The importance of the physical and energetic properties of straw briquettes

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Abstract. The paper makes a comparison between two types of straw briquettes (batch 2018 and batch 2019), from the point of view of the physical and energetic properties. Two types of briquettes were analyzed, straw briquettes year 2018 and straw briquettes year 2019 (grown in different condition of precipitations), to observe which have better physical properties and energy efficiency. The main properties that were studied were the density and moisture content of the straw briquettes as physical properties, and also calorific power and ash content as energetic properties. The calorific value of straw biomass with values of 17689 kJ/kg for straw briquettes of production year 2018 and 19767 kJ/kg for straw briquettes of production year 2019 are high because it has a big percentage of lignin compared to biomass for other agricultural residues. Ash content of 5.5% and 5.8% respectively were similar with other vegetable waste. A general conclusions rise from paper, respectively the vegetable biomass is a renewable material and briquettes from it remains the best option of the combustible material.

Keywords: briquette, density, calorific value, ash content

1. Introduction

Biomass is a renewable energetic source, and represents the vegetal component of the nature. As a way of keeping the sun's energy under a chemical form, the biomass is one of the most popular and universal energetic resources on Earth. It assures not only food, but also energy, construction materials, paper, homespun, medicines and chemical substances. Reducing pollutant emissions is one of the main objectives of international environmental policy. According to the New Energy Policy of the European Union, the European Commission aims to increase the share of energy sources from 7% in 2005 to 20% in 2020. Vegetable biomasses are a part of the category of regenerative and alternative energies, that, although is used from the oldest times, it remains for actuality because don't provoke acid rains, don't provoke water contamination, don't produce irradiations (like the radioactive substances), and don't produce climate change [1-3]. The vegetable biomass was used in energetic purposes from the moment when the human discovered fire. Nowadays the fuels resulted from vegetable biomass can be used in different applications, from the home's heating to the production electric energy and fuels for vehicles [4].

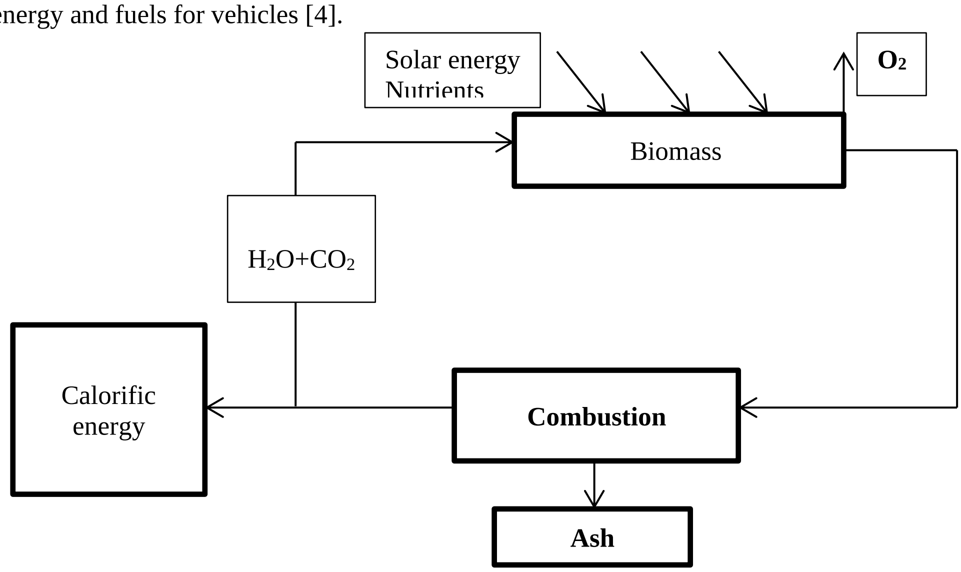

Fig. 1 Chain of biomass growth and combustion in relation with environment

There is a positive balance of the carbon dioxide's emission and consume in the nature, in the case of vegetable biomass, and which is one of the reasons that make wood biomass a part of the regenerative energies [5-7]. Plant biomass grows year after year due to photosynthesis process, taking solar energy and CO_2 from the atmosphere. A small amount of oxygen is eliminated in the atmosphere during the growth of biomass, but a equal quantity of CO_2 with that is consumed in the plants live is released in atmosphere (Fig.1). It is clearly observed that there is a closed circle. Plants usually contain 25% lignin and 75% glucoses (cellulose and hemicelluloses) or sugars. The sugar fraction is constituted from a great number of sugar molecules, united in between by long polymers chains. One of the most important sugars is the cellulose. The lignin component is constituted from sugarless molecules. Nature is made out of long polymeric cellulosic molecules that form tissues, which assure the integrity and stability of plants. The lignin which appears in plants is a glue-like composite, which sticks the cellulosic molecules between them.

Romania, in the given conditions of the actual geographic space, is appreciated as a country with a high energetic potential derived from vegetable biomass, of almost 8000 tep/year which represents approximately 19% from the total consume of primary resources for the year 2000, with the following categories of fuels [8]: wood waste from forest exploitation and firewood, wood remains (sawdust and other wood residues, agricultural residues (cereal straws, corn waste, vegetable waste from grape, rape stems etc, biogas.

Any human activity has a certain impact on the natural environment, whether positive or negative. The most disadvantageous activities, with a strong negative impact on the environment, are the burning of fossil fuels, especially coal and oil [9-11]. During biomass combustion a quantity of CO_2 equivalent to that absorbed during growth is emitted in the natural environment. Also, during combustion, oxygen is absorbed, energy is produced and ash is resulted. This produces a closed circuit of CO_2, the absorbed quantity being equal to the one released [12]. From this point of view, vegetable biomass is a neutral, environmentally friendly combustible. The more biomass is friendly to the environment, the more it comes from sources obtained from wood processing, in the form of remnants and waste [13-16]. The vegetable biomass and the firewood are used for the following purposes: for stove-heated buildings and houses that have central heating, for the technical processes in the industry by using combustion gases. As disadvantages of using vegetable waste as a fuel is that it produces ash (which has to be periodically eliminated) as well as supplying with primary and secondary air needed for combustion. As main advantages of using vegetable biomass as a fuel are the low price, a good caloric power and the fact that the wood is a regenerative material. Fig.2 show a hierarchy of all fuel types where vegetable biomass (in the form of wood pellets and poplar wood) is visible and positioned in front of inferior coals.

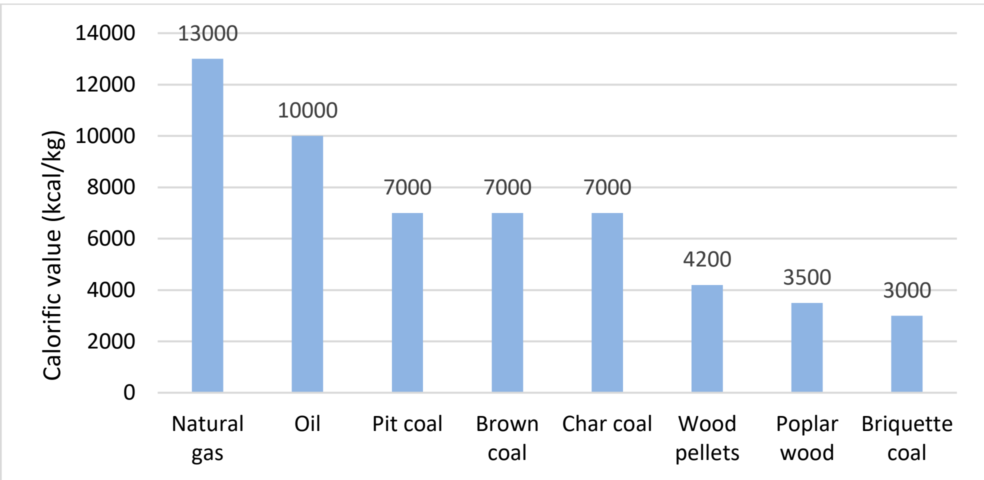

Fig.2 Calorific value of some fuels

There are also several properties of vegetable biomass which make it so good to be used as fuel, properties such as [17]: vegetable biomass is a regenerative material, that has an easy and constant growth in the mountain area as well as in plains; is an easy material, easily to be transported or manipulated, can be used in a natural state, without major treatment for combustion, and can be easily stockpiled due to its solid state.

Through briquettes it can be understood the small-dimensioned compressed material, usually in the form of chips and sawdust [18]. This product has as characteristic an important density increase [19]. Usually, the briquette's density is bigger than the specie's from which the remains and sawdust was obtained, or than the corresponding firewood' density. The briquettes have an exceptional thermal capacity and as a result they retain the heat on a longer period of time and maintain a risen temperature inside the fireplace, permitting an easy burning of the newly introduced briquettes [20]. Consequently, the major advantages of using briquettes as fuelling material are the following ones: improves the physical characteristics (density and uniformity, reduces with 10-12 times the storage volume, have a caloric power greater with 38-60% than the firewood, increases the quantity of energy obtained towards the wood consume, improve and protect the thermal system's performances, few remains are left after burning (the ash content is of 0.5% towards 1-2% in the case of firewood), and the boiler is much cleaner, is easy to manipulate and transport due to their compactness; are cleaner and environmental-safety, having an ecological grade of 100%, and don't contain additives or chemical cements. If briquettes are compared with other burning products, it can be shown that 10 kg of briquettes are the equivalent of 5.5 l of oil, 1 kg of briquettes has the caloric power of 4769 kcal/kg or 19.97 MJ/kg and a tone of briquettes is equivalent to 4 m^3 of firewood [21]. Due to these considerations 1 tone of briquettes can be made a saving of 52-62 Euros, versus the 4 m^3 of equivalent firewood [22].

2. Background

Kaliyan and Morey [23] studied the characteristics of biomass densification from wheat residues. It has been shown that the moisture content from 10% to 15% increases the briquettes durability from 62% to 84%. This article helps all producers to select parameters in order to produce strong and durable densified products. The effect of moisture content on the briquettes durability was also studied by Mani [24]. The authors argue that the optimum moisture content is within 10% - 20%. Carbon, hydrogen and oxygen don't differ from one type of biomass to another. Calorific power is influenced by the ratio between these elements. Agricultural biomass is composed of 90% carbon and oxygen, 6% hydrogen, elements that are absorbed by the plant in the form of CO_2, O_2, H_2O or HCO_3. The biomass chemical compounds are divided into two classes: carbohydrates (2/3 of the volume of sintered substances) and organic substances with nitrogen content. The most important carbohydrates are cellulose molecules, surrounded by hemicelluloses and lignin which is disposed between fibres. Lignocellulosic biomass includes agricultural residues, hardwood waste, softwood, as well as dedicated biomass crops. Wang and Yang [25] studied the durability of straw briquettes. This chapter of book reviews the recent advances in solid state fermentation system that can be directly obtained with low-cost biomaterials as starch and chitin and with minimal pre-treatment and less energy. According to Kim and Dale [26], the estimated residue from some crops (such as corn, wheat, oats, rice, sorghum, and sugarcane) throughout the world is approximately 1.5 billion tonnes. It is stated that the chemical compounds of the biomass would generally be: 3.62% protein, 1.91% fat, 0.11% starch, 17.13% lignin, 33.25% cellulose, 20.36% hemicelluloses, and 2.18% ash. For canola biomass (oilseed rape) is found the next composition: 6.53% protein, 0.69% fat, 0.34% starch, 14.15% lignin, 42.39% cellulose, 16.41% hemicelluloses, and 2.10% ash. For oat there is found other composition: 5.34% protein, 1.65% fat, 0.12% starch, 12.85% lignin, 37.60% cellulose, 23.34% hemicelluloses, 2.19% ash and for straw the composition was less different: 2.33% protein, 1.59% fat, 2.58% starch, 13.88% lignin, 34.20% cellulose, 23.68% hemicelluloses, 2.36% ash.

Martin et al [27] studied the chemical compounds for types of briquettes namely that are obtained from straw and corn stalks. The main composition of straw was: 39.25% cellulose, 23.5% hemicelluloses, 36.1% lignin, 12.4% ash, 6.58 % moisture content, and for corn stalks the composition was rather different: 61.2% cellulose, 19.3% hemicelluloses, 6.9% lignin, 10.8% ash, 6.40 % moisture content, sawdust: 45.1% cellulose, 28.1% hemicelluloses, 24.2% lignin, 1.2% ash, and 1.12 % moisture content. Nigam et al [28] studied the chemical compounds for other two types of briquettes obtained from two types of vegetable biomass as cotton stalks and straw. The chemical composition of cotton stalks was: 58.5% cellulose, 14.4% hemicelluloses, 21.5% lignin, 9.98% ash, and 7.45 % moisture content. Different chemical composition was obtained for straw: 32.9% cellulose, 24% hemicelluloses, 8.9% lignin, 6.7% ash, and 7 % moisture content. Okonko et al [29] have studied the chemical compounds for two types of briquettes realized from straw and cotton stalks. Consequently the chemical compounds of straw waste was: 39.4% cellulose, 27.1% hemicelluloses, 17.5% lignin, 8% ash, and 8 % moisture content. In the same way the chemical compounds for cotton stalks was: 58.5% cellulose, 14.1% hemicelluloses, 21.5% lignin, 9.98% ash, and 7.45 % moisture content. Felfli et al [1] made a study of the status of biomass briquetting and its perspectives in Brazil. It was conducted to the availability and characteristics of the agro-residues for briquetting as rice husk and coffee husk. Dhillon and von Wuelhlisch [4] made a review on causes and consequences of global climate change and its impact on nature and society. In this way the renewable biomass will have a great potential to mitigate the global warming.

Objective

The paper aims to make a comparative analysis of two types of straw briquettes batch 2018 and 2019, in order to observe the influence of soil, air humidity and vegetation conditions on the properties of briquettes obtained from these types of wheat straw. To solve this general objective some briquette proprieties such as density, calorific value and ash content of the straw briquettes were intended to be investigated.

3. Materials and methods

Two types of briquettes were realized and analysed straw briquettes of year 2018 and straw briquettes of year 2019, to observe which have better density and energy efficiency. A study about climatic condition where the straws were collected shows that the months March-June of year 2018 was much moist than year 2019 with an average of 51.3 l/m^2 precipitations, comparison with an average of about 40 l/m^2 in year 2019. The amount of fertilizers was the same in the both years and the same type of wheat was used. Firstly, twenty pieces of each briquette category have been used to determine the density. The classical method of determining the mass and volume of these pieces of briquettes was used, namely the European norm EN 15103 [30]. The briquettes were weighted using an electronic balance TP KERN EW 1500-24 with a precision of 0.1 grams. The density determination relationship took into consideration mass of briquettes and their volume as cylindrical one (Eq. 1):

$$\rho = \frac{4 \cdot m}{\pi \cdot d^2 \cdot l} \cdot 10^6 \quad [kg/m^3] \tag{1}$$

where: m is mass of briquette, in g; d- diameter of briquette, in mm; l- length of briquette, in mm.

Ten determination of gross calorific value and net calorific value have been done accordingly to German norm DIN 51900-1 [31].The net calorific value is the difference between gross calorific value and the amount of heat released for evaporate water from the combustion gases [32]. The equipment used to determine the calorific value is the calorimetric apparatus with explosive bomb presented in Fig. 3.

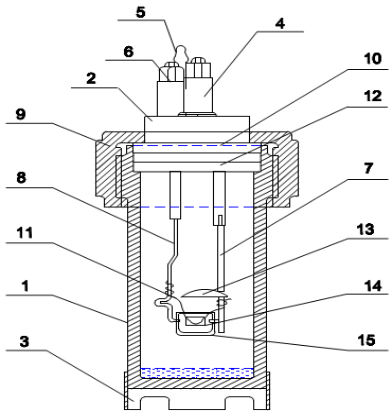

Fig. 3 Bomb of calorimetric apparatus XRY-1C for determining the calorific value:

The dried state of the briquette is verified by successive weightings, until the difference between two successive weightings is smaller than double of the value of the weighing precision, or covering at least 2 hours of maintaining the sample in the oven. After drying, the samples are kept in the desiccators for cooling without changing the humidity content until they are inserted in the calorimetric bomb. Preparation of the installation in view of performing the trial refers to checking the quantity of water in the tank calorimeter (so that it exceeds by 1-2 mm the lid of the calorimetric bomb), the stirrer of the water in the tank, the computer software, the electrical thermometer. The test sample1istied to the cotton thread and is inserted in to the crucible of the bomb. The spiral thread is tied to the sample and the cotton thread, after which the protection lid is positioned correctly. The body bomb is connected to the lid of the bomb by two electrodes and, which continue with the electric wires connecting to the electric source of calorimeter. By screwing the lid to the bomb, the bomb is coupled by means of the nozzle to the oxygen tank, thereby inserting 30 atmospheres. The bomb is inserted in the calorimeter of the installation. After that the two electric wires are connected, the superior lid of the calorimeter is closed and the thermo-resistance is inserted for continuously displayed the temperature.

For determining the caloric value, three phases are performed: the initial phase, the main phase, and the final phase. The initial phase represents the determination of water temperature variation inside the calorimeter, due to the heat exchange with the exterior before combustion. At the end of the initial phase it begins the burning of the samples extracted of the briquettes. The good way of process test is displaying on the screen of computer up to the end of test (Fig. 4).

Calorific value of briquette samples is determined with a relationship that keep into account all temperatures, mass of sample and coefficient of installation (Eq. 2).

$$CV = \frac{k \cdot (t_f - t_i) - q_i}{m} 10^{-3} \quad [MJ / kg] \tag{2}$$

where: CV is calorific value, in MJ/kg; k- calorific coefficient of calorimeter, in MJ/Celsius; t_f –final temperature, in Celsius degrees; t_i-initial temperature, in Celsius degrees; m-mass of sample, in kg; q_i –supplementary heat obtained by cotton and nickel wire burn, in MJ.

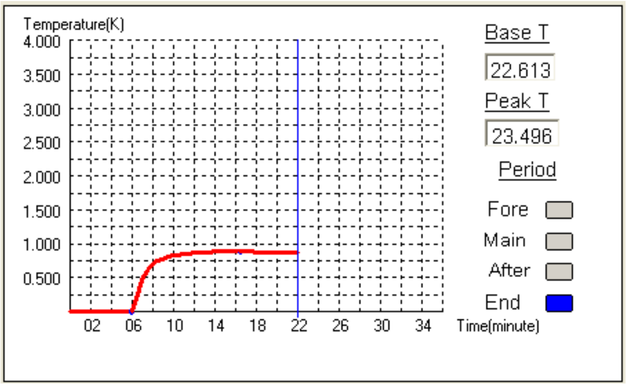

Fig. 4 Image of the computer soft for explosive combustion in order to determine the calorific value

For determining the ash content of briquettes the general method of standard determination was used accordingly to European Norm EN 14775 [33]. With respect to this method, the small and dry material up to 0% moisture content is calcinated at 750 ºC in a laboratory oven, for three hours (Fig.5). The advanced combustion operation is carried out in a high temperature resistant metal crucible and weight was carried out on an analytical balance with an accuracy of three decimal. When determining the ash content, it shall be taken into account that the sample is completely dried and the mass of the clean and empty crucible was obtained (Eq.3):

$$A_c = \frac{m_{a+c} - m_c}{m_{s+c} - m_c} \cdot 100 \quad [\%] \tag{3}$$

where: m_{a+c}-mass of calcinated ash, considering also the crucible mass, in g; m_{s+c}- mass of sample considering also the crucible mass, in g; m_c- mass of empty crucible, in g.

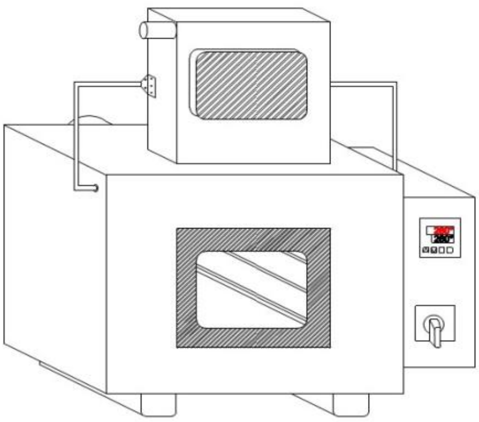

Fig. 5 Calcination furnace for determination ash content

4. Results and discussion

The moisture content the two types of briquettes was about 10% and was in concordance with EN 14774-1 [34]. The density values for the two types of briquettes are 1094 kg/m^3 for straw briquettes for production year 2018 and 1184 kg/m^3 for straw briquettes of production year 2019. In the fig. 6 shows the value of the density for the two types of briquettes. We correlate with the amount of precipitation in 2018 and 2019, it is clear that the straw from the rainier year had a lower density. This is normal because with a larger amount of water the straw grows larger but with a lower lignocellulosic density and the straw with a higher structural density will provide a higher density of briquettes.

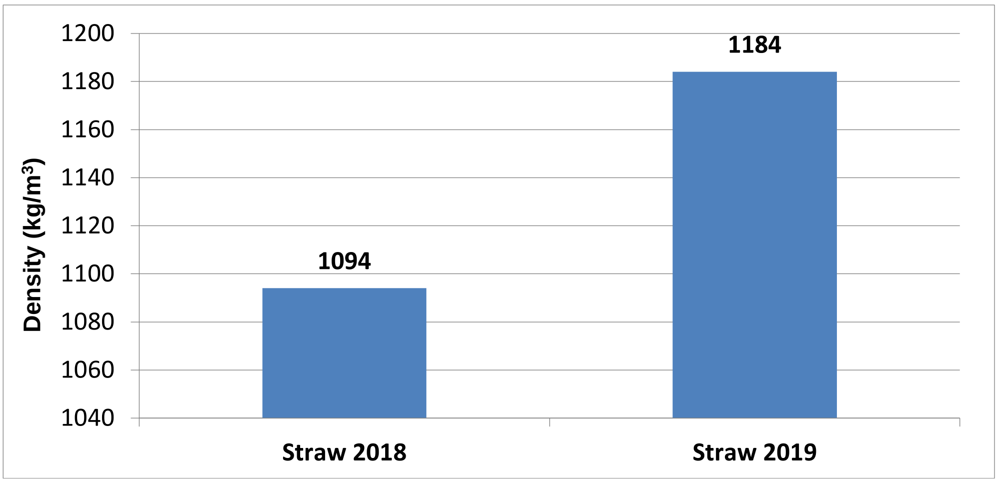

Fig. 6 The value of density for two types of briquettes

The gross calorific value for the two types of briquettes are 17689 kJ/kg for straw briquettes production year 2018 and 19767 kJ/kg for straw briquettes production year 2019. The net calorific value for the two types of briquettes are 16830 kJ/kg for straw briquettes production year 2018 and 16979 kJ/kg for straw briquettes production year 2019. Calorific power for straw briquettes production year 2019 is higher than straw briquettes year 2018. As in the case of densities, if we correlate calorific value with the amount of precipitation in 2018 and 2019, it is clear that the straw from the rainier year had a lower calorific value. This is due to the structural density of the straw, but mainly due to the fact that the lignin content in dry years is higher. These values of calorific value obtained inside of research were also found by Okonko et al [29] who obtained a value of 17200 kJ/kg wheat straws. Fig.7 shows the value of calorific power for the two types of briquettes.

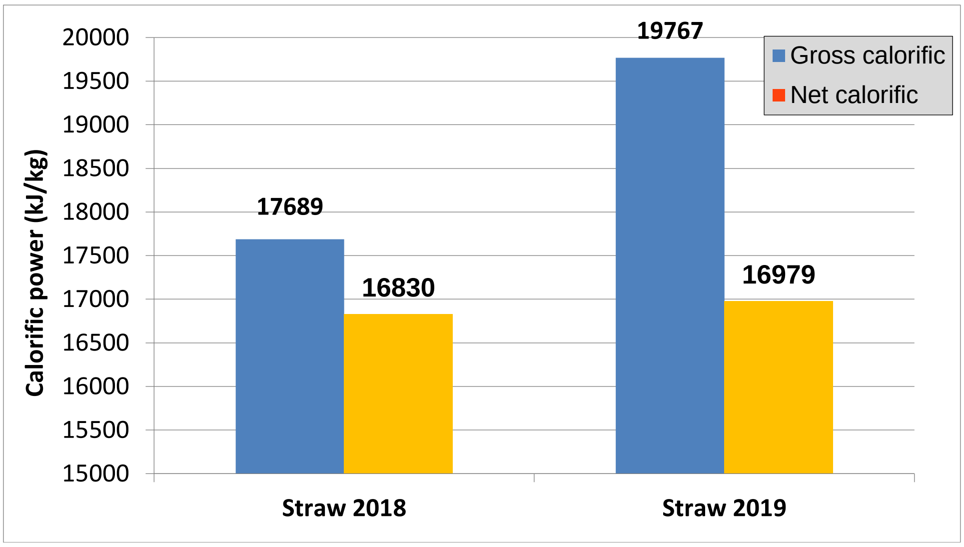

Fig. 7 The calorific value for the two types of briquettes

The ash content value for the two types of briquettes are 5.5% for straw briquettes of production year 2018 and 5.8% for straw briquettes of production year 2019. Fig. 8 shows the value of the ash content for the two types of briquettes.

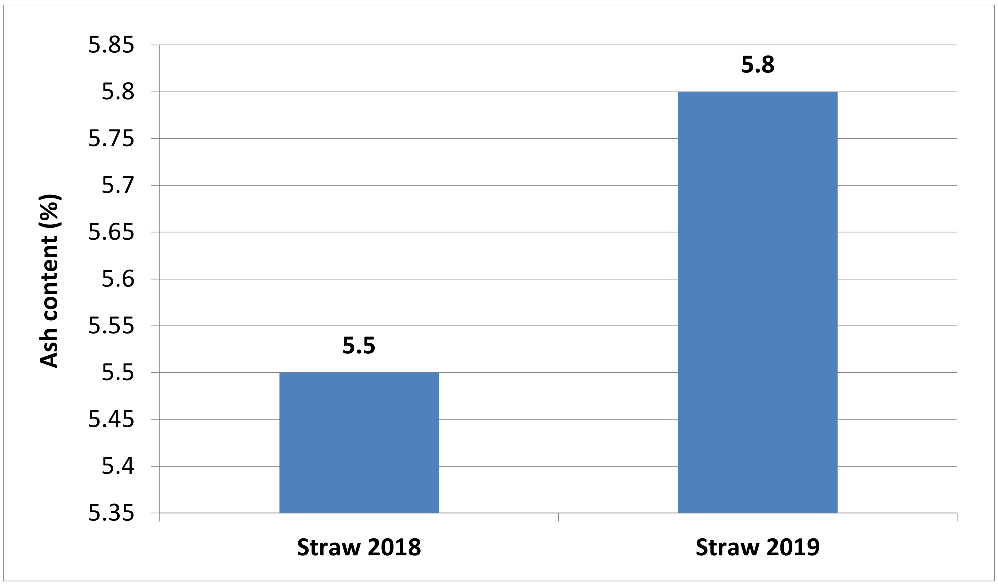

Fig. 8 The value of the ash content for the two types of briquettes

If we correlate ash content of briquettes with the amount of precipitation in 2018 and 2019, it is observed that the straw from the rainier year had low ash content. This was determined by the structural density of the straw, but mainly due to the fact that in the dry years the amount of secondary substances in the straw increases substantially. Even if the values obtained are much higher than those specified by the standards in the field (EN plus) which specify values lower than 3%, they are within the normal limits found by other authors [26] for straw and even lower than other biomass categories such as bark trees [11]. On the other hand, this small flaw of straw to have higher ash content than firewood can become an advantage if we consider that ash can becomes a very good fertilizer used on the same land where wheat is cultivated.

5. Conclusions

Following this study, it was observed as a first conclusion that the straw can be used in the briquetting process as well as any other biomass category. This is highlighted by the fact that the briquettes obtained have a good density and calorific value, similar to other materials.

Regarding the use of straw from dried year (2019) related to moist year (2018), it can be stated that although they are weaker in quantity, in terms of density, calorific value and ash content are better. Therefore an increase with 8.2 for density, 11.7% for gross calorific power, and 5.4% for ash content was highlighted for briquettes obtained in 2019. It makes possible the classification of this vegetal fuel in the category of high-performance solid fuels.

All briquette features were within European Norm EN plus or other regional norm, exception from this rule being ash content. Beyond this fact, the ash content is in the area of other categories of plant biomass and even wooden biomass such as bark. Transforming wheat biomass in briquettes by grinding and pressing can be a good solution and possibly mixed of it with wood sawdust would be a good solution to improve the weakness.

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