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A STUDY ON PELLETS AS AN ALTERNATIVE SOURCE OF ENERGY FOR FOSSIL FUEL USING ADIABATIC COMBUSTION CALORIMETRY

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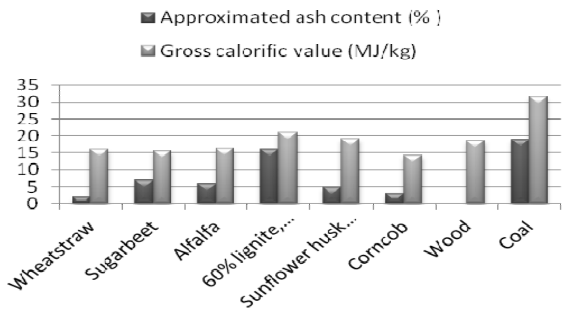
This paper describes the importance of thermochemical parameters that are needed to discuss whether biomass pellets are a feasible alternative to fossil fuel. Using an oxygen bomb calorimeter heating values as well as ash content were obtained for seven types of pellets and for a fossil fuel. The research was conducted on pellets bought from a local factory in Prahova county, Romania. The chemical composition of the selected species differs and so does their heating values. Taking in consideration both advantages and disadvantages of the biomass fuel it can be concluded that pellets could represent an alternative to coal, especially for domestic uses.



INTRODUCTION

At the current rate of use the crude oil reserves of the world are predicted to deplete in about 40 years. Therefore, it has become necessary to find efficient methods of processing a renewable raw material for conversion into an alternative fuel.[1]

Vegetative biomass consists of living plants species all around us. As they grow, plants store the sun's energy in their leaves, stems, bark, fruits, seeds and roots. Bioenergy crops are so diverse that they grow in virtually every part of the world. Energy crop species are understood to mean those annual and perennial species that can be cultivated to produce solid, liquid or gaseous energy feedstocks.[2]

Generally biomass is the matter that can be derived directly or indirectly from plant which is utilized as energy or materials in a substantial amount. "Indirectly" refers to the products available via animal husbandry and food industry. The resource base includes hundreds of thousands of plant species, terrestrial and aquatic, various agricultural, forestry and industrial residues and process waste, sewage and animal waste.[3]

Since the earliest times, humankind has used biomass for heating and cooking purposes. In present day, this type of fuel is used for the same purpose in developing countries.

Modern technologies made it possible to switch over from traditional use of biomass to modern biomass utilization which emphasize on sustainability of biomass and less carbon emission such as biomass conversion to liquid biofuels or combined heat and power generation.[4]

Ash content and composition, heating value, elemental ratios and proportion of lignin, cellulose, and hemicellulose are some of the broad compositional characteristics used to screen biomass feedstocks for biofuels applications.[5]

The general composition of lignocelluloses in agro-forestry biomass is accounted as 40-50% cellulose, 20-30% hemicellulose and 10-25% lignin. Cellulose is a major structural component of plant cell walls, which is responsible for mechanical

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strength while, hemicellulose macromolecules are often repeated polymers of pentoses and hexoses. Lignin contains three aromatic alcohols (coniferyl alcohol, sinapyl alcohol and p-coumaryl alcohol) produced through a biosynthetic process and forms a protective seal around the other two components *i.e.*, cellulose and hemicelluloses.[6]

Lignin plays a crucial part conducting water in plant stems. It also plays an important role in the carbon cycle, capturing atmospheric carbon into living tissues of woody perennial vegetation.[7]

Lignocellulose is a complex carbohydrate polymer of cellulose, hemicellulose and lignin. Cellulose is linear and crystalline. It is a homopolymer of repeating sugar units of glucose linked by β-1,4 glycosidic bonds. Hemicellulose is a short and highly branched polymer. It is a heteropolymer of D-xylose, D-arabinose, D-glucose, D-galactose and D-mannose. Lignin is hydrophobic in nature and is tightly bound to these two carbohydrate polymers.[8]

Wheat straw has the greatest potential of all agricultural residues because of its wide availability and low cost, with a world production of wheat estimated to be around 680 million tons in 2011. Wheat straw contains 35-45% cellulose, 20-30% hemicelluloses and around 15% lignin, which makes it an attractive feedstock to be converted to ethanol and other value-added products.[9]

Alfalfa (*Medicago sativa*) is a highly heterozygous, perennial forage legume. Legumes are important components of sustainable agricultural systems due to their capacity for symbiotic nitrogen fixation. Perennial alfalfa can contribute to mitigate the negative impacts due to soil erosion, fertilizer run-off, and insecticide/pesticide leaching into rivers, wetlands or canals.[10]

An advantage of using alfalfa for lignocellulose biofuel production, compared to other crops, is the ability to easily separate leaves and stems to produce co-products. The high protein leaf portion could be utilized as an animal feed, while the high lignocellulose stem portion could be used as a biofuel feedstock.[11]

Corn cobs are desirable as a sustainable feedstock because they represent about 12 percent of corn stover remaining on the field, their removal has negligible impact on soil carbon and they have limited nutrient value to the soil. Similar to stover, the moisture content of corn cob is assumed to be 20 percent.[12]

As a renewable raw material, the corncobs from grain maize are a potential feedstock for the production of biogas, biodiesel and bioethanol to fulfil the increasing demand for biofuels. Corncobs are a lignocellulosic material composed of cellulose, hemicellulose and lignin. These polymeric fibres are embedded in a complex matrix which is very resistant to enzymatic degradation.[13]

Sugar beets (*Beta vulgaris* L.) may be an eligible feedstock for advanced biofuel provided that production and conversion to biofuel meets 50% greenhouse gas reduction threshold required for advanced biofuel designation. Sugar beets are tuber crops composed of about 75% water, 18% sugar(sucrose), and 7 % insoluble and soluble materials. Industrial beets are not required to be low in nitrogen, sodium and potassium, enabling easier crop management. These non food beets would not be efficient feedstock for the production of table sugar for human consumption, but are under development for industrial use including bioenergy production.[14]

The sunflower (*Helianthus annuus*) is a large herbaceous crop, widely cultivated worldwide due to its relatively short growth cycle, high resistance to drought and adaption to different soil conditions. Sunflower husk represents a weight percentage of 45-60% of the seed depending on the sunflower variety, and is separated from kernel in the grinding process, to obtain a better pressing of the seed and higher oil yield. The high energy content of this biomass-by-product makes it optimal for use as heating fuel.[15]

During an industrial production of plant oil from sunflower seeds a considerable amount of husk remains, which may constitute 20% of the weight of processed seeds and may serve as energy raw material.[16]

The soybean (*Glycine max*), a native of China, is one of the oldest crops of the Far East.[17] A close-up look on soy shows that the bran (hulls) of all seeds and legumes contain substances called lignin. The highest level of lignin is found in soybeans.[7]

For the lignin of soybean hulls, it is not usually utilized as a major value product, due to its lower content. However, the soybean hull is a good resource for lipid production due to its low lignin content and it has been proven in the bioconversion process that soybean hulls can be utilized without any pretreatment.[18]

The genus Populus comprises 25 to 35 species of deciduous plants native to the Northern Hemisphere. Common names used for the different species include poplar, aspen and cottonwood. Reported heating values for hybrid poplar species are around 19 MJ/kg. These values are comparable to other woody (*e.g.*, oak, pine), herbaceous (switch grass, Sudan grass) biomass feedstocks and agricultural residues (corn stover, wheat straw, sugarcane bagasse). Popular species and hybrids have cellulose contents raging from aprox. 42-49%, hemicellulose from 16-23%, and total lignin contents from 21-29%.[5]

RESULTS AND DISCUSSION

Combustion calorimetry played a key role in obtaining the data necessary to evaluate the feasibility of using biomass pellets as a source of fuel. The experimental data obtained for the pellets and coal was: gross calorific value and the approximated ash quantity resulting from combustion in adiabatic oxygen bomb calorimeter. Gross heating value is an important data for fuels like biomass or coal, which will usually contain some amount of water prior to burning.

The study was conducted on pellets obtained from wheatstraws, sugarbeet, alfalfa, corncobs, wood, a mix containing 60% lignite, 20% petroleum coke, 20% wheat straws, and another mix containing soy and sunflower bark. The experimental results obtained for pellets and coal is presented in Table 1.

Experimental data reveal that the gross calorific value increases in the following order: corncobs, sugarbeet, wheatstraw, alfalfa, soy and sunflower mix, wood, 60% lignite, 20% petroleum coke, 20% wheatstraw and coal. The average value of the gross calorific value is affected by significant deviations due to the inhomogeneity of the samples.

Biomass has 3 main components: lignin, cellulose and hemicelluloses, each one of them playing a key role in the characterization of pellets. Taking into account the higher content of carbon present in lignin, the thermal energy will be higher than that of cellulose and hemicellulose. For example, pellets produced from wood biomass have a higher gross calorific value because of a higher percentage of lignin. The lowest heating value was obtained for pellets made of corncobs. This can be explained by the chemical composition of corncobs: 39.1% cellulose, 42.1% hemicellulose and 9.1% lignin.[19] From an environmental perspective, corncobs pellets have an advantage because of their low ash content: ~ 3%.[20]

The average gross calorific value and approximated ash content for the selected species are presented in Figure 1.

Table 1

Gross calorific values and ash content for the selected species

Type of fuel	**q ($cal \cdot g^{-1}$)**
Corncobs	3386.71 ± 78.87
Sugarbeet	3692.64 ± 35.185
Wheatstraw	3850.38 ± 119.50
Alfalfa	3893.40 ± 45.41
Sunflower husk and soy mix	4545.89 ± 40.63
Wood	4440.73 ± 14.34
60% Lignite,20% petroleum coke and 20% wheatstraw	5038.24 ± 38.24
Antracite	7571.70 ± 162.52

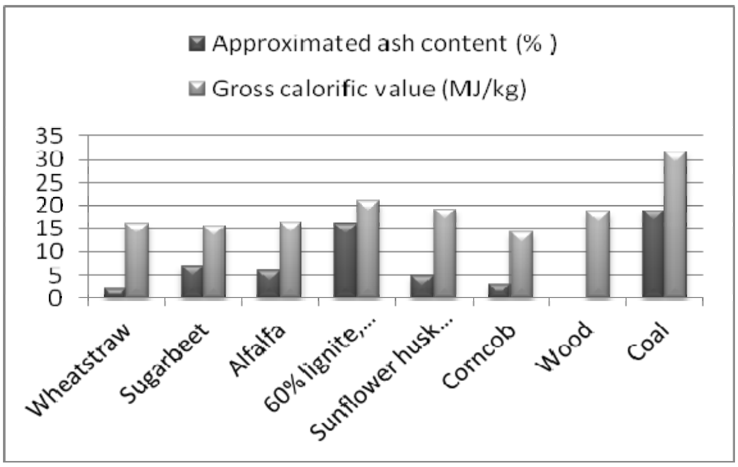

Fig. 1 – Average gross calorific value and approximated ash content for the selected species.

During the combustion of biomass, ash is one of the main generated secondary products. High ash content is a negative feature because it makes the automation of biomass combustion process more difficult. Combustion of fuel with high ash content involves additional expenses related to ash disposal and maintenance of combustion equipment.[21]

The ash content of plant biomass may reach values up to 10% because it is influenced by the biomass type, soil type, fertilization and the maturity of the plants.[22]

Among all of the studied species, wood pellets have the best advantage because a very small amount of ash resulted after the combustion. Other pellets such as: wheat straw, corncobs had the lowest values for resulted ash. As expected, the highest values of ash were determined for fossil fuel and wheat straw mix.

EXPERIMENTAL

Materials

The researched material consisted of seven types of pellets and one fossil fuel (antracite) was used as received. The pellets are obtained from chopped and pressed vegetable debris, have small dimensions and a cylindrical shape. Following the pelletization process, non-homogeneous pellets are obtained. Because of the lack of homogeneity, multiple determinations were necessary in each case.

The considered biomass samples weighed between 0.80 grams and one gram with the Partner XA balance with a precision of 10 µg.

Method and equipment

The combustion took place in a Parr oxygen bomb calorimeter equipped with a digital thermometer model 6775, an oxygen bomb with an inner volume of 300 mL and a stirrer. Inside the bomb there is a crucible provided with two electrodes. The sample will be tied to the Ni-Cr wire connecting the two electrodes using a cotton thread. The oxygen pressure during the experiment was 25-30 atmospheres.

The first step in the experiment was to calibrate the calorimeter using benzoic acid pill for which the calorific value is known (q = 6318 cal/g). The gross calorific value of the solid fuel was calculated using equation:

$$q = \frac{C_{system}\Delta T^{*} - Q_{cotton} - Q_{Cr-Ni}}{m}$$

where Q_{cotton} and Q_{Cr-Ni} are the heat released during the combustion of the cotton thread and the Cr-Ni wire respectively.

Approximate ash quantity was calculated by weighing the crucible before and after the combustion using the following formula:[23]

$$Ac = \frac{m_3 - m_1}{m_2 - m_1} \times 100$$

where: m_1 = mass of the empty crucible, g;
m_2 = mass of crucible with a sample, g;
m_3 =mass of both crucible and the ash resulted after combustion, g;

CONCLUSIONS

Biomass, whether it is from the forestry sector, agricultural or the urban sectors has a great potential in the production and utilization of clean, renewable energy. Therefore, it is important to correctly asses the feasibility of pellets as a form of biofuel.

The chemical composition of biomass is an important factor in the evaluation of solid biofuels. As it can be observed in this paper, this assembly of various parameters can be determined using a convenient and inexpensive method such as calorimetry.

Summarizing the results obtained during the experiment it can be concluded that pellets have a lower gross calorific value than coal but they are at an advantage when it comes to ash content. Out of all selected species the following had the best results: wood with an average calorific value of 18.58 MJ/kg, sunflower and soy mix pellets 19.02 MJ/kg and the mix between fossil fuel and wheat straw pellets 21.08 MJ/kg. The best alternative for fossil fuel should have a similar higher heating value but it must be less detrimental to the environment.

Based upon the respective results, it can be concluded that there is a clear correlation between lignin, cellulose and hemicellulose content and the gross calorific values.

However further experimental analysis of more than six types of pellets is necessary to find the best alternative for fossil fuel.

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