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THE INFLUENCE OF HYDROGEN ON THE COMBUSTION VELOCITY OF SOLID BIOMASS

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Abstract: Solid biomass combustion is characterized by two main issues: fuel high moisture weight (that generates some ignition failures) and the high rate of carbon monoxide from flue-gasses (that diminishes the efficiency of the burner an increases the pollution). Hydrogen injection (with a higher combustion velocity) disables the disadvantages mentioned above, allowing the design and operation of more efficient and less pollutant biomass boilers. The paper enhances the theoretical and experimental issues related to the hydrogen use during solid biomass combustion.
Keywords: combustion, solid biomass, efficiency, pollution

INTRODUCTION

Romania has a huge potential to produce and use the solid biomass for energy purposes. Related to the agricultural biomass, we mention important achievements in the use of straw briquettes in hot water boilers up to 300 kW [7].

The both agricultural and wooden biomass is characterized by a high volatile matters amount, which influences the whole combustion process. The combustion is also dependent on the high moisture content of the fuel, especially the ignition phase. The large difference between the combustion velocity of volatile matters and respectively those of solid mass (fix carbon) composed of lignin and cellulose leads finally to a high Co concentration in the flue-gasses. This is the main obstacle to achieving an efficient combustion of solid biomass [2], [5].

According to the measurements, the higher calorific value (HCV) of the cellulose is lower than the lignin. In relation to the fixed carbon content C_f, HCV can be computed using (1), C_f being reported at anhydrous status of the fuel:

$$HCV = 196C_f + 14{,}119 \quad [kJ/kg] \qquad (1)$$

The hydrogen, with its own very high combustion velocity, contributes to the increase of volatile matters velocity combustion, canceling the combined combustion of volatile and fixed carbon. In this manner, a better control of the fixed carbon combustion is achieved, leading to a significant diminution of the CO emission content.

In paper [6] it was used a mixture of hydrogen, named hydrogen enriched gas (HRG), produced by an electrolytic system. This electrolytic system is a dynamic one, keeping thefluid in a permanent flow and it is producing a quasi-stoichiometric gaseous mixture of hydrogen and oxygen. In fact this gas consists of a mixture of hydrogen and oxygen molecules,almost respecting the stoichiometric water ratio [3].

HRG is a gas with a high degree of reactivity which, by adsorption, diffuses into the biomass. Thus, the ignition and combustion rate are improved and the pollutant emissions are reduced. HRG is a colorless gas which has a density of 0.503 kg/m^3, molecular weight 12.3 kg/kmol, auto-ignition temperature 591-605 °C and flammability limit concentration between 7.3–100 % [4]. The free diffusion process (equation Legendre) is the basis for HRG/porous biomass combustion technology. Maximum capacity of producing HRG is 1500 litters/h. Electricity consumed to produce 1000 litters of HRG is between 3–3.5 kWh. This means approximately 0.4 Euro/1000 litters.

HRG injection in solid biomass [4] contributes to reducing the carbon monoxide concentration (OH radical having leading role) by reactions (2) [1]:

$$\begin{aligned} &CO + OH \rightarrow CO_2 + H; \\ &H + O_2 \rightarrow OH + O; \\ &O + H_2O \rightarrow 2OH. \end{aligned} \qquad (2)$$

The improvement of the biomass combustion performances by hydrogen injection is possible to be made for all known combustion technologies, such as:

- Fixed bed combustion systems: with fixed grate, with mobile-rolling grate, with forward or backward push, with inferior supply for pellets;
- Fluidized bed systems: stationary or recirculating;
- Air-driven system (fuel is milled and pulverized);

For biomass with high moisture content and ash, with particle dimension larger than 1 mm, it is recommendable to select boilers provided with fixed bed furnaces, with a maximum output of 20 MWt.

Some mixtures between agricultural biomass with wooden biomass can be prepared for combustion, excepting the mixture straw-wood, due to some large differences between combustion characteristics, such as moisture and ash melting temperature.

MATERIAL AND METHOD

The release and burning velocity for volatile matters is described in paper [8] by the differential equation (3):

$$\frac{dV_c}{d\tau} = (V_i - V_c)\cdot\alpha_v \qquad (3)$$

where: V_i is the initial content of volatile, V_c – volatile burnt content in period τ, α_v - release and burning velocity of volatile matters (processes ruled by gaseous diffusion and the combustion reactions kinetic).

$$\alpha_v = \frac{1}{\frac{1}{\alpha_{v,dif}} + \frac{1}{\alpha_{v,cin}}} \quad [1/s] \qquad (4)$$

$$\alpha_{v,dif} = \frac{2{,}22\cdot 10^{-6}}{d^2} \quad [1/s] \qquad (5)$$

$$\alpha_{v,cin} = K_{ov}\, e^{-\frac{E_v}{RT}} \quad [1/s] \qquad (6)$$

Equation (5) is very common in literature [8], but not so accurate for biomass as it is for coal

However, due to bale or briquette breakage due to the swelling phenomenon in the first phase of combustion occurs an auto-correction by reconsidering the particle's diameter value; the hydrogen contributes too for reducing the diameter in the ignition phase.

For equation (6), the values are:

d - particle diameter, [m]; K_{ov} - volatile release value, [1/s]; E_v - activation energy, [kJ/mol], T - temperature, [K]. For solid biomass, the reaction constants have the values: K_{ov} = 80-111 [1/s], E_v = 38.4-60.12 [kJ/kmol]

For fixed carbon combustion, the equation is given by (7), while for the combustion velocity was used equation (8) [8] :

$$K_c = 8710\, e^{-\frac{35700}{RT}} \quad [1/s] \qquad (7)$$

$$c_{CO_2} = \tau(\alpha_v + K_c) S\cdot d^2 \quad [m/s] \qquad (8)$$

where: $\tau = \frac{12}{32}$ is the stoichiometric ratio $O_2 \longrightarrow CO_2$, and S the specific reaction surface, [m²/m³].

For the solid biomass, according to the physical process of densification, $\alpha_{v,dif}$ is dominant versus $\alpha_{v,cin}$. In such manner, it appears as necessary a limitation criterion for briquette dimension. The expertise allows to asses the optimal domain: $\alpha_{v,dif} = \max(10\,\alpha_{v,cin})$.

RESULTS

In the paper [6] are presented the results of some experimental tests for the fixed bed combustion of five types of solid biomass injection HRG in the primary air.The following biomass categories have been tested: sawdust (1), wooden pellets (2), cereal straw briquettes (3), vineyard wastes (4), corncobs (5). Biomass power characteristics taken into account were: low calorific value – Q^i_i [kJ/kg]; moisture – W^i_t [%]; ash – A^i [%]. The results of the analysis are:

- Fuel 1: Q^i_i=16500 kJ/kg; W^i_t =14 %; A^i =2,5 %;
- Fuel 2: Q^i_i=17500 kJ/kg; W^i_t =10,5 %; A^i=0,5 %;
- Fuel 3: Q^i_i=14700 kJ/kg; W^i_t =10,2 %; A^i=4,7 %;
- Fuel 4: Q^i_i =13600 kJ/kg; W^i_t=16,1 %; A^i=4,9 %;
- Fuel 5: Q^i_i =12800 kJ/kg; W^i_t=18,8 %; A^i=3,9 %;

A constant thermal load of the boiler presented in figure 1 has been maintained during tests, by controlling the fuel mass-flow rate.

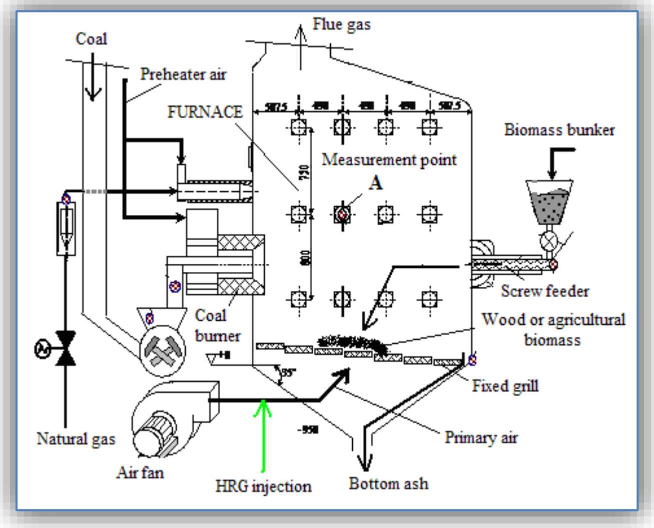

Figure 1 - Pilot plant of 2 MWt used to test the hydrogen injectionin biomass combustion

Findings:

- Significant reduction of CO emissions for wooden biomass derivates (reduction limit until 158 ppm);

» Lower reduction for agricultural biomass (upper limit to 1700 ppm);

In figures 2 and 3 is shown the flame shape for wooden and agricultural biomass, with and without HRG injection.

We found as remarkable the diminution of the flame length in the case of HRG combustion, due to a higher intensity of the oxidation processes in the inferior zone of the fuel bed.

a) wooden biomass

b) agricultural biomass

Figure 2 - Flame shape without HRG injection

a) wooden biomass

(b) agricultural biomass

Figure 3 - Flame shape without HRG injection

Finaly, an elemental analysis of the ash was performed, presented in Table 1, in order to draw a conclusion related to future possible use.

The high phosphorus, potassium and calcium contents, related to very low concentrations of heavy metals, indicate the possibility to use the biomass ash as agricultural fertilizer. Such approach is very important not only for economic reasons, but give the hope to eliminate a potential hazard.

Table 1. Elemental analysis of the ash

Chemical Species	Wooden Biomass	Agricultural Biomass
Si	19.14 %	19.72 %
Ca	6.66 %	6.04 %
Fe	3.65 %	5.61 %
Al	2.88 %	4.30 %
Mg	1.44 %	1.26 %
S	1.31 %	1.23 %
P	0.81 %	0.59 %
Na	0.28 %	0.36 %
Ti	0.27 %	0.29 %
Cl	0.16 %	0.15 %
Ba	0.10 %	0.10 %
Zn	0.03 %	0.03 %
Cu	0.01 %	0.01 %
Cr	86 ppm	95 ppm
Ni	68 ppm	83 ppm

CONCLUSIONS

In order to challenge some obstacles occurred in biomass combustion, such as the ignition difficulties due to high moisture content, respectively the high concentration of carbon monoxide in flue-gasses, we have tested a new technology – hydrogen injection as HRG in the primary air flow, at a permissive cost in comparison to the advantages. The research is fully original, according to our knowledge there are no similar paper in the literature.

The effects of this procedure were:

» Separation between the volatile and fixed carbon combustion trough high burning velocity of the hydrogen;
» Reduction of the flame length and flame stabilization;
» Decrease of pollutant emissions, especially carbon monoxide.

Beside these advantages, the ash resulted from biomass combustion is a good fertilizer for agriculture and horticulture.

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