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PLANT BIOMASS AS NATURAL SOURCE OF HIGH-QUALITY SOLID BIOFUEL

Research article

Abstract

The purpose of this study was to obtain high-quality pellets from natural biomass sources with improved fuel properties and durability. Two biomass types, namely residues of mixed coniferous wood and olive pomace, were selected as feedstock for this purpose. It was found that olive pomace is a promising natural source for the production of fuel pellets. The chosen biomasses were used for pelletization along with auxiliary materials, such as starch, polyvinyl acetate (PVA) and pine wood resin (PWR). The milled biomass samples and their mixtures with binders were compacted under increased pressure and temperature, and then cooled. Besides, part of the pellets was coated with layer of hydrophobic agent, such as melt of PWR. The pellets were studied by methods of calorimetry, water vapor sorption and durability testing. The results have shown that fuel characteristics of the pellets containing starch binder were lesser than those of coals; moreover both fuel properties and durability of these pellets were reduced after sorption of water vapor. The use of hydrophobic binder (PVA) improves durability of the pellets, whereas the additional coating with PWR layer allows obtaining the especial high-quality pellets with high fuel properties and high durability both in dry and wet state. As a result, the energetic features of these especial solid biofuels become comparable with those of fossil coals.

Keywords: fuel pellets, heat of combustion, density of thermal energy, durability.

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РАСТИТЕЛЬНАЯ БИОМАССА – ПРИРОДНЫЙ ИСТОЧНИК ВЫСОКОКАЧЕСТВЕННОГО ТВЕРДОГО БИОТОПЛИВА

Научная статья

Аннотация

Целью данного исследования было получение высококачественных топливных пеллет из природных источников биомассы с улучшенными топливными свойствами и долговечностью. Для этой цели в качестве сырья были выбраны два типа биомассы, а именно, отходы смешанной хвойной древесины и оливковый жмых. Было установлено, что оливковый жмых является перспективным природным источником для производства топливных пеллет. Выбранные биомассы использовались для гранулирования вместе со вспомогательными материалами, такими как крахмал, поливинилацетат (PVA) и сосновая смола (PWR). Размолотые образцы биомассы и их смеси со связующими уплотняли при повышенных давлении и температуре и затем охлаждали. Кроме того, часть гранул покрывали слоем гидрофобного агента - расплавом PWR. Пеллеты изучали методами калориметрии, сорбции водяного пара и испытания на долговечность. Результаты показали, что топливные характеристики пеллет, содержащих крахмальное связующее, были ниже, чем углей. Кроме того, как топливные характеристики, так и долговечность этих пеллет ухудшались после сорбции водяного пара. Использование гидрофобного связующего (PVA) повышала долговечность пеллет, а их дополнительное покрытие слоем PWR позволило получить особые высококачественные пеллеты с высокими топливными свойствами и высокой прочностью как в сухом, так и во влажном состоянии. В результате, энергетические характеристики этих особых твердых видов биотоплива становятся сопоставимыми с характеристиками ископаемых углей.

Ключевые слова: топливные пеллеты, теплота сгорания, плотность тепловой энергии, долговечность.

1. Introduction

Currently, the main solid fuels are fossil coals, which provides 28-30% of annual energy consumption in the world, about 160-180 EJ [1]. To generate such energy, more than 6 billion tons of coals are burned each year. However, this fossil source of energy is not reproduced in nature, and therefore its reserves are permanently depleted. Besides, the burning of coals is accompanied by emission of greenhouse gas - carbon dioxide, in the huge volume of 1700-1800 m^3 from each ton, which can exacerbate the problem of global warming [2].

An alternative to coals can be solid fuels based on plant biomass, which in contrast to fossil fuels, are reproduced in nature. The term "biomass" means here a variety of plant materials, as well as their residues and wastes [3]. As is known, monosaccharides are photosynthesized in chlorophyll pigment of plant leaves from carbon dioxide and water, absorbing red and blue-violet sunlight [4, 5]. Then, the biosynthesis reactions occur in the plant cell walls, as a result of which the monomeric sugars are transformed into polysaccharides (cellulose, hemicellulose, starch, pectin, etc.), lignin, waxes, resins, vegetable oil and other components of biomass. In fact, plant biomass can be considered an accumulator of solar energy. To generate the heat energy, the biomass is burned, resulting in the release of accumulated solar energy. A specific feature of the biomass that it is neutral for emission of carbon dioxide, since its combustion produces the same amount of this greenhouse gas as it was absorbed from the atmosphere during photosynthesis. Total biomass resources, which can be used for direct burning or producing of liquid and gaseous biofuels, are estimated at 8-10 billion tons [6].

However, the plant biomass is a heterogeneous material of low bulk density, which consists of pieces of different shapes, sizes and compositions. The bulk density of the biomass varies from 40-80 kg/m^3 (grasses), to 150-200 kg/m^3 (wood chips), whereas the energy density is relative low, from 0.5 to 5 GJ/m^3. Besides, the natural biomass is usually wet containing from 10 to 55% of moisture. Some biomass types, such as rice straw or husk, packaging and printing papers, can contain from 15 to 30% of inorganic components. These negative features of the plant biomass leads to deterioration in fuel properties during direct burning – low and unstable calorific value, low density of thermal energy and insufficient combustion efficiency [7].

On the other hand, such energetic components as lignin and organic extractives (waxes, resins, lipids, etc.) boost the calorific value of biomass [2, 8]. Thus, in order to improve the energy potential of solid biofuels, firstly it is necessary to choose the biomass with enough high content of energetic components, as well as with small content of inorganic admixtures and moisture. Secondly, to increase the small energetic density, the loose biomass may be converted into dense pellets. Pelletization of the plant biomass is a well-known process, which includes a number of steps: selection, removal of foreign pieces and materials, drying to a moisture content of 10%, shredding, grinding to particle size of 1 to 3 mm, hot pressing into pellets [9]. Addition of binders (e.g. starch) to biomass before compacting improves the durability of pellets. Currently, the fuel pellets are produced from residues (sawdust, chips) of coniferous wood specifies, mainly from pine and spruce having an increased content of lignin [10]. However, the yield of these residues is small (<10%), which hinders the further production expansion of such pellets. This is one of the reasons, why the global annual production of fuel pellets is low, 28-30 million tons [11]. To expand the base of raw materials for the production of fuel pellets, the search of alternative biomass source is needed.

Thus, the main purpose of this study was to find an alternative non-wood biomass cource in order to obtain especial high-quality pellets with improved fuel properties and durability.

2. Methods

2.1. Biomass samples

Two types of biomass were used: (1) common feedstock such as chips of mixed coniferous (pine and spruce) wood and (2) alternative feedstock such as olive pomace. The biomass samples were cut, knife-milled and screened through a sieve to obtain the fraction of 1 mm and then conditioned to moisture content of 10%.

2.2. Auxiliary materials

Some other materials were used for pelletization, such as potato starch, latex of polyvinyl acetate (PVA) and solid resin isolated from pine wood (PWR).

2.3. Pelletization

The milled biomass samples and their mixtures with binders (starch or PVA) were compacted under pressure 150 MPa at temperature of 100°C. Besides, part of the pellets was coated with a melt of PWR at 100°C and then cooled.

2.4. Study of chemical composition

The chemical composition of the biomass samples was determined by conventional methods of chemical analysis [2].

2.5. Combustion calorimetry

Combustion of dehydrated samples (cca. 1 g) was carried out in a bomb calorimeter Parr-1341 at oxygen pressure of 3 MPa with 1 ml of added deionized water. The temperature and its rise (ΔT) were measured with accuracy ±0.001 K. The value of energy equivalent of the calorimetric system (C) was determined by combustion of standard benzoic acid. To calculate the specific energy of combustion (Q), the needed correction for ignition (e_1), as well as for formation and dissolution of nitric and sulfuric acids (e_2) were taken into account:

$$Q = (C\Delta T - e_1 - e_2)/m, \quad (1)$$

where m is true mass of sample.

To obtain the standard value of specific energy of combustion (Q^o) the Washburn's correction was introduced. Furthermore, the density of thermal energy (ED) was calculated as follow:

$$ED = Q^o \times d, \quad (2)$$

where d is bulk density of the pellets (kg/m^3)

For each sample three experiments were performed to obtain the reliable result.

2.6. Sorption of water vapor

The pellets were kept at 25°C in a desiccator having relative humidity (RH) of 85% to constant weight. The percentage of sorbed water (S) was calculated as follows:

$$S = 100\% \, [(W/W_o) - 1], \quad (3)$$

where W and W_o is weight of wet and dry sample, respectively.

For each sample three experiments were performed to obtain the reliable result.

2.7. Durability testing

Durability of the biomass pellets was measured in accordance with ISO 17831-1 [12]. For each sample three experiments were performed to obtain the reliable value of durability.

3. Results

Study of chemical composition of selected biomass types showed that olive pomace (OP) contains more energetic components (lignin, organic extractives) than sample of mixed coniferous wood (CW), which is a conventional feedstock for the production of fuel pellets (Table 1). As a result, the dry pellets made from OP with additive of starch binder have better fuel properties (Table 2).

Table 1 - Percentage of main components of biomass samples*

Biomass	Cellulose	Hemi	Lignin	OE	Ash	Others
CW	48	20	27	3	1	1
OP	24	26	32	11	4	3

*Note: Hemi denotes hemicelluloses; OE denotes organic extractives

Table 2 - Fuel characteristics of biomass pellets containing 10% starch binder*

Biomass	Binder	Q^o, MJ/kg	ED, GJ/m^3
CW	Starch	20.14 (19.22)	12.10 (10.57)
OP	Starch	22.73 (20.32)	13.64 (11.18)

*Note: the fuel characteristics in wet conditions at RH=85% are shown in brackets

However, fuel characteristics of the pellets containing starch binder were lesser than those of coals with Q^o = 25-30 (MJ/kg), ED = 17-20 (GJ/m^3) [13]. Significant shortcoming of these fuel pellets is their hydrophility. Therefore, after storage of the pellets in the humid atmosphere (RH=85%), there is an appreciable decrease in fuel characteristics (Table 2) and durability (Figure 1) is observed.

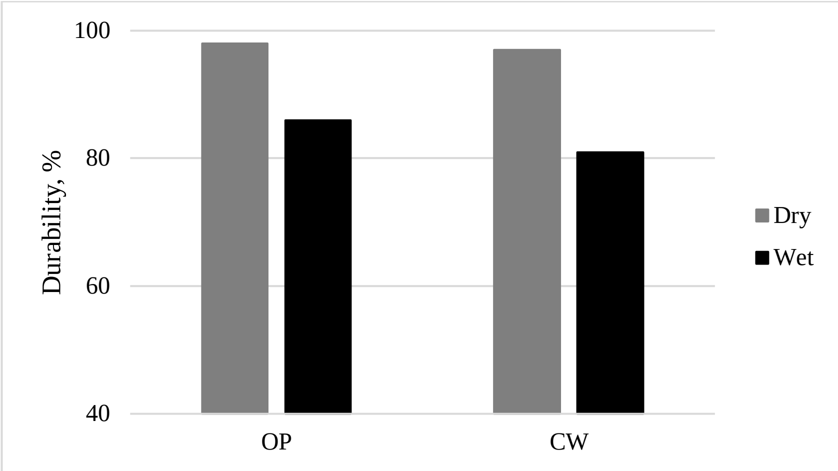

Figure 1 - Durability of dry and wet pellets containing starch binder

The further studies have shown that the use of hydrophobic binder, PVA, instead of hydrophilic starch in amount of 10% improves durability of the pellets both in dry and wet state (Figure 2).

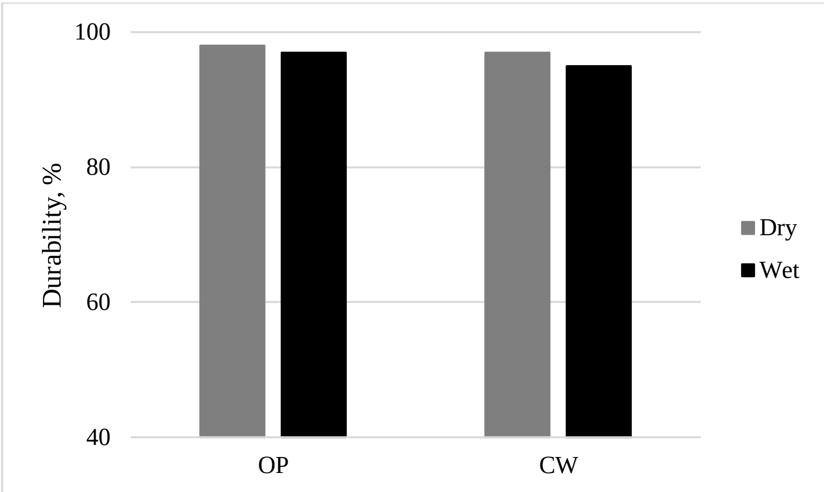

Figure 2 - Durability of dry and wet improved pellets containing 10% PVA binder, as well as of especial pellets

However, introduction of PVA binder does not prevent the sorption of water vapor by biomass (Figure 3) and does not improve fuel properties of the wet pellets.

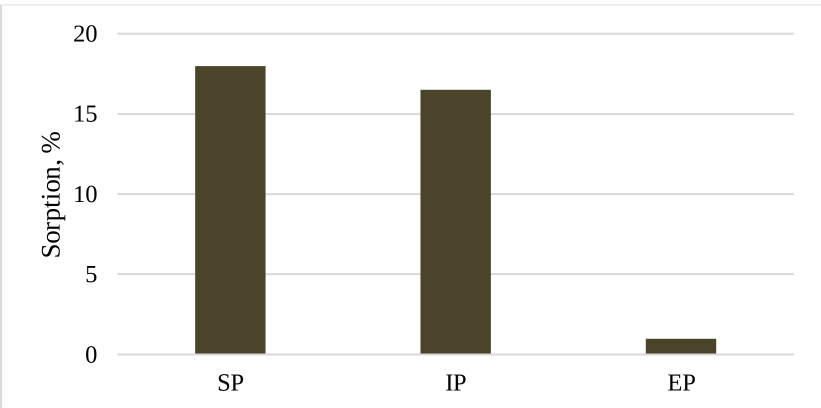

Figure 3 - Sorption of water vapor at RH=85% by pellets containing strch binder (SP), improved pellets (IP) and especial pellets (EP)

When the pellets containing PVA binder were additionally coated with a hydrophobic coating agent (HCA) such as melt of PWR, this leads to obtaining of especial high-quality pellets having low hydrophility (Figure 3), high durability in dry and wet conditions (Figure 2), as well as high fuel properties (Table 3). As a result, the energetic features of especial pellets become comparable with those of fossil coals (Figure 4).

Table 3 - Fuel characteristics of of especial pellets*

Biomass	Binder	HCA	Qº, MJ/kg	ED, GJ/m³
CW	PVA	PWR	27.52 (27.20)	19.26 (19.04)
OP	PVA	PWR	25.73 (25.62)	18.01 (17.93)

*Note: the fuel characteristics in wet conditions at RH=85% are shown in brackets

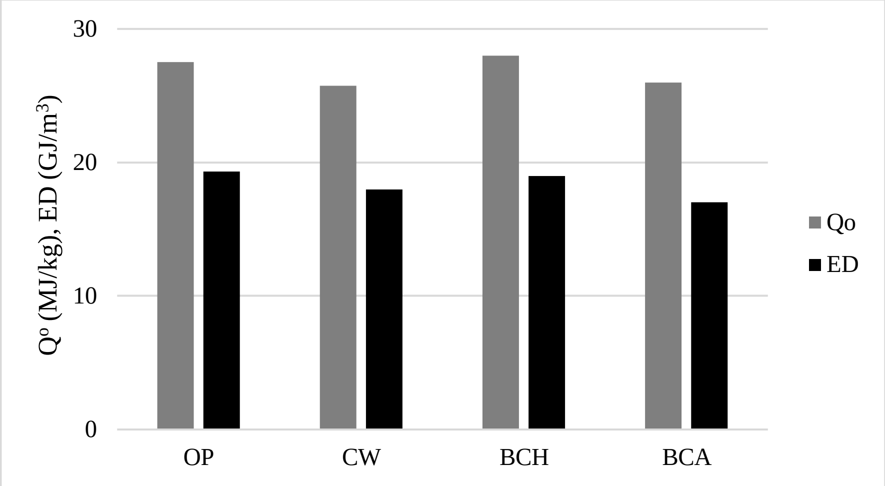

Figure 4 - Energetic features of especial pellets in comparison with high-quality (BCH) and average quality (BCA) bituminous coals

4. Conclusions

It was found that olive pomace can be a promising alternative natural source for the production of high-quality fuel pellets. The fuel pellets made from plant biomass and hydrophilic starch binder are characterized by increased hydrophility. As a result, after storage of these pellets in the humid atmosphere, there is an appreciable decrease in fuel characteristics and durability was observed.

The use of hydrophobic binder, PVA, instead of hydrophilic starch, promotes to obtaining improved pellets having high durability in dry and wet conditions; however, the fuel properties of resulting pellets in the wet conditions were reduced.

To significantly increase both fuel properties and durability of the solid biofuel, the pellets containing hydrophobic binder should be additionally coated with hydrophobic agent such as PWR. As a result, the energetic features of especial solid biofuels become comparable to those of fossil coals.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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