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THE USE OF BIOMASS AS A RENEWABLE ENERGY SOURCE IN A FLUIDIZED BED COMBUSTION PLANT

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Abstract: *The use of renewable energy sources (RES), which also includes waste biomass, is a current national and global concern for sustainable development by reducing greenhouse gas emissions (GHG). Partial replacement of fossil fuels with biomass is a possibility, together with other sources of non-polluting energy production such as hydropower, wind, solar and geothermal, to reduce greenhouse gas emissions as the amount of* CO_2 *resulting from the combustion of biomass is equal to that captured during its training. Optimizing waste biomass utilization technologies ensures GHG reduction.*

Key words: *energy, renewable sources, biomass, combustion, pilot plant.*

1. Introduction

The progressive global warming, which was only a hypothesis to be considered in the middle of the last century, has become scientifically confirmed and directly felt by the population, and so it is increasingly falling into the major concerns of governments [11].

The forecasts for global energy consumption during 2000-2100 are illustrated in this paper by the relative energy consumption (REC) variation curves, considered equal to the unit (REC=1) for 2000 (Figure 1) [2].

It is noticed that for industrialized countries the REC index was considered to have a steady value for the period, but for developing countries, the value of this index is growing extremely - the explanation lies in the trend of rapid consumption / person growth in Asian

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countries China, India and not only) to Europe and America. Global growth figures are based on the World Bank's 1992 projection, namely 11.7 billion inhabitants at 2100 [2].

With regard to the projections of global energy consumption, these are numerous, but the key issue is the degree of confidence [16-17]. Of course, there may be doubts, sometimes sufficiently arguable, both about the world population growth over the course of a century and about the energy consumption per person. Energy specialists say that "it would be wise to anticipate an increase in global primary energy requirements, reported to 1995 values, with a factor of less than 1.4 - at 2020, 2 - at 2050 and 5 - at 2100" [15].

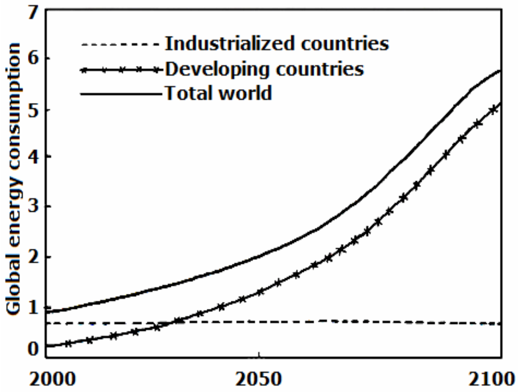

Fig. 1. *Projections on global energy consumption*

Synthesizing the literature, some authors [8-10] point out that global warming and cooling have taken place from time to time on Earth, with temperature changes being very slow, although there have been times when the changes occurred somewhat suddenly. For almost 10 millennia, the average temperature has risen by about 2 °C, but since the mid-nineteenth century growth has been exceeding the reference level. The recently evolution of global average temperature is the synergy effect of two distinct categories of causes: natural and anthropogenic.

2. Biomass Properties

Biomass is the natural component of nature. As a form of preserving the sun's energy in chemical form, biomass is one of the most popular and universal resources on earth. It provides not only food, but also energy, building materials, paper, fabrics, medicines and chemicals. If biomass is actually burning (we extract the chemical energy), then the oxygen in the atmosphere and the carbon together with the hydrogen in the plants react to form carbon dioxide and water. This process is cyclic, as carbon dioxide can again participate in the biomass formation process.

In the literature [18] is indicated as possible sources of biomass to be converted into fuel, the following: waste and phytomass. Under the conditions of the existing topo-geographic environment, it is estimated that Romania has a high energy potential of biomass [13], estimated at about 7.594 thousand toe / year ($318 x 10^9$ MJ/year), which represents almost 19% of total consumption of primary resources in the year 2000, divided into the following fuel categories [18]:

- Forest residues and firewood [1.175 thousand toe ($49.8 x 10^9$ MJ/year)];
- Wood waste [487 thousand tep ($20.4 x 10^9$ MJ/year)];
- Agricultural wastes: [4.799 thousand toe* ($200.9 x 10^9$ MJ/year)];
- Biogas [588 thousands toe* ($24.6 x 10^9$ MJ/an)];
- Urban waste and municipal waste [545 thousand toe * ($22.8 x 10^9$ MJ/year)].

Combustion of biomass in addition to the released thermal energy produces a quantity of CO_2 equal to that consumed in the process of its formation. Due to this fact, biomass is a renewable fuel, which is included in the so-called "green fuel" category, which does not contribute to the "greenhouse effect" by combustion. Another aspect that should be considered in favor of using biomass as a fuel is that if it were left to rot naturally, greenhouse gases such as CO_2 and CH_4 would be produced by decomposition. Indicative values of the composition, volatiles (COV) and power calorific values (PCV) of biomass waste are presented in Table 1. By comparing the physicochemical characteristics of the coals presented in the literature, it is noted that biomass has characteristics similar to those of coal, especially those of lower coal.

Charcoal has a higher carbon content and ash, and biomass has higher oxygen content and hence the calorific value is higher for coal than for biomass. Ash content, as well as its characteristic temperatures, is lower for biomass fuels than for coal (especially lignite). Figure 2 [14] shows the ash content for different fuels.

COV and PCV composition Table 1

Name	Straw	Hardwood	Sunflower seed husks	Old mixed wood
C^{mc} [%]	50	50.5	51.5	41
H^{mc} [%]	6.2	6.10	5.9	6.2
O^{mc} [%]	43.1	42.80	41.9	43.1
N^{mc} [%]	0.6	0.6	0.5	0.6
S_c^{mc} %]	0.1	-	0.2	0.1
V^{mc} [%]	-	85	-	-
W_t^i [%]	10	40	15	10
A^{anh}[%]	5	1	3	6
S_t [%]	0.09	-	0.17	0.09
H_s^i [MJ/kg]	20.03	20.02	20.44	20.03
H_i^i [MJ/kg]	15.93	9.25	15.76	15.93

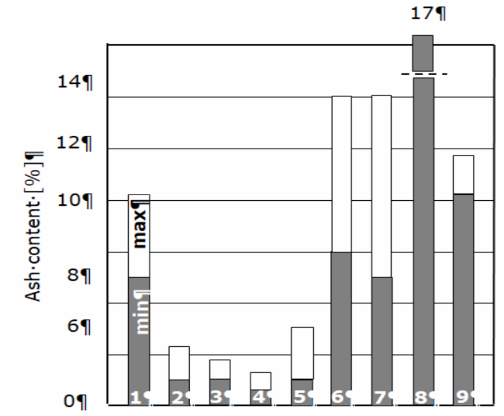

Fig. 2. *Ash content for different fuels:*
1 – bark; 2 – barked bark; 3 – bushless bark; 4 – saw blade; 5 – wood (hardwood, softwood); 6 – mixed old wood; 7 – straw and straw; 8 – brown coal; 9 – huil

3. Installations and Techniques for Biomass Combustion

Biomass as a renewable fuel comes directly from forests or agricultural crops or indirectly from waste from the transformation of primary biomass into finished products (sawdust, seed husks etc.). Biomass can be burnt directly (such as burning wood or incinerating waste) or burning simultaneously with coal (co-firing). Modern boilers are designed to use co-firing to reduce CO_2 emissions. When designing the combustion system, account shall be taken of the characteristics of the fuel to be used, the environmental legislation, the cost and performance of the equipment available. During burning, a biomass particle passes through several phases. In comparison to coal, biomass generally has less carbon, aluminum and iron and more oxygen, silica and potassium, has lower calorific power, higher water content, lower density and reduced friability [4-5].

Perfect and complete combustion of biomass involves changing the previously used coal burning plant due to the composition of biomass, especially volatile content. The calorific value of biomass is much lower than that of coal because of its high moisture and oxygen content.

It is recommended that solid biofuels to be used in domestic, commercial and industrial installations are subjected to pretreatment processes such as washing, drying, size reduction and compaction in order to achieve greater uniformity, easier handling and a reduction in humidity to an acceptable level. Wood is the most used solid biofuel. This can be used, where possible, directly as fuel, or can be processed in forms that are easier to transport, stored and burned, such as pellets, lighters, etc.

In Figure 3 [7] the main biomass conversion directions are schematized.

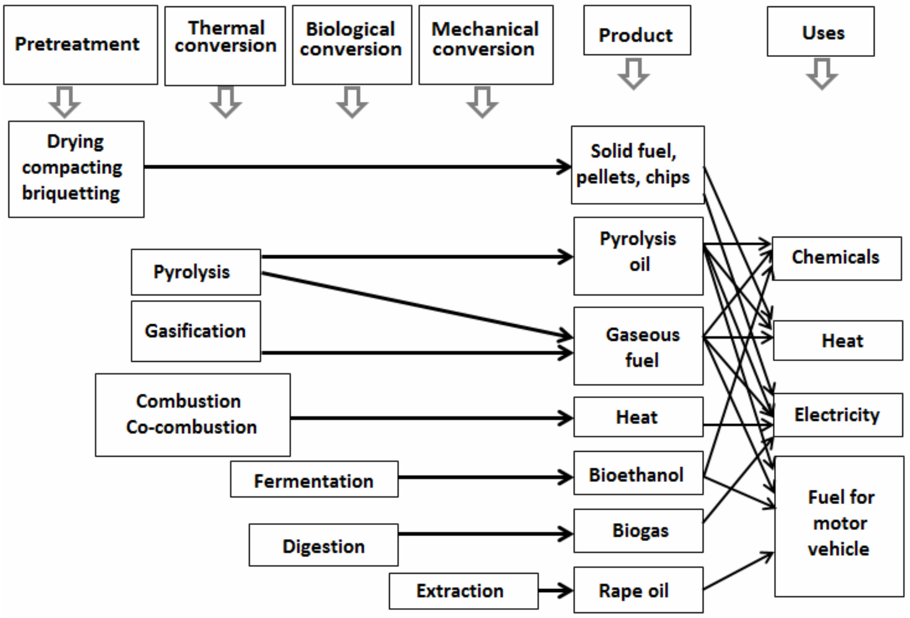

Fig. 3. *Biomass conversion modalities*

The nominal heat output of a combustion plant is defined as the product of B [kg/s] fuel consumption and Hi [kJ / kg] lower heating value:

$$P_{tn} = B \cdot H_i \ [\mathrm{kW_t}] \,\mathrm{or}\, [\mathrm{MW_t}] \qquad (1)$$

Effective thermal power is defined by the relationship:

$$P_{t.ef} = \eta_{ef} \cdot B \cdot H_i \ [\mathrm{kW_t}] \,\mathrm{or}\, [\mathrm{MW_t}] \qquad (2)$$

where η_{ef} is the actual thermal efficiency of the plant [6, 8-10, 12, 15].

Biomass combustion technologies have some problems. Most important are the soiling and corrosion of heat exchange surfaces. Slugging and fouling reduce heat exchange on heating surfaces and cause corrosion. Corrosion and erosion lead to shorter equipment life. The deposits or dirt of the heating surfaces are caused by the inorganic matter present in the burning biomass. Sodium (Na) and Potassium (K) lower the ash melting temperature and therefore the ash deposition on the boiler pipes is increased. In Romania, urban heating systems include the following two:

- System consisting of cogeneration plant (CHP) with condensing turbines and adjustable sockets, hot water transport network of 150 °C, thermal points, hot water distribution network 90/70 °C to consumers;
- A system consisting of a single thermal plant, hot water transport network of 150 °C, thermal points, hot water distribution network to consumers [1].

Of these two systems only the latter can be transformed more easily to operate with biomass. This modernization of the existing heat generation plants has two solutions:

- Replacement of existing boilers with new boilers running on biomass;
- Transformation of existing boilers for biomass operation.

The transformation system involving the smallest constructive changes consists of introducing into the existing boiler furnace of a screw feeder and provision of gas treatment plants.

This system reduces the capacity of the boiler by about 10% due to the fact that in the area where the feeder grid is located requires a minimum reduction, which reduces the combustion space.

A second transformation system consists in providing a pre-combustion chamber in the front of the boiler.

Biomass combustion installations, alone or together with a fossil fuel, must necessarily include the outbreak and the associated installations used for the introduction of fuel, combustion air, evacuation of ash and flue gas, as well as gas purification plants waste.

Taking into account the above criteria, the main types of biomass combustion plants can be classified as in Figure 4.

Research on the fluidized bed combustion theory has demonstrated the possibility of applying the stationary fluidized bed combustion technology of indigenous lignite and underpinned the design and realization of hot water boilers with thermal power between 1.86 and 11.65 MW, process steam boilers with flow rates from 0.55 to 2.75 kg/s [14].

The furnace has the shape of a conical trunk in the lower part, where fluidization of the fuel layer occurs, and in the upper part it has a parallelepiped shape with square section. The upper part is bordered by membrane walls formed from pipes through which water flows.

The fuel is introduced into the furnace by means of a worm, driven by an electric motor equipped with a speed variator to adjust the fuel flow. The grill of this type of outbreak is usually made up of a metal plate provided with nozzles which feeds the fluidizing air (primary air). One or more automated hydrocarbon burners are used to ignite the fuel layer, which, after the fluidized bed has ignited, the burning becomes self-heating, can be decommissioned. In order to complete the burning, there is the possibility of inflating secondary or even tertiary air into the upper part of the furnace.

The temperature inside the furnace must be maintained between 700 and 900°C, adjusted by fuel flow, air flow and temperature, as well as by means of the submerged heat exchanger.

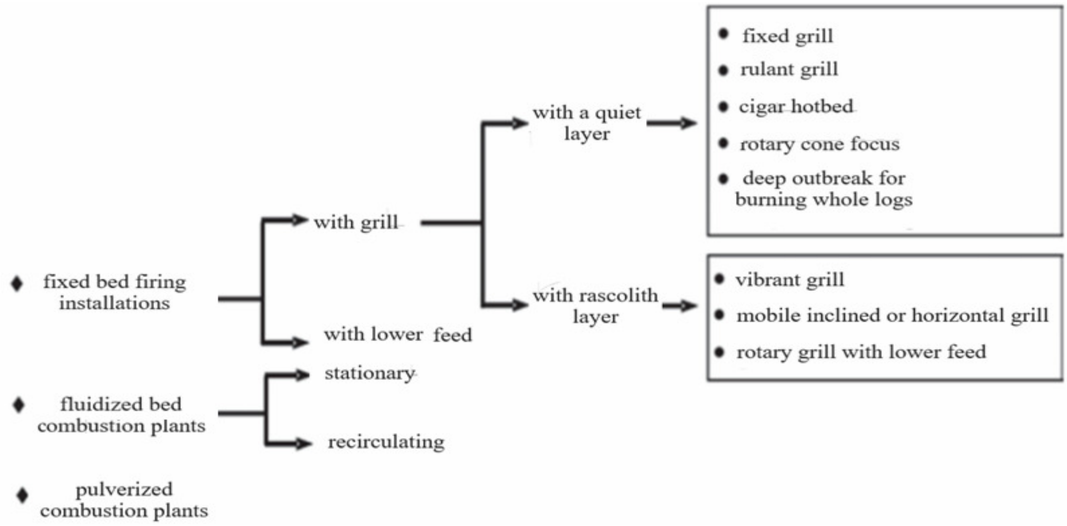

Fig. 4. *The main types of combustion plants*

Among the advantages of this technique compared to the others are the following:

- Simpler and cheaper fuel preparation. If the particle size range is at 0.1 mm in the sprayed combustion outbreaks, the fluidised bed combustion furnace reaches 7 mm and the circulating fluidized bed combustion (ASFC) can reach 15-20 mm. This results in lower energy consumption and reduced wear of fuel preparation equipment;
- The combustion stability in relation to fuel quality (variation in moisture or ash content) is better due to the characteristic of ASFC outbreaks, which have a combustion zone separate from convection and by controlling the amount of ash recycled but also by changing the flow ratio primary, secondary and tertiary air;
- Increases burning efficiency (98-99% for ASFC, 95-96% for ASF) due to the turbulence of the environment in the outbreak. Due to the different collision, the ash layer formed at the surface of the particles during the combustion is removed and the combustion improves;
- It reduces the pollutant emissions [16-18] and especially NOx due to the low

temperature of the furnace (700-900°C) and the substoichiometric combustion at the bottom of the ASFC furnace;

- The biomass has a low sulphur and therefore no desulphurisation of the combustion gases is required;
- Burning is self-heating, hydrocarbon burners are only used at start-up.

4. Experimental Research on the Combustion of Biomass in a Fluidized Bed

The article presents a case study on the operation of the pilot plant for the use of sunflower seed husk as a waste fuel for the operation of the station with rated thermal input P_{tn} = (60-90) [kWt].

Experimental research was conducted on a pilot plant in the Multifunctional Heat & Non-Conventional Laboratory, with a thermal capacity of 0.05 - 0.1 Gcal (Figure 5).

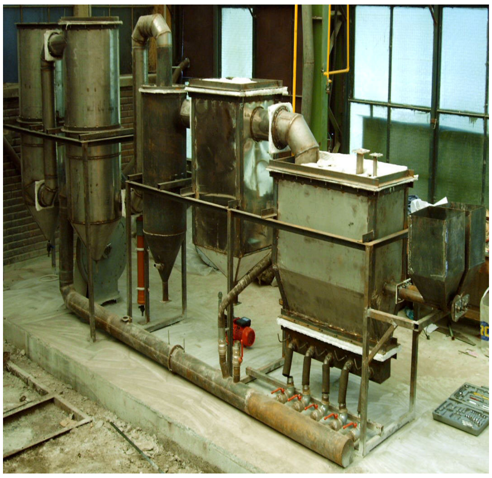

Fig. 5. *Overview of the pilot station*

Following calculations and experimental researches, we obtained:

- A fuel consumption of between 14.724 kg / h and 22.086 kg/h;
- A coefficient of excess air λ_f = 3.192 – 5.43 to ensure that the furnace is cooled so that the temperature of the combustion gases at the outlet of the furnace is between 600 and 900 °C.

The thermal calculation of the plant was made from agricultural waste (sunflower seed husk), which is composed of the following:

C^{mc} = 51.5%;
S^{mc} = 0.2%;
H_s^i = 20.44 MJ/kg;
H^{mc} = 5.9%;
S_t = 0.17%;
H_i^i = 15.765 MJ/kg;
O^{mc} = 41.9%;
W_t^i = 15%;
N^{mc} = 0.5%;
A^{anh} =3%.

Using the calculation relationships in Table 2 [3], the elemental composition was determined relative to the initial sample, yielding the results:

C^i = 42.462%;
N^i = 0.412%;
W_t^i = 15%;
H^i = 4.865%;
S_c^i = 0.165%;
O^i = 34.546%;
A^i = 2.55%.

The lower calorific value was calculated with the relation (3), for which the value was obtained: H_i^i = 15281,359 kJ/kg.

$$H^i_i = 33900\,C^i + 103000\,H^i - 10900\,(O^i - S^i_c) - 2512\,W^i_t \text{ [kJ/kg]} \qquad (3)$$

Factors for passage of solid fuel analysis results from one state to another Table 2

Results reported to	Initial state	Status for analyze	Fuel anhydrous	Fuel mass	The organic mass
Initial state	1	$\frac{100-W_a^a}{100-W_t^i}$ *)	$\frac{100}{100-W_t^i}$	$\frac{100}{100-W_t^i-A^i}$	$\frac{100}{100-W_t^i-A^i-S_s^i}$
Status for analyze	$\frac{100-W_t^i}{100-W_a^a}$ **)	1	$\frac{100}{100-W_a^a}$	$\frac{100}{100-W_a^a-A^a}$	$\frac{100}{100-W_a^a-A^a-S_s^a}$
Fuel anhydrous	$\frac{100-W_t^i}{100}$	$\frac{100-W_a^a}{100}$	1	$\frac{100}{100-A^{anh}}$	$\frac{100}{100-A^{anh}-S_s^{anh}}$
Fuel mass	$\frac{100-W_t^i-A^i}{100}$	$\frac{100-W_a^a-A^h}{100}$	$\frac{100-A^{anh}}{100}$	1	$\frac{100}{100-S_s^{mc}}$
The organic mass	$\frac{100-W_t^i-A^i-S_s^i}{100}$	$\frac{100-W_a^a-A^a-S_s^a}{100}$	$\frac{100-A^{anh}-S_s^{anh}}{100}$	$\frac{100-S_s^{mc}}{100}$	1

*) If $W_a^a = W_h^u$ the transform factor can be written 100/100-W_i^i;

**) If $W_a^0 = W_h^u$ transform factor can write 100/100-W_i^i, where W_i^i is the wetting humidity. where: W is Moisture or external moisture; W_i - Humidity of soaking; W_h^u - Hygroscopic or internal humidity; W_t^i - Total humidity in the initial state; W_a^a - Moisture of the test sample; A^i - The ash content in the initial state; A^a - Content of ash for the analysis sample; S_s^i - Sulfur sulfide in the initial state; S_s^a - Sulfur sulfide for the analysis sample; A^{anh} - Anhydrous ash content; S_s^{anh} - Sulfur content of sulfur in anhydrous state; S_s^{mc} - The sulfur content of the fuel mass.

5. Conclusions

The experimental results highlight that biomass has a low CO content in the combustion gases, the combustion being considered as appropriate, falling within the values recommended by the literature on the coefficient of excess air (1.6-2.25). The focus temperature, for reasons of avoiding the agglomeration of the fuel particles, should be kept below the agglutination temperature, which varies between t_{agl} = 662°C for wheat grain and t_{agl} = 1188°C for spruce wood with shell [7].

Another reason for temperature limitation in the outbreak is related to the temperature resistance of materials from which the walls of the furnace, including thermal insulation, are made, as the walls of the furnace are not cooled. Cooling the furnace is only done by the cold air introduced. For this reason, the air flow is higher than that required for combustion, the air excess coefficient being around 3.2 (as can be seen from the calculation example) or sometimes even higher. Consequently, the relative heat losses with the flue gas evacuated to the chimney are higher, and the gross thermal output of the plant is negatively affected. This deficiency can be eliminated by using a cold-boiled hearth, in which case the excess air coefficient can be λ_f = 1.1 – 1.3. If this measure is also associated with a decrease in the temperature of the combustion gases at values of t_{gc} = (110-120) °C by correspondingly increasing the surface of the convective body, a sensible improvement (by about 10-12 %) of the current gross thermal yield. The concentration of dust in the dry combustion gases is small and is due to the presence of cyclone at the exhaust of the combustion gases in the convective surface, its presence being unnecessary in the case of the burning of low ash biomass. Cyclone presence is required.

Based on the above assertions, it can be concluded that in the case of the combustion of waste biomass alone, the combustion plant can be greatly simplified, with only the furnace itself (with stationary fluidized bed combustion), the gas heat exchanger combustion - water and, on a case-by-case basis, possibly a cyclone for exhausting the combustion gases.

If it is intended to use the plant and to co-incinerate biomass with coal or only coal, it is necessary to equip it with flue gas cleaning equipment (cyclone, scrubber, reactor and drop separator). In this case, the quality of the waste water used for flue-gas cleaning must be investigated and the extent to which it meets the requirements of to be able to be discharged into municipal sewerage.

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