Monika Smaga
Research and Innovation Centre Pro-Akademia
Innowacyjna 9/11, 95-050 Konstantynów Łódzki, Poland, monikaturek@op.pl

Grzegorz Wielgosiński
Lodz University of Technology, Faculty of Process and Environmental Engineering,
Wólczańska 213, 90-924 Lódź, Poland, grzegorz.wielgosinski@p.lodz.pl

Aleksander Kochański
Research and Innovation Centre Pro-Akademia
Innowacyjna 9/11, 95-050 Konstantynów Łódzki, Poland, aleksander.kochanski@proakademia.eu

Katarzyna Korczak
Research and Innovation Centre Pro-Akademia
Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, Institute of Heat Engineering
Nowowiejska 21/25, 00-665 Warszawa, Poland, katarzyna.korczak@proakademia.eu

BIOMASS AS A MAJOR COMPONENT OF PELLETS

Abstract
The article describes the quality parameters of the selected elements of biomass as a potential ecological biofuel. Several selected elements of a type of biomass were tested to determine the calorific value, humidity, content of sulfur and amount of ash produced in burning process. The concept of biomass and the legal aspects of its combustion are described. The research of biomass samples revealed that they may be turned into a high-energy, ecologically solid biofuel. Production of biofuel from the tested biomass does not require any additional binders. Studies have shown that the tested material can also act as a component of composite pellets. The quality parameters of such pellets can be determined with the composite calculator that is described in this article. The article also describes the technical aspects of the pellet production line, which should be applied to produce good-quality pellets from the tested types of biomass.

Key words
biomass, bio waste, pellet, composite calculator, pellet production lines

Introduction

Currently, there are three definitions of "biomass" that have been formulated in several legal acts. Although these definitions are often consistent with one another, they represent a different approach to biomass itself. The first definition states that biomass is the entire organic matter that exists on earth, including all materials of plant or animal origin that are biodegradable. The second definition describes biomass as the biodegradable parts of products, waste or residues of biological origin from agriculture, including plant and animal materials that result from forestry, fisheries and from other related industries, including aquaculture and fish farming. They also include the biodegradable fraction of industrial and municipal wastes, including installations for waste management, water treatment and sewage treatment. The third definition of biomass assumes that it is solid or liquid materials of plant or animal origin that are biodegradable and derived from products, waste and residues from agriculture and forestry and other related industries. They could also be from other wastes that are biodegradable or from cereal grains that do not meet the quality requirements for cereal [1-8].

Biomass is described by many laws and regulations, both in Polish and European law. The greatest concern related to biomass, however, is that it is often mistakenly treated as a waste. This is due to the meaning of the word "waste", which indicates all the useless substances and materials disposed of. Biomass may also match this description. However, waste is treated mainly as substances or materials that need to be disposed of and could be hazardous to the environment. While biomass is environmentally friendly and can be used to produce energy, it could also become a super-efficient ecological or alternative fuel.

Properties of pellets and briquettes made from biomass has been investigated by many Polish research teams. Niedziółka et al. assessed in [9] the energetic and mechanical properties of pellets produced from agricultural biomass, mainly wheat straw, rape straw, maize straw and its combinations. Obidziński presents in [10-11] the results of a research on the influence of potato pulp content in a mixture with cereal residuals (oat bran, buckwheat hulls) on the pellets quality and its elemental composition. Stolarski et al. investigated the quality and cost of small-scale production of briquettes, made from agricultural and forest biomass in north-eastern Poland [12]. Kijo-Kleczkowska et al. on the other hand performed experimental studies from a comparative analysis of on the mechanisms and kinetics of the combustion of pellets of sewage sludge, coal and biomass [13-14]. Some alternative pellets substrates were investigated as well: Ciesielczuk et al. checked the possibility of using spent coffee ground in energy recycling using a combustion process [15], while Cichy et al. investigated properties of pellets made from Pruning Operations in Fruit Orchards [16]

Alternative fuel, also known as non-conventional fuel, is a fuel of standardized quality properties, such as calorific value, humidity or content of certain chemical elements. This kind of fuel is made from non-hazardous waste and is used as a source of energy in incineration or co-incineration processes of waste. Biomass and its components are not hazardous. Biomass does not contain any harmful chemicals and it does not pollute the environment in any way, even if it is burned, because it consists of organic matter of plant or animal origin.

Fuel produced from biomass is ecological and has solid briquettes or pellets, burns well, is highly energetic and produces a small amount of ash in the combustion process. The production of such fuel does not require any additional chemical substances. Pellets are produced by drying and compressing biomass in special pellet production lines. Since no additional binder is needed to produce the pellets, they are a clean, dried and compressed biomass. Additionally, if the calorific values of all the components of biomass are known, then it is possible to create a high calorific mixture. The composite biomass calculator allows creating a biomass mixture by combining low energy compounds with high energy compounds in the proper proportions to produce a good quality pellet. Besides determining the calorific value of a composite pellet, the biomass calculator will also determine the humidity, content of sulfur, carbon, hydrogen, and the percentage of ash. It appears that biomass, which is frequently treated as waste to be disposed of, can be successfully used to produce a high-quality ecological fuel.

Definition of biomass and the legal aspects in the processes of its incineration

Biomass, according to the encyclopedic definition, is the whole organic matter, all vegetable- or animal-derived biodegradable substances existing on Earth. It has been known to and used by man since the dawn of time. Historically, it was the first source of energy used by man.

Today, biomass is often the source of primary energy. In poorer countries it is the primary source of thermal energy, while in richer countries it a renewable energy source (RES) that partially displaces non-renewable fossil fuels such as coal, lignite, crude oil or natural gas whose global resources have been steadily shrinking. The use of biomass as a renewable energy source is also the result of a globally-implemented policy of climate protection and systematic reduction of greenhouse gas emissions, including carbon dioxide (CO_2). This is based on the belief that carbon dioxide, which is inevitably emitted during the combustion of hydrocarbons, has already been collected from the atmosphere by plants and converted in the process of photosynthesis into biomass. This means CO_2 circulates in the environment without increasing its amount. Hence, biomass is commonly regarded as an emission-free CO_2.

Biomass is the third largest natural source of energy in the world. The global energy potential of biomass is estimated at approximately 100-440 EJ/year, which corresponds to roughly 30% of the global energy demand. According to available data, the current consumption of biomass in the world produces approximately 40 EJ per year [17-20]. In Poland, approximately 212 PJ is produced annually from biomass, and with the mean demand for primary energy amounts to approximately 4 480 PJ, or 4.7% [21]. To obtain energy, biomass is used both in unprocessed and processed forms into the so-called biofuels, which are used for both generation of power and heat as well as in transport.

The formal definition of biomass was included in several legal acts, including the act on waste (art. 162 and art. 2) [1], the act on bio-components and liquid biofuels (art. 2) [2], the Regulation of the Minister of Economy on the detailed scope of obligations for the obtainment and presentation for remission of certificates of origin, payment of the substitute fee, purchase of electricity and heat generated from renewable energy sources and the obligation to confirm the data concerning the amount of electricity generated from a renewable energy source (§ 2) [3], Regulation of the Minister of Environment on the emission standards from installations (§ 2) [4], as well as in European law - Directive of the European Parliament and of the Council 2010/75/EC on industrial emissions [5]Directive of the European Parliament and of the Council 2009/28/EC on the promotion of the use of energy from renewable sources [6] and the Regulation of the European Parliament and of the Council 1099/2008/EC on energy statistics [7].

In European law, the concept of biomass shall be understood as the biodegradable fraction of products, waste or residues of biological origin from agriculture (including vegetable and animal substances), forestry and the associated industries, including fishery and aquaculture, as well as the biodegradable fraction of industrial and urban waste [6]. Biomass also means products consisting of any vegetable substances from agriculture or forestry that can be used as fuel to recover their energy and the following waste [5]:

- vegetable waste from agriculture and forestry;
- vegetable waste from the food processing industry, if the generated heat is recovered;
- fibrous vegetable waste from the process of production of primary wood pulp and from production of paper from pulp, if such waste is co-incinerated at the place of production and the generated heat is recovered;
- cork waste;
- wood waste, except wood waste that may contain halogenated hydrocarbon derivatives of organic compounds or heavy metals introduced as a result of the application of agents for wood preservation or coating, including wood waste originating from construction and demolition works.

In Polish law, however, biomass has been defined as the biodegradable fractions of products, waste or residues of biological origin from agriculture, including vegetable and animal substances, from forestry and fishery and the associated industries, including breeding of fish and aquaculture, as well as the biodegradable fraction of industrial and municipal waste, including waste from installations for the management of waste as well as water treatment and wastewater treatment [2]. The scope of the concept of biomass has recently been extended in the Regulation of the Minister of Economy [3], according to which biomass is a solid or liquid vegetable or animal substance that is biodegradable, derived from products, waste and residues from agriculture and forestry as well as the associated industries. They should also contain fractions of other wastes that are biodegradable, and cereal grains that do not meet the quality requirements for intervention purchases.

As can be seen, a clear definition of what can be considered biomass is quite difficult. Determination of what could theoretically be considered to have satisfied the above-mentioned definitions and be treated as biomass, but what should not be considered as biomass, seems slightly easier. The list of types of waste that can be considered as biomass is specified both by the act on waste [1] and the Regulation of the Minister of Environment [4]. In line with the act on waste, biomass in the form of animal manure, which is subject to the provisions of the Regulation of the European Parliament and of the Council specifying health rules concerning animal by-products and derived products not intended for human consumption [7]. In addition, straw and other non-hazardous natural substances derived from agricultural or forestry production used in agriculture, forestry or for energy production from such biomass with the use of processes or methods that do not harm the environment or endanger human life and health are not considered to be waste.

The following are also not regarded as waste (e.g. in the processes of thermal treatment):

- vegetable waste from agriculture and forestry;
- vegetable waste from the food processing industry, where the generated thermal energy is recovered;
- fibrous vegetable waste from the process of production of primary cellulose mass and from production of paper from mass, if such waste is incinerated at the place of production and the generated thermal energy is recovered;
- cork waste;
- wood waste, except that which is contaminated with impregnating agents and protective coatings that may contain halogenated organic compounds or heavy metals, the content of which includes wood waste from construction, overhauls and demolitions of structures and road infrastructure.

Despite the existence of the above-mentioned legal definitions, the problem of distinguishing between biomass and wood waste is a very frequent one. Generally, the concept of biomass in all legal acts shall be understood as uncontaminated wood that originates from sawmills or, more broadly, is delivered directly by the forestry and agricultural sectors (firewood, brushwood, wood chips, wood pellets, bark, sawdust, shavings, chips, scrap, or energy crops), as well as waste such as straw, rice husks, nut shells, poultry litter, and crushed citrus dregs. There are also many other wooden materials that are the product of certain industrial processes, particularly in the wood and paper industry. In contrast, contaminated wood originating in furniture factories and demolitions cannot be considered biomass [8].

Proper classification of combustible material, whether biomass or waste, is of paramount importance in the use of its fuel properties. Biomass is treated the same way as fossil fuels (Chapter 2), while incineration and co-incineration of waste is described in Chapter 3. In combustion for energy generation purposes, only the emission of dust, sulfur dioxide and nitrogen oxide is subject to limitation, while in the case of waste, the emission of carbon monoxide, hydrogen chloride, hydrogen fluoride, total organic compounds and heavy metals as well as polychlorinated dibenzo-p-dioxins and polychlorinated furans are subject to limitation. Although from the chemical standpoint, the process of combustion of solid fossil fuels (coal, lignite, peat) biomass or waste is similar [22] and similar contaminations are generated, their quantities will vary depending on the quality of the combustion process, and it is closely connected with the uniformity and the homogeneity of the incinerated material.

Despite many undeniable advantages, such as the widespread availability, renewability, or CO_2 "zero-emission", biomass as fuel also has many flaws, which could include [23-26]:

- relatively low density, which causes difficulties with transport and storage,
- high variability of moisture content, which is the source of numerous problems in the process of combustion,
- calorific value lower than in the case of fossil fuels (particularly coal),
- high variability of properties and elemental composition.

The use of biomass as an energy source has been the subject of many studies during the recent years. They concerned both the fuel properties of biomass [27-30] and the technology of energy use, whether directly through incineration [31-34], or as fuel for co-incineration with coal [35-40]. However, regardless of the adopted technology of incineration or co-incineration, in recent years we have been observing more and more widespread use of biomass as a fuel for energy purposes [41-43].

The argument frequently raised with the burning of biomass is the small emissions of sulfur dioxide and particulate matter, which is much smaller than in the case of coal. This obviously involves much lower sulfur content in the biomass and much lower content of flame retardants. However, due to the high content of volatile substances and the presence of chlorine, biomass burns differently than carbon, producing much higher emissions of the so-called products of incomplete combustion (i.e. PICs) hydrocarbons resulting from numerous chemical reactions taking place outside of the combustion zone. Of those, one will find a long list of aromatic hydrocarbons, simple aliphatic hydrocarbons (including formaldehyde), as well as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) [44-52]. Also, sometimes the emission of carbon monoxide and hydrocarbons from combustion of biomass is higher than in the case of coal combustion [53].

Quality indexes of the biomass components

The most common component of pellets is an organic matter derived from plants. Pellet is a biofuel made in special presses called pellet mills, from compressed under high pressure wood waste such as sawdust, shavings, wood chips, bark, energy crops, or straw. Pellet is a kind of a small briquette with the form of granules shaped like spheres or cylinders, with a diameter of 6-25 mm and a length of several centimeters. Pellets have a calorific value similar to wood, low humidity (4,3-10%), and during the combustion process they produce a low amount of ash. For these reasons, their use is convenient in the private central heating boilers and fireplaces equipped with a pellet tank, dispenser and feeder [54-55]. Such pellets can be composed entirely of a plant organic biomass, which so far was often treated as waste that needed to be disposed of. The composition of such biofuel may include, for example, grass cuttings, fallen leaves, fragments of cut down trees and shrubs, weeds or plant origin waste from the production of food, such as fruit stones, nut shells and inedible peels from fruits and vegetables.

Pellet produced from such biomass can meet the quality requirements for the solid organic fuels. Moreover, it does not contain any harmful chemicals and does not pollute the environment in any way, even if it is burned, because it consists of organic matter of vegetable or animal origin.

Production of such fuels does not require any additional chemicals. Pellets are formed by drying and compacting a biomass in special pellet production lines. There is no need to add any additional binders to produce such biofuels. Pellet is a pure, dried and compacted biomass. It's a bio fuel made of wood waste such as sawdust, woodchips and bark or energy plants. Pellet is a kind of a good quality briquette, having the form of granules in the shape of spheres or cylinders that are the size of a few centimeters [56].

Due to its composition, pellets have a calorific value similar to wood (16,00-19,00MJ/kg), low humidity (<%), low sulfur content (<1%), and produce a small amount of ash (<1.00%). These attributes make them a convenient fuel to use in the individual boilers and stoves that are equipped with a reservoir, dispenser and feeder [57].

It appears that the majority of pellets available on the market consist only of timber that comes from sawmills or from energy plants that are specially bred for this purpose. There is also a pellet produced from straw, but it is not so common because such pellet produces more ash than pellets from wood (3-5%), which causes users to clean and service their boilers more frequently.

Recently, agripellets are also becoming a popular biofuel on the energy market. There are no specific standards for quality requirements of agripellets. Although agripellets lag wooden pellets in terms of calorific value, they are becoming more widely used by industry. The calorific value of agripellets oscillates between 12 and 18MJ/kg, and the ash content is relatively high (over 1%).

Nowadays, the biomass that is being "produced" by the people becomes an issue and begins to transform into troublesome waste. Getting rid of unwanted biomass may be a problem for municipalities (e.g. mown grass), forestry management (e.g. material left after deforestation), orchards owners (e.g. waste from fruits and cut down trees), and food manufacturers (e.g. post-production waste, such as peels, seeds and stones). The idea to produce biofuel from such biomass, seems very interesting. Production of such biofuels may solve the problem of a bio-waste disposal and places a new environmentally friendly product on the energy market. Such composite pellet could be produced from grasses, straw, twigs, peels from fruits, vegetables and mushrooms, nutshells, weeds, or fallen leaves.

The study material consisted of samples from:

1. Mowed grass
2. Weeds
3. Walnut shells
4. Pistachio shells
5. Peels of citrus fruits (orange, lemon, lime)
6. Straw
7. Peels of vegetables (beets, carrots, potato)
8. Fallen leaves
9. Peels of fruits (banana, apple, pear)
10. Onion skins
11. Champignons skins
12. Plum seeds

In the first stage of the study, samples were dried in a laboratory oven for 5 hours at 105^{o}C. After that, quality parameters used to describe solid fuels were measured in tested samples. The aim of the study was to determine the quality parameters of the biomass samples, including the calorific value, to confirm whether such biomass is suitable as a component of pellets or other solid biofuels. To determine the calorific value, the following parameters had to be measured for each sample:

1. humidity content
2. content of hydrogen
3. Higher heating value

The following formula has been used to calculate the Lower heating value:

LHV = HHV – r*(a*h + w) [MJ/kg]

LHV – Higher heating value
HHV – Lower heating value
r – heat of vaporization of water (2,455 MJ/kg)
a – hydrogen to water conversion rate 8,94
h – hydrogen content [kg]
w – humidity content [kg]

Additionally, the percentage content of sulfur and the percentage content of ash left after combustion were determined.

Tests were carried out on 3 different measuring devices:

1. Calorimeter Parr 6400 CALORIMETER – Higher heating value
2. Thermogravimetric Analyzer TGA ELTRA THERMOSEPT – humidity, ashes
3. Carbon Hydrogen Sulfur Determinator PC Controlled ELTRA CHS 580 – sulfur, hydrogen

Tests were carried out at room temperature (ca 25^{o}C). Each measurement was carried out in three repetitions. It was assumed that the tested material has a high calorific value, but it may also have a higher content of sulfur in comparison to wood pellets and thus can produce more ash after combustion (Table 1).

Table 1. The quality parameters measured from samples of selected elements of biomass

No.	**Tested material**	**Lower heating value [MJ/kg] (after drying)**	**Humidity [%] (after drying)**	**Ash content [%]**	**Sulfur content [%]**
1.	Mowed grass	15.92	10.0	1.70	0.45
2.	Weeds	1.23	7.47	2.50	0.79
3.	Walnut shells	18.20	7.90	0.59	0.64
4	Pistachio shells	16.54	6.65	0.75	0.99
5.	Peels of citrus fruits (orange, lemon, lime)	18.05	3.13	3.04	0.84
6.	Straw	16.10	9.14	4.89	0.52
7.	Peels of vegetables (beets, carrots, potato)	16.43	1.58	6.76	0.69
8.	Peels of fruits (banana, apple, pear)	16.37	4.19	4.80	0.96
9.	Fallen leaves	18.70	7.78	4.73	0.54
10.	Onion skins	15.89	9.99	6.15	0.57
11.	Mushroom skins (champignons)	14.81	8.19	7.63	0.40
12.	Plum seeds	19.58	7.34	0.46	0.62

Source: Author's

Studies have shown that quality parameters of tested samples of biomass are slightly below the average quality of wooden pellets available on the market, but they are very similar to agripellets. The calorific values of tested materials oscillate between 13.23 and 19.58 MJ/kg. As samples were pre-dried before examination, they also met humidity requirements of wooden pellets. Drying components is one of the steps of pellet production in pellet mills, so humidity value of the examined samples should be consistent with the humidity of pellets produced from the examined material.

Research showed that the tested biomass contains sulfur in the amount that meets the criteria of the standards for wood pellets. Besides that, the presence of sulfur is a natural consequence of sulfur content in the vegetable proteins, which is a building material of tested biomass.

It appears that the greatest issue of the tested samples is the high content of ash (even up to 7.6%). The high content of ash in the burned pellets results in the faster clogging of heating boilers and stoves. However, this is the only disadvantage of such fuel, which can be eliminated or reduced by applying a dedicated boiler that is suitable for this specific type of biomass. Additionally, various types of biomass mixtures can be created.

High- and low-energy biomass components can be combined in suitable proportions. Components that produce a high amount of ash can be mixed with components that produce a low amount of ash to create a good-quality pellet. Choosing the relevant ingredients and mixing them in adequate proportions adjusts the calorific value and moisture content as well as the ash content. Such biomass can be also mixed with other components, such as wood or coal dust to improve quality parameters.

It is important to note that plum seeds have very good energy parameters. They have high calorific value and very low ash content. Additionally, it turns out that such biomass does not need to be pelletized.

The possibility of forming pellets from biomass was also examined. The study was conducted in a laboratory conditions. Pellet granules were produced by the manual press for pellets - Parr Pellet Press. Research has shown that production of pellets from tested biomass components does not require any additional binder to form pellet granules. Figure 1 presents a sample of pellets made from straw.

Fig. 1. Pellets made of straw
Source: Author's

The composite biomass calculator

The composite biomass calculator is a tool used on a first step of a development of new composite pellet. It is used to make a preliminary assessment of properties of the composite, to estimate energy input required for the process as well as costs of production. It accounts for available mass flows of substrates and shows the effectiveness of the production in several production scales and on different pellet production lines. It also optimises the composition of a pellet before starting more complex research.

The structure of the calculator consists of four parts: (1) *input data*, (2) *energy properties*, (3) *production expenditures* and (4) *comparison to other fuels*. Calculations can be done in one of two levels of accuracy. For more general purposes, users only need to input mass flows/capacities and acquisition costs of available substrates. Implemented parameters (calorific value, moisture contents, ash content and sulfur content) for several examined components of biomass, energy plants and of course wood, proceed in further calculations. In more advanced research, the user can change these implemented parameters based on the results of actual substrates tests and add new substrates and their properties. Second, part of the calculator, *energy properties*, calculates and shows the following properties of composite pellets: net mass of a composite pellet, calorific value, sulfur content, ash content, moisture content and total ash mass in a given pellet mass. Third, part of a calculator, *production expenditures,* calculates and shows all production costs. User needs to input following parameters: outcome moisture content of a pellet and cost rate of the electricity. Parameters like moisture content of input substrates and cost rate of biomass are taken from previous parts of a calculator. As a result, this part shows how much water is evaporated in a process and how much biomass is required to fuel the process and cannot be used for pellet production including the costs of biomass and electricity. The final result is a total cost of the production of the pellet, given as a total value for the total given capacity of a substrates, as well as a unit value for one tonne of a pellet and for one GJ of energy (Fig.). Fourth, part of the calculator, *comparison to other fuels*, compares parameters of a composite pellet and other popular fuels such as hard coal, oil, natural gas, traditional pellet, and firewood. The parameter that is compared is a unit price of the energy that is carried out by these fuels (PLN/GJ). For more complex analysis, the user can add new fuels. Parameters of fuels in this part need to be updated regularly, because of dynamic changes of prices of fuel on the market.

INPUT

Component	Higher heating value	Lower heating value	Sulfur content [%]	Ash content [%]	Humidity [%]	Cost [PLN]	Mass [kg]
Miscanthus		16,280	0,145%	6,896%	20,00%	560,00	1000,00
Jerusalem artichoke		15,320	0,060%	5,367%	23,00%	430,00	1000,00
Grass		14,820	0,145%	4,129%	50,00%	500,00	1000,00
Sawdust		17,140	0,079%	1,043%	45,00%	400,00	1000,00
TOTAL	-	-	-	-	-	1890,00	4000,00

OUTPUT

Mass of pellets [kg]	Average HHV [MJ/kg]	Average LHV [MJ/kg]	Average sulfur content [%]	Avrage ash content [%]	Average humidity [%]	Avrage ash content [kg]
2 647,00	-	15,89	0,11%	4,36%	34,50%	115,38

Fig. 2 Calculation of properties of hybrid biomass pellets made from Miscanthus, Jerusalem artichoke, grass and sawdust
Source: Author's

The calculator was already used in research on composite pellets. It gives accurate results for a pellet production line with an output of 1500 kg/h. A plan for further development of the calculator includes adding modules of several different size of production lines to improve results of the calculations for smaller and larger flows of biomass. We are also going to continuously validate all algorithms using the results of tests of new composite pellets, produced in different pellet production lines with different line sizes and substrates of the pellet.

At the current stage, the calculator is mainly used in industrial research to estimate the parameters of a pellet and to optimize its composition. It seems it would be valuable to develop a substrates database and add more components, including atypical ones like industrial wastes from the wood industry, paper industry, or textile industry, sewage sludge, or green waste from cities. This would apply the calculator not only to industrial research, but also for estimation of an energy potential of a given area, such as that of a city or an industrial park.

In sum, the Biomass Calculator estimates quality parameters of designed composite pellets. The input of the Biomass Calculator application are the quality parameters of tested biomass components, such as calorific value, moisture content, ash content and sulfur content.

The composition of tested biomass need to be updated in the application by entering the weight of individual biomass components (in kg). The outputs of the application are the quality parameters of pellet composed of input materials in given proportions. Input data can be modified or adjusted to determine the most suitable composition that meets the required quality parameters. Examples of calculations done in the biomass calculator are shown below. In these examples, the production of pellets composed of 25% wood, 25% miscanthus (energy plant) and 50% mown grass are proposed.

Technical aspects of pellet production lines

On the Polish market, there is a wide diversity of pellet producing technological lines. The most common division among them is based on the material they operate on and production capacities. Large technological lines are able to produce over a dozen of tones per hour, which is an impressive feature even if compared with western and American technologies, especially if one takes into account that this kind of facility was introduced in Poland almost 15 years later.

Two of the most common materials of which Polish pellet is made is straw and wood. Scientific studies are currently conducted on a 3rd type of fuel called urban biomass, such as branches, boughs, mown grass, weeds and other biomass found in cities. Thus far, the economical aspect of such pellet is questionable, and until the final report is ready it is impossible to elaborate on the economical aspect of this matter.

The first material that is commonly used in Poland in the process of pellet production is straw. Poland is a highly developed agriculture region that is rich in this kind of biomass. Another large part of the market belongs to wood pellets. These pellets are made either from leftovers of wood from mills or other production facilities. Due to the high competition on the market and growing market needs, producers often use forest wood, which is harder to process. The third category of pellet source material is urban biomass. This sector is rather unexplored and could potentially be very profitable, depending on the economical and caloric aspects of pellets.

There is hardly a typical pellet producing line, and lines designs are bases on the specific materials that the producer wants to process. Therefore, pellet producing lines destined to process forest wood shall be equipped with several devices that are not required by the enterprise producing furniture. For scientific reasons, we shall cover all the required devices below [56]:

1. Debarker- this device is useful for the production of pellets from forest wood. After the material is acquired from the forest it is very often dragged via forest roads for several hundred meters or even further. This enables sand to invade the bark. Sand is a highly undesired material in pellet production and bark makes the final pellets look darker, which is not welcomed by the buyers. The best way to avoid sand and bark is to remove it completely.
2. Wood chipper- this kind of machine is required to preprocess wood. There are sever kinds of chippers. depending on the cutting technology and scale of the material. As a desired product, pellet producers require the smallest clean wood chips as possible. On the picture below, one can observe operating a mobile wood chipper.
3. Wood crusher- this kind of device sometimes replaces the before mentioned wood chipper. The principle of operation is the same; however, if the material provided is small enough, investors can omit the expensive wood chipper by mounting a larger wood crusher into the pellet producing line.
4. Separator- device which separates proper fuel from undesired particles such as stones, rocks, metals, and glass. A separator is a mandatory device for processing weeds.
5. Strawchopper/grinder – before drying straw, it needs to be cut and ground into smaller particles. A commonly used device to archive this goal is a strawchopper/grinder, which is a variation of the strawchopper used in agriculture. The material is shredded and cut/ground into smaller bits to provide a more efficient drying process, and counter the possible problems that might occur in the dryer – small bits are more easily processed by the drying infrastructure. Depending on the size of provided material packages, a strawchopper/grinder might have significant dimensions and power consumption. The main reason for the production of large dimensions strawchoppers /grinders is the need to provide as compatible device as possible to most common solutions already operating on the agriculture market.
6. Dryer – When the material has desirable dimensions, it can be processed by the drying machinery. There are several types of dryers. However, the principal in all of them is alike: material is dried and when it is moisture free (10%-15%) it can be pelletized. As mentioned before, there are several kinds of dryers which operate on different bases. The mechanism of supplying a dryer in either heat or air might vary, as well as the method of material transportation within the drying facility. After the drying

process material is either reground or if the dimensions are appropriate, it is directly transported into a pelletizer unit.

7. Pelletizers – These machines vary depend on size and construction. The idea of operation is to squeeze the disordered material thru a matrix that results in gaining the desired length and diameter pellet. To archive this goal, operating staff needs to both provide proper material and have the pelletizer set to process material with strict parameters.

After the pellet is “produced” by the pelletizing unit it needs to be cleared from the dust and cooled. The cooling process can be done either mechanically by the blowers which blow air into the pellet that cools it or passively, for example by the long transportation conduct that is between the pelletizer and the storage unit.

Among the problems encountered during pelletizing mixed materials, the first question that arises is, “What is mixed material”? By the phrase mixed material, we understand weeds, grass, and wood bits. These materials are mixed together and induced in to the line. There are several difficult stages when mixed material is provided to the pellet production line. First, although pelletizing mixed materials is possible, if the process is to be conducted fast, an undisturbed proportion of the mix should be strictly maintained to avoid recalibrating the machines. This can prove to be quite difficult in non-laboratory conditions when several hundred kilograms or even more of material is processed on a daily basis. The mix should also contain up to 15-20% of added material. For example, the main 80-85% of material should be wood chips and 15-20% should be mown grass. Another problematic part of the drying unit which can cause many difficulties, since the particles of the mix and the humidity are different. Extreme lighter particles can stand over the dryer for an extended period of time and ignite.

If both the before mentioned difficulties are avoided, the pelletizing process should be conducted without obstacles. As the product is considered a mixed origin pellet, it is suspected to be less caloric than wooden pellets and the color of the material to be not as light, which can be a factor of choice for the final user.

Summary

Considering the quality parameters of selected elements of the biomass, production simplicity of pellets from such material and legal regulations related to processing and combustion of bio-waste and biomass, it can be stated that the production of such pellets is beneficial for the economy.

It not only solves the problem of unmanaged bio-waste, but also provides a new product on the energy market in the form of biocomposite pellets. Quality parameters of such pellets may be similar to parameters of wooden pellets available on the market and additionally do not pollute the environment.

The production of such pellets will require using a special matrix to form pellet granules in pellet production lines, which would be more suitable for soft vegetables, not for hard woods. However, that would be the only necessary modification of the existing pellet production lines needed.

There is no need for any additional binders or other chemicals to form such pellets. The only disadvantage of the pellets is the high content of ash produced during the combustion process. However, this can be eliminated or significantly reduced by applying dedicated stoves that are suitable for this specific type of pellet. It is possible that in the future such a pellet will revolutionize the European energy market and solve the problem of disposal of organic waste at the same time.

References

[1] Act dated December 14, 2012 on waste (Journal of Laws of 2013. item 21, 888, 1238, of 2014 item 695, 1101, 1322, of 2015 item 87, 122, 933, 1045, 1688, 1936, 2281).

[2] The Act of 25 August 2006 on biocomponents and liquid biofuels (consolidated text Journal of Laws of 2015, item 775, amendments in the Journal of Laws of 2016, item 266, 1165).

[3] Regulation of the Minister of Economy on the detailed scope of obligations for the obtainment and presentation for remission of certificates of origin, payment of the substitute fee, purchase of electricity and heat generated from renewable energy sources and the obligation to confirm the data concerning

the amount of electricity generated from a renewable energy source (Journal of Laws of 2012. item 1229 of 2013 item 1362, of 2014 item 1688, 671, 1912).

[4] Regulation of the Minister of Environment of 4 November 2014 on emission standards for certain types of installations, sources of combustion of fuels and equipment for incineration or co-incineration of waste (Journal of Laws of 2014, item 1546).

[5] Directive of the European Parliament and of the Council 2010/75/EU of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Official Journal of the EU L 334 of 17.12.2010, 17-119).

[6] Directive of the European Parliament and of the Council 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Official Journal of the EU L 140 of 05.06.2009, 16-62).

[7] Regulation of the European Parliament and of the Council No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation) (Official Journal of the EU L 300 of 14.11.2009, 1-33, as amended).

[8] Regulation of the European Parliament and of the Council No 1099/2008 of 22 October 2008 on energy statistics (Official Journal of the EU L 304 of 14.11.2008, 1-62).

[9] I. Niedziółka, M. Szpryngiel, M. Kachel-Jakubowska, A. Kraszkiewicz, K. Zawiślak, P. Sobczak, R. Nadulski, Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass, Renewable Energy 2015, 76, 312-317

[10] S. Obidziński, Pelletization of biomass waste with potato pulp content, International Agrophysics, Volume 28, Issue 1, 85–91

[11] S. Obidziński, J. Piekut, D. Dec, The influence of potato pulp content on the properties of pellets from buckwheat hulls, Renewable Energy 2016, 87, 289-297

[12] Mariusz J. Stolarski, Stefan Szczukowski, Józef Tworkowski, Michał Krzyżaniak, Paweł Gulczyński, Mirosław Mleczek, Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass, In Renewable Energy, Volume 57, 2013, Pages 20-26

[13] Agnieszka Kijo-Kleczkowska, Katarzyna Środa, Monika Kosowska-Golachowska, Tomasz Musiał, Krzysztof Wolski, Combustion of pelleted sewage sludge with reference to coal and biomass, In Fuel, Volume 170, 2016, Pages 141-160

[14] Agnieszka Kijo-Kleczkowska, Katarzyna Środa, Monika Kosowska-Golachowska, Tomasz Musiał, Krzysztof Wolski, Experimental research of sewage sludge with coal and biomass co-combustion, in pellet form, In Waste Management, Volume 53, 2016, Pages 165-181

[15] Ciesielczuk, T. , Karwaczyńska, U. , Sporek, M., The Possibility of Disposing of Spent Coffee Ground With Energy Recycling, Journal of Ecological Engineering, 2015, Vol. 16, 133--138

[16] Wojciech Cichy, Magdalena Witczak, Małgorzata Walkowiak, Fuel Properties of Woody Biomass from Pruning Operations in Fruit Orchards, BioResources, 2017, Vol. 12, 6458-6470

[17] M. Parikka, Global biomass fuel resources, Biomass and Bioenergy, 2004, 27, 613-620.

[18] British Petroleum, BP Statistical Review of World Energy, London, June 2015.

[19] R. Slade, R. Saunders, R. Gross, A. Bauen, Energy from biomass: the size of the global resource, Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre, London, 2011.

[20] World Energy Council, World Energy Issues Monitor, London, 2014.

[21] Central Statistical Office, Statistical Yearbook of Environmental Protection, Warsaw 2015.

[22] G. Wielgosiński, Pollutant Formation in Combustion Processes. - in: Advances in Chemical Engineering, Zeeshan Nawaz & Shahid Naveed (Ed.), InTech Rijeka 2012, 295-324.

[23] H.L. Chum, R.P. Overend, Biomass and renewable fuels, Fuel Processing Technology 2001, 71, 187-195.

[24] L.I. Darvell, J.M. Jones, B. Gudka, X.C. Baxter, A. Saddawi, A. Williams, A. Malmgren, Combustion properties of some power station biomass fuels, Fuel 2010, 89, 2881-2890.

[25] S.V. Vassilev, D. Baxter, L.K. Andersen, C.G. Vassileva, T.J. Morgan, An overview of the organic and inorganic phase composition of biomass, Fuel 2012, 94, 1-33.

[26] S.V. Vassilev, C.G. Vassileva, V.S. Vassilev, Advantages and disadvantages of composition and properties of biomass in comparison with coal: An overview, Fuel 2015, 158, 330-350.

[27] A. Demirbas, Combustion characteristics of different biomass fuels, Progress in Energy and Combustion Science 2004, 30, 219-230.

[28] B.M. Jenkins, L.L. Baxter, Jr.T.R. Miles, T.R. Miles, Combustion properties of biomass, Fuel Processing Technology 1998, 54, 17-46.

[29] A.M. Kanury, Combustion characteristics of biomass fuels, Combustion Science and Technology 1994, 97, 469-491.
[30] H. Heykiri-Acma, Combustion characteristics of different biomass materials, Energy Conversion Management 2003, 44, 155-162.
[31] R. van den Broek, A. Faaij, A.D. van Wijk, Biomass combustion for power generation, Biomass and Bioenergy 1996, 11, 271-281.
[32] C. Yin, L.A. Rosendahl, S.K. Kær, Grate firing of biomass for heat and power production, Progress in Energy and Combustion Science 2008, 34, 725-754.
[33] A.A Kahn, W. de Jong, P.J. Jansens, H. Spliethoff, Biomass combustion in fluidized bed boilers: potential problems and remedies, Fuel Processing Technology 2009, 90, 21-50.
[34] D.I. Barnes, Understanding pulverised coal, biomass and waste combustion – A brief overview, Applied Thermal Engineering 2015, 74, 89-95.
[35] D.A. Tillman, Biomass cofiring: the technology, the experience, the contribution consequences, Biomass and Bioenergy 2000, 19, 365-384.
[36] R. Garcia, C. Pizarro, A. Alvarez, A.G. Lavin, J.L. Bueno, Study of biomass combustion wastes, Fuel 2015, 148, 152-159.
[37] A. Demirbas, Sustainable cofiring of biomass with coal, Energy Conservation and Management 2003, 44, 1465-1479.
[38] M. Sami, K. Annamalai, M. Wooldridge, A review of cofiring of coal: bio-solid fuels cofiring, Progress in Energy and Combustion Science 2001, 27, 171-214.
[39] L. Baxter, Biomass-coal co-combustion: opportunity for affordable renewable energy, Fuel 2005, 84, 1295-1302.
[40] S.G. Sahu, N. Chakraborty, P. Sarkar, Coal-biomass co-combustion: An overview, Renewable and Sustainable Energy Reviews 2014, 575-586.
[41] E.A. Sondreal, S.A. Benson, J.P. Hurley, M.D. Mann, J.H. Pavlish, M.L. Swanson, Review of advances in combustion technology and biomass cofiring, Fuel Processing Technology 2001, 71, 7-38.
[42] T. Nussbaumer, Combustion and co-combustion of biomass: fundamentals, technologies and primary measures for emission reduction, Energy and Fuels 2003, 17, 1510-1521.
[43] E. Hughes, Biomass co-firing: economics, policy and opportunities, Biomass Bioenergy 2000, 19, 457-65.
[44] J.M. Jones, A.R. Lae-Langton, L. Ma, M. Pourkashanian, A. Williams, Pollutants generated by combustion of solid biomass fuels, Springer Verlag London 2014.
[45] P. Samaras, G. Skodras, G.P. Sakellaropoulos, M. Blumenstock, K.W. Schramm, A. Kettrup, Toxic emission during co-combustion of biomass-waste wood-lignite blends in an industrial boiler, Chemosphere 2001, 43, 751-755.
[46] J.M. Williams, L.M. Jones, M. Pourkashanian, Pollutants from the combustion of solid biomass fuels, Progress in Energy and Combustion Science 2012, 38, 113-137.
[47] M. Cerqueira, L. Gomes, L. Tarelho, C. Pio, Formaldehyde and acetaldehyde emissions from residential wood combustion in Portugal, Atmospheric Environment 2013, 72, 171-176.
[48] A. Musialik-Piotrowska, W. Kordylewski, J. Ciołek, K. Mościcki, Characteristics of air pollutants emitter from biomass combustion in small retort boiler, Environment Protection Engineering 2010, 36, 123-131.
[49] A. Demirbas, Hazardous Emissions from Combustion of Biomass, Energy Sources, Part A 2008, 30, 170-178.
[50] C.K.W. Ndiema, F.M. Mpendazoe, A. Williams, Emission of pollutants from a biomass stove, Energy Conversion and Management 1998, 39, 1357-1367.
[51] E.D. Lavric, A.A. Konnov, J. De Ruyck, Dioxin levels in wood combustion – a review, Biomass Bioenergy 2004, 26, 115-145.
[52] B. Schatowitz, G. Brandt, F. Gafner, E. Schlumpf, R. Bühler, P. Hasler, T. Nussbaumer, Dioxin emissions from wood combustion, Chemosphere 1994, 29, 2005-2013.
[53] G. Wielgosiński, P. Łechtańska, O. Namiecińska, Emission of some pollutants from biomass combustion in comparison to hard coal combustion, Journal of the Energy Institute 2016, 89, in press.
[54] J. Morell, K. Hill, All About Pellet Stoves, This Old House Magazine, 2012.
[55] P. Frederick, 2012 VT Wood Chip & Pellet Heating Conference, Biomass Energy Resource Center, January 2012.
[56] R. Fuller, Pelleting Process, University of Illinois, December 2011.
[57] Wood pellets standard EN 14961-2.