

# Comparative results between densified agricultural and woody biomass in fixed bed combustion

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**Abstract**— The paper analyses the behaviour of cereal straw briquettes in combustion at energy installations equipped with fixed grates for powers below 75 kW, intended for uses in the field of agriculture. A comparison was made with the combustion of sawdust briquettes. A wider involvement of the energy use of cereal straws, which are in large quantities in certain agricultural regimes, is envisaged. The research includes a new production of cereal straw briquettes from the Oltenia area, previous research being carried out with briquettes made in the agricultural area of North-Eastern Moldova. The use of cereal straw for energy purposes, however, collided with the final processes of combustion when the ash becomes adherent to the elements of the combustion plant, so this new approach will contribute to broadening the knowledge about this biofuel that represents a certain future. The work presented experimental combustion tests comparing the two fuels (cereal straw briquettes and wood sawdust respectively) at a 55 kW pilot plant, plant equipped with a fixed grill.

**Keywords**— densified agricultural biomass, woody biomass, comparative combustion, densification efficiency, experimental results

## I. GENERAL ISSUE

The agricultural waste left after its use for animal feed, after the formation of beds in animal breeding halls and after those returned to the soil, by prohibiting incineration on fields, requires a new management of agricultural waste that leads either to their transformation into compost, or to a direction towards a use for energy production. In fact, a step is taken towards achieving a circular economy, especially if it is admitted that the ash resulting from the combustion for energy purposes becomes an agricultural fertilizer by concentrating the shares of phosphorus (P) and calcium (Ca).

Today, the use of cereal straws, maize and sunflower stalks (including corn cobs) and sunflower husks is particularly being considered for energy purposes. Lately, rapeseed stalks have been added to these.

The densification of the shreds of these agricultural wastes, followed by drying and pressing, leads to obtaining their qualities as competitive as possible with the requirements of combustion installations. In this way, briquettes and pellets are made, with a high calorific value (over 12000 kJ/kg). The high density, in the range of 500-1400 kg/m<sup>3</sup>, facilitates feeding operations and volume occupied by fuel in the hearth.

Initially used with success for woody biomass, densification is currently being researched to be applied to agricultural residues as well.

The production of energy from agricultural residues is also imposed by the very large amounts resulting in agricultural regions. This problem will have to be looked at with an application of some regional policies, given to the specifics and climate of the agricultural region (European Union and even national policies, remaining to represent only the general framework). In this support of this concept come the amounts of agricultural residues resulting in a hectare, comprising:

- cereal straw, 2300-3000 kg/ha
- corn and sunflower stalks; 3000-4500 kg/ha.

Considering the use for the agricultural field and a little compost, these amounts will represent about 40-60% of the presented values.

The first researches in the EU to use the densification of cereal straw included the use of straw bales, a technology replaced today by the more efficient technologies related to briquettes and pellets.

The feed and combustion plants for bales, briquettes and pellets are very different from each other. This paper presents the results of the combustion of briquettes in energy installations with fixed bed combustion, installations intended for medium thermal powers, in the range of 50-75 kW

## PHYSICAL AND ENERGY CHARACTERISTICS OF THE ANALYZED BRIQUETTES

The quality of the briquettes will depend both on the qualities of the raw waste and on the physical and chemical operations carried out.

From the point of view of energy characteristics, technical analysis and lower calorific value are the main benchmarks.

Technical analysis includes:

$$W+V+A+C_f=100 \text{ [%]}$$

where: W is the humidity in mass percent, %; V – volatiles, %; A – mineral mass (ash), %; C<sub>f</sub>- fixed carbon, %.

Agricultural biomass is generally characterized by a high content of volatiles (which ensures the ignition phase without difficulty), a relatively low ash content and a wide range of humidity.

Raw grain straw (at harvest) is characterized by:

W =11-14 %, A=5 -5,6 %, V=70-73%, C<sub>r</sub>= 6,5 -14%, lower calorific value,  $H_i^i = 14000 - 17500 \text{ kJ/kg}$

The other agricultural wastes mentioned, corn and sunflower stalks as well as sunflower seed husks are hygroscopic, so the humidity increases up to about 35%. As a result, the calorific value will be presented in an anhydrous state known as the higher calorific value (the lower one can be calculated according to the actual moisture value), denoted  $H_s^i$ :

$$H_i^i = H_s^i - 25.10 W \quad (2)$$

For wood, the humidity varies within very wide limits, from about 65-73% at harvest, up to the use value after various forms of drying.

The values are mentioned:

Corn Stems  $H_s^i=15750-16500 \text{ kJ/kg}$

Sunflower stems,  $H_s^i=20000-12000 \text{ kJ/kg}$

Sunflower seed pods,  $H_s^i=16200-16900 \text{ kJ/kg}$

Reed stalks,  $H_s^i=16000-16500 \text{ kJ/kg}$

Wood,  $H_s^i=15800-16500 \text{ kJ/kg}$ .

The first cereal straw briquettes used for energy purposes came from the North-Eastern part of Moldova. The lighters had a cylindrical, round or polygonal shape, with an inner hole to ensure the diffusion of oxygen and from its center, with the dimensions:

- diameter 72-80 mm.
- length 100-160 mm.

The briquettes successively fed the 80, 150 and 300 kW boilers with the average density of  $900 \text{ kg/m}^3$ . Later, pellet combustion installations were developed, creating the 480 kW boilers and bread ovens (Huși).

In the briquette manufacturing technology, it requires a heating to about  $250^\circ\text{C}$  and a piston pressure in the range of 60 – 200 bar. Electricity consumption is 0.033-0.035 kWh/kg. In the area of Dobrogea, reed briquettes, or composite briquettes made of reed, straw and sawdust, with a diameter of  $\varnothing 70$  and a length of 100 – 300 mm, with a pressure of 10 bar, were made.

Currently in Oltenia (Caracal) straw briquettes and pellets are produced, with the characteristics shown in table 1, which will find the energy use niche.

The briquetting of wheat straw in the Oltenia region involves a working temperature of approximately  $100^\circ\text{C}$ , the initial humidity of the straw being 10-12%. Energy consumption during pressing is  $0.12 \text{ kWh/kg}$ . Figure 1 shows an overview of the facilities, with a production of 300kg/h.



Fig. 1. General view of the briquetting installation

The briquetting station in the Oltenia region also produces pellets of 95% wheat straw and 5% flour bran, with a diameter of 4-6 mm and a length of 20-25 mm. The total energy consumption (shredder plus pressing) is  $0.19 \text{ kWh/kg}$ . Figure 2 shows an overview of the pelletizing plant, for a production of 400 kg/h.

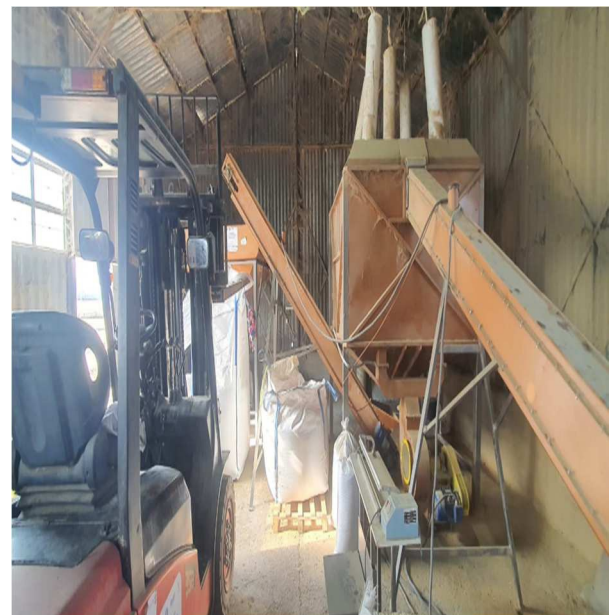


Fig 2. General view of the pelletizing plant

Experimental results of the combustion of briquettes from the Oltenia region compared to those of sawdust

The experimental testing aims to highlight the combustion results of the briquettes from the Oltenia region by comparing them with the sawdust briquettes available in the market. For this, the pilot boiler of 55kW from the Faculty of Mechanical Engineering at the Polytechnic University of Bucharest was used, a boiler on which multiple similar experiments were carried out. Figure 3 shows the pilot boiler.



Fig. 3. General view of the pilot boiler

The pilot boiler is equipped with a grill and has a natural draft. After the firebox, the boiler is fitted with a heat exchanger with flue pipes. Combustion efficiency is measured by sampling combustion gases at the exit from the boiler, with a TESTO-350 analyzer. Figure 4 shows the experimentally tested briquettes in the combustion process.

During the experiments, the following criteria were respected for comparison:

- the same mass loading for the two fuels (5.5 kg);
- flame analysis (visual) at the same time sequences;
- combustion gas analysis at the same time sequences.

Figure 5 shows comparative images for the two fuel categories for certain periods of the combustion process. The images demonstrate a proper combustion dynamics, and the total burning time for the masses of 5 kg of briquettes for each sample was about 45 minutes.

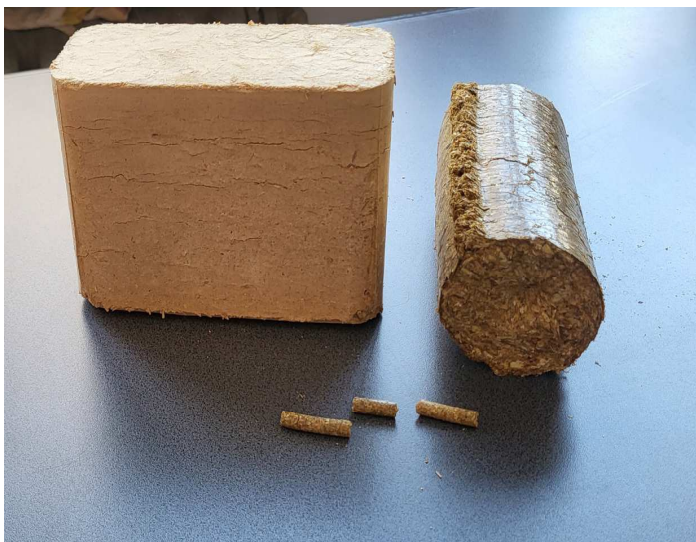
Analyzing the combustion dynamics for the two categories of briquettes, there were very few differences, which demonstrates the ability of cereal straw briquettes to be used for energy purposes. Comparatively, the burning speed of cereal straw briquettes was about 10% higher than for sawdust briquettes are presented in table 2.

Value	$t_{ev}$ (°C)	$CO_2(\%)$	$\lambda$	$CO$ (ppm)	$NO_x$ (ppm)
Straw lighters	218	4.4	3.89	1010	53
Sawdust briquettes	208	4.1	7.80	968	16

TABLE 2 The average values of the combustion gas

Measurements of pollutant emissions in the combustion gases demonstrated reduced emissions of carbon dioxide and  $NO_x$ .

The pilot boiler had a heat load of 75% for both samples. The result was about 72%, mainly due to the exhaust gas temperature of about 210 – 220 °C.



a. Straw briquettes and pellets



b. Straw briquettes on the grate

Fig. 4. Experimentally tested briquettes (straw pellets from the Oltenia region were also positioned in the center)



Fig. 5 Combustion of biomass briquette

### III CONCLUSIONS

The paper carried out an analysis of the quality of briquettes and pellets from agricultural waste compared to those from woody biomass.

The energetic characteristics of briquettes and pellets from cereal straw processed at a station in the Oltenia region are presented. The data related to the densification of cereal straws were compared with those from the region of Moldova, which was the subject of a previous research.

The use of cereal straw to produce energy is required due to the very large quantities existing in Romanian agronomy.

Another category of solid biomass considered was that of reeds. The combustion tests were carried out on a 55 KW pilot plant. Combustion experiments were carried out under the same conditions for both grain straw briquettes and sawdust briquettes.

The results of the experiments showed similar performances for both categories of biomass.

Gasification tests were carried out for the pellets, the results of which were also very positive.

The experimental results demonstrated the possibility of positive use of the agricultural biomass represented by cereal straw for energy purposes.

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