HRG to raise the ignition and combustion capacity of biomass on the grid of a 1 MW thermal installation is shown in Figure 5.

The technology allows the capture of the thermal power of installations over 1 MW, the total power being a consequence of the number of burner models. The experiments were carried out at the pilot boilers from the University Politehnica of Bucharest and of 2 MW, a boiler equipped with a burner with the turmoil of the flame. HRG gas was introduced into the place of natural gas in one case, and into the body of the eddy burner in the second case. The fuel used was formed by the shredder of wood waste, with a humidity of 30%. The thermal input of HRG gas was on average 5%. The CO emission value was between 40 and 85 ppm, representing very low values.

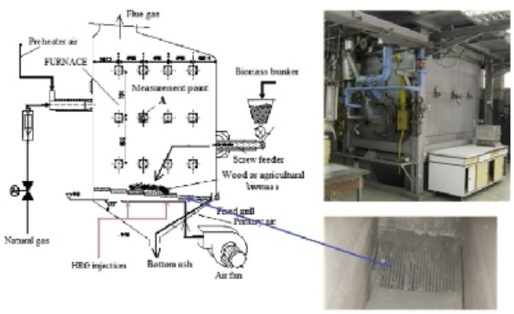

Figure 5. Use of HRG gas injection at a 2 MW thermal installation.

CONCLUSIONS

Experiments have highlighted the advantages of co-combustion of solid biofuels with hydrogen-rich gas. The aim was to increase the burning rate, reflected in the decrease in CO emission.

Two types of testing have been carried out, comprising two combustion technologies, namely:

- Layered burning with application for avian waste;
- Burning in air current, with application for wood and agricultural waste.

Experimental measurements have highlighted the theoretical premises, relating to the increase in the performance of the combustion of solid biofuels under the influence of hydrogen-rich gas, manifested in particular in the decrease in CO emission.

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