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RAPESEED PELLET - A BYPRODUCT OF BIODIESEL PRODUCTION - AS AN EXCELLENT RENEWABLE ENERGY SOURCE

WYTŁOKI RZEPAKOWE - PRODUKT UBOCZNY W PRODUKCJI BIODIESLA - JAKO DOSKONAŁE ŹRÓDŁO ENERGII ODNAWIALNEJ

Abstract: Vegetable oils are renewable feedstock currently being used for production of biofuels from sustainable biomass resources. The existing technology for producing diesel fuel from plant oils, such as rapeseed, soybean, canola and palm oil are largely centered on transesterification of oils with methanol to produce *fatty acid methyl esters* (FAME) or biodiesel. Rapeseed pellet - crushed seed residue from oil extraction is a byproduct of biodiesel production process. As other types of biomass, it can either be burned directly in furnaces or processed to increase its energetic value. The interest to use different types of biomass as fuels has grown rapidly during the last years as a mean to reduce the CO_2 emissions of energy production. Biomass is renewable, abundant and has domestic usage, the sources of biomass can help the world reduce its dependence on petroleum products and natural gas. Energetically effective utilization of rapeseed pellet could substantially improve the economic balance of an individual household in which biodiesel for fulfilling the producer's own energetic demand is obtained. In this article the experimental results of analyzing the emissions levels of different pollutants in exhaust fumes during different stages of biomass boiler operation were presented. It has been proved that that the pellet, a byproduct of biodiesel production, is an excellent renewable and environmentally-friendly energy source, especially viable for use in household tap water heating installations.

Keywords: biodiesel, rapeseed, pellet, biomass, combustion

Introduction

Fatty acid methyl esters, commonly known as biodiesel, are one of the most popular forms of substituting liquid oil-based fuels with renewables - an environmentally-friendly alternative for diesel, beneficial in many ways. Among environmental benefits of biodiesel use, it is very important to list the reduced emission of carbon oxides, benzene derivatives or PAH's (*polycyclic aromatic hydrocarbons*) as well as eliminated emission of sulfur oxides. This comes in pair with excellent engine working parameters obtained, some even surpassing these of standard diesel oil, such as engine part lubrication. Beside the ecological aspects, introducing biodiesel provides a number of economic benefits for its users, such as

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previously mentioned engine work improvement or legal reliefs concerning household biodiesel production, which according to Polish legislation is excise tax-free. This allows for better biodiesel production dispersion and provides wide access to methods of gaining independence from outside energy providers.

The amount of fuel produced is however not the only factor deciding on the economical worthwhileness of biodiesel production process. Other byproducts of biodiesel include rapeseed pellet - crushed seed residue from oil extraction, most commonly formed in a pellet shape, rape straw and glycerin phase.

Combusting rapeseed pellet solves waste problem in biodiesel production through waste-to-energy technology.

This paper aims to prove that the effective utilization of rapeseed pellets from RME production improves the overall energetic and economic balance of household, while respecting harmful substance emission standards. Result of developing and introducing such a solution is promoting the idea of individual biodiesel production as a way of satisfying the producer's energy demand.

Characteristic of biomass

The term 'biomass' is used to describe a wide range of liquid or solid substances, animal or plant-originating, susceptible to biodegradation and produced from byproducts and product of forest and agricultural operations, as well as from industries utilizing the products of these operations. In plant biomass, a certain amount of solar energy, used to transform carbon dioxide into organic compounds in the photosynthesis process, is stored. That amount of energy stored quantifies the actual biomass potential of plant biomass [1].

Biomass is considered one of the most important and promising renewable energy sources. In some UN countries, such as Poland or Slovakia, renewable energy cover only approx. 6% of energy demand (in which biomass share is less than 3%) - that is why the European Commission encourages all investments concerning the introduction of technologies of renewable energy sources utilization, biomass included. One of the reasons behind this is to encourage the realization of goals of national energetic strategies (in Poland: Energetic Strategy of Poland until 2030) [2]. Biomass utilization plays a curtail part in these strategies because of a number of issues - first of all, there's a wide range of available plant materials as a potential energy source - agricultural plan waste, cereal plantations (corn, rapeseed, sunflower, soya), wood and finally energetic plants, such as willow or miscantus.

On a global scale, biomass takes 4th place among the most popular energy sources, after natural gas, oil and coal. Among the most important examples of biomass materials are such as [3]:

- Wood from energetic plantations, forests, orchards or wood conversion industries (most common in form of sawdust)
- Agricultural crops which are of lower than expected quality
- Straw, hay and other plant waste from agricultural production
- Waste from plant conversion industries: pellets, oil waste, molasses, diary waste, decaying seeds, organic communal waste, organic industrial waste

There is a number of physical and chemical factors, evaluating the usefulness of biomass for energy production. Certain characteristic values are measured, such as humidity, elemental composition, level of emissions of harmful substances during combustion, however the most important parameter is the energetic value. Table 1 shows a comparison of energetic values of selected types of biomass, available for energetic utilization.

The energy available from biomass is expressed in two main forms: gross heating value (GHV), also expressed as higher heating value (HHV) and net heating value (NHV), also expressed as low heating value (LHV). Although for petroleum, for example, the difference between the two is rarely more than 10 per cent, for biomass fuels with widely varying moisture content, the difference can be substantial [4].

Table 1

Energetic values of selected fuels with moisture content taken into account [5]

	Rapeseed pellet	**Bituminous coal**	**Wood chips**
Moisture [%]	11.1	4.1	34.5
Proximate analysis, w-% on dry basis			
Ash, 815°C	6.5	12.5	0.8
Volatile content	75.7	29.7	84.6
Lower heating value [kJ/kg]	19 780	27 980	18 590

One of the most important benefits of energetic utilization of biomass is the Carbon Dioxide circulation balance close to zero. It means that CO_2 emitted in combustion processes is approx. equal to the amount of CO_2 previously absorbed by the plants burned in their growth processes. Another important positive aspects are: utilization of excess food and converting food which does not meet the necessary quality standards, and utilization of wood industry waste. Exploiting biomass for energetic purposes has also positive impact on economic activation - it encourages creating new jobs, especially in rural areas, and decentralizes the energy production in a direction of increased individual production, independent from outside energy supply. Finally, biomass decreases the total area of unused and degraded agricultural lands.

Some drawbacks of biomass use include high costs of production, conversion and transport. Additionally, increased amount of ash in the air is observed in biomass conversion plants, when compared to fossil fuel production. Finally, it is important to note that some aspects of planting and growing biomass may have negative impact on the environment - soil degradation or a decrease in biodiversity.

Rapeseed pellets as a potential energy source

The attractiveness of on-farm biodiesel production is based on the ability of an individual farmer to become self sufficient in their fuel use. According to research, 5% of the total cropping area needs to be sown with rapeseed to meet the farm's annual fuel requirements. There are a number of solutions in on-farm biodiesel production that are currently being investigated by farmers:

They include:

- Buying oil and having a contractor produce biodiesel from it.
- Buying oil and individually producing biodiesel.
- Buy oil and cooperatively producing biodiesel.
- Growing rapeseed, extracting oil via a contract crush and producing biodiesel.
- Growing rapeseed, extracting oil individually or cooperatively and producing biodiesel.

The potential feedstock for rapeseed biodiesel production is: 320 to 360 dm^3/ha.

Rapeseed oil can be extracted from the seed by a continuous mechanical press. There are a number of processes that are performed around the press in order to extract the most amount of oil. Rapeseed pellets (expellers), also known as the extraction paste, are crushed residue of oleic plants, obtained after the oil extraction process, either conducted mechanically - pressing hot or cold seeds, or chemically. Expellers are - according to standard "PN-80/R-64773 Loose fodders. Rapeseed meals and oil plants expellers" - "oil plants residues obtained through pressing oil out of them in presses in continuous processes". Pellets (expellers) and rapeseed meal, frequently termed by the common name "rapeseed cake", constitute a by-product in the production of rapeseed oil from rape. In Poland three various technologies are applied for obtaining oil and oil cake depending on the raw material processed. The industrial seed processing in the largest fat plants, of processing capacity of 200-700 10^3 kg diurnally, is based on pressing-extraction technology, preceded by seed conditioning aimed at increasing the efficiency of oil extraction. In smaller plants and in individual farms there exist two technologies of mechanical oil extraction, by means of hydraulic or expeller presses [6]. Depending of the extraction method, pellets may contain different amount of plant oil - and so: cold pressing, the least effective method of oil production, creates a pellet containing 15% weight of oil, while with chemical extraction this share is decreased below 10% [7].

Rapidly increasing amount of biofuels produced worldwide causes an increase in the amount of pellets being produced, which is why the problem of utilizing the pellets draws more attention. Because of high protein content and a well-balanced amino acid composition, fresh pellets may be used as an excellent food for farm animals. However, even a short storage period causes the oil in pellets to oxidize, not only quickening the decay of plant mass but also increasing the risk of a fire outbreak, especially in very large storage facilities, because of high amounts of energy being freed during the chemical processes taking place in the pile. It is also important to note that not all agricultural households keep or breed farm animals. The use of biomass products provides substantial benefits as far as the environment is concerned. Biomass absorbs carbon dioxide during growth and emits it during combustion. Therefore, biomass helps the atmospheric carbon dioxide recycling and does not contribute a net greenhouse effect. These factors support a search for alternative ways of pellet utilization, among which energetic conversion in heating boilers is one of the most promising.

Table 2

Elemental composition of different types of fuels [5]

	Rapeseed pellet	**Bituminous coal**	**Wood chips**
Ultimate analysis [% of dry basis]			
C	49.9	72.4	50.6
H	6.5	4.3	6.1
N	7.15	1.32	0.23
S	0.74	0,75	< 0.02
O	29.2	8.6	> 42.2
Cl	0.02	0.13	0.008

The elemental composition of rapeseed pellets is one of the decisive factors when taking into account its energetic worthwhileness. It allows for an estimation of burning heat, and through it - the energetic value of the pellet. Elemental composition also allows predicting the amount of air needed for effective combustion and evaluating the exhaust fumes composition, from fresh as well as dry biomass, which is very important when considering the environmental impact of the utilization process. Table 2 presents the approx. elemental composition of selected types of biomass in comparison to anthracite. Values presented below do not include humidity of the material, however do include ash content.

The calorific value of bio-char equalled 25.3 MJ/kg [6]. Figure 1 presents a comparison of calorific values among selected renewable energy sources and hard coal.

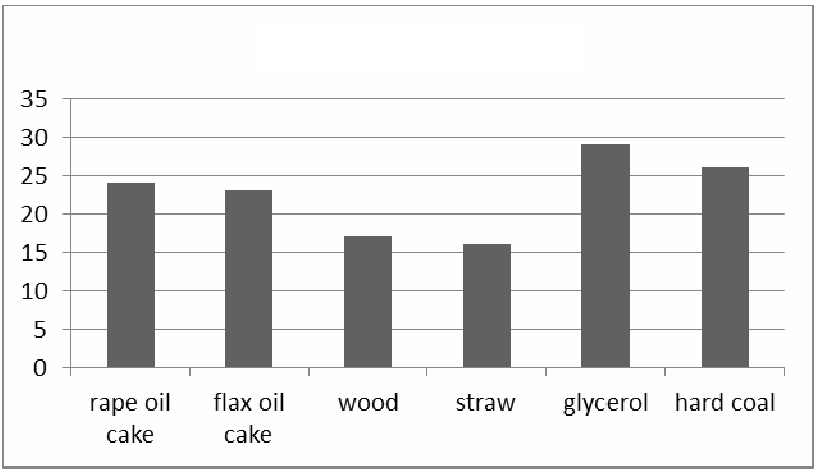

Fig. 1. The calorific value [MJ/kg] of selected RES and hard coal [8]

As previously mentioned, energetically effective utilization of rapeseed pellet could substantially improve the economic balance of an individual household in which biodiesel for the producer's own energetic demand is obtained, which in turn increases the attractiveness of introducing such solutions among other farmers.

A simple indicator of energy efficiency - the measure of Energy Return On Energy Investment (EROI or EROEI) which is calculated as: EROEI = E_{out}/E_{in}, where E_{out} is the amount of energy produced, and E_{in} is the amount of energy used in production was calculated for biodiesel production in [9]. It was stated that it is quite low and that improving the energy efficiency of rapeseed biodiesel is certainly crucial if we want it to become a viable substitute for fossil fuels such as oil and gas, which still have much higher EROEIs.

To answer the question: "Can Rape Seed Biodiesel Meet the EU Sustainability Criteria for Biofuels?" in [10] the authors concluded that to comply with the GHG saving limit after 2017 of 60%, the rape seed biodiesel system should at a minimum include rape cake for animal feed and glycerol for heat production.

An important factor of individual biodiesel production is the ease in obtaining basic reactions substrates - seeds of oleic plants, source of natural oil for the transestrification process, which can easily be planted and harvested within the farm. Because, in such a situation, oil is obtained directly from the producer's crops, it is essential to include oil extractors in a fully operational biodiesel production line. Hydraulic presses, such as Hybren® H6 oil extraction hydraulic press are most commonly used. This oil expeller is dedicated for the following raw materials: rapeseed, linseed, hemp, mustard and sesame and has a capacity of 5-6 kg/hour (for rapeseed) and yield equal to 18-37% (depending on seed moisture condition). Produced pellets (expellers) have a diameter of 6-6.5 mm [11].

Method

Conducted research involved the process of pellet combustion in a boiler heater, in order to evaluate the heater's work efficiency and to measure the polluting substance's emission levels during combustion, in order to compare these results with Polish and UN emission limits.

The heating installation used in the experiment contains an oven and a buffer container, filled with water. The HDG Pelletmaster heater is a special type of oven for burning solid biomass. Depending on the objective of studies, it is possible to read theoretical as well as useful work effectiveness of the installation. Important characteristics of the device have been presented in Table 3.

Table 3

Technical parameters of HDG Pelletmaster biomass heater

Boiler power	25 kW
Nominal power	7.5-25 kW
Maximum work pressure	3.0 bar
Chimney draft required	20 Pa
Exhaust mass stream	63.36 kg/h
Maximum exhaust temperature	180ºC
Fuel container volume	65 dm^3
Length	825 mm
Width	936 mm
Height	1614 mm
Weight	288 kg

Figure 2 shows an idea schematic of the installation. The heating installations comprises a fuel container, connected through a feeder with the burning chamber and a buffer vessel, equipped with two temperature measurement point.

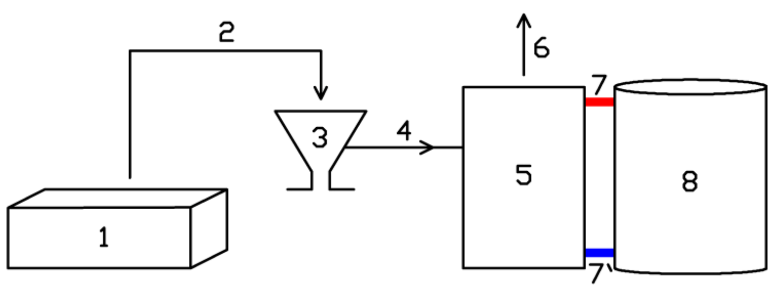

Fig. 2. Heater installation schematic: 1 - fuel container; 2 - fuel feeder; 3 - loading vessel; 4 - fuel transport into the boiler; 5 - boiler; 6 - exhaust fumes; 7 - hot water pipeline; 7' - cold water pipeline; 8 - buffer vessel

The use of pellets in itself can be viewed as an emission-reducing measure, since pellets are of very consistent quality (relative to other wood fuels), burn very clean as they do not contain any bark (white premium pellets), thus have very low ash contents of around 0.5% with consistent and low moisture of about 8%. Depending on the combustion technology, particulate emissions while using pellets may be as low as 50-70 mg/m^3 [12]. The primary criteria of air contamination (commonly regulated or included in air discharge permits) are particulate matter (PM), nitrogen oxides (NO_x), carbon monoxide (CO), and sulphur dioxide (SO_2). Depending on the source (or process), volatile organic compounds (VOC) and hazardous air pollutants, including PAH, dioxins and furans may also be required to be monitored and controlled at specified levels. Table 4 presents Polish criteria for gas emissions from small power solid biomass boilers - these types of boiler are most commonly used among individual household producers - the designated receiver of the developed technology.

Table 4

Emission limits in exhaust fumes from biomass boilers [13]

	Parameter	Unit	Criteria
Concentration in exhaust fumes [1]	SO_2	[mg/m^3]	≤ 800
	CO	[mg/m^3]	≤ 1200
	NO_x [2]	[mg/m^3]	≤ 600
	Ash	[mg/m^3]	≤ 125
	TOC	[mg/m^3]	≤ 75
	PAH	[mg/m^3]	≤ 5

[1] Limits for amounts in dry fumes in normal conditions, 10% oxygen content
[2] Nitrogen oxides calculated in NO_2

For the emission level reading, a Testo® 350 XL Portable Analyzer probe has been inserted into the boiler's chimney. The analyzer is capable of measuring parameters such as exhaust fumes content - carbon, nitrogen and sulfur compounds (1 ppm accuracy), fume temperature and, optionally, other parameters such as humidity and volume flow. The analyzer is capable of measuring the content in the exhaust gases (with an accuracy of 1 ppm), exhaust gas temperature and, optionally, other parameters such as gas flow rate.

In the UE, in view of an increase in biomass-based energy production, specific emission standards for this fuel are justified by now only for large combustion plants [14]. There is a mechanism proposed for ensuring that Renewable Heat Incentive financial support is only given to biomass boilers capable of complying with limits of 30 g/GJ (PM) and 150 g/GJ (NO_x) [15].

At the beginning of a work cycle, rapeseed pellet, introduced into the fuel container, is transported through the pipe feeder into the burning space. When the space is filled, a hot stream of air is blown into it, causing the biomass to ignite. Primary heating stage occurs and the amount of fuel transported into the burning space is gradually increased, until the desired work temperature is reached. Next, the work stage proceeds, in which the amount of fuel, as well as the amount of hot air, are automatically regulated based on the heating needs of the user. During this stage, heat from the boiler is transported into the buffer vessel through working medium, water.

Work effectiveness of the boiler is calculated with the following formula:

$$\eta = \frac{Q_{boiler} + Q_{water}}{Q_{boiler} + m_{pt,b} \cdot q_s} \cdot 100\% \quad (1)$$

Q_{boiler} - heat used for heating the boiler [MJ]; Q_{water} - heat used for heating the buffer vessel [MJ]; q_s - heat of combustion of rapeseed pellet [MJ/kg]; $m_{pt,b}$ - mass of fuel used for heating the buffer vessel [kg].

Amount of heat used for heating up the boiler was calculated through the following formula:

$$Q_{boiler} = m_{pt,k} \cdot q_s \text{ [MJ]} \quad (2)$$

$m_{pt,k}$ - mass of fuel used for heating up the boiler [kg].

Amount of heat used for heating up the water in the boiler vessel was calculated as follows:

$$Q_{water} = m_w \cdot C_w (t_2 - t_1) \text{ [MJ]} \quad (3)$$

m_w - mass of water inside the vessel, 500 kg; C_w - specific heat of water, 4181 kJ/(kg·K); t_1, t_2 - temperature of water at the inlet and outlet of the buffer vessel [K].

Useful work efficiency η_{use} of the boiler was calculated using the following formula:

$$\eta_{use} = \frac{Q_{water}}{m_{pt,b} \cdot q_s} \cdot 100\% \quad (4)$$

In order to calculate the work efficiency of the boiler, it was also required to evaluate the amount of pellet used for heating up the boiler, amount of pellet used for heating the buffer vessel and the amount of heat absorbed by the water inside the buffer through measuring the starting (t_1) and the finishing (t_2) temperature of water contained within the buffer.

Results

Results obtained during the operation of boiler heater have been presented in Table 5.

Table 5

Results of water temperature measurement

No.	Mass of pellet [g]		Temperature [^{o}C]	
	Boiler heating	**Buffer heating**	t_1	t_2
1.	1560.0	3182.9	37	72
2.	1834.7	5761.0	26	71
3.	2416.2	5128.6	25	72
4.	1718.9	5432.1	24	72
5.	1620.5	7530.9	39	71
6.	1623.6	5440.4	25	72
7.	1523.6	5007.6	34	71
8.	1632.7	5298.3	24	72
9.	1629.5	5524.0	25	73
10.	1644.3	5578.2	24	72
11.	1663.5	5867.6	24	72
12.	1654.0	5285.2	24	71

Based on the obtained results, average work efficiency of the boiler was calculated to **83.5%** and average useful work efficiency was estimated at **78.4%.**

Simultaneously, an exhaust analyzer was used to evaluate the level of emissions of different pollutants in exhaust fumes during different stages of biomass boiler operation - results of this study have been shown in Tables 6-8 and Figure 3.

Table 6

Emission levels during boiler heat-up stage [16]

Pollutants	**Average value [mg/m^3]**	***SD***
CO	750.5	299.2
NO	196.5	31.5
NO_x	315.5	50.3
SO_2	32.1	36.5

Table 7

Emission levels during boiler work stage

Pollutants	**Average value [mg/m^3]**	***SD***
CO	664.5	367.9
NO	219.4	25.5
NO_x	352.2	41.1
SO_2	540.9	51.8

Table 8

Emission levels during boiler cooling stage

Pollutants	**Average value [mg/m^3]**	***SD***
CO	384.4	29.7
NO	53.6	31.0
NO_x	154.7	89.2
SO_2	112.1	70.6

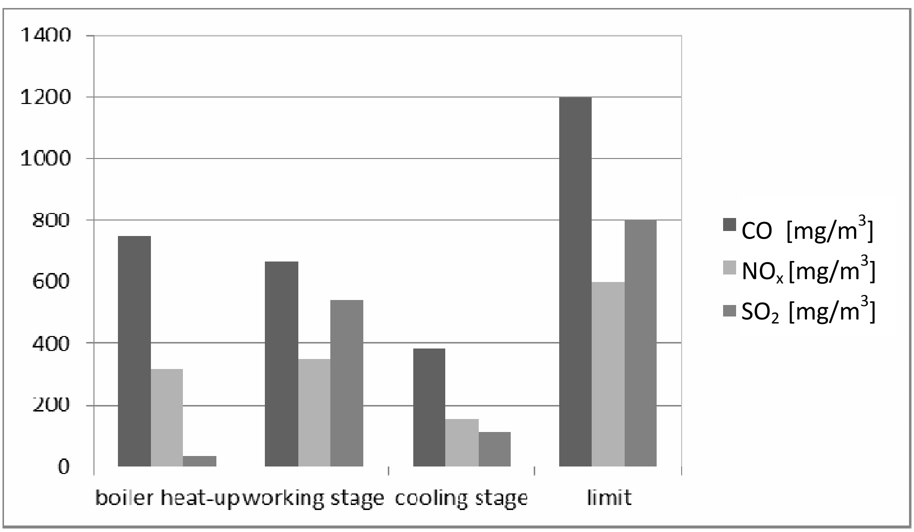

Fig. 3. Comparison of the emission levels and limits for CO, NO_x, and SO_2 during boiler heat-up, working and cooling stages

It has been observed that the measured emission levels of all the pollutants are below the maximum emission limits described in Polish and UN legislation. These results confirm the viability of using rapeseed pellets for fueling biomass boilers in individual households.

Conclusions

Utilization of rapeseed pellets has a positive influence on improving the energetic balance of an individual household in which biodiesel production is also conducted for covering the household's energetic demands. This paper described a series of studies confirming this thesis. Pellets have a high content of carbon, almost 54%. Results of combusting rapeseed pellets in a calorimeter, documented elsewhere, indicate that the caloric value of this type of biomass is nearly as high as that of bituminous coal, however, unlike coal, pellets are a fully renewable material. Research on effectiveness of heat acquisition from rapeseed extraction paste in a biomass boiler show that the useful effectiveness of this process reaches 80%. Simultaneously, the amount of sulfur, nitrogen and carbon oxides in gas fumes from the combustion process is well below the emission limits stated in Polish and UN legislation for biomass fueled heaters. All the above results indicate that rapeseed pellets, a byproduct of biodiesel production, are not only a valuable substitute of animal fodder, but also an excellent renewable and environmentally-friendly energy source, especially viable for use in household tap water heating installations.

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WYTŁOKI RZEPAKOWE - PRODUKT UBOCZNY W PRODUKCJI BIODIESLA - JAKO DOSKONAŁE ŹRÓDŁO ENERGII ODNAWIALNEJ

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Abstrakt: Oleje roślinne są obecnie - jako surowce odnawialne - wykorzystywane do produkcji biopaliw. Produktem odpadowym w produkcji biopaliw z roślin oleistych są wytłoki roślinne, pozostałe po uzyskaniu oleju metodą mechaniczną lub chemiczną. Odpady te, zwane też makuchami lub pelletem, mogą być wykorzystane jako dodatkowe źródło energii (np. do ogrzewania pomieszczeń) w gospodarstwach rolnych lub domowych. Zainteresowanie stosowaniem różnych rodzajów biomasy jako paliwa gwałtownie wzrosło w ostatnich latach i traktowane jest jako sposób na zmniejszenie emisji CO_2 w procesie produkcji energii, a także na ograniczenie zależności od produktów naftowych i gazu ziemnego. Tak jak inne rodzaje biomasy, pellet rzepakowy może być albo spalany bezpośrednio w piecach, albo przetwarzany w celu zwiększenia jego wartości energetycznej. Energetycznie efektywne wykorzystanie odpadu rzepakowego może znacznie poprawić równowagę ekonomiczną indywidualnego gospodarstwa domowego, w którym biodiesel produkowany jest dla zaspokojenia własnego zapotrzebowania. W artykule przedstawiono wyniki badań eksperymentalnych analizy poziomu emisji substancji, zawartych w spalinach, podczas różnych etapów pracy kotła na biomasę. Udowodniono, że pellet, produkt uboczny produkcji biodiesla, jest doskonałym odnawialnym i przyjaznym dla środowiska źródłem energii, szczególnie opłacalnym do stosowania w instalacjach centralnego ogrzewania i podgrzewania wody użytkowej w gospodarstwach rolnych.

Słowa kluczowe: biodiesel, rzepak, pellet, wytłoki, biomasa, spalanie