ISSN 2083-1587; e-ISSN 2449-5999
2020,Vol. 24,No.3, pp.1-9
Agricultural Engineering
www.wir.ptir.org
DOI: 10.1515/agriceng-2020-0021

ANALYSIS OF ENERGY PROPERTIES OF GRANULATED PLASTIC FUELS AND SELECTED BIOFUELS

Maciej Domański[a], Jarosław Paszkowski[b *], Otroshko Sergey[c], Janusz Zarajczyk[d], Dariusz Siłuch[d]

[a] Neuropsychiatric Hospital in Lublin Independent Public Healthcare Establishment, Poland, e-mail: maciej.domanski@interia.pl
[b] Immobilia Polska Sp. z oo.; Sp. Kom., Lublin, e-mail: jpaszkowski76@gmail.com
[c] Federal Williams Research Center of Forage Production & Agroecology, st. Nauchnyi gorodok, k1, Lobnya, Russia
[d] University of Life Sciences in Lublin, Lublin, Poland, e-mail: janusz.zarajczyk@up.lublin.pl, ORCID 0000-0001-5954-6575

** Corresponding author: e-mail: jpaszkowski76@gmail.com*

ARTICLE INFO

Article history:
Received: August 2020
Received in the revised form: September 2020
Accepted: September 2020

Key words:
biofuels,
solid RDF, energy

ABSTRACT

The paper discusses the possibility of using alternative fuels from biomass and plastics in Poland. Their physiochemical properties and possible application in the chemical, cement and energy industries were determined. The heat of combustion of the tested samples was 26.169 $MJ \cdot kg^{-1}$. On the other hand, the moisture content in the tested material was 1.6%, i.e. within the requirements for this raw material. Since the chlorine content in relation to the sulfur content in the waste is an indicator of the corrosive potential of the fuel, the content of chlorine and sulfur was determined in laboratory tests. The analyzed waste samples were within the specified requirements. The tested material, in which the chlorine content was determined (0.577%), indicates that the tested fuels can be included in the power industry, in accordance with PN-EN 15359:2012.

Introduction and purpose of the work

In 2019, an average of 332 kg of waste per capita was collected in Poland. This is 7 kg more than in 2018 (Central Statistical Office, 2020). In general, in our country, in 2014 there were over 141 million tons of waste, including over 10 million tons of municipal waste (268 kg/capita), most of which was destined for landfilling (Nowak and Szul, 2016). There are 394 active municipal waste landfills in Poland, with a total area of 1927.0 ha (Central Statistical Office, 2015). The term "alternative fuel" appears in economic practice and is used to describe the fuel obtained from waste processing. However, this term is not legally defined, and the legal acts in force do not contain the definition of this type of waste. This does not mean, however, that this term doesn't appear at all in the Regulation of the Minister of the Environment of 9 December 2014 on the waste catalog. Combustible waste (alternative fuel) is listed under code 19 12 10. This type of waste is included in group 19 12, i.e. waste from the mechanical treatment (e.g. from manual processing, sorting, crushing, granulating) not otherwise classified (Górski, 2015). The available literature (Dalai at al., 2009) uses the term Refuse Derived Fuel (RDF), which refers to a medium that increases the recovery of the raw material from municipal waste and is a priority solution in industrialized countries. RDF is a material with a high calorific value and a homogeneous particle size. According to the National Waste Management Plan (KPGO, 2010), mechanical and biological treatment of waste is, or will be preferred in regions with over 120,000 inhabitants (Marczuk et al., 2015; Sarna at al, 2013, Szmigielski et al., 2014, Wilk, 2006, Szyszlak-Bargłowicz et al., 2013). Mechanical-Biological Treatment (MBT) plants are not the installations for ultimate waste management, but for preparation to recovery or disposal. In Poland, cement plants are one of the main recipients of RDF. RDF is used neither in power plants, nor in heat and power plants due to formal and legal requirements for the waste incineration or co-incineration process, emission of pollutants and the potentially unfavorable changes in ash parameters. It is estimated that Polish cement plants use approx. 1,000,000 Mg of alternative fuels per year and may increase the amount by approx. 400,000 Mg (Błachowicz, 2013; Kalisz, 2013). The possibilities for waste co-incineration in this sector are limited. Cement plants will not be able to use all of the domestic alternative fuel. Therefore, it can be proposed that some domestic RDF producers won't find buyers for the produced fuel, unless the possibility of its use in power and heating production is opened. On the other hand, the resolutions of the respective province parliaments on the implementation of the Province Waste Management Plans show that over 70 MBT installations are to operate in Poland, in which fractions fully or partially suitable for energy recovery will be separated. According to the Regulation of the Minister of Economy of 16 July 2015 on the criteria and procedure of approval of waste for storage, the potential for producing alternative fuel in Poland is 4.5 to 6 million $t \cdot year^{-1}$ (Krawczyk and Szczygieł, 2013). The high moisture content of the alternative fuels increases the risk of spontaneous combustion (Caban et al., 2019; Niemczuk et al., 2018; Tucki et al., 2019). It has a negative effect on the combustion process by increasing the volumetric flow of exhaust gases as well as the emission of pollutants, and reduces the amount of net energy obtained (Mokrzycki et al., 2000; Krawczyk, Szczygieł, 2013; Błachowicz, 2013; Wasiak and Orynycz, 2015). On the other hand, one of the undesirable components of fuels is sulfur, which adversely affects the boilers and the natural environment as the source of sulfur oxides emissions. SO2 is not dangerous as long as it does not react with water vapor to form sulfuric (VI) or sulfuric (IV) acid, which are highly corrosive to steel used in furnaces. The purpose of pelleting (granulation) is to reduce the volume of fuel, increase its bulk density, facilitate transport, storage and feeding to energy-producing equipment and to standardize the composition (Nowak and Szul, 2016; Górski, 2015).

Table 1.
Characteristics of solid fuels and their possible usages

Fuel property	Impact
Moisture	dry matter losses, storage life, impact on calorific value, self-ignition, type of power plant
Ash	dust emission, ash utilization and removal, impact on combustion
Carbon	heat of combustion
Hydrogen	heat of combustion and calorific value
Sulfur	SO_x emissions, corrosion
Calorific value	fuel use, type of power plant

Due to the significant difference in the density of alternative fuels, their co-combustion requires careful selection of both the raw materials themselves and the installation in which such a mixture is used. Their addition to hard coal changes the time fuel resides in the furnace chamber of the boiler and increases the volume of exhaust gases per unit of energy in the fuel. Low bulk density and low calorific value create problems in transportation, storage and dosing into the furnace. A significant amount of ash, alkali metals and the presence of chlorine can cause such unfavorable effects as slagging and accelerated corrosion of some boiler components (Boer, 2013; Warpechowska, 2018; PN-EN 15375:2011; PN-EN 15359:2012). The way to unify solid biomass fuels is to granulate them into pellets, preceded by grinding and mixing of the raw material. In Poland, only 8-9% of the generated waste is currently reused, while in the "Old EU" countries the average is 22%. However, the waste management policy in Poland aims to persuade waste producers to act pro-ecologically. As a result, following the example of EU countries, the Polish authorities are starting to promote recycling and recovery, instead of landfilling. Co-combustion of granulate in the existing fine coal boilers does not require additional investment. In the future, establishing a local center for the processing of solid fuels into pellets could contribute to a better, more economical and more efficient organization of the obtaining process. This could lower the pellet price and allow for additional income (Wzorek and Król, 2012; Pronobis et al., 2010).

The research objective of this study is to develop and demonstrate that RDF waste and corn straw are an important raw material for the production of high-energy granular fuel for cement plants and the power industry.

The scope and methodology of research

The research material was pellets made of RDF and corn straw delivered to Bioenergia Invest SA and Ursus SA. Energy parameters of corn straw and the content of selected elements was analyzed in an accredited laboratory, according to the methods presented in Tables 4 and 5.

The subject of the research was to determine the chemical and physicochemical properties of solid RDF and corn straw. The obtained results are to demonstrate the suitability of using pellets for co-combustion with coal in Polish power and cement plants. The pellets' calorific value and heat of combustion were determined in accordance with the PN-ISO 1928:2002 standard. The differences in calorific values did not exceed the value of 200 $kJ \cdot kg^{-1}$ identified in the procedure between the two determinations. During the pelleting process, the moisture content of the tested raw materials played an important role as the water content level in the tested material impacted the processing and forming into a pellet shape in the granulator.

Table 2.
Average size of pellets produced by the ring granulator

Material	External diameter (mm)	Length (mm)
RDF pellets	8	approx. 10
Straw pellets	25	30-50

Table 3.
Characteristics of the analyzed material (RDF) – type of the sample: recovered fuel (waste code: 19 12 10), analysis was carried out between 2016-12-02 and 2016-12-05

The tests were carried out on: 2016-11-30	
Sample code number:	417/Z/16
Tested object:	Solid recovered fuel
Sample description:	Solid sample, condition: good, fine fraction, pellet form, sample weight approx. 0.15 kg. Type of packaging: plastic zipper bag.
Sample condition:	Meets the requirements.
The sample was prepared according to:	PN-EN 15443:2011 and PN-EN 15413:2011

Table 3 shows that the tested raw material was properly prepared, in accordance with the recommendations and regulations (meeting the technical requirements of the classification according to the specifications listed in EN 15359:2011).

The above table describes methods for sampling solid recovered fuel from production facilities, deliveries or dumps. Both manual and mechanical methods were included. Also, the methods of reducing the general samples of the solid recovered fuel to the laboratory samples, and the laboratory samples to the sub-samples and the general sample for analysis are presented, according to the applied standards. The standards listed in the table apply to the samples that are fine and of regular particle shape, up to approx. 10 mm in size and which can be further sampled with a shovel or a pipe.

Table 4.
Analytical methods of the tested object (RDF)

Tested characteristic	Test method/Standard or test procedure
Total moisture content	CEN/TS 15414-2.2010 Weight method %
Moisture content of the analytical sample	PN-EN 15414-3.2011 Thermogravimetric method
Ash content	PN-EN 15403.2011
Ash content	Thermogravimetric method
Total sulfur content	PN-EN 15408.2011
Total sulfur content	High-temperature combustion method with IR detection
Total hydrogen content	PN-EN 15407.2011
Total hydrogen content	High-temperature combustion method with IR detection
Heat of combustion	PN-EN 15400:2011
Calorific value	Calorimetric method
Calorific value	Calculated calorific value
Chlorine as Cl	The analysis was performed with the WDX RF X-ray fluorescence spectrometer, according to the manufacturer's instructions

The input material was pre-milled RDF (a fraction of approx. 10 mm) with a maximum moisture of up to 30%. Similar parameters were maintained in the case of corn straw. An important aspect in the production of alternative solid fuels is to obtain the smallest possible fraction at the outset. This allows achieving higher quality granules from the tested raw materials. In addition, the grinding process precipitates moisture from the raw material.

Table 5.
Analytical methods of the object under study – pellets from corn straw

Test	Testing method
Bulk density	PN-73G-04531
Total moisture	ISO 589:2003, Met. B2
Ash content	ISO1928:1997
Calorific value	ISO1928:1995
Sulfur content	AST MD 4239-05, Met. B
Chlorine content	PN ISO 587:2000
Potassium content	AST MD 6349:2001
Nitrogen content	AO.AC 976.5:2000

These methods (Table 5) were specified in the laboratory accredited by: PCA no. AB079. Test sampling and processing were performed according to the standard: PN-90/G-04502.

Results

The results of the analysis presented in Table 6 include tests covered by the scope of accreditation, as well as non-accredited tests. Tests outside the scope of accreditation are marked with (*). The given test results refer only to the tested sample. Meaning of symbols: ad-analytical condition, d-dry condition, ar-working condition. Conversion to a different state was made according to PN-EN 15381:2010. PN-EN 15296:2011.

Table 6.
Physico-chemical parameters of the fuel under study (RDF)

Tested characteristic	Unit	Test result
Total moisture content (A_{ar})	(%)	21.8
Moisture content of the analytical sample (M_{ad})	(%)	1.6
Ash content (A_d)	(%)	17.0
Ash content (A_{ar})		13.3
Total sulfur content ($S_{\cdot ad}$)	(%)	0.17
Total sulfur content ($S_{\cdot ar}$)		0.14
Total hydrogen content ($H_{\cdot d}$) (*)	(%)	8.04
Total hydrogen content ($H_{\cdot ar}$)		6.29
Combustion heat (qv, $_{gr\ d}$) (*)		26.169
Calorific value (qv, $_{net\ d}$)	($MJ \cdot kg^{-1}$)	24.513
Calorific value (qv, $_{net\ ar}$)		18.670
Chlorine as Cl (*)	(%)	0.577

The calorific value of the tested sample in the working condition was 24.513 MJ/kg and was higher than the range of typical values for RDF (13 MJ·kg^{-1} – 20 MJ·kg^{-1}). On the other hand, the heat of combustion was 26.169 MJ·kg^{-1}. The moisture content in the tested material was 1.6%, i.e. within the requirements for this raw material. High-quality alternative fuels are obtained from materials with high calorific value and low moisture content, e.g. plastics, and can be a valuable recovered fuel. Since the chlorine content in relation to the sulfur content in the waste is an indicator of the corrosive potential of the fuel, the content of chlorine and sulfur was determined in laboratory tests. The analyzed waste samples were within the specified requirements. The tested material, in which the chlorine content was determined (0.577%), can be included as fuel for the power industry, in accordance with PN-EN 15359: 2012.

Table 7.
Results of the analysis of pellet from corn straw produced by Ursus S.A. Tests were carried out in Połaniec S.A. power station

Details	Power plant requirements	Product from Ursus SA	Comments
Pellet dimensions	Accepted	Cylinder with a diameter of 25 mm and a length of 30-50 mm	N/A
Raw material	Agro biomass	Straw	N/A
Calorific value in the working condition	Nominally 14.3 GJ·t^{-1}	11.9-16.5 GJ·t^{-1}	N/A
Bulk density	-	600-700 kg·m^{-3}	N/A
Moisture	Max. 30%	10-25%	N/A
Ash	-	4-17%	typically 6-8%
Sulfur	-	0.02-0.21%	typically <0.1
Chlorine	Preferred <0.4% Max. 0.5%	0.04-0.47%	For gray straw: <0.1%; for yellow straw: 0.25-0.47%

Table 7 shows that the average calorific value of pellets produced in Ursus SA from corn straw, using the ring granulator, sold to the Połaniec SA power plant, ranged between 11.9 and 16.5 GJ·t^{-1} and their bulk density ranged between 600 and 700 kg·m^{-3}. On the other hand, the moisture content ranged from 10 to 25%. Thus, the mentioned parameters correspond to good quality raw material for co-combustion. The tested fuel was produced by waste processing, with energy potential sufficient to provide an energy source, or with properties allowing for its processing into energy products and for separation of the combustible fraction from municipal waste (paper, plastics, textiles, wood, rubber) by sorting, as well as by subjecting to a multi-stage process of grinding and then pelleting, both corn straw and RDF.

Conclusion

The paper points to significant presumptions for the development of alternative fuel technology in Poland. The issues related to the granulation (agglomeration) processes presented in this paper indicate the existing large and even growing (theoretical) research, as well as technological interest in these processes.

The publications on the technological issues of the granulation process are dominated by agricultural products, and in many cases these are forms of adequate pellet quality. A significant number of research papers demonstrate that various measurement techniques used to test the properties of raw materials and granulated products obtained as a result of granulation processes, and to control these processes on a production scale, are constantly developed. The calorific value of pellets produced for the commercial power industry is important because this index affects the price of the product supplied to the power plant. The nominal calorific value of the raw material set by Polish power plants is 14.3 $GJ \cdot t^{-1}$. Thus, if a biomass producer contracted with a power plant supplies a raw material with a calorific value lower than specified, they will obtain a lower price, and vice versa. The maximum moisture of biomass allowed for the production of RDF pellets and corn straw should not exceed 20%. However, the energy value of pellets as an alternative fuel depends on the type of raw material used for its production, and its moisture content. Pellets with too high moisture content not only have a lower energy value, but also emit more pollutants during combustion. An alternative solid fuel made from plastic (RDF) and maize straw, produced for energy recovery in an incineration or co-incineration plant, should meet the technical classification requirements according to the specifications listed in EN 15359:2011 “Solid recovered fuels – Specifications and classes”.

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ANALIZA WŁAŚCIWOŚCI ENERGETYCZNYCH GRANULOWANYCH PALIW Z TWORZYW SZTUCZNYCH ORAZ WYBRANYCH BIOPALIW

Streszczenie. W artykule omówiono możliwość wykorzystania paliw alternatywnych z biomasy i tworzyw sztucznych w Polsce. Określono ich właściwości fizyko-chemiczne oraz możliwości zastosowania w przemyśle chemicznym, cementowym i energetycznym. Ciepło spalania badanych próbek wynosiło 26,169 $MJ \cdot kg^{-1}$. Natomiast wilgotność w badanym materiale wynosiła 1,6% i mieściła się w zakresie wymagań dla tego surowca. W badaniach laboratoryjnych określono zawartość chloru i siarki. Zawartość chloru w stosunku zawartości siarki w odpadach jest wskaźnikiem potencjału korozyjnego paliwa i w analizowanych próbkach odpadów mieściła się w określonych wymaganiach. Badany materiał, w którym oznaczona została zawartość chloru (0,577%), wskazuje, iż można zgodnie z normą PN-EN 15359:2012, zaliczyć badane paliwa do zastosowania w energetyce.

Słowa kluczowe: biopaliwa, paliwa stałe z tworzyw sztucznych