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PRODUCTION TECHNIQUES AND PROPERTIES OF FUEL PELLETS PRODUCED FROM POST-CONSUMER WOOD

An estimation of the energy potential has been made for woody biomass – wood waste and post-consumer wood (PCW) – which amounted to 6.438 million tonnes in 2012, the share of PCW being 2.0 million tonnes. It has been substantiated that these resources, when converted info solid fuel, could enhance the energy potential from 2.703 to 3.548 million tonnes of equivalent fuel, that is by 24%. Up-to-date production techniques have been developed and existing equipment has been improved to produce fuel pellets from PCW as being high energy capacity raw material. Operating conditions of the production process have been considered and the optimal pellet composition was determined with various contents of solid and soft PCW particles from broadleaved and coniferous species, particles from composite material, ect. based on their pressing capability. Also presented here are the results of comparative analysis of properties of fuel pellets with varied PCW content for the following parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.

Keywords: post-consumer wood, biomass, classification of used wood, energy potential, pellets, production techniques, properties of fuel pellets, socio-economic efficiency.

Topicality. In view of today's tendency toward increase in the cost of conventional types of fuel, the problem of searching for alternative sources of energy, particularly for heating, has become especially pressing nowadays. The technological effectiveness of utilizing wood waste from wood-processing industry and PCW is sufficiently high at the forest and woodworking enterprises at the expense of reduced raw material cost. According to the draft of the updated "Ukraine's energy strategy up to 2030" [38, 39] and also in line with predictions made by the researchers G. Geletukha and T. Zhelezna, the share of biomass in the total energy consumption in Ukraine is likely to increase from 0.7% to 10% in 2030 (for comparison, this figure n the EU is to increase from 6.7% to 19%). In 2010 use of woody biomass (wood waste) for energy purposes in Ukraine amounted to 0.14% (including firewood – 0.34%) of the total supply of primary energy. The EU countries have many years of experience with producing solid biofuel such as wood pellets from wood waste. At present, about one thousand enterprises can be counted in Europe producing biofuel pellets and briquettes; the demand for this kind of fuel is to increase to 80-135 million tonnes by 2020. The major producers of biofuel pellets are the USA (2 million tonnes per year), Sweden (1.7 million tonnes), Canada (1.3 million tonnes), Germany (0.9 million tonnes), Austria (0.8 million tonnes). The United Kingdom is planning to increase the consumption of biofuel pellets up to 5 million tonnes by the end of 2013, while China has an intention to produce no less than 50 million tonnes of pellets annualy. In 2012, an estimated 810 thousand tonnes of solid fuel was produced in Ukraine, including almost 150 thousand tonnes of fuel pellets from wood waste. According to the Ukrainian Association of alternative solid fuel producers, over a hundred of companies are now in this kind of business, while the country as a whole is exploiting only about 3% of its potential in this sphere; Ukraine, however, is able to produce no less than 20 million tonnes of fuel pellets annualy. A certain amount of PCW is predicted to be used as energy resource of derivative raw material to produce fuel pellets on the basis of improved technologies and by developing alternative approaches.

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Problem formulation. This paper covers the issues of generating energy from additional wood resources, in particular PCW, by way of converting this into fuel pellets. As of now, the problems of raw material and waste are sure to remain the "hottest" problems in the woodworking industry and power economy all over the world and particularly in Ukraine. At least partial solution of the latter problem is a rational and holistic approach to settle the first problem – the problem of raw material. PCW reserves are potential resources and untapped base for wood raw material whose supplies are increasing with the development of wood-processing industry and the economy as a whole. The solution to the given problem is complicated through the existing varieties in PCW and especially because of the presence of various impurities (antipyren, antiseptic additives, insecticides, fungisides, biocides, complex compounds, etc.) which, through inadequate sorting and cleaning, may cause significant divergence from the predicted properties: calorific value, ash content, mechanical strength of fuel pellets from PCW as compared with those obtained from primary raw material, this being unacceptable from the environmental and economic standpoint.

The works by the foreign and Ukrainian researchers on this problem are mainly concerned with the use of wood processing residue without PCW involvement into production of fuel pellets. The results of their studies show that the given problem has not been solved yet, nor developed are the scientific basis or practical quidance for effective prediction of PCW fuel pellets properties.

PCW issues have been much investigated by various researchers in many countries, special attention being given to the impurities which has become a determinant factor as to PCW classification, that is its belonging to one or other category and, consequently, the way of its usage. For example, "PCW management regulations" has been adopted in Germany, in which the peculiarities of this waste management are given. In particular, this document clearly specifies the permissible concentration of chemical elements in PCW chips which can be used for energy purposes.

The production technology for fuel pellets was first proposed in 1947, this being constantly improved and changed according to the requirements of modern techniques and the peculiarities of one or other type of raw material used, in our case – the use of PCW, which motivates improvement of the production techniques.

Thus, the development of science-based technical basis, improvement of the existing technologies, upgrading of PCW processing equipment, development of adequate operating conditions and shaping practical advice supported by the results from experimental investigations concerning the production of fuel pellets from PCW with specified properties – all this presents an important and topical problem of the present time.

According to the standards for PCW adopted in Ukraine [27], nonhazardous kinds of the above kind of used wood are to be recommended for conversion into fuel pellets.

The objective of the study is to develop production techniques and improve the existing equipment for manufacturing fuel pellets from PCW; to develop a science-based, technical-and-technological, basis for effective prediction of the fuel pellets properties as well as to work out hands-on guidelines for quality assurance of PCW-produced fuel pellets.

The objective has been achieved by way of doing the following tasks:

- to carry out monitoring and make an estimation of the amount of PCW suitable for energy purpose – the production of fuel pellets;
- to substantiate ways and methods for cleaning PCW from various impurities;

- to develop production techniques, for manufacturing fuel pellets, through improvement of the existing technology: upgrading the system of automated control over the microprocessor-based autoproportioner; upgrading the blender for dry and wet chips with partial speed control of feed speed depending on the engine drive loading; upgrading the gravity segregator of chipped material and foreign materials; to install suspended magnetic strip and metal detector at the point of entry onto the vibrating screen;
- to improve tool equipment of the line for converting PCW into pellets, namely, the control system of temperature conditions for pelletizing, the control system of the chips moisture content at the entry as well as the digital moisture stabilizer at the point of exit;
- to validate experimentally the technological feasibility of obtaining fuel pellets from PCW in terms of pressability without application of a binder;
- to make a particle-size distribution analysis for chipped PCW;
- to carry out experimental investigations in order to determine qualitative characteristics of the pellets produced from softwoods and hardwoods species of PCW as well as from composite material;
- to check the influence of operating conditions of the fuel pellet production process on the controlled parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density;
- to make a comparative analysis with various PCW contents;
- to work out guidelines for practical implementation on the results obtained;
- to make an estimation of economic efficiency from the use of PCW for fuel pellets production.

The object of the study is the production process of fuel pellets from PCW by using upgraded and improved equipment.

The subject of the study is the patterns of technological parameters influence on the properties of PCW- produced fuel pellets in terms of predicting and quality assurance.

The methods of the study. Theoretical and experimental investigation were carried out with the application of a system approach involving computer engineering and software.

The methods used to perform the task:

- of mathematical statistics: to study qualitative characteristics of fuel pellets and to process the results;
- experimental methods for mechanical and thermomechanical cleaning; wood chipping; pellets manufacturing – pressing;
- mathematical modeling – for construction of mathematical model;
- methods of comparison – for the analysis of PCW- produced pellet properties and the properties of pellets produced from wood waste;
- methods of measurement: dry weight method – for measurement of moisture content; perforation method – for measurement of impurities content in the PCW, calorimetric method – for measurement of calorific value.

The means used to perform the task:

- upgrading automatic control system for pelletizing process by means of the microprocessor-based autoproportioner;
- upgrading the blender for dry and wet chips with partial control of feed speed depending on the engine-drive loading;
- upgrading the gravity segregator of chipped material and foreign materials;
- working out hands-on guidelines for manufacturing fuel pellets.

The approaches used to perform the task:

- application of methods for mechanical and thermomechanical cleaning of PCW;
- construction of the line for manufacturing fuel pellets from PCW;
- engineering study of suitability of certain categories of PCW as raw material for manufacturing fues pellets.

Underlying ideas to perform the task:

- improvement of the equipment to be used as the basis for constructing commercialized lines for manufacturing fuel pellets form PCW.
- development of the operating conditions for manufacturing fuel pellets from PCW
- improvement of the equipment for temperature conditions control system
- improvement of the control system for chip moisture content at the point of entry and of the digitat moisture stabilizer at the point of exit.
- installation of magnetic strip and metal detector at the point of entry onto the vibrating screen.

Working hypotheses used to perform the task:

- energy generation from additional wood resources in particular PCW, by way of turning them into fuel pellets;
- improvement of the production techniques and equipment for manufacturing fuel pellets from PCW;
- the application of wood flour pelletizer for experimental purpose;
- the advantages of fuel pellets: calorific value is 3,500-4,800 kcal/kg, moisture content within 8-12%, smaller volume, increased homogeneity of the component particles, which makes the pellets more convenient in handling and storing, also the use of pellets for heating makes it possible to apply automated systems of fuel feed.

The study of energy potential of woody biomass (wood waste and PCW).

The determination of energy potential for wood biomass was done on the basis of statistical data from the state agency of forest resources in Ukraine concerning timber harvest in 2012 (Table 1). At a level of timber harvest of 12.18 million tonnes (17.4 million m^3) in 2012 [36, 40], the volume of technically available logging residue (an average of 50% of the total wood residue quantities) amounted to 1.072 million tonnes (0.229 million tonnes of equivalent fuel), while the amount of by-products and residue from wood processing industry made up 3.362 million tonnes (1.544 tonnes of equivalent fuel) .

The total amount of green firewood (with moisture content of 45-50%) amounted to 17% of harvested volume that is 2.071 million tonnes with the energy potential being 0.523 million tonnes at the given moisture content level.

It has been found that a certain amount of PCW waste in which the share of wood amounts to over 50% – become available in Ukraine each year. Taking into account that the level of wood consumption is dependent on export-import, which compensate each other in the total balance of raw materials, the level of available PCW was calculated as 13% of the total harvested volume (a generally recognized way of calculation in the EU countries), which made up 1.58 million tonnes in 2012. In addition, an average of 50 to 60 million tonnes of solid residential waste (SRW) is available in Ukraine each year, in which the share of PCW amounts to 2 to 4%. According to the data from the ministry of regional development, housing construction, residential and public utility services, about 14 million tonnes of SRW was available in 2012, of which 0.42 million tonnes (3%) was PCW.

Thus, 2 million tonnes of PCW was available in Ukraine in 2012, with energy potential amounting to 0.936 million tonnes of equivalent fuel (27.442 PJ or 7.623 billion kWh). On turning the PCW, that was available in 2012, into fuel (with the following distribution: chips-50%, fuel pellets – 25%, fuel briquettes – 25%) it would be possible to increase the energy potential to 1.024 million tonnes of equivalent fuel, that is by 9%.

With the energy potential (excluding firewood), obtained in 2012, of 6.438 million tonnes (2.703 million tonnes of equivalent fuel or 79.4 PJ, or 22.056 billion kWh) it is possible to enhance this potential by converting the given resources into energy kinds of fuel. The resulted calculations show that the increase is likely to amount to 24%, this means that the energy value will rise to make up: 3.548 million tonnes of equivalent fuel or 104.00 PJ, or 28.889 billion kWh. With the annual power output of 198 billion kWh in 2012 in Ukraine, this would amount to 14.6% or 19.2% of an amount consumption.

Table 1. The energy potential of waste wood and used wood in Ukraine in 2012

Wood biomass and biofuels	W-%	Net Calorific Value, kkal/kg	The coefficients			Biomass - waste			Logging wood, million tons	Energy potential / year		
			t f. / t f.e.	MJ/kg	kWh	%	K	%		million t f.e.	PJ	billion kWh
Estimated numbers		7000	1	29.31	8.14	100.00			12.18			
Logging residues:												
Waste logging	60	1170	0.17	4.90	1.36	6.00	0.6	3.60	0.438	0.073	2.148	0.597
Green chips	60	1200	0.17	5.02	1.40	4.00	0.5	2.00	0.244	0.042	1.224	0.340
Chips of stumps and roots	40	2050	0.29	8.58	2.38	8.00	0.4	3.20	0.390	0.114	3.346	0.929
Total						**18.00**		**8.80**	**1.072**	**0.229**	**6.718**	**1.866**
By-products and residues WPI:												
Cutter chips (5-50 mm)	45	1950	0.28	8.16	2.27	18.00	0.1	1.80	0.219	0.061	1.790	0.497
By-products and residues						47.00						
• Furniture residues	20	3600	0.51	15.07	4.19	31.30	0.62	19.40	2.364	1.216	35.629	9.897
• Construction residues	45	2120	0.30	8.88	2.47	6.30	0.42	2.60	0.322	0.098	2.861	0.795
• Pulpwood residues	40	2370	0.34	9.92	2.76	6.30	0.33	2.10	0.253	0.086	2.513	0.698
• Plywood residues	30	2870	0.41	12.02	3.34	3.10	0.54	1.70	0.204	0.084	2.450	0.681
Total						**65.00**		**27.60**	**3.362**	**1.544**	**45.243**	**12.567**
Total by-products and residues						**83.00**		**36.41**	**4.434**	**1.773**	**51.961**	**14.433**
Firewood:												
Forest firewood (25-3000 mm)	50	1620	0.23	6.78	1.88	12.00	1	12.00	1.462	0.338	9.914	2.754
Smallwood (50-500 mm)	45	2120	0.30	8.88	2.47	5.00	1	5.00	0.609	0.184	5.406	1.502
Total						**17.00**		**17.00**	**2.071**	**0.523**	**15.320**	**4.255**
Total forest biomass						**100.00**		**53.40**	**6.505**	**2.295**	**67.281**	**18.689**
Used wood (RW, PCW):						Mio.t						
Commerce (package)	15	3850	0.55	16.12	4.48	0.301	0.15	15.00	0.301	0.165	4.847	1.346
Construction waste	18	3700	0.53	15.49	4.30	0.461	0.23	23.00	0.461	0.244	7.142	1.984
Wood-processing industry	20	3600	0.51	15.07	4.19	0.120	0.06	6.00	0.120	0.062	1.813	0.504
Furniture	10	4100	0.59	17.17	4.77	0.261	0.13	13.00	0.261	0.153	4.473	1.242
Municipal waste	40	2370	0.34	9.92	2.76	0.341	0.17	17.00	0.341	0.115	3.381	0.939
Solid domestic waste	35	2600	0.37	10.89	3.02	0.421	0.21	21.00	0.421	0.156	4.582	1.273
Other	30	2870	0.41	12.02	3.34	0.100	0.05	5.00	0.100	0.041	1.204	0.335
Total used wood mixtures	25	3280	0.47	13.73	3.81	**2.004**		**100.0**	**2.004**	**0.936**	**27.442**	**7.623**
Total waste									**6.438**	**2.709**	**79.403**	**22.056**
Wood fuels:												
Wood chips used wood	22	3250	0.46	13.61	3.78			50.00	1.002	0.465	13.637	3.788
Wood chips (5-50 mm)	30	3000	0.43	12.56	3.49			8.80	1.072	0.459	13.464	3.740
Log wood (200-2000 mm)	20	3520	0.50	14.74	4.09			4.00	0.487	0.245	7.181	1.995
Firewood (150-1000 mm)	20	3600	0.51	15.07	4.19			8.00	0.974	0.501	14.688	4.080
Chunkwood (50-150 mm)	18	3700	0.53	15.49	4.30			5.00	0.609	0.322	9.435	2.621
Wood pellet from virgin wood	7	4500	0.64	18.84	5.23							
Wood pellet from waste wood	9	4300	0.61	18.00	5.00			27.61	3.362	2.065	60.537	16.815
Wood pellet from used wood	8	4100	0.59	17.17	4.77			25.00	0.501	0.293	8.602	2.389
Wood briquette from virgin wood	10	3800	0.54	15.91	4.42							
Wood briquette from waste wood	15	3650	0.52	15.28	4.25							
Wood briquette from used wood	12	3700	0.53	15.49	4.30			25.00	0.501	0.265	7.763	2.156
Char	8	7430	1.06	31.11	8.64							
Energy potential of used wood		3850	0.55	16.12	4.48				**2.004**	**1.024**	**30.00**	**8.334**
Potential exluding firewood									**6.438**	**3.548**	**104.00**	**28.889**
Total energy potential		3700	0.53	15.49	4.30				**8.509**	**4.616**	**135.31**	**37.584**

Sources of waste wood – used wood (recovered wood, PCW).

A number of studies carried out previously have shown that waste wood arises from several different waste streams and can be categorized into different waste streams. It is important to try and categorize wood waste as it arises from a wide variety of sources and, therefore, the amount of contaminants it contains varies also.

Approximately 2.0-2.8 million tonnes of waste wood are generated each year by construction, demolition, commercial and industrial sectors in Ukraine (Table 2). Waste wood can, therefore, be categorized as coming from the following waste streams:

- Municipal waste stream;
- Commercial and Demolition waste stream;
- Commercial and Industry waste stream.

Table 2. Sustainable potential of post-consumer wood in Ukraine[26-33]

Origin and source	Potential amount used wood (recovered wood, PCW)					
	2010		2011		2012	
	%	Mio. t	%	Mio. t	%	Mio. t
Commerce (package)	13.00	0.363	12.00	0.288	15.00	0.301
Construction waste	18.00	0.503	22.00	0.527	23.00	0.461
Wood-processing industry	7.00	0.196	6.00	0.144	6.00	0.120
Furniture	12.00	0.335	12.00	0.288	13.00	0.261
Municipal waste	16.00	0.447	16.00	0.383	17.00	0.341
Solid domestic waste (SDW)	27.00	0.755	24.00	0.575	21.00	0.421
Other	7.00	0.196	8.00	0.192	5.00	0.100
Total used wood mixtures	**100.00**	**2.795**	**100.00**	**2.396**	**100.0**	**2.004**
Estimated numbers						
Uses of wooden resours (UWR)	15	13.600	15	12.140	13	12.180
Solid domestic waste (SDW)	6	12.583	4.5	12.778	3	14.033

Municipal waste. Municipal waste wood (used wood) consists of disposal by households e.g. furniture (0.261 million tonnes), fencing, decking, wood cuts from DIY, arboriculture arisings and wood packaging e.g. pallets. The two main categories of waste wood collected are from civic amenity sites and packaging suppliers. It is normal practice for Local Authorities to provide skips at civic amenity sites for the public to leave their municipal wood waste which is then collected by waste handlers such as premier waste where it is then taken to recycling facilities or disposed to landfill depending on its quality.

The waste wood is usually collected through the following:

- Civic amenity sites (CA sites or Household Waste Recycling Centres)
- Kerbside collection of household waste
- Special collections by council (bulky waste)

In the past, sorting and segregating wood waste was difficult to do due to the fact that the municipal waste stream contains mixed waste varying in its nature and composition. In recent years Local Authorities have improved the recycling facilities offering separate skips for wood waste such as pallets etc. The figures reveal that in 2012 (Table 2), 0.341 million tonnes of municipal waste and 0.1 million tonnes of non-household waste were potentially evaluated (potential amount), however these figures are not entirely accurate nor do they give recycled waste wood figures.

There is no individual figure for the recycling rates of waste wood, therefore, it is included in the ‘Other’ or the ‘Co-mingled’ category which could include waste such as electrical goods and hence not giving a true representation.

Due to these gaps of information further research needs to be carried out in order to find out how much of the ‘Other’ and ‘Co-mingled’ municipal waste sent for recycling was wood.

Construction waste. It is estimated that 0.461 million tonnes of waste wood (used wood) arises from the construction industry every year in Ukraine. The potential of the used packaging for 2012 totalled 0.301 million tonnes.

The construction and demolition waste stream is usually classed as one category; however, it produces different waste streams such as:

- Construction – Includes off-cuts from structural timbers, timber packaging, scaffolding, cladding etc.
- Demolition – Used structural timber, floorboards, joists, doors and frames etc.

These different waste streams cause a number of problems because it makes hard for the recycling industry to segregate the wood waste into different categories and, therefore, separate wood containing contaminants. In order to tackle the issue of mixed waste streams and sorting difficulties, the Government have introduced a new requirement called "Procedure of Register of the origin, processing, and utilization of waste" – the Resolution of the Cabinet of Ministers of Ukraine of August 31, 1998, No. 1360.

This demonstrates that greater support and recycling facilities are needed for smaller businesses to efficiently recover and re-use wood waste from construction sites. There seems to be a need for small sorting and segregation sites to which smaller industries could off load their waste so that the sorting process was carried out for them. This may be a practical solution to help reduce the amount of wood ending up in landfill sites as well as reducing charges from Landfill Tax. However, the problem of unidentified contaminants that may be present on the waste wood would still need to be addressed.

Wood-processing industry. Some of the main sources of wood waste that come from this sector include:

- Furniture manufacture;
- Wood waste during manufacture of packaging;
- Wood waste from wooden packaging

A large proportion of waste wood under this category is likely to be wood packaging such as wood pallets producing the highest grade of waste wood. Most of this waste coves from wood processing enterprises. The volume of wood waste (PCW waste) that can be processed outside the enterprise amounted to 0.120 million tonnes in 2012.

The analysis of European standards. Over the past decade there has been a substantial increase in the amount of biomass being used for energy in Europe [1]. As trade between countries becomes more widespread, it is necessary to create international standards to facilitate buying and selling biomass fuels. Solid biofuel is a wide field and includes woody biomass (chips, hogfuel, firewood, wood pellets, briquettes). Demolition timber is considered a hazardous waste and is not included in the solid biofuel category. The main standards in the area of biomass fuels are the EN 14961 series [4-9].

Under this code six European standards are already printed, and thus available, in all the EU countries through their National Standardisation Bodies. These documents are, at the moment, the unique European Standards dealing with solid biofuel specifications, and, even if they refer to biofuels for non industrial use (as stated in their titles), they could also be used as a reference for industrial uses while waiting for more specific standards (EN ISO 17225) [24, 25].

An overview of these standards is given in the box below:

- European Standard EN 14961-1:2010 (EN ISO 17225-1:2012) determines the fuel quality classes and specifications for solid biofuels originating from the following sources: a) products from agriculture and forestry; b) vegetable waste from agriculture and forestry; c) vegetable waste from the food processing industry; d) wood waste, with the exception of wood waste which can contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coating, and which includes in particular such wood waste originated from construction and demolition waste; e) fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and heat generated is recovered; f) cork waste.

- European standard EN 14961-2:2011 determines the fuel quality classes and specifications of wood pellets for non-industrial use. European standard EN ISO 17225-2:2012 determines the fuel quality classes and specifications of wood pellets that are sold to be used as fuel in domestic pellet stoves and pellet boilers as well as industrial heating systems. They can also be used for other applications such as horse bedding and pellet grill fuel. This European standards covers only wood pellets produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-3:2011 determines the fuel quality classes and specifications of wood briquettes for non-industrial use. This European standard covers only wood briquettes produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-4:2011 determines the fuel quality classes and specifications for non-industrial wood chips. This European standard covers only wood chip produced from the following raw materials: Forest, plantation and other virgin wood; By-products and residues from wood processing industry; Used wood.
- European standard EN 14961-5:2011 determines the fuel quality classes and specifications for firewood for non-industrial use. This European standard covers only firewood produced from the following raw material: Whole trees without roots; Chemically untreated wood residues; Stem wood; Logging residues (thick branches, tops, etc.).
- European Standard EN 14961-6:2012 determines the fuel quality classes and specifications of non woody pellets for non-industrial use. This European Standard covers only non-woody pellets produced from herbaceous biomass, fruit biomass and their blends and mixtures. Herbaceous biomass is from plants that have a non-woody stem and which die back at the end of the growing season. It includes grains or seeds crops from food processing industry and their by-products such as cereals. Blends are intentionally mixed biofuels, whereas mixtures are unintentionally mixed biofuels.

EN 14961-1 is a very general standard that explains how to classify the biomass to be used for energy purposes. Based on this classification, developed and detailed category added is the used wood as a possible resource for the production of solid fuel. (Table 3).

Table 3. Classification of woody biomass for fuel pellets [4, 24, 29]

№	Sub-categories	Code	Group origin	Sub-code	Sub-group source
1.1	Forest plantation and other virgin wood	1.1.1	Whole trees without roots	1.1.1.1	Broadleaf
				1.1.1.2	Coniferous
				1.1.1.3	Short rotation coppice
				1.1.1.4	Bushes
				1.1.1.5	Blends and mixtures
		1.1.2	Whole trees with roots	1.1.2.1	Broadleaf
				1.1.2.2	Coniferous
				1.1.2.3	Short rotation coppice
				1.1.2.4	Bushes
				1.1.2.5	Blends and mixtures
		1.1.3	Stemwood	1.1.3.1	Broadleaf
				1.1.3.2	Coniferous
				1.1.3.3	Blends and mixtures
		1.1.4	Logging residues	1.1.4.1	Fresh/green, broadleaf (including leaves)
				1.1.4.2	Fresh/Green, Coniferous, (including needles)
				1.1.4.3	Stored, Broadleaf
				1.1.4.4	Stored, Coniferous
				1.1.4.5	Blends and mixtures
		1.1.5	Stumps/roots	1.1.5.1	Broadleaf
				1.1.5.2	Coniferous

				1.1.5.3	Short rotation coppice
				1.1.5.4	Bushes
				1.1.5.5	Blends and mixtures
		1.1.6	Bark (from forestry operations)		
		1.1.7	Segregated wood from gardens, parks, roadside maintenance, vineyards and fruit orchards		
		1.1.8	Blends and mixtures		
1.2	Byproducts and residues from wood processing industry	1.2.1	Chemically untreated wood residues	1.2.1.1	Without bark, Broadleaf
				1.2.1.2	Without bark, Coniferous
				1.2.1.3	With bark, Broadleaf
				1.2.1.4	With bark, Coniferous
				1.2.1.5	Bark (from industry operations)
		1.2.2	Chemically treated wood residues, fibers and wood constituents	1.2.2.1	Without bark
				1.2.2.2	With bark
				1.2.2.3	Bark (from industry operations)
				1.2.2.4	Fibers and wood constituents
		1.2.3	Blends and mixtures		
1.3	**Used wood (recovered wood, post-consumer wood)**	1.3.1	Chemically untreated wood	1.3.1.1	Without bark
				1.3.1.2	With bark
				1.3.1.3	Bark
		1.3.2	Chemically treated wood	1.3.2.1	Without bark
				1.3.2.2	With bark
				1.3.2.3	Bark
		1.3.3	Blends and mixtures	1.3.3.1	Wood-based panel (particleboards, MDF, OSB, plywood and other composite materials)
				1.3.3.2	Packaging
				1.3.3.3	Waste wood from the construction industry
				1.3.3.4	Furniture, with no halogenated organic compounds in the coating
				1.3.3.5	Municipal waste wood
				1.3.3.6	Solid domestic waste wood
				1.3.3.7	Other blends and mixtures
1.4	Blends and mixtures.	1.4.1	Blends		
		1.4.2	Mixtures		

Following this general part, the most relevant standards for larger heating applications in the EN 14961 series are part 2 (wood pellet) and part 4 (wood chips).

EN 14961-2 defines the main parameters that should be considered for stating the quality of wood pellet and for each of them typical values for three quality classes (A1, A2 and B) are specified.

Class A1 and A2 represents pellets from virgin wood or chemically untreated wood residues. They differ mainly for the ash content, while class B allows chemically treated industrial wood byproducts and residues, and used wood.

A note: the detailed research and practical recommendations to be written about class B since not all the national legislations in EU allow the use of treated wood, thus the standard contain deviations according with the situation in Ukraine.

The same approach is adopted by EN 14961-4 on wood chips that defines 4 classes (A1, A2, B1, B2). Class A1 and A2 represent wood chips from virgin wood or chemically untreated wood residues, in this case with different ash and moisture contents. Class B1 and B2 extend the source of biomass to include (B2) chemically treated industrial wood by-products and residues and used wood.

All the quoted standards define a list of parameters to be used for stating the quality of each biofuel, and for each parameter a set of values is defined. The main parameters to be considered for non-industrial pellets and woodchips are listed in Table 4.

Table 4. Key parameters for non-industrial pellets and woodchips according to EN 14961-2 (EN ISO 17225-2:2012) **and EN 14961-4** (EN ISO 17225-4:2012)

Parameter	Meaning	Notes for Pellet	Notes for Wood Chip
Origin and source	It has to be clearly stated according with the different sources allowed by each standards.		
Diameter, D; Dimension	It is a physical value that could influence the plant/appliance feeding system.	For pellet diameter could vary from 6 to 8 mm ± 1 mm. A higher diameter could affect the correct functioning of the stove.	The dimension is important for the appliance feeding systems; it also could lead to bridging phenomena in the bulk storage
Moisture, M	This parameter mainly affect the energy content and the storage. Moreover it is often used to define the contractual price of the biofuel.	It has to be lower than 10% since an higher content could scale and damage the pellet.	It is on of the key parameter for the chips. For class A moisture could vary up to 35 %.
Ash, A	Ashes are the mineral residues remaining after a complete combustion. Their amount has to be as low as possible. An high value means bad quality of biomass or a bad management during the production of the biofuel. An high ash content leads to a more frequent maintenance of the plant/appliance/boiler (removing of ashes in the combustion chamber or cleaning of the glasses).	High quality pellet (A1) shall have an ash content lower than 0,7%. A2 class allows a higher (up to 1,5%) ash content, while B admits and ash content up to 3%.	Ash content for wood chips is approached in a similar way as for the pellet.
Mechanical durability, DU	It represents the capability of pellets to resist to crumble and break down to sawdust. It is one of the main requirements for pellet since affects its storability and integrity especially if pellet is subjected to several handling steps	It has to be the highest, more than 97,5%	Not relevant
Fines at factory gate, F	It represents the percentage of sawdust in the package. Sawdust can't be handled by the feeding systems of pellet appliances.	It has to be the lowest; no more that 1% is allowed.	Not relevant
Additives	Additives are materials which should improve the efficiency of pellet production. Pellet producers generally use starch, corn or potato flour, vegetable oil.	Type and amount have to be clearly stated. In any case a maximum amount of 2% is allowed.	Not relevant
Net Calorific Value, Q	It represents the energy content of the biofuel and is strongly connected with moisture content. Attention has to be paid for the unit used to declare this parameter. A typical mistake is to declare the gross value instead of the net, giving an overestimation of the fuel energy content.	An high calorific value could mean that pellet is made by other material than wood (plastics, glues, etc.)	
Bulk Density, BD	It is a key parameter that allows to calculate "quantities". It represents the weight (mass) of the bulk for unit volume.	It has to be higher than 600 kg/m^3	It has to be higher than 150-200 kg/m^3
N, S, Cl, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn	Chemical compounds/elements have to be considered indicators of possible contaminants of the original biomass. For this reason higher contents than expected can indicate a pollution (voluntary or involuntary) of the raw material.		

In order to give an overview of the approach used by this EN, in Table 5 an excerpt from of EN 14961-2 is shown.

The size distribution of wood chips is somewhat complicated, which is why the size requirements for the different classes are given in Table 6, while the full requirements for wood chips are given in Table 7.

Table 5. Specification of wood pellets for non-industrial use according to EN 14961-2 [5]

Parameter	Analysis method	Unit	Normative		
			A1	A2	B
Origin and source	EN 14961-1		1.1.3 1.2.1	1.1.1; 1.1.3 1.1.4; 1.1.6 1.2.1; 1.3.1	1.1 1.2 1.3
Diameter, D; Length, L	EN 16127	mm	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40	D06, 6±1; 3,15≤L≤40 D08, 8±1; 3,15≤L≤40
Moisture, M	EN 14774-1 EN 14774-2	as received, w-% wet basis (wb)	M10≤10	M10≤10	M10≤10
Ash, A	EN 14775	w-% dry	A0.7≤0.7	A1.5≤1.5	A3.0≤3.0
Mechanical Durability, DU	EN 15210-1	as received (a.r.), w-%	DU97.5≤97.5	DU97.5≤97.5	DU96.5≤96.5
Fines at factory gate, F	EN 15149-1	w-% a.r.	F1.0≤1,0	F1.0≤1,0	F1.0≤1,0
Net Calorific Value, Q	EN 14918	a.r. , MJ/kg or kWh/kg	Q16.5: 16.5≤Q≤19 Q4.6: 4.6≤Q≤5.3	Q16.3: 16.3≤Q≤19 Q4.5: 4.5≤Q≤5.3	Q16.0: 16.0≤Q≤19 Q4.4: 4.4≤Q≤5.3
Bulk Density, BD	EN 15103	kg/m3	BD600≥600	BD600≥600	BD600≥600
Additives		w-% dry	≤2w-% Types and amount to be stated		
Nitrogen, N	EN 15104	w-% dry	N0.3≤0.3	N0.5≤0.5	N1.0≤1.0
Sulphur, S	EN 15289	w-% dry	S0.03≤0.03	S0.03≤0.03	S0.04≤0.04
Chlorine, Cl	EN 15289	w-% dry	Cl0.02≤0.02	Cl0.02≤0.02	Cl0.03≤0.03
Arsenic, As	EN 15297	mg/kg dry	≤1	≤1	≤1
Cadmium, Cd	EN 15297	mg/kg dry	≤0.5	≤0.5	≤0.5
Chromium, Cr	EN 15297	mg/kg dry	≤10	≤10	≤10
Copper, Cu	EN 15297	mg/kg dry	≤10	≤10	≤10
Lead, Pb	EN 15297	mg/kg dry	≤10	≤10	≤10
Mercury, Hg	EN 15297	mg/kg dry	≤0.1	≤0.1	≤0.1
Nickel, Ni	EN 15297	mg/kg dry	≤10	≤10	≤10
Zinc, Zn	EN 15297	mg/kg dry	≤100	≤100	≤100

Table 6. Product standard for wood chips EN 14961-4 – Particle size (P) [7]

Luokka	Minimum 75 w-% (main fraction), mm	Fine fraction, w-%, < 3,15 mm	Coarse fraction, w-% maximum length of particle, mm
P16A	3.15 ≤ P ≤ 16 mm	≤ 12 %	≤ 3% > 16 mm, and all < 31.5 mm The cross sectional area for oversized particles < 1 cm^2
P16B	3.15 ≤ P ≤ 16 mm	≤ 12 %	≤ 3% > 45 mm, and all< 120 mm The cross sectional area for oversized particles < 1 cm^2
P31,5	8 ≤ P ≤ 31,5 mm	≤ 8 %	≤ 6% > 45 mm, and all < 120 mm The cross sectional area for oversized particles < 2 cm^2
P45A	8 ≤ P ≤ 45 mm	≤ 8 %	≤ 6% > 6 mm and maximum 3.5 % > 100 mm, The cross sectional area for oversized particles < 5 cm^2

The numerical values (P-class) for dimension refer to the particle sizes (at least 75 w-%) passing through the mentioned round hole sieve size (EN 15149-1).

Table 7. Some qualitative values for non-industrial wood chip according to EN 14961-4 [7]

Property class	Analysis method	Unit	Normative			
			A1	A2	B1	B2
Origin and source	EN 14961-1		1.1.1; 1.1.3 1.2.1; 1.1.4.3	1.1.1; 1.1.3 1.2.1; 1.1.4.1	1.1 1.2.1	1.2 1.3
Particle size, P	EN 15149-1 EN 15149-2	mm	To be selected from Table 1			
Moisture, M	EN 14774-1 EN 14774-2	as received, (a.r.), w-%	M10≤10 M25≤25	M35≤35	To be specified	
Ash, A	EN 14775	w-% dry	A1.0≤1,0	A1.5≤1.5	A3.0≤3.0	
Net Calorific Value, Q	EN 14918	a.r. , MJ/kg or kWh/kg	Q13.0≥13,0 or Q3.6≥3,6	Q11.0≥11,0 or Q3.1≥3,1	To be specified	
Bulk Density, BD	EN 15103	kg/loose m3	BD150≥150 BD200≥200	BD150≥150 BD200≥200	To be specified	
Nitrogen, N	EN 15104	w-% dry	N0.3≤0.3	N0.5≤0.5	N1.0≤1.0	
Sulphur, S	EN 15289	w-% dry	S0.03≤0.03	S0.03≤0.03	S0.1≤0.1	
Chlorine, Cl	EN 15289	w-% dry	Cl0.02≤0.02	Cl0.02≤0.02	Cl0.05≤0.05	
Arsenic, As	EN 15297	mg/kg dry	≤1	≤1	≤1	
Cadmium, Cd	EN 15297	mg/kg dry	≤0.5	≤0.5	≤02,0	
Chromium, Cr	EN 15297	mg/kg dry	≤10	≤10	≤10	
Copper, Cu	EN 15297	mg/kg dry	≤10	≤10	≤10	
Lead, Pb	EN 15297	mg/kg dry	≤10	≤10	≤10	
Mercury, Hg	EN 15297	mg/kg dry	≤0.1	≤0.1	≤0.1	
Nickel, Ni	EN 15297	mg/kg dry	≤10	≤10	≤10	
Zinc, Zn	EN 15297	mg/kg dry	≤100	≤100	≤100	

Analysis data collections showed how inadequate is the current status of pellet standardization and certification in Europe. The existing national standards with individual quality requirements were not accepted by all stakeholders and did not spread within Europe. In most European countries, pellet quality standards are not used at all. Thus, national standards may have contributed to the development of single national pellet markets but the absence of common European standardisation was an important barrier to further development of the European pellet market in general and to increased international pellet trade in particular.

It can be expected that this situation will improve greatly with the implementation of new European standards for solid biofuels, including pellets.

The experience gained during the analysis was that standards alone are not sufficient to promote European pellet markets. The diversity of raw materials, the rapidly increasing number of producers and the critical importance of pellet quality for consumer satisfaction and, therefore, for market growth in general make the reinforcement and compliance with standards necessary. In order to reinforce the compliance with quality standards, internal quality management needs to be accompanied by regular, external and unannounced control at the production sites. The end-consumer needs a reliable and recognisable quality label facilitating buying decisions. Quality labels also are an important marketing instrument for pellet producers. Finally, quality labels are used by pellet appliance manufacturers in warranty conditions that exclude the use of pellets without quality label.

All this can be provided by quality certification schemes that award a reliable and recognizable quality label following regular external controls. Therefore, already in

2013, recommended EN 14961, EN ISO 17225 and EN 15234 as a basis for a pan-European certification system could be used across Europe and facilitate international pellet trade and market development.

This recommendation will be followed by Ukrainian certification bodies who decided to adapt their systems to the framework set by European standards.

The testing methods for in-house sampling and quality assurance.

The test of wood pellets for in-house sampling and quality control (physical and mechanical properties) was conducted immediately after their manufacture. Wood pellets have been tested in accordance with European standards biofuel soil (Table 8).

Table 8. The methodology for testing experimental fuel pellets [10-23]

Parameter	Analysis method	Unit	Repeatability limit
Origin and source	EN 14961-1:2010 EN 17225-1:2012		1.2. Byproducts and residues from wood processing industry 1.3. Used wood (recovered wood, post-consumer wood)
Sampling	EN 14778:2011	kg ar	individual samples
Sample preparation	EN 14780:2011	kg ar	individual samples
Diameter, D;	EN 16127:2012	mm	D06, 6±1
Length, L	EN 16127:2012	mm	3,15≤L≤40 (95 w-%)
Moisture, M as received (ar)	EN 14774-1:2009 EN 14774-2:2009	w-% ar	< 0.2 % absolute (M≤10%)
Ash, A of dry basis (db) (550 ºC)	EN 14775:2009	w-% db	<2 % of the mean result (A≥10 %) < 0.2 % absolute (A<10 %)
Mechanical Durability, DU	EN 15210-1:2009	w-% ar	<0.4 % absolute (DU≥97.5 %) < 2 % absolute (DU<97.5 %)
Fines at factory gate, F	EN 15149-1:2010	w-% ar	< 0.2 % absolute (F≤1.0 %)
Net Calorific Value, Q	EN 14918:2010	MJ/kg ar	< 120 J/g (Q ≥16.0 MJ/kg)
Bulk Density, BD	EN 15103:2010	kg/m^3	<4 % (BD ≥ 300 kg/m^3) <6 % (BD < 300 kg/m^3)

Sampling [2, 3]. The sampling and sample portioning for the tests in the scope of external inspections are conducted according to EN 14778:2011 (Sampling) and EN 14780:2011 (Sample preparation). As the procedures listed in the respective standards are very extensive, a simplified procedure for drawing samples for in-house analyses will be described in the following. Single samples (increments) should, if possible, be taken from the moving material, as the quality of the total batch can be best indicated in this way. During sample partitioning for the individual analyses, it should also be made certain that the respective subsamples represent the quality of the total batch. The subsamples should be taken with a small sampling scoop in order to assure that the fine material quantity can also be tested.

- ***From moving material.*** At least five individual samples, with a mass of 4 kg per sample, will be taken. Attention should be paid that at least 20 kg of material passes through the sampling point between the individual sampling procedures. The individual samples will be thoroughly mixed and compiled into a cone. This will subsequently be pressed flat and divided into four equally large parts by a vertically inserted scoop. The process is to be so often repeated until the required sample size for the respective test is approximately achieved. Care must be taken to assure that all subsamples possess the same consistency.
- ***From static material.*** At least five individual samples, with a mass of 4 kg per sample, are to be taken at different points of the filling process. With bagged wood pellets, an individual sample will be respectively taken from one bag. The individual samples will be thoroughly mixed and compiled into a cone. This will subsequently be pressed flat and divided into four equally large parts by a vertically inserted scoop. The process is to be so often repeated until the required sample size for the respec-

tive test is approximately achieved. Care must be taken to assure that all subsamples possess the same consistency.

Mechanical durability (DU). The subsequent determination of the mechanical durability is done on the basis of EN 15210-1:2009. Firstly, two subsamples drawn from the sieved pellets, with a mass of (500±10) g respectively, are formed and weighed. They are successively put into the testing chamber of the measuring device, which rotates at (50±2) revolutions per minute. After 500 rotations, the drum is to be emptied and the fine material is to be sieved again. Afterwards, the remaining wood pellets will be weighed and the mechanical durability will be determined using the following formula (1):

$$DU = (m_A/m_E) \times 100, \qquad (1)$$

where: DU – mechanical durability, w-%; m_A – mass of the sieved wood pellets after the handling process, g; m_E – mass of the pre-sieved wood pellets before the handling process, g.

An average value will be generated from the results of the testing of both subsamples. On account of the expected divergence from the determination, a divergence of the mean value from the threshold value of an abrasion of up to 0.2 % must be accepted.

Fine material amount (F). The mass will be determined by taking a sample of approximately 1.2 kg. Subsequently, the amount of fine material will be separated with a 3.15 mm – Certification of Wood Pellets for Heating Purposes 31 sieve according to ISO 3310-1. When the sieving is done manually according to EN 15210-1:2009, care must be taken that, on one hand, all fine particles are separated and, on the other hand, that no new fine material forms through the mechanical strain. This can be achieved by shaking the sample in 5 to 10 circular motions using a sieve with a diameter of 40 cm. Then the sieved particles will be weighed. The fine material amount (F, w-%) will be calculated as follows (2):

$$F = (m_A/m_E) \times 100, \qquad (2)$$

where: m_A – mass of the sieved particles, g; m_E – mass of the sample before sieving, g.

Bulk Density (BD). The determination of the bulk density follows on the basis of EN 15103:2010. Wood pellets will be poured from a height of 200 to 300 mm into a measuring cylinder, with a volume of five liters and a defined diameter-height ratio, until the cylinder is full and a debris cone has formed. Subsequently, the cylinder will be dropped three times from a height of 150 mm onto a hard surface in order to consolidate the wood pellets. After excess material has been removed by striking a straight edge along the top and larger cavities have been filled, the mass of the wood pellets in the cylinder is determined.

The bulk density (BD) will be calculated using the following formula (3):

$$BD = (m_2-m_1)/V, \qquad (3)$$

where: BD – bulk density, kg/m^3; m_1 – mass of the empty container, kg; m_2 – mass of the full container, kg; V – net volume of the measuring cylinder, m^3.

Afterwards, the sample material is poured out and mixed with the remaining wood pellets before the procedure is repeated. An average value will be generated from the results of both measurements.

Moisture content (M_{ar}). The determination of the moisture content follows on the basis of EN 14774-2:2009. First, the mass of the empty drying dish will be determined (accuracy: 0.1 g). Subsequently, the dish will be filled with at least 300 grams of wood pellets and re-weighed. The sample will then be dried in a drying chamber (oven) at (105 ± 2) °C until constant mass has been achieved. After the mass has been determined within 15 seconds of removing it from the drying chamber (weighing as hot), the moisture content will be calculated using the following formula (4):

$$M_{ar}=(m_2-m_3)/(m_2-m_1)\times100, \qquad (4)$$

where: M_{ar} – moisture content as received, w-%; m_1 – mass of the empty drying pan, g; m_2 – mass of the drying pan and sample before drying, g; m_3 – mass of the drying pan and sample after drying, g.

Ash content (A_d). Ash content is another important test for determining wood fuel properties. Ashing temperature for wood fuel standards is a significant point of difference with coal ashing standards. EN 14775:2009 describes the method for ash content of solid biofuels. Ash, the material remaining, calculated on the basis of the dry weight of the original sample, after the sample is ignited at a specified temperature. Ash at 550± 10°C, the ash content of the sample when the ignition temperature is 550±10°C.

Carefully clean the empty crucible and ignite in a muffle furnace at 550±10°C for 60 minutes. After ignition, cool slightly and then place in a desiccator. When cooled to room temperature, weigh the ignited crucible on the analytical balance to the nearest 0.1 mg. A 1 g sample is initially ashed at 250±10°C until volatiles are burnt off slowly (to avoid losing entrained particles with fast burning) and then a heating regime is followed to finish with an ashing temperature of 550±10°C for at least 2 hours. When the specimen is completely combusted as indicated by the absence of black particles, remove the crucible from the furnace, replace the cover, and allow to cool somewhat; then place in a desiccator containing indicating grade anhydrous alumina and cool to room temperature. Weigh the crucible with ash to the nearest 0.1 mg. Repeat the ignition and weighing until the weight of the ash is constant to ±0.2 mg.

Calculate the ash content as follows (5):

$$A_d = (m_3\text{-}m_1)/(m_2\text{-}m_1) \times 100 \times (100)/(100\text{-}M_{ad}),\ \text{w-\%} \tag{5}$$

where: m_1 – mass of empty crucible, g; m_2 – mass of crucible with breakdowns, g; m_3 – mass of crucible with ash residue, g; M_{ad} – mass shake in the moisture of analytical samples, w-%.

Report the ash content in the sample as an average of two determinations to the nearest 0.01 % when the ash content is below 10 %, or to the nearest 0.1 % if the ash content is 10 % and higher.

Determination of calorific values. The net calorific value of solid fuels for dry matter is determined in accordance with standard EN 14918:2010.

Gross calorific value is the absolute value of the specific energy of combustion, in joules, for unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under the conditions specified. The products of combustion are assumed to consist of gaseous oxygen, nitrogen, carbon dioxide and sulfur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under the conditions of the bomb reaction, and of solid ash, all at the reference temperature.

Net calorific value at constant volume is the absolute value of the specific energy of combustion, in joules, for unit mass of the biofuel burned in oxygen under conditions of constant volume and such that all the water of the reaction products remains as water vapour (in a hypothetical state at 0.1 MPa), the other products being as for the gross calorific value, all at the reference temperature.

As the third calorific value, the *net calorific value as received* can be given. This calorific value is the lowest one, as the energy used for evaporating water contained naturally in the fuel and water formed in combustion are reduced when calculating the calorific value. The calorific value is usually given as megajoules for kg fuel (MJ/kg, 1 MJ = 0.2778 kWh).

Gross calorific value. In EN 14918:2010 method about 1 g±0.1 of air-dry (equilibrium moisture content) analysis sample is burnt in high-pressure oxygen in a bomb calorimeter under specified conditions. The effective heat capacity of the calorimeter is determined in calibration experiments by combustion of certified benzoic acid under similar conditions, accounted for in the certificate. The corrected temperature rise is established from observations of temperature before, during and after the combustion reaction takes place. The duration and frequency of the temperature observations depend on the type of calorimeter used. The duration and frequency of the temperature observations depend on the type of calorimeter used. Water is added to the bomb initially to give a saturated vapour phase prior to combustion, thereby allowing all the water formed, from the hydrogen and moisture in the sample, to be regarded as liquid water. The gross calorific value is calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the biofusels) and for thermal effects from side reactions such as the formation of nitric acid. Furthermore, a correction is applied to account for the difference in energy between the aqueous sulfuric acid formed in the bomb reaction and gaseous sulfur dioxide, i.e. the required reaction product of sulfur in the biofuel.

The net calorific value at constant volume and the net calorific value at constant pressure of the biofuel are obtained by calculation from the gross calorific value at constant volume determined on the analysis sample. The calculation of the net calorific value at constant volume requires information about the moisture and hydrogen contents of the analysis sample. In principle, the calculation of the net calorific value at constant pressure also requires information about the oxygen and nitrogen contents of the sample. As the moisture content of the actual analysis sample is of interest merely in connection with the calculation to other bases, it is recommended to calculate a value for the gross calorific value at constant volume for the dry fuel, using the following equation (6):

$$q_{V,gr,d} = q_{V,gr} \times 100/(100\text{-}M_{ad}) \quad (6)$$

where: $q_{V,gr,d}$ – gross calorific value at constant volume of the dry (moisture-free) fuel, J/g; M_{ad} – moisture in the analysis sample, w-%; $q_{V,gr}$ – gross calorific value at constant volume of the fuel as analysed, J/g.

The result shall be reported to the nearest multiple of 10 J/g with unambiguous statements concerning the states constant volume, gross (liquid water), and moisture basis (e.g. dry or "as sampled").

Net calorific value. The energy of vaporization (constant volume) for water is at 25 °C is 41.53 kJ/mol. This corresponds to 206 J/g for 1% (weight) of hydrogen in the fuel sample or 13.05 J/g for 1 w-% of moisture, respectively. The net calorific value at content volume is derived from the corresponding gross calorific value according to equation (7) (EN 149186:2010).

$$q_{p,net,d} = q_{V,gr,d} - 212{,}2 \times w(H)_d - 0{,}8 \times [w(O)_d + w\,(N)_d] \quad (7)$$

where: $q_{p,net,d}$ – net calorific value for dry matter at constant pressure, MJ/kg; $q_{V,gr,d}$ – gross calorific value for dry matter, MJ/kg; $w(H)_d$ – the hydrogen content of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance), w-%; $H(O)_d$ – the oxygen content of the moisture-free biofuel, w-%; $w(N)_d$ – the nitrogen content of the moisture-free biofuel, w-%.

***Net calorific value of fuel as received* (Q_{ar}).** Net calorific value as received is calculated according to equations 8. The calorific value can be either determined for that particular lot or a typical value can be used. The net calorific value (at constant pressure) as received (the moist biofuel) can be calculated on the net calorific value of the dry basis according to equation (8).

$$q_{p,net,ar} = q_{p,net,d} \times (100 - M_{ar})/100 - 0{,}02443 \times M_{ar} \quad (8)$$

where: $q_{p,net,ar}$ – net calorific value (at constant pressure) as received, MJ/kg; $q_{p,net,d}$ – net calorific value (at constant pressure) in dry matter, MJ/kg; M_{ar} – moisture content as received (total moisture), w-%; 0,02443 – the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C (MJ/kg per 1 w-% of moisture).

The results of experimental investigation. The data obtained from physical and mechanical testing of pilot PCW-containing wood pellets for moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density, the length and diameter are shown in Tables 9-14.

Table 9. The results of testing PCW-containing wood pellets for moisture content

No	Factor value in the experiment						Moisture content measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	6.90	7.10	7.00	7.20	7.10
2	100	8	0	1	-1	-1	6.20	6.40	6.40	6.10	6.50
3	0	16	0	-1	1	-1	11.80	12.00	12.20	12.10	11.60
4	100	16	0	1	1	-1	11.10	10.90	10.80	10.90	10.80
5	0	8	3	-1	-1	1	9.80	9.90	9.70	9.60	9.90
6	100	8	3	1	-1	1	8.90	9.20	9.10	9.00	8.90
7	0	16	3	-1	1	1	10.80	10.90	10.70	10.80	10.90
8	100	16	3	1	1	1	9.80	9.80	9.90	10.00	9.90

Table 10. The results of testing PCW-containing wood pellets for ash content

No	Factor value in the experiment						Ash content measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	0.21	0.26	0.25	0.27	0.24
2	100	8	0	1	-1	-1	0.36	0.38	0.35	0.39	0.34
3	0	16	0	-1	1	-1	0.26	0.29	0.31	0.28	0.29
4	100	16	0	1	1	-1	0.46	0.42	0.46	0.48	0.45
5	0	8	3	-1	-1	1	0.53	0.57	0.55	0.59	0.54
6	100	8	3	1	-1	1	0.68	0.72	0.78	0.71	0.74
7	0	16	3	-1	1	1	0.62	0.64	0.63	0.65	0.65
8	100	16	3	1	1	1	0.86	0.88	0.84	0.94	0.90

Table 11. The results of testing PCW-containing wood pellets for mechanical durability

No	Factor value in the experiment						Mechanical durability measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	98.00	97.90	98.00	98.30	98.20
2	100	8	0	1	-1	-1	96.90	97.10	97.20	97.00	97.10
3	0	16	0	-1	1	-1	95.00	94.80	95.00	95.20	95.10
4	100	16	0	1	1	-1	94.00	93.80	94.20	94.00	93.90
5	0	8	3	-1	-1	1	98.90	99.00	98.70	98.90	99.00
6	100	8	3	1	-1	1	97.80	98.10	98.20	98.20	97.90
7	0	16	3	-1	1	1	97.10	97.30	97.30	96.90	97.00
8	100	16	3	1	1	1	95.90	96.00	96.20	96.20	96.30

Table 12. The results of testing PCW-containing wood pellets for fines at factory gate

No	Factor value in the experiment						Fines at factory gate measurements, w-%				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	0.99	0.98	0.97	0.99	0.96
2	100	8	0	1	-1	-1	0.88	0.95	0.97	0.95	0.95
3	0	16	0	-1	1	-1	0.87	0.92	0.95	0.88	0.93
4	100	16	0	1	1	-1	0.86	0.9	0.87	0.84	0.83
5	0	8	3	-1	-1	1	0.55	0.58	0.51	0.52	0.54
6	100	8	3	1	-1	1	0.48	0.53	0.49	0.49	0.46
7	0	16	3	-1	1	1	0.4	0.38	0.44	0.42	0.41
8	100	16	3	1	1	1	0.39	0.34	0.42	0.4	0.4

Table 13. The results of testing PCW-containing wood pellets for net calorific value

No	Factor value in the experiment						Net calorific value measurements, MJ/kg				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	19.21	19.20	19.32	19.28	19.08
2	100	8	0	1	-1	-1	19.10	19.11	19.16	18.92	18.95
3	0	16	0	-1	1	-1	18.14	18.15	17.96	18.12	17.98
4	100	16	0	1	1	-1	17.81	17.96	17.82	17.90	17.96
5	0	8	3	-1	-1	1	20.40	20.96	20.76	20.34	20.56
6	100	8	3	1	-1	1	20.15	19.97	19.88	20.22	20.16
7	0	16	3	-1	1	1	18.13	18.22	18.40	18.20	18.30
8	100	16	3	1	1	1	18.25	17.50	17.82	18.10	18.20

Table 14. The results of testing PCW-containing wood pellets for bulk density

No	Factor value in the experiment						Bulk density measurements, kg/m^3				
	actual values			actual values							
	Pc	Mc	Ac	x_1	x_2	x_3	y_{1j}	y_{2j}	y_{3j}	y_{4j}	y_{5j}
1	0	8	0	-1	-1	-1	640	642	640	643	637
2	100	8	0	1	-1	-1	628	632	629	631	633
3	0	16	0	-1	1	-1	658	657	659	662	658
4	100	16	0	1	1	-1	648	651	651	647	652
5	0	8	3	-1	-1	1	662	660	659	659	661
6	100	8	3	1	-1	1	653	652	650	654	652
7	0	16	3	-1	1	1	678	675	674	675	677
8	100	16	3	1	1	1	668	667	665	669	668

On calculating mean values and sample variances, the check on variance homogeneity in the experiments by means of Kohren G-criterion indicated that all the variances were homogeneous. By using similar procedure, the variances of reproducibility of measurements of physical and mechanical properties of wood pellets were calculated: for moisture content: $\mathbf{S_{re}^2}$ = 0.0201; for ash content: $\mathbf{S_{re}^2}$ = 0.0007; for mechanical durability: $\mathbf{S_{re}^2}$ = 0.0239; for fines at factory gate: $\mathbf{S_{re}^2}$ = 0.0007; for net calorific value: $\mathbf{S_{re}^2}$ = 0.0286; for bulk density: $\mathbf{S_{re}^2}$ = 3.3625. The root-mean-square deviation for calculated coefficients of regression equations made up: for moisture content: $\mathbf{S\{b_i\}}$ = 0.0224; for ash content: $\mathbf{S\{b_i\}}$ = 0.0041; for mechanical durability: $\mathbf{S\{b_i\}}$ = 0.02; for fines at factory gate: $\mathbf{S\{b_i\}}$ = 0.0042; for net calorific value: $\mathbf{S\{b_i\}}$ = 0.03; for bulk density: $\mathbf{S\{b_i\}}$ = 0.2899. On checking regression equations coefficients for meaningfulness and establishing their confidence intervals, the calculations showed that the regression equations coefficient are meaningful except for six ones (Tables 15-20), but we do not ignore them in consideration of system approach.

Table 15. Checking regression equation coefficients for meaningfulness, their confidence intervals for moisture content

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{tab}*S\{b_i\}$	$b_i+t_{tab}*S\{b_i\}$
b_o	9.465	0.046	Meaningful	9.419	9.511
b_1	-0.435	0.046	Meaningful	-0.481	-0.389
b_2	1.420	0.046	Meaningful	1.374	1.466
b_3	0.410	0.046	Meaningful	0.364	0.456
b_{12}	-0.060	0.046	Meaningful	-0.106	-0.014
b_{13}	0.010	0.046	No meaningful	-0.036	0.056
b_{23}	-0.945	0.046	Meaningful	-0.991	-0.899

Table 16. Checking regression equation coefficients for meaningfulness, their confidence intervals for ash content

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{tab}*S\{b_i\}$	$b_i+t_{tab}*S\{b_i\}$
b_o	0.519	0.008	Meaningful	0.511	0.528
b_1	0.088	0.008	Meaningful	0.079	0.096
b_2	0.046	0.008	Meaningful	0.038	0.055
b_3	0.182	0.008	Meaningful	0.173	0.190
b_{12}	0.016	0.008	Meaningful	0.007	0.024
b_{13}	0.016	0.008	Meaningful	0.008	0.025
b_{23}	0.014	0.008	Meaningful	0.005	0.022

Table 17. Checking regression equation coefficients for meaningfulness, their confidence intervals for mechanical durability

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{таб}*S\{b_i\}$	$b_i+t_{таб}*S\{b_i\}$
b_o	96.790	0.050	Meaningful	96.740	96.840
b_1	-0.490	0.050	Meaningful	-0.540	-0.440
b_2	-1.230	0.050	Meaningful	-1.280	-1.180
b_3	0.755	0.050	Meaningful	0.705	0.805
b_{12}	-0.020	0.050	No meaningful	-0.070	0.030
b_{13}	0.025	0.050	No meaningful	-0.025	0.075
b_{23}	0.305	0.050	Meaningful	0.255	0.355

Table 18. Checking regression equation coefficients for meaningfulness, their confidence intervals for fines at factory gate

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				$b_i-t_{таб}*S\{b_i\}$	$b_i+t_{таб}*S\{b_i\}$
b_o	0.690	0.009	Meaningful	0.681	0.698
b_1	-0.020	0.009	Meaningful	-0.028	-0.011
b_2	-0.047	0.009	Meaningful	-0.056	-0.039
b_3	-0.232	0.009	Meaningful	-0.241	-0.224
b_{12}	0.002	0.009	No meaningful	-0.006	0.011
b_{13}	0.002	0.009	No meaningful	-0.006	0.011
b_{23}	-0.010	0.009	Meaningful	-0.019	-0.002

Table 19. Checking regression equation coefficients for meaningfulness, their confidence intervals for net calorific value

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				b_i-t_{ra6}*$S\{b_i\}$	b_i+t_{ra6}*$S\{b_i\}$
b_o	18.891	0.055	Meaningful	18.837	18.946
b_1	-0.144	0.055	Meaningful	-0.199	-0.090
b_2	-0.845	0.055	Meaningful	-0.900	-0.791
b_3	0.335	0.055	Meaningful	0.280	0.389
b_{12}	0.030	0.055	No meaningful	-0.024	0.085
b_{13}	-0.057	0.055	Meaningful	-0.111	-0.002
b_{23}	-0.269	0.055	Meaningful	-0.323	-0.214

Table 20. Checking regression equation coefficients for meaningfulness, their confidence intervals for bulk density

Coefficient	Coefficient value	$t(q,f_y)S\{b_i\}$	Conclusion	Confidence interval boundaries	
				b_i-t_{ra6}*$S\{b_i\}$	b_i+t_{ra6}*$S\{b_i\}$
b_o	654.400	0.591	Meaningful	653.809	654.991
b_1	-4.400	0.591	Meaningful	-4.991	-3.809
b_2	8.550	0.591	Meaningful	7.959	9.141
b_3	9.500	0.591	Meaningful	8.909	10.091
b_{12}	0.050	0.591	No meaningful	-0.541	0.641
b_{13}	0.300	0.591	No meaningful	-0.291	0.891
b_{23}	-0.850	0.591	Meaningful	-1.441	-0.259

The regression equation coefficients obtained as a result of the full-factorial plan realization possess a clean physical meaning. The coefficient $\mathbf{b_o}$ is equal to the output value and of all factors are fixed at the basic level. The sigh of the coefficient $\mathbf{b_i}$ points to the nature of corresponding factor influence: if $\mathbf{b_i>0}$, the output value tends to increase with an increase of the factor $\mathbf{X_i}$ value, and vice versa. The absolute value of the regression coefficient in the model points to the extent to which the response function is affected by the corresponding factor. The higher absolute value of the coefficient, the stronger influence on the output parameter change has the factor to which the given coefficient corresponds. Thus, the extent of the factors effect on the output values can be compared by means of linear regression model and so revealing the most important factors.

In order to evaluate the ability of the obtained models to describe output values with the same degree of accuracy as the experimental results, the mathematical models were checked for their adequacy by Fisher F-criterion by means of which the variances of adequacy $\mathbf{S_{ad}^2}$ and reproducibility $\mathbf{S_{re}^2}$ are compared.

The calculated adequacy variances for physical and mechanical properties of PCW-containing wood pellets made up: for moisture content $\mathbf{S_{ad}^2}$ = 0.009; for ash content $\mathbf{S_{ad}^2}$ = 0.0042; for mechanical durability $\mathbf{S_{ad}^2}$ = 0.009; for fines at factory gate $\mathbf{S_{ad}^2}$ = 0.0011; for net calorific value $\mathbf{S_{ad}^2}$ = 0.0043; for bulk density $\mathbf{S_{ad}^2}$ = 0.9.

The calculated values for Fisher criterion for physical and mechanical properties of PCW-containing wood pellets made up: for moisture content $\mathbf{F_{cal}}$ = 2,236; for ash content $\mathbf{F_{cal}}$ = 1,592; for mechanical durability $\mathbf{F_{cal}}$ = 2,653; for fines at factory gate $\mathbf{F_{cal}}$ = 1,549; for net calorific value $\mathbf{F_{cal}}$ = 1,5; for bulk density $\mathbf{F_{cal}}$ = 3,736.

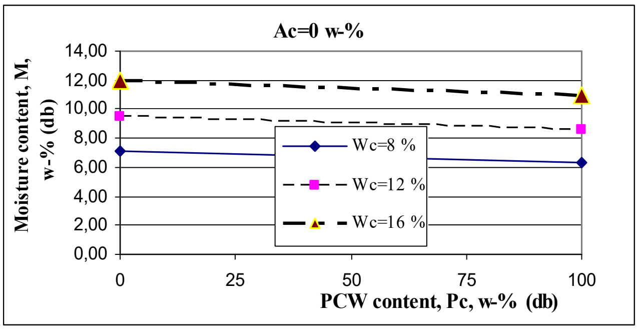
The tabulated value for Fisher criterion is equal to $\mathbf{F_{tab}}$ = ***F(7; 5) =6,1***. By comparing the calculated values for Fisher criteria with the tabulated ones, we can see that the inequality $\mathbf{F_{cal}} < \mathbf{F_{tab}}$ is accomplished for physical and mechanical properties of PCW-containing wood pellets. That is, the mathematical models obtained are considered adequate and can be used to describe objects.

Thus, the calculations done made it possible to obtain the following regression equations of the full-factorial plan with actual factor values for physical and mechanical properties.

$$M = 2{,}225 - 0{,}0051Pc + 0{,}6063Wc + 2{,}157Ac - 0{,}06PcWc + 0{,}00013PcWc - 0{,}1575WcAc$$
$$A = 0{,}216 + 0{,}00048Pc + 0{,}0042Wc + 0{,}083Ac + 0{,}00008PcWc + 0{,}00022PcWc + 0{,}0023WcAc$$
$$DU = 101{,}095 - 0{,}0091Pc - 0{,}37875Wc - 0{,}1234Ac - 0{,}0001PcWc + 0{,}00033PcAc + 0{,}05083WcAc$$
$$F = 1{,}062 - 0{,}00058Pc - 0{,}0981Wc - 0{,}13583Ac + 0{,}00001PcWc + 0{,}00003PcAc - 0{,}00171WcAc$$
$$Q = 20{,}464 - 0{,}0035Pc - 0{,}1517Wc + 0{,}7985Ac + 0{,}00015PcWc - 0{,}00076PcAc - 0{,}0448WcAc$$
$$BD = 621{,}55 - 0{,}097Pc + 2{,}34Wc + 7{,}83Ac + 0{,}00025PcWc + 0{,}0004PcAc - 0{,}1417WcAc$$

The data of regression equations describe the physical and mechanical properties of PCW-containing wood pellets and allow output values to be calculated for any point of the experiment zone provided that $\mathbf{X_i = [-1;+1]}$, where $\mathbf{i = 1, k}$.

Since the influence of factors and their interaction on the response function is best analyzed graphically, six groups of diagrams were constructed by regression equations: the relationship between output value (moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density) and PCW content, chips moisture at the constant values for the additives content at the minimum, mean, and maximum levels (Fig. 1-6).



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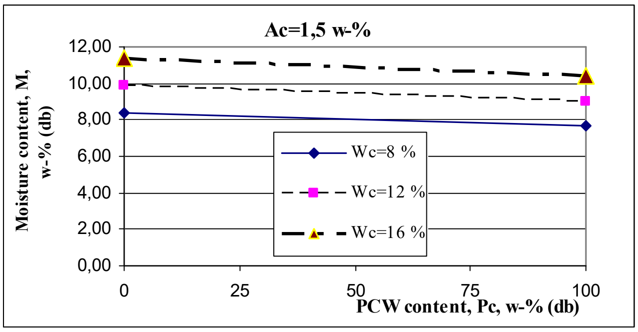

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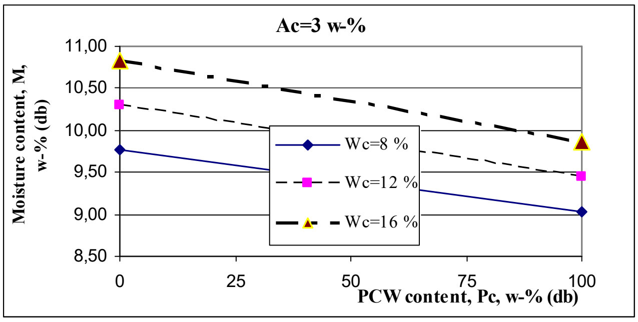


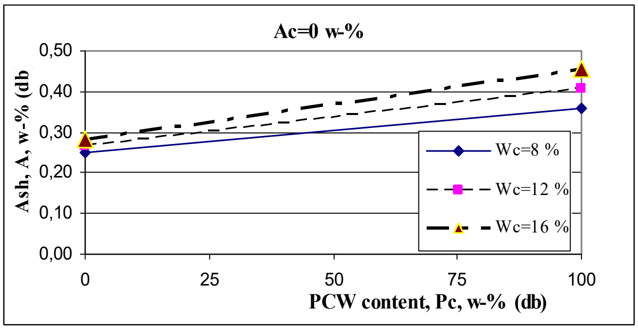
c

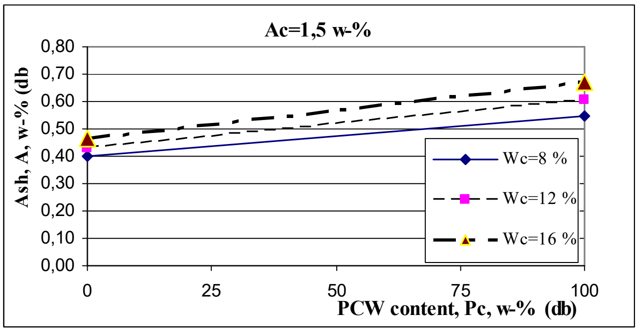
Fig. 1. The dependence of the <u>moisture content</u> of wood pellets on the content of PCW, chips moisture, content of additives:
a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

Graphical representation of the relationships obtained allows for revealing the character of variable factors influence on the properties of the resulting wood pellets, since the full-factorial plan was realized here, all the dependences have linear character. The diagrams also show that the lines do not run parallel to one another, and the angle of their slope varies as certain variable factors change. This points to the fact that the influence of factors interaction is just as significant as the influence of the individual factors.

As is easily seen from the diagrams, PCW content in fuel pellets has a linear dependence (either increases or decreases) within a 0-100% range at different additive (binder) content. In particular, at a 1.5% value for the additive content and chips moisture content prior to pressing of 12% the ash content increases from 0.43 to 0.61% (by

41.8%), while all the other tested pellet parameters decrease: the moisture content – from 9.90 to 9.03% (by 9.8%), mechanical durability – from 97.28 to 96.3% (by 1.0%); wear resistance – from 0.71 to 0.67% (by 5.6%), calorific value – from 19.04 to 18.75% MJ/kg (by 1.5%). For the first variable factor (PCW content), the change in moisture content and wear resistance are of positive character, while all the other parameters meet the requirements for fuel pellets for non-industrial use of B-class. The mechanical durability value, though less than 96.5%, can be raised by slightly increasing the dose of additives or by reducing the initial moisture level of the chips.





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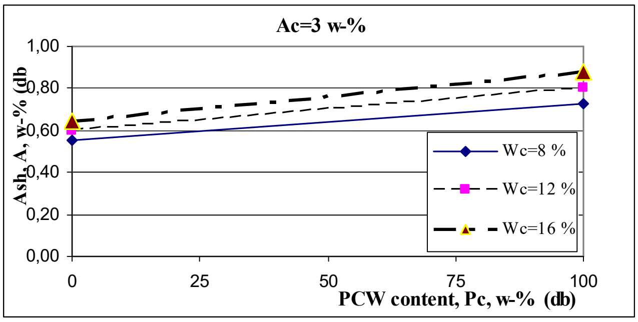
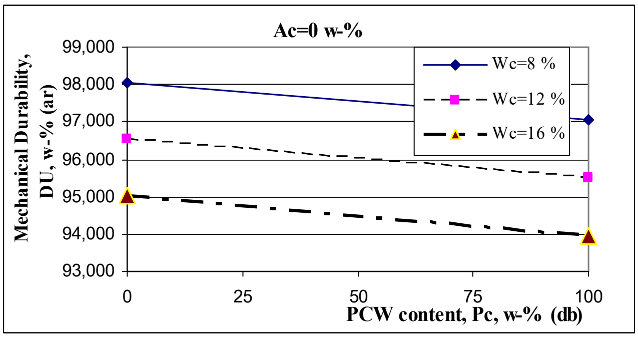
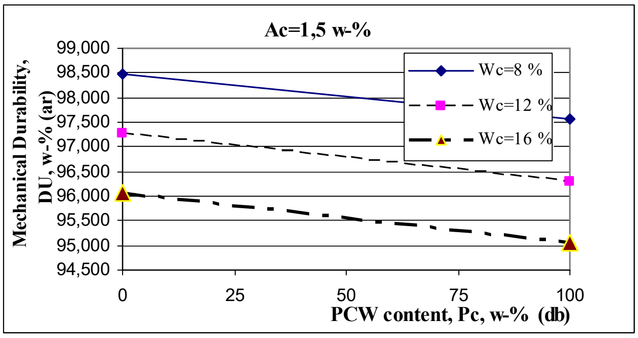


c

Fig. 2. The dependence of the <u>ash content</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %





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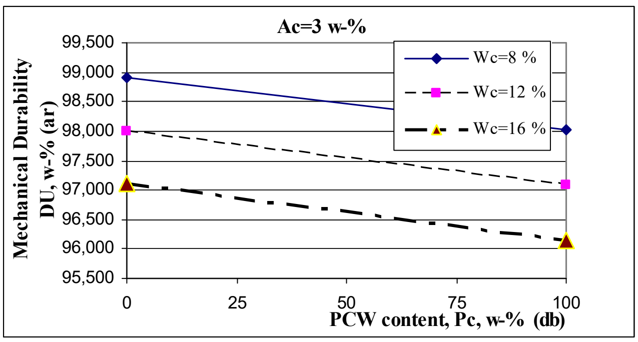


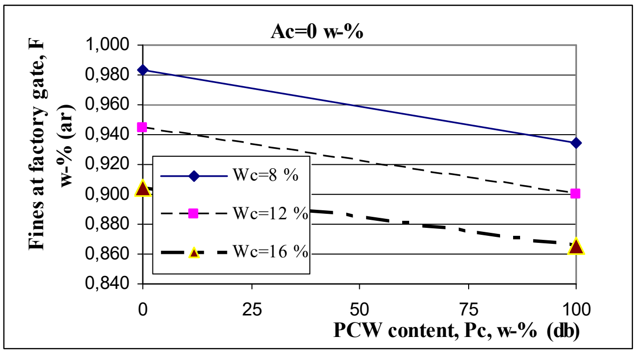
c

Fig. 3. The dependence of the <u>mechanical durability</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

The studies revealed that for pellets with a 100% PCW content with no additives, the chips initial moisture content (8-16%) has varied effects jn their characteristics namely, there is an increase in: ash content – from 0.364 to 0.464% (by 24.7%); moisture content – from 6.32 to 10.9% (by 72.5%); bulk density – from 630.6 to 649.8

kg/m3 (by 3%), while all the other tested pellet parameters decrease: mechanical durability – from 97.06 to 93.98% (by 3.9%); wear resistance – from 0.94 to 0.86% (by 8.5%); calorific value – from 19.05 to 18.89 MJ/kg (by 6.1%).



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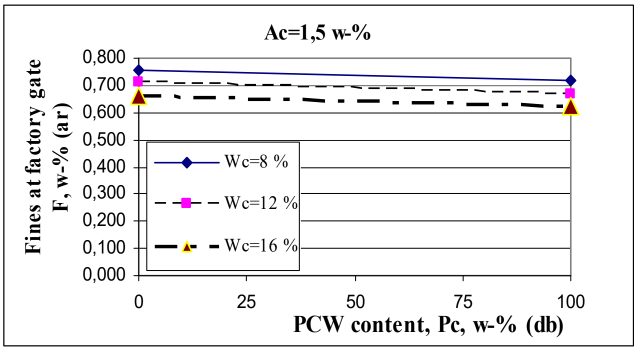

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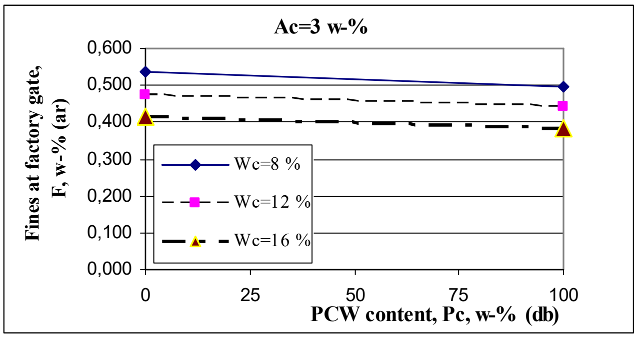

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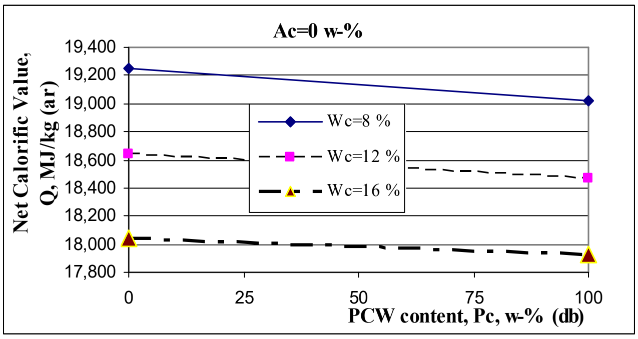
Fig. 4. The dependence of the <u>fines at factory gate</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %



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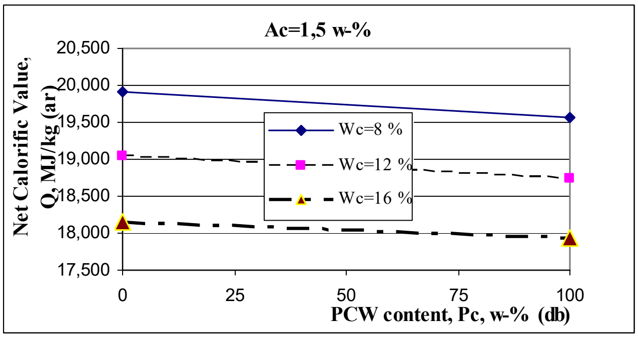

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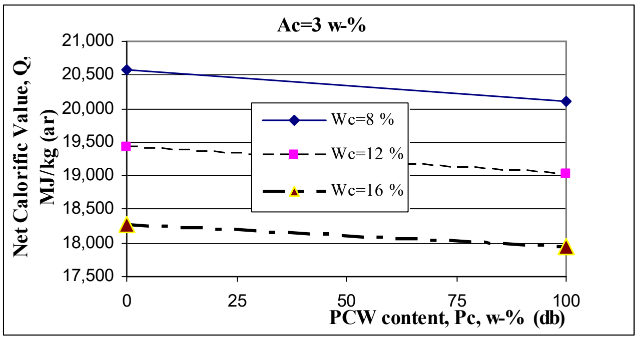


c

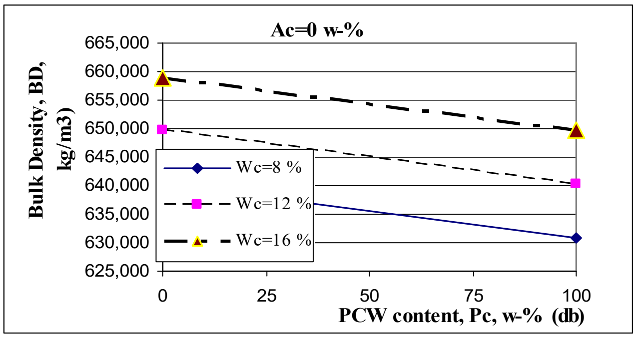
Fig. 5. The dependence of the <u>net calorific value</u> of wood pellets on the content of PCW, chips moisture, content of additives:

a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

For the second variable factor (chips moisture content), the change in the bulk density is of positive character. All the other parameters need to be corrected by drying wood particles and regulating surface moisture prior to blending in order to ensure the moisture content within a 11-12% range, since smaller moisture level would lead to increased energy consumption during the pellets manufacture.

The results of the experiments also show that the properties of pellets, with a 100% PCW content and chips initial moisture of 12%, are strongly affected by the additive content (0-3%), that is there is an increase in: ash content – from 0.41 to 0.81% (by

97.5%); moisture content – from 8.61 to 9.45% (by 9.8%); mechanical durability – from 95.52 to 97.08% by 1.6%); calorific value – from 18.47 to 19.03 MJ/kg (by 3%); bulk density – from 640.2 to 659.8 kg/m3 (by3.1%), while wear resistance decreases from 0.9 to 0.44% (by 51.2%). For the third variable factor (additive content), the changes in bulk density, mechanical durability, calorific value, and wear resistance are of positive character. The increased ash content is accounted for by using starch as an additive the ash content of which being 4%. Besides starch is able to intensely absorb the initial moister, which results in increased moister content of the fuel pellets. Since the standard EN 1496-2 does not allow the additives to exceed 2%, then it is possible, by meeting the given requirement, to obtain fuel pellets for non-industrial use which would correspond to class B. Moreover, the use of additives allows the pelletizing of chipped material to be made at less energy consumption at an average pressure of 20-100 MPa.



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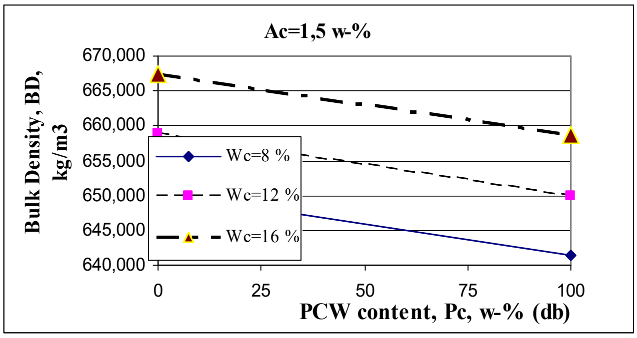

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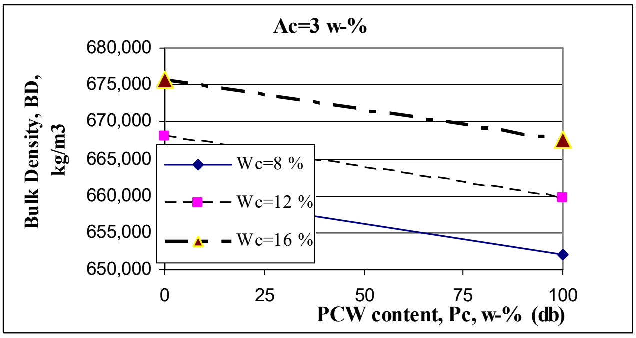


c

Fig. 6. The dependence of the bulk densit of wood pellets on the content of PCW, chips moisture, content of additives:
a) Ac=0 %; b) Ac=1.5 %; c) Ac=3 %

A change (decrease or increase) in the physical and mechanical properties of wood pellets with increased PCW content is caused by the following reasons:

- age characteristics of PCW – 20-50 years;
- reduction of lignin content in PCW (by 18 to24 % for hardwood and for softwood from 28 to 30 %) as the main component of chips for quality bonding and pressing;
- contamination with soil or sand;
- contamination during use, storage and transport;
- presence or high content of bark;
- presence or high content of inorganic or organic additives;
- initial PCW ash content;
- presence of coatings (paint);
- chemical treatment;
- the use of wood preservatives;
- the presence of flammable substances (glue, tar, oil, plastics, laminates);
- higher initial moisture of wood particles – 16%;
- fractional composition of chips;
- temperature of the chips.

The large number of factors effecting the properties and quality parameters of fuel pellets has motivated extension of the studies on fuel pellets production from PCW of various origin and sources. In this connection, a classification of PCW, as raw material for fuel pellets production, has been developed (Table 21) based on Table 3 and the developed PCW classifier [20]

Table 21. Classification of woody biomass for experimental studies of test pellets

Code	Sub-group source	Kind	Varieties
By-products and residues from wood processing industry			
1.2.1.1	Without bark, Broadleaf	Wood waste from woodworking and machining	Waste, cuttings, shavings from solid wood in its natural state
			Waste, cuttings, shavings from derived timber products and other treated wood (with no harmful contaminants)
1.2.1.2	Without bark, Coniferous	Wood waste from woodworking and machining	Waste, cuttings, shavings from solid wood in its natural state
			Waste, cuttings, shavings from derived timber products and other treated wood (with no harmful contaminants)
Used wood (recovered wood, post-consumer wood)			
1.3.1.1	Without bark, Broadleaf	Blends	Oak, beech, birch, ash, hornbeam, maple and other
1.3.2.1	Without bark, Coniferous	Blends	Pine, spruce, fir, larch, cedar and other
1.3.3.1	Wood-based panel	Composite materials	Particleboards (PB), MDF, OSB, plywood and other composite materials
1.3.3.2	Packaging	Palettes	Palettes made from solid wood such as: Europalettes, industrial palettes made from solid wood
			Palettes made from derived timber products
			Other palettes with composite materials
		Boxes	Transport cases, crates made from solid wood
			Transport cases made from derived timber products
			Boxes for fruit, vegetables and ornamental plants as well as similar boxes made from solid wood
			Ammunition boxes
		Cable reels	Made from solid wood (made before 1989)
			Made from solid wood (made after 1989)
1.3.3.3	Waste wood from the construction industry	Waste wood from buil-ding sites	Solid wood in its natural state
			Derived timber products, barked wood, treated solid wood (with no harmful contaminants)
		Waste wood from tearing down and sorting out	Boards, false ceilings, planks from interior works (with no harmful contaminants)
			Door leaves and frames (with no harmful contaminants)
			Profile boards for the fitting out of rooms, ceiling panels, ornamental beams etc. (with no harmful contaminants)
		Waste wood from demolition and restoration work	Chipboard used in construction
			Wood used in construction for load-bearing elements
			Timber framework and rafters
1.3.3.4	Furniture	Different setting	Furniture, solid wood in its natural state
			Furniture, with no halogenated organic compounds in the coating
1.3.3.5	Municipal waste wood	Blends and mixtures	Various wood used in horticulture and landscaping, impregnated garden furniture
			Various wood used in agriculture
			Other blends and mixtures
1.3.3.6	Solid domestic waste wood	Blends and mixtures	Blends and mixtures of woody biomass

Re-use/recycling. The waste wood Sub-group source may be used for the manufacture of fuel pellets, active carbon/industrial charcoal and the production of synthetic gas as well as in incineration and gasification plants that are licensed pursuant to the Fourth Ordinance on the Imple-mentation of the Federal Emission Control Act and with regard to emissions are subject to the Seventeenth Ordinance on the Implementation of the Federal Emission Control Act. During these procedures, the organic pollutants contained in the waste wood are completely destroyed due to the high temperatures. Heavy metals are bound as solid in the residues or dispersed during waste gas purification. Only certain pollution-free or low-pollution waste woods can be considered for use in manufacturing derived timber products. Compliance with this requirement is guaranteed by binding pollutant limit values, including relevant sampling and analysis provisions, for the wood chips produced for use as raw materials for the manufacture of derived timber products. Waste wood processed in this manner for the derived timber products industry ceases to be waste and can be processed there as a primary raw material.

Comparative studies of fuel pellets with different PCW. The raw material for the experiments on manufacturing fuel pellets was woody biomass, according to the classification of PCW (Table 3, Sub-code). To compare the properties of pellets from PCW, waste from virgin wood was taken. According to the developed technology for producing fuel pellets from PCW with different woody biomass the following operating parameters for pelletizing process were proposed:

- wood particles selected sample – 100%;
- particles moisture prior to pressing – 12%;
- fractional composition: less than 3.15 mm – > 97%; less than 2.0 mm – > 90%; less than 1.0 mm – > 50%; less than 0.1 mm – < 5%;
- chips bulk density – 200-250 kg/m^3;
- additives – 0%;
- hole diameter – 6 mm;
- temperature range for compression – 90-100 °C;
- compacting pressure – 20-150 MPa;
- distance between the die and rollers – 0.3 mm;
- the ratio of the length of the die channel to its diameter – 3.5;

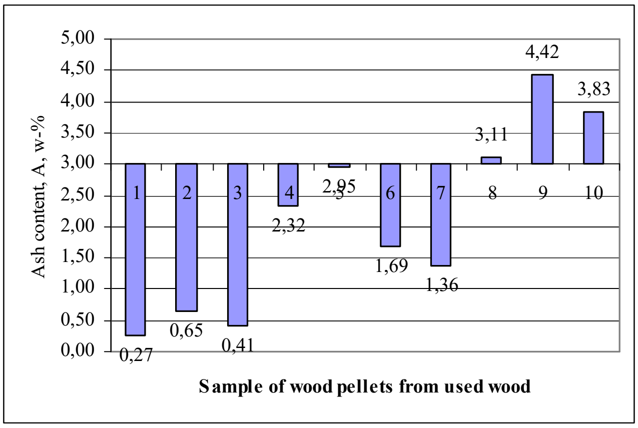
Fuel pellets test was performed according to the standards EN methodology.

Results of comparative experimental study. Data obtained from the physical and mechanical testing of experimental fuel pellets from different PCW (ten samples) for moisture content, ash content, mechanical durability, fines at factory gate, net calorific value, bulk density, diameter and length are given in Table 22.

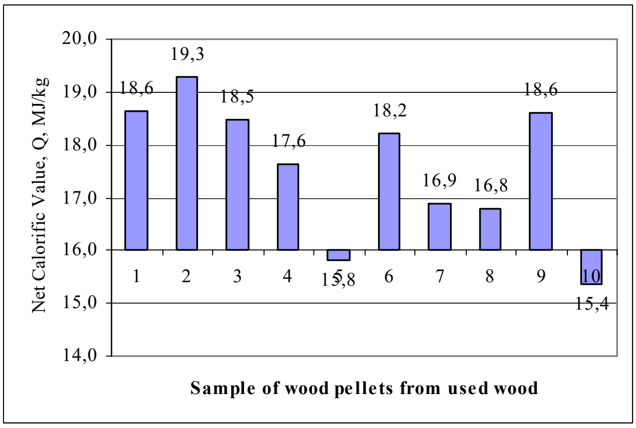
Table 22. Comparative analysis of the properties of wood pellets from the virgin wood and used wood, the results of the research

Parameter	Unit	Method EN	Limit EN B	The results of testing wood pellets from different origins and sources of biomass (Table 3)									
				virgin wood		**used wood – recovered wood, post-consumer wood**							
Origin and source		14961-1		1.2.1.1 Broadleaf	1.2.1.2 Coniferous	1.3.1.1 Broadleaf	1.3.2.1 Coniferous	1.3.3.1 WBP	1.3.3.2 Coniferous	1.3.3.3 Coniferous	1.3.3.4 Furniture	1.3.3.5 Blends	1.3.3.6 Blends
Diameter, D	mm	16127	6±1	6.2	6.1	6.2	6.1	6.3	6.2	6.2	6.4	6.4	6.3
Length, L	mm	16127	≤40	≤3.15 mm length ≤40 mm, maximum ≤45 mm (1 %)									
Moisture, M	w-%	14774-2	≤10	9.5	8.2	8.6	7.9	7.6	8.0	7.7	8.6	8.9	9.6
Ash content, A	w-%	14775	≤3.0	0.27	0.652	0.41	2.322	2.952	1.685	1.363	3.111	4.424	3.825
Mechanical Durability, DU	w-%	15210-1	≤96.5	96.55	99.2	95.52	98.31	95.64	96.65	97.25	93.44	92.63	92.81
Fines at factory gate, F	w-%	15149-1	≤1.0	0.94	0.452	0.9	0.651	1.112	0.78	0.886	1.2	0.954	1.545
Net Calorific Value, Q	MJ/kg	14918	≤16.0	18.64	19.28	18.47	17.62	15.8	18.22	16.9	16.8	18.6	15.36
Bulk Density, BD	kg/m^3	15103	≥600	649.6	660.7	640.2	652.3	610.5	654.6	632.8	612.2	611.9	605.8
Additives	w-%		≤2	0	0	0	0	0	0	0	0	0	0
Sample of wood pallets				1	2	3	4	5	6	7	8	9	10

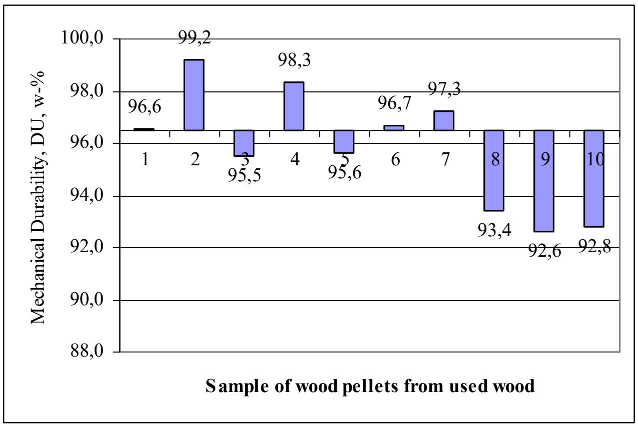
For the sake of convenience of analysing test parameters of all 10 samples, nomograms for each fuel pellet characteristics have been constructed (Fig. 7-8).



a

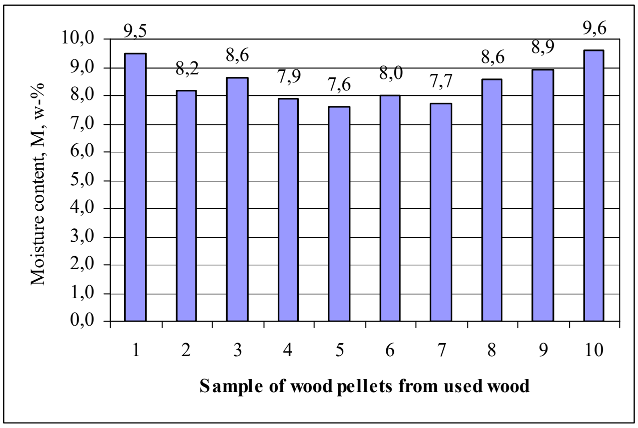


b

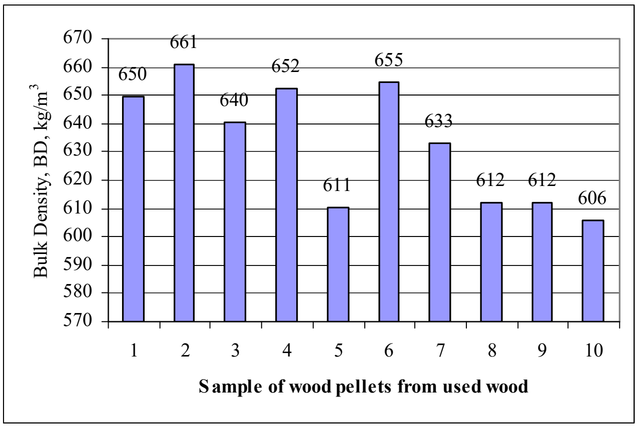


c

Fig. 7. Nomograms for ten samples of fuel pellets from different used wood for: *a) Ash content; b) Net Calorific Value; c) Mechanical Durability*



a



b

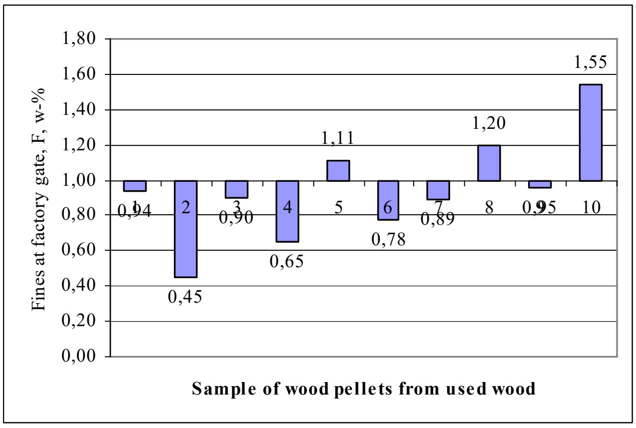


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Fig. 8. Nomograms for ten samples of fuel pellets from different used wood for: *a) Moisture content; b) Bulk Density; c) Fines at factory gate*

The nomograms, constructed according to the results of comparison studies, gave an insight into the nature of the used biomass: two samples from virgin wool and eight samples of PCW of various origin. The values for the controlled parameters of the samples were compared to normative values for fuel pellets of class B.

The value for ash content in samples 8, 9, and 10 exceeded the normative value of 3% and, respectively amounted to 3.11%, 4.42%, and 3.83%, which might have been caused by PCW contamination introduced during the process of usage, storage, transportation; the presence of increased content of bark; the presence of increased content of either organic or inorganic foreign material; chemical treatment (wood preservation, impregnation, modification); the presence of surface coating (varnish, paint, enamel, etc.).

The calorific value for eight samples were lower than the normative value of 16 MJ/Kg for fuel pellets of class B, which was due to the presence of flammable material in some samples (resin, oils, plastic, laminate) that have high combustion heat level. Samples 5 and 10 showed reduced calorific value, which stems from natural ash content in PCW and the presence of flammable material such as glues that have low combustion heat value.

The mechanical durability for five samples was lower than the normative value of 96.5%, which is explained by: age characteristics of the PCW; species composition; reduced lignin content in some PCW; presence of increased content of bark; particles initial moisture content; fractional composition of the chips; the temperature of the chips. In the other five samples, the mechanical durability value was in compliance with EN14961-2:2011 for pellets of class B. The parameter such as wear resistance had a deviation (1%) from the normative value, which was possibly due to contamination with soil or sand; contamination introduced during utilization, storage, transportation; increased particles initial moister content. The other controlled parameters such as bulk density, moister content, diameter and length of the fuel pellets in all of the samples were in compliance with EN 14961-2:2011 for pellets of class B.

The production process for commercial manufacturing fuel pellets from PCW should include the following stages: segregation of the wood and foreign material (contaminants), crushing the wood to a particle size of no more than 25×25×2 mm; drying; rechipping the particles to a size of more than 4mm; mixing of the chipped material with water and vapor; pelletizing on the pellets making mill; the pellets screening to separate the fines; packing the end-product. The production line and the auxiliary premises should be located over an area of about 600-700 m^2. The approximate consumption of material resources will amount to: electric power – estimated 120 kW per tonne of finished product; water vapor – 70 kg/tonne; water – 10 kg/tonne; heat consumption for wood drying – about 1 MWh/tonne for dried wood with the initial moister content of 35-40%. A team of 8 to 9 men will suffice to serve the line in operation. The recoupment the enterprise will depend on the line production capacity, the type of equipment installed, raw material cost, market price for the end-product, the level of manufacturing expenses. The maximum economic gain is likely to be found at those enterprises which will make a maximum use of PCW since the raw material cost will be minimal there. An estimated bound box of the line with a capacity of 2 tonnes per hour, on condition of exporting the product at a price of 70-90 euro/tonne , will make up 15 to 20 working months. The analysis of the existing pelletizing lines shows the need for upgrading individual units and installation of devices, which would jointly provide for manufacturing quality fuel pellets from PCW.

In this connection, the following measures have been taken:

- The improvement of the equipment of the fuel pellets production line.
- The improvement of the equipment of the drum chippers, in particular they need to be fitted with a net-like insert for chip sizing. This will eliminate the need for further sizing and, consequently, further chipping of PCW. In order to enhance the chippers cutting performance and improve the quality of the produced chips, the cutting part of the machine needs to be made in the form of several sections where the cutters in the adjacent section should be installed at the right angle relative to each other.
- The development of the temperature control system for the pelletizing die.
- Upgrading the system of control over the pelletizing process with the aid of microprocessor-based autoproportioner.
- The improvement of the chips moisture content controller at the point of entry, and the digital stabilizer of moisture at the point of exit.
- Upgrading the blender for dry and wet chips with partial control of feed speed depending on the loading of engine drive.
- Upgrading the gravity segregator for the chipped material and impurities.
- Installation of metal detector on the line at the point of entry, a suspended magnetic strip and magnetic vibrating screen – the moving floor.

Conclusions and recommendations

Conclusion with respect to the work as a whole:

- The topicality of PCW usage for fuel pellets manufacture has been substantiated.
- On the basis of ideas, hypotheses, approaches and means, there have been formulated the aim, object, subject, and tasks of the studies.
- Carried out here was a detailed analysis of the European standards EN which set requirements for solid biofuel (fuel pellets) depending on the biomass used, its origin; also these standards define the main technical specifications, fuel quality and standardized methods for its determination.
- A thorough study has been conducted on the biomass raw material base including PCW for manufacturing fuel pellets.
- A multifactorial experiment has been performed according to the procedure of the study.
- Investigated was the influence of the PCW content within a 0 - 100% range of chip moisture content, and additive content upon the physical-and-mechanical properties of the fuel pellets: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.
- A comparative analysis of physical-and-mechanical properties of fuel pellets for their compliance with the standards has been made for 10 biomass samples: two samples included pure waste form broadleaved and coniferous species, and eight samples – PCW of various sources and origin: in blended – and pure forms.
- The equipment for manufacturing fuel pellets form PCW has been developed for PCW preparation and pelletizing.
- An estimation has been made for socio-economic efficiency resulting from the implementation of the practical recommendations for manufacturing fuel pellets from PCW.

Conclusions with respect to the studies:

- Blending waste (used wood) materials with wood sawdust to make pellets from such blends can result in an acceptable pellet ash content, i.e., 3%.
- Blending waste (used wood) materials with wood sawdust to make pellets from such blends produces pellets of acceptable mechanical strength.
- Blending waste (used wood) materials with wood sawdust exspands the raw material base needed to make fuel pellets.
- Waste (used wood) biomass substances that are presently being landfilled can be used in pellet manufacturing. This will reduce the pressure on landfills.
- Such waste biomass substances are available at a negative cost, unlike wood sawdust, so pellet production costs will be lower.

Conclusion with respect to the PCW issue:

- Monitoring of PCW in Ukraine has been fulfilled

- The sources and PCW origin have been examined: solid domestic waste, municipal waste, commerce (package, pallets), construction waste, wood-processing industry by-products and residue, and others.
- The amount of PCW produced in Ukraine has been estimated, which made up 2.0 million tonnes in 2012.
- Classification has been developed with reference to the degree of PCW contamination, PCW source and origin as well as corresponding categories and codes are provided.
- It has been found that the proposed classification, on the basis of the most important characteristics, represents adequately the source and origin for production of solid biofuel – fuel pellets form PCW.
- It has been shown that there is an obvious need for PCW identification in order to obtain information on physical-and-mechanical properties considering that PCW is realizable additional biomass for obtaining a quality product.
- It has been proved that 50% of PCW (1.0 million tonnes) is suitable for energy use in particular for producing fuel pellets.

Conclusions with respect to the analysis fo PCW-containing fuel pellets:

- For the purpose of the end – product identification, it has been proposed, by applying the above mentioned classification, to perform differentiation of the biofuel, and PCW – made fuel pellets in particular, based on the raw material (here: PCW) origin.
- The determination of the particle-size distribution was done by using vibrating screen with mesh size of 3.51mm and under. The fraction composition of chip for various PCW samples, according to the experimental results, made up: < 3.15mm – 97.2 – 98.1%; < 2.0mm – 90.3 – 91.4%; < 1.0mm – > 54.7 – 62.2%; < 0.1mm – < 2.8 – 4.3%, which is in compliance with the requirements of EN 15149-2:2010 (DSTU-P CEN/TS 15149-2:2009).
- Investigated was the influence of PCW content, chips moisture content and additive content on the physical-and-mechanical properties of PCW-containing fuel pellets: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density, – these having been determined by standard methods.
- It has been found that the PCW content within the range of 0-100% has a linear dependence on various additive contents. In particular, at a 1.5% additive content and the chips moisture content of 12% prior to pressing, the ash the increases from 0.43 to 0.61% (by 41.8%), while all the other tested parameters of the fuel pellets are reduced: moisture content – from 9.90 to 9.03% (by 9.8%), mechanical strength – from 97.28 to 93.3% (by 1.0%), wear resistance – from 0.71 to 0.67% (by5.6%), calorific value – from 19.04 to 18.75 MJ/kg (by 1.5%), bulk density – from 658.8 to 650 kg/m^3 (by 1.3%). For the first variable factor (PCW content), the change in moisture content and wear resistance is of positive character, all the other parameters, are in compliance with the requirements for fuel pellets of non-industrial use, class B. The mechanical property, though less than 96.5%, is possible to raise in this case, by a slight increase in the additive content or by reducing the initial moisture content of the particles.
- It has been established that for the fuel pellets with a 100% PCW content and without additives, the chips moisture content (ranging from 8 to 16%) has different effects on the change of fuel pellets characteristics, namely, there is an increase in: ash content – from 0.364 to 0.464% (by 24.7%), moisture content – form 6.32 to 10.9% (by 72,5%), bulk density – from 630.6 to 649.8 kg/m^3 (by 3%), while all the other tested parameters of the pellets decrease: mechanical strength – from 97.06 to 93.98% (by 3.9%), wear resistance – from 0.94 to 0.86 (by 8.5%), calorific value – from 19.05 to 17.89 MJ/kg (by 6.1%). For the second variable factor (chips moisture content), the change in the bulk density is of positive character. All the other parameters need to be improved by way of drying the wood particles and dosing the surface moisture content prior to blending in order to ensure the moisture content prior to pressing to be within the range of 11-13% since lower moisture content leads to increased energy consumption during the pelletizing process.
- It has been revealed that the properties of pellets with a 100% PCW content and the chips initial moisture content of 12%, are essentially influenced by the additive content (0-13%), namely, there is an increase in: ash content – from 0.41 to 0.81% (by 97.5%), moisture content – from 8.61 to 9.45%

(by 9.8%), mechanical strength – from 95.52 to 97.08% (by 1.6%), calorific value – from 18.47% to 19.03 MJ/kg (by 31%), bulk density – from 640.2 to 659.8 kg/m^3 (by 3.1%), while the wear resistance decreases from 0.9 to 0.44% (by 51.2%). For the third variable factor (additive content), the change in bulk density, mechanical strength, calorific value, and wear resistance are of positive character. The increased ash content is 4%, was used as an additive. Besides, starch as able to intensely absorb initial moisture, which resulted in increased moisture content of the fuel pellets. Since the standard EN 14961-2 does not permit the additive content to exceed 2%, then, on satisfying this requirements, it is possible to obtain fuel pellets for non-industrial use in accordance with class B. Besides, the use of additives allows pelletizing of chipped material to be performed with lower energy consumption – at average pressure values of 20-50 MPa.

- Obtained are adequate mathematical models of the fuel pellets parameters depending on the three variable factors: PCW content, chips moisture content, and additive content.
- A comparative analysis was made concerning the properties of fuel pellets made from PCW of various origin for the following parameters: moisture content, ash content, mechanical strength, wear resistance, calorific value, bulk density.
- It has been found that the ash content exceeded the normative value (3%) in 3 of 10 samples, which is possibly due to PCW contamination with dirt or sand; contamination in the process of usage, storage, transportation; availability or high content of bark; availability or due to increased content of either organic or inorganic matter; chemical treatment (preservation, impregnation, modification); the presence of surface coating (varnish, paint, enamel) and others.
- It has been found: the lower ash content in fuel pellets, the higher their calorific value.
- It has been revealed that mechanical strength (durability) for five samples was lower than the normative value (96.5%), which is attributable to age characteristic of the PCW; the species composition, reduced content of lignin in some kinds of PCW, the presence of increased content of bark, higher initial moisture content of the particles, fraction composition of the chips, the temperature of the chips.
- It has been found that mechanical strength of fuel pellets made from PCW, as the main limiting factor, can be increased by reducing the initial moisture content of the particles (energy consumption increases in this case) and introducing additives to 2% (by the user's agreement).
- It has been established that PCW (in its characteristics) is not inferior to other kinds of biomass, and can be used for manufacturing solid biofuel – fuel pellets.
- It has been proved that fuel pellets made from PCW meet the requirements of the EN 14961-2:2011 standard for pellets of class B.

Conclusions with respect to solving socio-economic problems:

- It has been shown that the implementation of the developed technological techniques concerning the use of PCW for fuel pellet production will make it possible to enhance the economic efficiency of their manufacturing as well as to achieve significant economy of primary wood raw material.
- It has been found that PCW-containing fuel pellets are particularly advantageous for premises heating due to their high calorific value, they are convenient in storage and handling in automatic combustion units, they are not flammable due to lack of dust in them, also they do not contain any allergenic substances that could cause allergy in people.
- The use of PCW for fuel pellets production results in enormous saving on costs. The fabrication of such pellets does not involve any chemical additives under high pressure. The environmental impact from burning PCW-containing pellets in minimal since the amount of the resulting ash in the combustion units is insignificant, There exist many other advantages, For example, energy-intensity of one kilogram of woody pellets and 0.5 liter of diesel fuel is the same.
- It has been estimated that about 2 million tonnes of PCW was produced in 2012 in Ukraine, the energy potential being 0.936 million tonnes of equivalent fuel (27.442 PJ or 7.623 billion kWh). Converting the amount of PCW produced in 2012 into fuel (by distribution: 50% – chips, 25% fuel pellets, 25% fuel briquettes), would make it possible to increase the energy potential to 1.024 million tonnes of equivalent fuel, that is by 9%.
- The calculations show that with this sizable energy potential (excluding firewood) consisting of wood waste and PCW produced in 2012 and estimating at 6.438 million tonnes (2.703 million tonnes of equivalent fuel or 79.4 PJ or 22.056 billion kWh), it is possible to increase it by converting the giv-

en resources into energy fuel. The resulting calculations indicate that the increase could make up to 24% that is the energy indexes will amount to: 3.548 million tonnes of equivalent fuel or 104.00 PJ or 28.889 billion kWh. With annual electricity production in Ukraine in 2012 being 198 billion kWh, this would amount to 14.6% or 19.2% of the annual energy consumption.

Recommendations concerning raw material:

- PCW sorting is to be performed according to the established categories (degree of contamination): PCW-1 – virgin and mechanically processed wood with insignificant contamination by natural compounds (paraffin, ceresine, petrolatum, wax, oil and others) as well as the wood coming from natural disasters; PCW-2 – wood and wooden items treated without wood preservatives and without halogenated organic compounds in surface coating; PCW-3 – wood and wooden items treated without wood preservative and with halogenated organic compounds in surface coating; PCW-4 – wood and wooden items treated with wood preservatives,
- For categories PCW-3 and PCW-4, thorough examination shall be done concerning the PCW impurities composition, in particular for presence of wood preservatives: antipyren, antiseptic material, insecticides, fungicides, biocides, complex compounds and others.
- PCW biofuel mixtures shall be excluded from manufacturing fuel pellets for household heating as long as these contain halogenated organic compounds that had been used for preservation of virgin wood.
- A PCW biofuel mixture containing both chemically treated and chemically untreated wood shall be classified as that which is chemically treated.
- Rot PCW shall be excluded from manufacturing fuel pellets.
- PCW biofuel mixtures containing chemically treated material shall be checked for presence of polychlorinated terphenyls (PCT), polybrominated biphenyls (PBB) with concentration of 50 mg/kg and over, as well as fraction of coal tar, which contains benzapyren and its components exceeding the normative values.
- An analysis of chemically treated wood shall be made concerning the presence of chemical elements such as arsenic, cadmium, cooper, mercury, plumbum, sulphur, nitrogen, chlorine, zinc and others as well as their compounds, in accordance with the standards EN 15289:2011 and EN 15297:2011.

Recommendation on the raw material preparation (treatment):

- If the PCW contains some harmful elements or their compounds exceeding the normative value, it is necessary that a thermo-chemical treatment should be provided at a temperature of 100-130°C or else burn the fuel in combustion units of capacity over 100 kW.
- Relevant methods and ways have been developed to remove various impurities from the PCW.
- The PCW suitable for fuel pellets manufacturing should be cleaned by one of the following ways: surface cleaning (for solid PCW) on machine tools such as brushing machine, milling machine, grinding machine, sandblast machine and other; internal cleaning (for chipped PCW) by equipment such as air separator, vibratory feeder, air cleaner, magnetic strip, metal detector, swinging sieve.
- In order to reduce ash content in PCW-containing fuel pellets, it is necessary that the PCW should be cleaned form dirt or sand; it is necessary to avoid contamination introduced during handling, storage, transport; it is necessary that bark content should be reduced; the production process should be kept free from PCW containing inorganic or organic impurities, chemically treated wood including finishing (varnish, paint, enamel and others).
- The used composite material, as a raw material of high calorific value, (WPB, OSB, MDF and others) can be utilized for manufacturing fuel pellets only after they have been cleaned from polyvinylchloride films (PVC), plastics, laminate.

Recommendations concerning the production process:

- With respect to the fuel pellets production process, the following measures have been realized:
- The improvement of the existing fuel pellets production techniques, which make use of traditional primary raw material, has been carried out.
- The development of the technological process for converting PCW into solid fuel: fuel pellets. Accordingly, it was proposed to establish an area for PCW preparation which will involve: PCW sort-

ing for contamination, wood species, the type of the used construction material, etc.; removal of impurities and various foreign material; removal of plastics, non-ferrous and ferrous metals from both solid (unchipped) and chipped PCW.

- The following measures should be effectuated: to install a metal detector at the point of entry – before loading of the chipped material; to fix a suspended magnetic strip over the moving belt conveyor and mount a magnetic vibrating screen called "moving floor" in the mechanized storehouse.
- To install a scraper conveyor for the purpose of providing a controlled speed of the raw material feed to the disk separator (gravity segregator) to remove stones, sand and other impurities.
- To install a dynamic segregator which, during the drying process, will separate the dry and fine fraction form the wet and coarse particles returning the latter to the rotary chipper.
- The chipped and dried PCW chips are to be fed to the cyclone where they settle down due to the centrifugal force and then are fed via the upgraded screw conveyor to the pellet mill bunker.
- To install inside the bunker a device which will prevent the chips form becoming caked (bridging).
- To upgrade the system of automatic control over the pelletization process by means of microprocessor-based autoproportioner.
- To upgrade the blender for dry and wet chip with partial control of feed speed depending on the loading of the engine drive.
- To equip the wood pellets line with control system of temperature conditions for the pelletization process as well as with system of the chip moisture control at the point of entry together with a device for water supply directly into the pellet mill.
- To equip the wood pellet line with a digital moisture content stabilizer at the point of exit since the pellets after pelletizing have rather a high temperature and low mechanical strength.
- To provide transport of the hot pellets by an elevator (noria) to the cooler ensuring sucktion of the non-pelletized PCW chip into the cyclone.
- To provide packing of the PCW-containing fuel pellets into bags weighing as much as 15 kg.

Recommendations for fuel pellet production:

1. Developed are operating conditions parameters for fuel pellet production process.
2. Determined is the rational composition of fuel pellets with various PCW contents for broadleaved – and coniferous species (1:1), as well as composite material (not more than 50%) with consideration of pressability.
3. According to the developed technology for producing fuel pellets from PCW with different type ofwood biomass, the following operating conditions parameters for pelletizing process have been proposed:

- wood particles selected sample – 100%;
- particle moisture before pressing – 12%;
- fractional composition: less than 3.15 mm – > 97%; less than 2.0 mm – > 90%; less than 1.0 mm – > 50%; less than 0.1 mm – < 5%;
- chips bulk density – 200-250 kg/m^3;
- additives – 0%;
- hole diameter – 6-8 mm;
- temperature range at pressing – 90-100 °C;
- compacting pressure – 50-150 MPa;
- distance between the die and rollers – 0.3-0.6 mm;
- the ratio of the length of the die channel to its diameter – 3.5.

4 Additives might be binding agent or extraneous material: wet mass basis quantity and type (e.g. starch, corn flour, vegetable oil) to be declared.

5 Bulk maximal temperature shall be checked when the pellets leave the final point of loading for delivery to the end-user. i.e leaving the final storage point or the factory: exact value must be declared and compared to ambiant temperature of delivery + 5°C

6 EN 14961-2 has ash melting informative (voluntary) and ENPlus DT temperature is requested and ashing temperature 815 ºC. Ash content is determinated at a temperature 550 ºC.

7 Fines for domestic pellets "The amount of fines shall be checked when the pellets leave the final point of loading for delivery to the end-user. i.e leaving the final storage point or the factory if delivering directly to the end-user". The amount of fines leaving the factory gate shall also be ≤ 1% (unless there is a different agreement between the producer and their customer).

8 Raw material origin and source of PCW has to be stated according to table 1 in EN 14961-1 and Table 3 of this article (1.3 used wood). Chemically treated wood residues from wood, processing and the production of panels and furniture (glued, painted, coated, lacquered or otherwise treated wood, 1.2.1) or used wood (1.3.2, 1.3.3) is included in EN 14961-2, as long as they do not contain heavy metals or halogenated organic compounds as a result of treatment with wood preservatives or coating. Chemically treated wood must meet same threshold values as virgin wood.

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УДК 674.81:662.638 ***Докторант С.В. Гайда, канд. техн. наук – НЛТУ України***

Технології виробництва та властивості паливних гранул із вживаної деревини

Розраховано енергетичний потенціал деревної біомаси – відходів деревини та вживаної деревини (ВЖД), який склав у 2012 р. 6,438 млн. т, зокрема, ВЖД – 2,0 млн. т. Обґрунтовано, що, перетворивши дані ресурси у тверді види палива, енергетичний потенціал зросте з 2,703 до 3,548 млн. т у.п., тобто на 24%. Розроблено технологію та удосконалено обладнання виготовлення паливних гранул із ВЖД, як енергоємної сировини. Запропоновано режимні параметри виготовлення паливних гранул, визначено раціональний склад гранул з різним вмістом твердих та м'яких частинок ВЖД листяних та хвойних порід, композитних матеріалів і ін., виходячи із здатності до пресування. Проведено порівняльний аналіз властивостей паливних гранул із різним вмістом ВЖД за такими показниками як вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.

Висновки та рекомендації

Висновки до роботи в цілому:

- Обґрунтовано актуальність та проблемність використання ВЖД для виробництва паливних гранул.
- Сформовано, на підставі ідей, гіпотез, підходів та засобів, мету, об'єкт, предмет та завдання досліджень;
- Проведено детальний аналіз Європейських стандартів EN, що забезпечують вимоги до твердого біопалива (паливних гранул) в залежності від біомаси, її походження, а також визначають основні технічні характеристики, якість палива та стандартні методи його визначення;
- Проаналізовано сировинну базу біомаси, в тому числі ВЖД для виготовлення паливних гранул;
- Проведено багатофакторний експеримент за використання ПФП-2^3 та реалізовано матрицю планувань згідно методики досліджень;
- Досліджено вплив вмісту ВЖД в діапазоні 0-100 %, вологості стружок та вмісту добавок на фізико-механічні властивості паливних гранул – вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.
- Здійснено порівняльний аналіз фізико-механічних властивостей паливних гранул за вимогами стандартів для десяти проб біомаси: двох – з чистих відходів листяних та хвойних порід; восьми – ВЖД різного походження та джерел одержання в чистому та змішаному вигляді;
- Удосконалено обладнання для виготовлення паливних гранул із ВЖД;
- Розроблено технологічний процес з підготовки ВЖД та її гранулювання;
- Розраховано соціально-економічну ефективність від впровадження практичних рекомендацій виготовлення паливних гранул з ВЖД.

Висновки до дослідження:

- Змішування відходів (вживаної деревини) з таким матеріалом як деревна тирса дозволяє одеожани гранули з таких сумішей з прийнятним вмістом золи, тобто 3%.
- Змішування відходів (вживаної деревини) з таким матеріалом як деревна тирса дозволяє одеожани гранули з таких сумішей з прийнятною механічною міцністю.
- Змішування відходів (вживаної деревини) матеріалів з деревною тирсою збільшує постави сировинної бази, яка необхідна виробництва паливних гранул.
- Відходи (ВЖД) біомаса речовин, які, в даний час, є на звалищах, можуть бути використані у виробництві гранул. Це дозволить знизити навантаження на звалища.
- Такі речовини відходів біомаси, на відміну від тирси, є доступними через низьку собівартість, тому витрати виробництва пелет будуть нижчими.

Висновки до вживаної деревини:

- Проаналізовано джерела походження ВЖД: тверді побутові відходи, муніципальні відходи, торгівля (тара, піддони), будівельні відходи, господарська діяльність, переробна промисловість та інші;

- Здійснено моніторинг ВЖД в Україні;
- Розраховано кількість ВЖД в Україні, яка становила у 2012 році 2,0 млн. т;
- Розроблено класифікацію ВЖД за ступенем забруднення та за джерелами походження з відповідними категоріями та кодами;
- З'ясовано, що запропонована класифікація, на основі найбільш характерних ознак, повноцінно відображає походження та джерела одержання твердого біопалива – паливних гранул з ВЖД;
- Доведено необхідність здійснення ідентифікації ВЖД для отримання інформації про фізичні та хімічні властивості як реальної додаткової біомаси для якісної продукції;
- Обґрунтовано, що 50 % ВЖД (1,0 млн. т) є придатною для енергетичного використання, зокрема, для виготовлення паливних гранул;

Висновки до аналізу властивостей паливних гранул з ВЖД:

- Запропоновано на підставі розробленої класифікації проводити диференціацію біопалива, зокрема паливних гранул з ВЖД, на основі походження ВЖД для можливості проведення ідентифікації даної продукції;
- Визначено гранулометричний склад з використанням вібраційного решета з отворами 3,15 мм і менше. Фракційний склад стружок для різних проб ВЖД за результатами експериментів становив: < 3,15 мм – 97,2- 98,1 %; < 2,0 мм – > 90,3-91,4 %; < 1,0 мм – > 54,7-62,2 %; < 0,1 мм – < 2,8-4,3 %, що відповідає вимогам стандартів EN 15149-2:2010 (ДСТУ-П CEN/TS 15149-2:2009);
- Досліджено вплив вмісту ВЖД, вологості стружок та вмісту добавок на фізико-механічні властивості паливних гранул з ВЖД – вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність, які були визначені стандартними методами;
- Визначено, що вміст ВЖД в діапазоні 0-100 % в паливних гранулах веде себе однаково при різному вмісті добавки (в'яжучого). Зокрема, при витраті добавки 1,5 % та вологості стружок перед пресуванням 12 %, зольність зростає від 0,43 до 0,61 % (41,8 %), а всі інші тестовані параметри гранул спадають: вологість – з 9,90 до 9,03 % (на 9,8 %), механічна міцність – з 97,28 до 96,3 % (на 1,0 %), стиранність – з 0,71 до 0,67 % (на 5,6 %), теплотворна здатність – з 19,04 до 18,75 МДж/кг (на 1,5 %), насипна щільність – з 658,8 до 650 кг/м^3 (на 1,3 %). Для першого змінного фактору (вмісту ВЖД) зміна вологості та стиранності мають позитивний характер, всі інші параметри відповідають вимогам до паливних гранул непромислового використання В класу. Механічна міцність хоч має значення менше, ніж 96,5 %, але підняти її, у даному випадку, можливо – несуттєво збільшивши вміст добавки або зменшивши початкову вологість частинок;
- Встановлено, що для гранул із вмістом ВЖД 100 % та без добавки вологість стружок (при її зміні від 8 до 16 %) по різному впливає на зміну характеристик паливних гранул – зростають: зольність від 0,364 до 0,464 % (на 24,7 %), вологість – з 6,32 до 10,9 % (на 72,5 %); насипна щільність – з 630,6 до 649,8 кг/м^3 (на 3 %), а всі інші тестовані параметри гранул спадають: механічна міцність – з 97,06 до 93,98 % (на 3,9 %), стиранність – з 0,94 до 0,86 % (на 8,5 %), теплотворна здатність – з 19,05 до 17,89 МДж/кг (на 6,1 %). Для другого змінного фактору (вмісту вологи стружок) зміна насипної щільності має позитивний характер. Всі інші параметри необхідно корегувати шляхом висушування деревних частинок та дозуванням поверхневої вологи перед змішуванням для забезпечення вмісту вологи перед пресуванням в межах 11-13 %, оскільки менше значення її приводить до збільшення енергозатрат під час виготовлення гранул;
- Виявлено, що на властивості гранул із вмістом ВЖД 100 % та початковою вологістю стружок 12 % суттєво впливає вміст добавки (0-3 %) – зростають: зольність від 0,41 до 0,81 % (на 97,5 %), вологість – з 8,61 до 9,45 % (на 9,8 %); механічна міцність – з 95,52 до 97,08 % (на 1,6 %), теплотворна здатність – з 18,47 до 19,03 МДж/кг (на 3 %), насипна щільність – з 640,2 до 659,8 кг/м^3 (на 3,1 %), а стиранність спадає з 0,9 до 0,44 % (на 51,2 %). Для третього змінного фактору (вмісту добавки) зміна насипної щільності, механічної міцності, теплотворної здатності та стиранності має позитивний характер. Зростання зольності зумовлене тим, що в якості добавки використовувався крохмаль, який має зольність 4 %. Крім того, крохмаль має здатність інтенсивно поглинати початкову вологу, що призвело до зростання вологості паливних гранул. Оскільки стандарт EN 14961-2 дозволяє здійснювати добавки у кількості не більше 2 %, то, забезпечивши дану вимогу, можливо одержати паливні гранули непромислового використання,

що відповідають В класу. Крім того, використання добавок дозволяє проводити грануляцію подрібненого матеріалу з меншими енергетичними затратами – при середніх тисках 20-50 МПа;

- Одержано адекватні математичні моделі залежності показників паливних гранул від трьох змінних факторів: вмісту ВЖД, вологості стружок та вмісту добавок;
- Проведено порівняльний аналіз властивостей паливних гранул з ВЖД різного походження за такими показниками як вологість, зольність, механічна міцність, стиранність, теплотворна здатність, насипна щільність.
- Встановлено, що зольність перевищувала нормативне значення (3 %) у трьох пробах з десяти, що можливо зумовлено забрудненням ВЖД ґрунтом або піском; забрудненням в процесі використання, зберігання, транспортування; наявністю або підвищеним вмістом кори; наявністю або підвищеним вмістом неорганічних або органічних добавок; хімічним обробленням (консервуванням, просочуванням, модифікуванням); наявністю лакофарбових матеріалів (лак, фарба, емаль) та інше;
- З’ясовано, чим менше золи в паливних гранулах, тим вища їх теплотворна здатність;
- Визначено, що механічна міцність у п’яти пробах була нижчою за нормативне значення 96,5 %, що обґрунтовується віковою характеристикою ВЖД; породним складом; зменшеним вмістом лігніну у деяких ВЖД, наявністю або підвищеним вмістом кори; більшою початковою вологістю частинок; фракційним складом стружок; температурою стружок;
- Встановлено, що збільшувати механічну міцність гранул з ВЖД, як основного обмежуючого фактору, можливо зменшуючи початкову вологість частинок (зростають енергозатрати на пресування), додаючи добавки до 2 % (за згодою споживачів);
- З’ясовано, що ВЖД за своїми характеристиками не поступається іншій деревній біомасі і може бути використання для одержання твердого біопалива – паливних гранул;
- Доведено, що паливні гранули з ВЖД відповідають вимогам стандарту EN14961-2:2011 для гранул В класу.

Висновки для розв’язання соціально-економічних проблем:

- встановлено, що впровадження розробок з використання ВЖД для виробництва паливних гранул дозволить підвищити економічну ефективність їх виготовлення, а також значно заощадити первинні сировинні деревні ресурси;
- досліджено, щопаливні гранули з ВЖД є ефективним паливом для опалення приміщень, оскільки мають більшу теплотворну здатність, під час зберігання вимагають невеликої площі, є зручними для переміщення в автоматичних системах спалювання, та не піддаються самозапалюванню, оскільки не містять пилу, а також речовин, які можуть викликати алергійну реакцію в людей;
- заощадження коштів величезне, адже для виготовлення таких гранул використовують ВЖД. Виробництво таких деревних гранул відбувається без жодних хімічних добавок під високим тиском. А спалювання їх у котельнях не шкодить довкіллю, бо навіть кількість золи в котлах є незначною. Існує й чимало інших переваг. Наприклад, енергоємність кілограму деревних гранул і 0,5 літра дизпалива — однакова;
- розраховано, що в Україні у 2012 р. утворилось 2 млн. т ВЖД, з енергетичним потенціалом 0,936 млн. т у.п. (27,442 ПДж або 7,623 млрд. кВт-год). Перетворивши утворену ВЖД за 2012 р. у паливо за розподілом 50 % тріска, 25 % паливні гранули та 25 % паливні брикети можливо збільшити енергетичний потенціал до 1,024 млн. т у.п. , тобто на 9 %;
- прораховано, що, маючи значний енергетичний потенціал (без врахування дров) з відходів деревини та ВЖД за 2012 р. у кількості 6,438 млн. т (2,703 млн. т у.п. або 79,4 ПДж або 22,056 млрд. кВт-год), можливо його збільшити, перетворивши дані ресурси в енергетичні види палива. Результати розрахунку свідчать, що зростання може становити 24 %, тобто енергетичні показники зростуть і будуть становити: 3,548 млн. т у.п. або 104,00 ПДж або 28,889 млрд. кВт-год. При виробництві річної електроенергії в Україні у 2012 р. у кількості 198 млрд. кВт-год, це склало б 14,6 %, або 19,2 % від річного споживання.

Рекомендації до сировини:

1. Здійснювати сортування ВЖД за розробленими категоріями (ступенями забруднення): ВЖД-I – природна та тільки механічно оброблена деревина з незначними забрудненнями натуральними зв’язками (парафін, церезин, петролатум, віск, мастило та ін.), а також деревина від

стихійних катаклізмів; ВЖД-ІІ – оброблена деревина та деревні матеріали без речовин захисту деревини та без галогеноорганічних зв'язків у покриттях; ВЖД-ІІІ – оброблена деревина та деревні матеріали без речовин захисту деревини та з галогеноорганічними зв'язками у покриттях; ВЖД-IV – деревина та деревні матеріали, які оброблені речовинами захисту;

2. Для категорій ВЖД-ІІІ та ВЖД-IV детально досліджувати склад та матеріал забруднювачів ВЖД, зокрема, на наявність речовин захисту деревини: антипіренів, антисептиків, інсектицидів, фунгіцидів, біоцидів, комплексних препаратів та ін.

3. Не обліковувати біопаливні суміші з ВЖД різного походження та складу для виробництва паливних гранул для побутових потреб, якщо вони містять галогеноорганічні сполуки та важкі метали, які були задіяні для захисту (консервування) первинної деревини;

4. Класифікувати біопаливну суміш з ВЖД, яка складається одночасно із хімічно обробленої і хімічно необробленої деревини, як хімічно оброблену;

5. Не допускати для виробництва паливних гранул гнилої ВЖД.

6. Перевіряти біопаливну суміш з ВЖД, яка містить хімічно оброблений матеріал, на вміст небезпечних складників, які містять поліхлоровані біфеніли (ПХБ), поліхлоровані терфеніли (ПХТ), полібромовані біфеніли (ПББ) концентрацією 50 мг/кг і більше, а також фракції кам'яновугільної смоли, які містять бенз(а)пірен та його сполуки більше норми та порівнювати з допустимими нормативними значеннями.

7. Проводити аналіз хімічно забрудненої деревини на наявність хімічних елементів (миш'як, кадмій, мідь, ртуть, свинець, сірка, азот, хлор, цинк та ін.) та їх сполук у відповідності до методів зазначених у стандартах EN 15289:2011 та EN 15297:2011;

Рекомендації до підготовки (очищення) сировини

8. За наявності у ВЖД шкідливих елементів та їх сполук більше норми необхідно проводити термо-хімічне очищення при температурі 100-130 °C або спалювати в котельних установках потужністю більше 100 кВт;

9. Обґрунтовано способи та методи очищення ВЖД від різних домішок;

10. Придатну для виготовлення паливних гранул ВЖД необхідно очищати одним із способів: поверхневим (для масивної ВЖД) – модернізованими верстатами (щітковим, фрезерним, голко фрезерним, шліфувальним, піскоструйним, пелюстковим); внутрішнім (для подрібненої ВЖД) – устаткуванням (повітряний сепаратор, вібраційний фідер, повітряний очищувач, магнітна стрічка, металодетектор, динамічне решето);

11. Для зменшення зольності паливних гранул з ВЖД необхідно очищати її від ґрунту або піску; уникати забруднення в процесі використання, зберігання, транспортування; очищати та зменшувати вміст кори; не допускати попадання у технологічний процес ВЖД із вмістом неорганічних або органічних добавок; хімічно забрудненої деревини, у тому числі лакофарбових матеріалів (лак, фарба, емаль) та інше;

12. Вживані композиційні матеріали (ДСП, ОСБ, МДФ та інші) повинні бути очищенні від полівінілхлоридних плівок (ПВХ), пластика, ламінату і, тоді, можуть бути використані у виробництві паливних гранул, як сировина з високою теплотворною здатністю;

Рекомендації до технологічного процесу

13. Удосконалено існуючу технологію виробництва паливних гранул, яка використовує традиційну первинну деревну сировину;

14. Розроблено технологічний процес перетворення ВЖД у тверде паливо – паливні гранули. Запропоновано у новій технології запровадити дільницю з підготовки ВЖД, яка включає сортування за забрудненням, за породою, за конструкційними матеріалами та інше; очищення від домішків та різноманітних включень; вилучення пластмаси, кольорових та чорних металів як з масивної, так і з подрібненої ВЖД;

15. Встановити у технологічному процесі детектор-металошукач на початковому етапі – перед завантаженням подрібненої сировини; закріпити підвісну підмагнічену стрічку над рухомим стрічковим транспортер та вмонтувати магнітний просіювач-вібратор під назвою «рухома підлога» на механізованому складі;

16. Забезпечити скребковим транспортером регульовану швидкість подачі сировини до дискового сепаратора (гравітаційного розділювача) для якісного відділення від каменів, піску та інших домішок;

17. Встановити динамічний розділювач, який в процесі сушіння розділяє суху і дрібну фракцію від вологих та великих частинок, повертаючи їх до ротора-подрібнювача;

18. Подрібнену та висушену стружку ВЖД подавати в осадовий циклон, в якому вона за рахунок відцентрової сили осідає на дно, і, завдяки модернізованому шнековому транспортеру, підвозити до бункера гранулятора;

19. Встановити у середині бункера гранулятора пристрій, який перешкоджає злежуванню стружки;

20. Модернізувати систему автоматичного керування процесом гранулювання за допомогою автоматизованого дозатора із мікропроцесорним керуванням;

21. Модернізувати змішувач сухої та вологої стружки із частковим регулюванням швидкості подачі залежно від завантаженості приводу двигуна;

22. Встановити в обладнання лінії перероблення ВЖД на гранули систему контролю температурного режиму гранулювання та системи регулювання вологості стружки на вході з пристроєм подачі води безпосередньо в гранулятор;

23. Запровадити у виробничий процес цифровий стабілізатор вологи на виході, оскільки гранули, які виходять з матриці, мають високу температуру та неміцні;

24. Забезпечити транспортування гарячих гранул вертикальним транспортером – норією в охолоджуючу колонку, забезпечуючи відсмоктування незранульованої стружки ВЖД в циклон;

25. Здійснювати дозування паливних гранул з ВЖД у мішки вагою 15 кг.

Рекомендації до виготовлення паливних гранул

1. Розроблено режимні параметри виготовлення паливних гранул,

2. Визначено раціональний склад гранул з різним вмістом ВЖД листяних та хвойних порід (1:1), композитних матеріалів (не більше 50 %), виходячи із здатності до пресування.

3. У відповідності до розробленої технології для виготовлення паливних гранул із PCW з різної деревної біомаси запропоновано наступні режимні параметри процесу гранулювання: деревні частинки вибраної проби – 100 %; вологість частинок перед пресуванням – 12 %; фракційний склад: < 3,15 мм – > 97 %; < 2,0 мм – > 90 %; < 1,0 мм – > 50 %; < 0,1 мм – < 5 %; насипна щільність стружок – 200-250 кг/м^3; добавки – 0 %; діаметр отворів – 6 мм; діапазон температури пресування – 90-100 °С; тиск пресування (в регуляторі люзу між матрицею та роликами) –10-150 МПа; віддаль між матрицею та роликами – 0,3 мм; співвідношення довжини каналу матриці до її діаметра – 3,5.

4. Добавки можуть бути у вигляді в’яжучого або наповнювача: тип (наприклад, крохмаль, кукурудзяна мука, олія) та кількість до основної маси гранул повинні бути задекларовані.

5. Загальна максимальна температура гранул повинна бути перевірена, коли вони залишають кінцеву точку відвантаження для доставки кінцевому користувачеві, тобто залишивши кінцевий пункт зберігання чи заводу, має бути зафіксована точна температура у відповідності до умов доставки (+5°С).

6. У відповідності до стандарту EN 14961-2 виробник повинен надавати інформацію щодо температури плавлення золи добровільно, а за стандартом ENplus DT температура має становити 815ºС. Зольність необхідно визначати за температури 550ºС.

7. Стиранність для гранул, які використовуються у домашніх умовах, необхідно перевіряти коли гранули залишають кінцеву точку відвантаження для доставки кінцевому користувачеві, тобто коли вони залишають кінцевий пункт зберігання чи заводу. Загальна стиранність гранул після заводу повинна бути ≤ 1% (якщо немає іншої угоди між виробником і клієнтом).

8. Походження сировини і джерел ВЖД повинно бути вказано у відповідності з табл. 1 (EN 14961-1) і табл. 3 цієї статті (1.3 – ВЖД). Хімічно оброблена деревина, яка утворюється під час оброблення деревини та виробництві плит і меблів (склеєна, пофарбована, покрита плівками, лакована або іншим чином оброблена деревина, 1.2.1) або ВЖД (1.3.2, 1.3.3) у відповідності до EN 14961-2, може використовуватись у виробництві паливних гранул, якщо вона не містять важких металів або галогеноорганічних сполук, утворених в результаті обробки деревини або у покриттях. Обмеження для хімічно обробленої деревини є однаковими, що й для первинної деревини.

Ключові слова: вживана деревина, біомаса, енергетичний потенціал, паливні гранули, технологія, властивості гранул, соціо-економічна ефективність.