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# COMPARISON OF THE EFFECTS OF MANAGEMENT OF APPLE POMACE FOR ENERGY PURPOSES IN FERMENTATION AND COMBUSTION PROCESSES

*Summary*

*The search for alternative fuels is becoming increasingly common due to exhausting conventional energy sources. One of the solutions is to manage waste from agricultural and food production for energy purposes. The aim of the study was to compare possible energy gains from the use of apple pomace as a fuel in two variants. The first option consisted in converting waste into solid fuel for combustion, while the second option included methane fermentation of pomace and the use of the resulting fermentation for combustion. The research was carried out to determine the energy usefulness of apple pomace extruders, among others. combustion heat, calorific value and biogas efficiency. The amount of energy that can be obtained from biogas resulting from the decomposition of pomace as well as from the post-process fermentation was also determined. Energy expenditures necessary for the processes that transform the raw material into fuel were simulated. Then an energy balance was carried out which showed that the fermentation of pomace and the combustion of the fermented pulp, taking into account the losses, resulted in an energy gain of 4.03 MJ·kg$^{-1}$ (1.12 kWh·kg$^{-1}$) higher than the use of pomace for combustion alone.*
***Key words**: renewable energy sources, energy balance, higher heating value, biogas, food wastes*

# PORÓWNANIE EFEKTÓW ZAGOSPODAROWANIA WYTŁOKÓW JABŁKOWYCH NA CELE ENERGETYCZNE W PROCESACH FERMENTACJI ORAZ SPALANIA

*Streszczenie*

*Ze względu na wyczerpujące się konwencjonalne źródła energii coraz powszechniejsze staje się poszukiwanie paliw alternatywnych. Jednym z rozwiązań jest zagospodarowywanie odpadów pochodzących z produkcji rolniczej oraz spożywczej na cele energetyczne. Celem pracy było porównanie możliwych zysków energetycznych z wykorzystania wytłoków jabłkowych jako paliwa w dwóch wariantach. Wariant pierwszy obejmował przekształcenie odpadu na paliwo stałe w celu spalenia, natomiast wariant drugi dotyczył fermentacji metanowej wytłoków oraz wykorzystania powstałego w jej wyniku pofermentu na sposób spalania. W pracy wykonano badania pozwalające określić przydatność energetyczną wytłoków jabłkowych m.in. ciepło spalania, wartość opałową oraz wydajność biogazową. Wyznaczono również ilość energii możliwą do uzyskania z biogazu powstałego w wyniku rozkładu wytłoków oraz z pofermentu pozostałego po tym procesie. Dokonano symulacji nakładów energetycznych potrzebnych na procesy przekształcające surowiec do postaci paliwa. Następnie wykonano bilans energetyczny, który wykazał, że w wyniku fermentacji wytłoków oraz spalania pofermentu przy uwzględnieniu strat możliwe jest uzyskanie o 4.03 MJ·kg$^{-1}$ (1.12 kWh·kg$^{-1}$) energii więcej niż przy przeznaczeniu wytłoków wyłącznie do procesu spalania.*
***Słowa kluczowe**: odnawialne źródła energii, bilans energetyczny, ciepło spalania, biogaz, odpady spożywcze*

## 1. Introduction

With the development of civilization and decreasing fossil fuel resources, interest in obtaining energy from renewable and ecological sources is increasing. Such sources include solar energy, wind energy, biomass and various types of waste that can be used for energy purposes. Fuels, which are by-products of agricultural or food production, have great potential. This type of raw materials have many advantages: they are produced at a given time and quantity, they are characterized by comparable parameters, they usually do not contain toxic compounds, and since often there is no specific management method for them, energy use seems to be the right solution [Jędrczak A., 2008].

Waste from the food processing industry includes pomace - residues from vegetable and fruit pressing, waste formed after wiping, seeds, spoiled fruit and vegetables [Gryss Z., 1972]. In fruit processing, the majority of waste is pomace produced during must production (approx. 110 thousand tonnes per year). When producing fruit purées for the production of marmalade and puddles, the so-called' milling is obtained (4-5 thousand tonnes). The rest of the fruit waste is produced during the production of frozen foods, pulp and compotes, including sorted spoiled fruits, stalks, leaves and other plant contaminants. The weight of this waste is very small and has practically no value [Gawęcki J., Czapski J., 2017]. In vegetable processing, most of the waste is produced when tomatoes are processed into concentrate. In this process, 7-8 thousand tons of mills are produced. In vegetable souring, large amounts of waste are produced during the pickling of cabbage, while small quantities are produced during the pickling of cucumbers.

Large amounts of waste are generated during root vegetables processing (up to 20%). The waste from the processing of vegetables without taking into account tomatoes is approximately 20-25 thousands tonnes annually [Zadernowski R., Oszmiański J., 1994].

Apple pomace is waste resulting from the processing of fruit into food products such as juices. They are characterized by a high water content, even up to 73%, which makes them easily compacting during storage in uncontrolled conditions [Kumider,1996]. Despite this, they have many important nutrients such as pectin, saccharides, vitamins, fiber, organic acids. Thanks to these substances, pomace is most commonly used in animal feed production. Due to the negligible heavy metal content and the high amount of carbon and nitrogen, apple waste is suitable for biogas production by methane fermentation. As Jewell writes [1984], as much as 80% of organic matter of pomace can be transformed into biogas with an energy value of 10-30 $W \cdot m^{-3}$ [Trakko et al., 2012].

Analysis of the level of knowledge indicates that it is possible to optimise the processes of obtaining energy from biomass. An example is the gasification of biomass in the dry distillation process with the subsequent use of combustible gases (carbon monoxide, methane, hydrogen) and combustible solid waste. Taking into account the similarity, it was indicated that it is possible to obtain energy from apple pomace in two stages. The possibility of obtaining biogas from waste such as pomace has been noticed, as well as the possibility of thermal utilization of the fermentation afterwards.

## 2. The aim of study

The aim of this study was to compare the energy effects of using apple pomace in fermentation and combustion processes. In the research the waste generated by the production of juices using NFC (Not from concentrate) technology has been tested.

In order to achieve the aim of the study, it was indicated that apple pomace would be dehydrated in detail in the work. The results will be compared with the energy effect of the two-stage pomace management process consisting in the initial fermentation of the substrate with the separation of methane and the subsequent combustion of the dehydrated fermentation.

The main objective of the work has been divided into specific tasks.

- combustion of dehydrated apple pomace for the determination of calorific value and combustion heat,
- fermentation of apple pomace in a mixture with biologically active additives in mesophilic margins according to the methodology of determining the cumulative biogas productivity,
- combustion of conditioned fermented pomace mixture for the determination of calorific value and combustion heat.

As part of the fermentation of the pomace mixture, it was assumed that the test mixture would be hydrated below the pumpability limit. The methane concentration and volume of the biogas released will be determined.

An important aim of the study was to compare energy expenditure incurred on preparation of substrates with energy obtained from them in the analysed processes.

## 3. Methodology

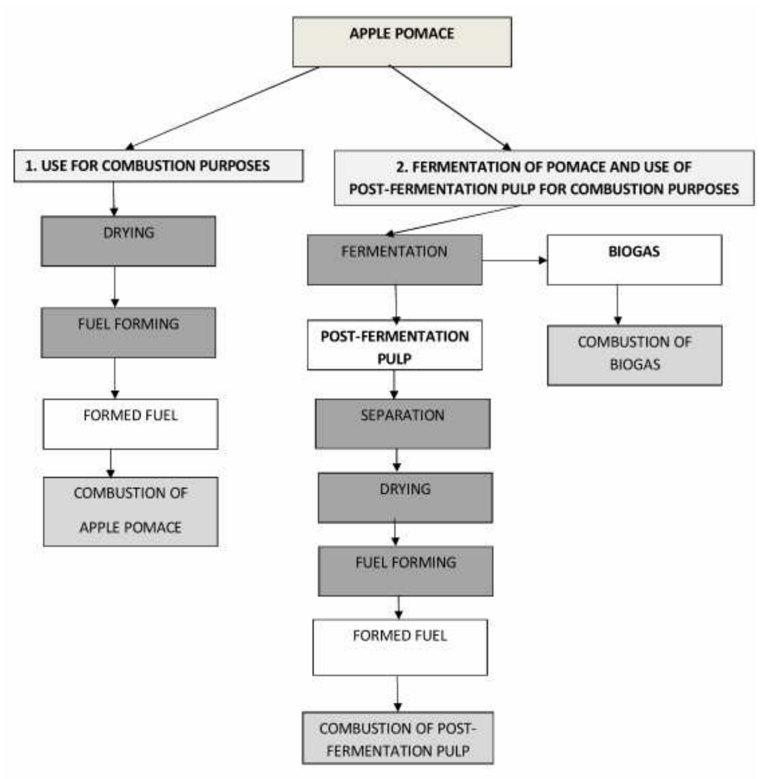
The project used pomace from apples produced in the production of NFC juices. NFC technology is the process of juices production, where fresh fruit is squeezed directly. The juices are pressed and pasteurised and can then be frozen or bottled into suitable bottles. The shells come from the company Maxfrut sp. z o. o., which is located in Jarogniewice, Kościański County, commune of Czempiń.

In order to achieve this objective, the moisture content of fresh pomace, combustion heat and calorific value of pomace, biogas yield of the pomace and slurry mixture with methane content, dry matter content of the resulting digestate, combustion heat and calorific value of the digestate were determined. The results obtained allowed us to calculate the amount of energy that can be obtained by burning and fermenting the pomace and using the fermentation for combustion purposes. The options analysed are shown in Fig. 1. They have been divided into individual processes, some of which require the supply of energy (drying, fuel forming and separation of solids from the fermentation pulp) and others that enable it to be obtained (fuel burning). The process that is on the verge of this classification is fermentation because it requires energy to be supplied, but at the same time it produces fuel.

The moisture content of fresh pomace was determined prior to the study of marc combustion heat. Due to the high water content, the pomace was dried to an air-dry dry state, enabling determination of combustion heat and calorific value. The pomace was subject to a milling process for examination and then sieving to obtain a representative sample with a 0.2mm fraction. The dust obtained was used to make a 1 g tablet of the combustion heat used for the test. The examination of combustion heat was carried out at the Institute of Chemical Wood Technology with the use of computer calorimeter KL-12Mn2 based on PN-81/G-04513 and PN-ISO 1928 standards (Fig. 2) The test consisted in the total combustion of the sample in an oxygen atmosphere, under pressure in a calorimetric bomb immersed in a water jacket, with simultaneous measurement of the increase in water temperature. To determine the calorific value, the moisture content was determined with the use of the drying and weigh-weight method in accordance with the PN-EN ISO 18134-3 standard.

A biogas efficiency study of the pomace was carried out in the Chemical Analysis Laboratory at the Institute of Biosystems Engineering. In the study there were used 451 g of slurry from a grating cattle farm and 160 g of apple pomace originating from the production of direct juices. The raw materials used to produce the mixture were tested to determine their dry matter and organic matter.

The biogas yield tests were carried out in accordance with DIN 38 414-S8 in a multi-chamber fermentation station (Fig. 3), based on an eudiometric system that stores the biogas generated on 1 $dm^3$ fermentation tank capacity [KTBL-Heft-84 2009]. A measurement station for methane, carbon dioxide, hydrogen sulphide, oxygen was used for the biogas gas concentration test (Alter Bio MSMR 16). To prepare inoculum, methanogenic thermostated biostat with a capacity of 1650 ml was used.




*Source: own study / Źródło: opracowanie własne*

Fig. 1. Diagram of the methods of energy use of apple pomace
*Rys. 1. Schemat sposobów wykorzystania energetycznego wytłoków jabłkowych*

*Source: own study / Źródło: opracowanie własne*

Fig. 2. Computer Calorimeter KL-12Mn2 (on the left), general view of the test stand (on the right)
*Rys. 2. Kalorymetr komputerowy KL-12Mn2 (po lewej), widok ogólny stanowiska badawczego (po prawej)*

*Source: own study / Źródło: opracowanie własne*

Fig. 3. Research stand for the study of biogas productivity of substrates according to DIN 38414 s.8 (on the left), inoculum station for quasi-continuous fermentation work (on the right)
*Rys. 3. Stanowisko badawcze do analizy wydajności biogazowej substratów zgodnie z DIN 38414 s.8 (po lewej), stanowisko do wytwarzania inokulum oraz do quasi-ciągłej fermentacji (po prawej)*

Measurements of concentration and volume of secreted gas were carried out at 24-hour intervals.

A mixture of identical composition was in three biofermentors to improve the correctness of the results. MG-72 and MG-73 series measuring heads have been used for measurement of the composition of the biogas produced with measuring ranges 0-100% of volume and measuring resolution in the order of 0.1ppm to 1% volume.

The following standards were used: [PN-74/C-04540/00, PN-75 / C-04616/01 - 04, PN-90 C-04540/01].

The parameter that is evaluated is the volume of generated biogas and the cumulative value [Dach et al. 2009]. During the study the process temperature was 36°C.

The object of the study included a mixture of solid and liquid substrates, subject to anaerobic degradation.

The study plans three repetitions of tests of biogas efficiency of the mixture of bovine slurry and pomace. Average results were converted into unit volume units of separated biogas [$m^3$] per unit of fresh matter, dry matter and dry organic matter.

### 3.1. Testing of combustion heat and determination of the calorific value of digestate

Investigation of the burning heat of the digestate was carried out using the same method as the analysis of the combustion heat of marc. The fermented product was liquid, therefore, in order to perform further analyses, it had to be dried to air-dry condition. Liquid digestate was subject to a test determining its moisture content, which allowed simulation of energy expenditure on separation and drying of the fermentation in the balance.

### 3.2. Comparison of the energy efficiency of the one-step system with the two-stage conversion of apple pomace

According to the proposed diagram (Fig. 1) an energy balance was made checking the amount of energy possible to be obtained from 1 kg of substrate.

1) Determination of energy effects using pomace for combustion purposes.
2) Determination of energy effects with the use of pomace on the fermentation method with the management of the resulting post-fermentation for combustion purposes.

The energy calculations were made using a generally accepted methodology, taking into account the power and efficiency of the equipment used for the process as well as the parameters of the substrate determined during the study.

The planned simulation does not take into account the energy consumption for heating the digester and agitator operation. The reason for this is the multiplicity of structural solutions and thus the differences in energy consumption, which should be further divided into many fermentations.

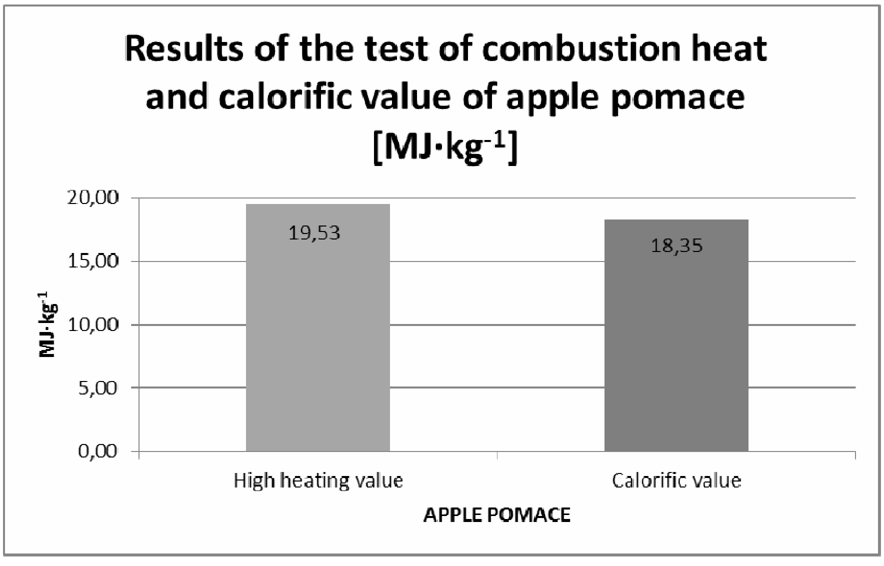
## 4. Results

### 4.1. Testing of combustion heat and determination of pomace calorific value

Fresh pomace moisture content was 74.34%. After drying to air-dry condition, the apple marc combustion heat was determined at 19.53 $MJ \cdot kg^{-1}$. The calorific value of marc at a moisture content of 6.73% was 18.35 $MJ \cdot kg^{-1}$. The results are shown in the Fig. 4.

### 4.2. Investigation of the biogas yield of pomace

Testing the biogas yield of the pomace took 24 days. After this time, experience was discontinued in accordance with the standard due to the fact that the daily volume of biogas produced did not exceed 1% of the current production. The resulting accumulated volume of biogas was determined at 168.78 $m^3 \cdot Mg$ dry matter. The average methane content was 57.375%. Mixture parameters are listed in the Table 1.



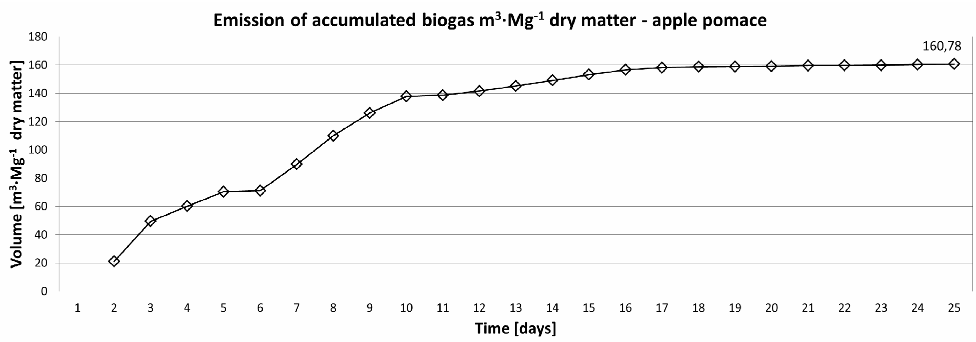

*Source: own study / Źródło: opracowanie własne*

Fig. 4. Results of the test of combustion heat and calorific value of apple pomace
*Rys. 4. Wyniki badania ciepła spalania i wartości opałowej wytłoków jabłkowych*

Table 1. Parameters of the mixture used for the methane fermentation test
*Tab. 1. Parametry mieszanki użytej do badań wydajności biogazowej*

| Component | Fresh mass used for testing | Share of components in the sample | Dry matter content | Dry mass in the sample | Dry organic matter |
|---|---|---|---|---|---|
| | g | % | % | g | % |
| Slurry | 451 | 75 | 1.25 | 5.6375 | 89.62 |
| Apple pomaces | 150 | 25 | 25.66 | 38.49 | 98.44 |
| TOTAL | 601 | 100 | - | 44.1275 | - |

*Source: own study / Źródło: opracowanie własne*



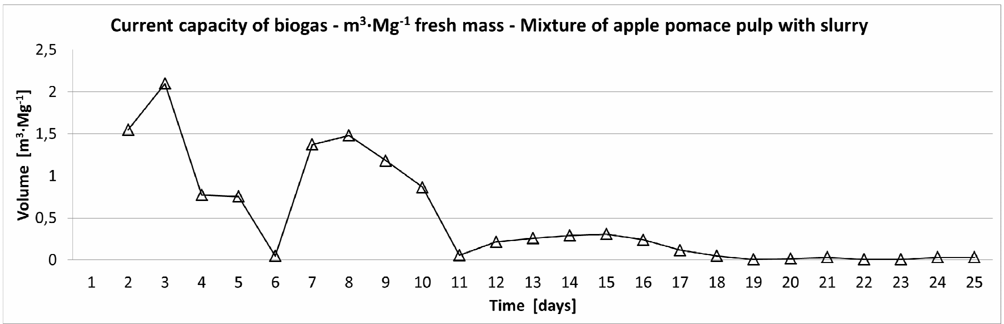

*Source: own study / Źródło: opracowanie własne*

Fig. 4. A graph of the emission of accumulated biogas obtained from a mixture of marc and slurry
*Rys. 4. Wykres emisji zakumulowanego biogazu otrzymanego z mieszanki wysłodków i gnojówki*

The fermentation results are presented graphically. Fig. 5 presents a graph of the capacity accumulated in m$^3$ per tonne of dry matter. It was determined that it is possible to obtain 160.78 m$^3$ of biogas from 1 Mg of dry matter. Discrete data have been linked by a trend line.

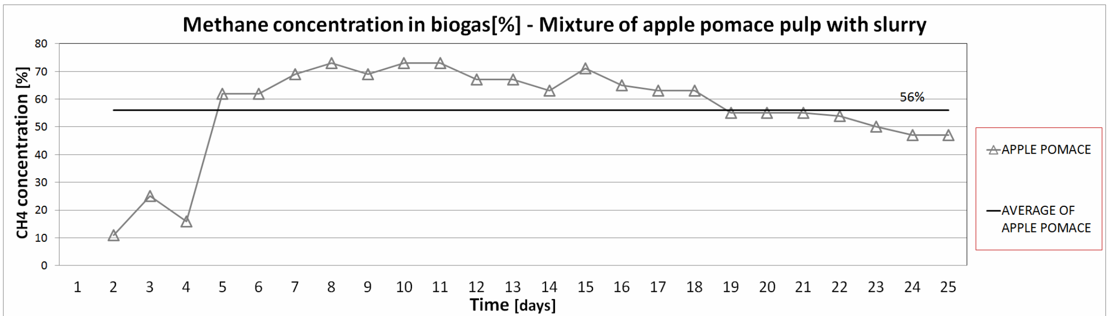
The current flow graph (Fig. 6) of biogas shows the process flow of biogas production during the process days. Dynamic biogas production is observed in the first 10 days of fermentation. After 18 days of experience, the mixture stopped producing biogas. After 25 days of production per day did not exceed 1% of the biogas obtained so far, so it was decided to stop the research.

In addition to the volume of biogas produced, its composition, including methane content, was also investigated (Fig. 7). After a period of 5 days, the gas content exceeded 50% until day 22.56% methane content was determined as an average. Discreet data have been linked by a trend line.




*Source: own study / Źródło: opracowanie własne*

Fig. 6. Chart of the output of temporary biogas from a mixture of marc and slurry
*Rys. 6. Wykres wydajności chwilowej biogazu z mieszanki wysłodków i gnojowicy*




*Source: own study / Źródło: opracowanie własne*

Fig. 7. Chart of methane concentration in biogas obtained from a mixture of pomace and slurry
*Rys. 7. Wykres stężenia metanu w biogazie uzyskanym z mieszanki wytłoków i gnojowicy*

### 4.3. Testing of combustion heat and determination of net calorific value of post-fermentation pulp

The dry matter content in the fermentation was 4.34%. Before the test of combustion heat, the digestate was dried. High heating value was 19.45 MJ·kg$^{-1}$. Humidity of the sample tested for combustion heat was 7.94%. Calorific value was determined at 18.26 MJ·kg$^{-1}$. The results are presented in the graph (Fig. 8).

### 4.4. Calculation of the energy balance

According to the proposed diagram (Fig. 1) an energy calculation was made to check the amount of energy available from 1 kg of substrate.

The energy gain was determined by estimating the difference between the process of energy generation (combustion) and the sum of processes enabling the waste to be transformed into fuel. Data for the energy balance were simulated based on the results of the research and technical parameters of a belt dryer, briquetting machine and a belt press for separating the solid fraction of digestate.

The briquetting machine adopted for calculation had a power of 15 kW and a capacity of 0.15 Mg·h$^{-1}$. The power of the belt press for the separation of digestate was 3 kW and its capacity was 0.6 Mg·h$^{-1}$. In the case of simulation of the drying process, the results obtained were taken into account with respect to the substrate moisture content before and after each process. Related water vaporization energy intensity was assumed at the level of 1.75 kWh·Mg$^{-1}$.

The efficiency of the solid fuel boiler has been assumed to be 80% for the calculation of the achievable energy. The energy potential of biogas was determined by calculating the methane volume in the accumulated biogas emissions from 1 kg, then multiplying this value by the methane net calorific value of 35.73 MJ·kg$^{-1}$.

1) Determination of energy effects using pomace for combustion purposes

In order to estimate the energy consumption of the process of drying the marc, the moisture content of fresh pomace and the moisture content of pomace were analysed at the moment of the analysis of the combustion heat, respectively 74.34% and 6.70%. The amount of energy needed to evaporate 0.6764 kg of water from 1 kg of raw material was calculated as 13.176 MJ·kg$^{-1}$ (3.66 kWh·kg$^{-1}$).

On the other hand, it was found that in order to convert 1 kg of raw material into briquette it is necessary to use 0.36 MJ·kg$^{-1}$ (0.1 kWh·kg$^{-1}$).

The energy obtained from the combustion process was determined as 14.68 MJ·kg$^{-1}$ (4.08 kWh·kg$^{-1}$).

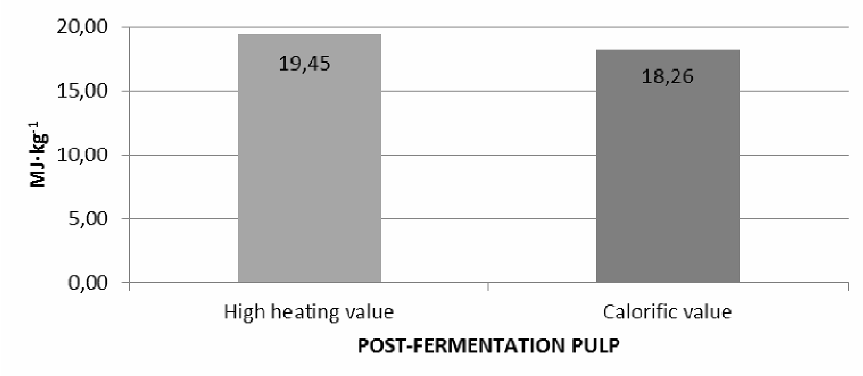
The energy gain from the conversion of marcs into solid fuel and the combustion of this fuel was 1.14 MJ·kg$^{-1}$ (0.32 kWh·kg$^{-1}$) (Table 2).

2) Determination of energy effects with the use of marc on the fermentation method with the management of the resulting post-fermentation for combustion purposes

Due to the liquid form of the fermentation, it was decided to simulate mechanical separation of the fermentation before drying. It has been assumed that the expected moisture content after the separation process will decrease by 25% to 74.13%. The expected separation energy is defined as 0.018 MJ·kg$^{-1}$ (0.005 kWh·kg$^{-1}$).

In order to estimate the energy consumption of the drying process of the fermentation, the estimated moisture content and the moisture content of the fermentation were taken into account at the time of the analysis of the combustion heat, i.e. 7.94%. The amount of energy needed to evaporate 0.6619 kg of water from 1 kg of raw material was calculated as 12.34 MJ·kg$^{-1}$ (3.43 kWh·kg$^{-1}$).

As in the case of marc, it was assumed that in order to convert 1 kg of raw material into briquette it is necessary to use 0.36 MJ·kg$^{-1}$ (0.1 kWh·kg$^{-1}$).




*Source: own study / Źródło: opracowanie własne*

Fig. 8. Test results of combustion heat and calorific value of digestate from apples
*Rys. 8. Wyniki ciepła spalania i wartości opałowej pofermentu z wytłoków jabłkowych*

Table 2. Energy balance for the use of apple pomace for combustion purposes
*Tab. 2. Bilans energetyczny wykorzystania wytłoków jabłkowych na cele spalania*

| No | Process | Energy expenditure | | Energy yield | | Energy balance [energy expenditure-energy yield] | |
|---|---|---|---|---|---|---|---|
| | | MJ·kg$^{-1}$ | kWh·kg$^{-1}$ | MJ·kg$^{-1}$ | kWh·kg$^{-1}$ | MJ·kg$^{-1}$ | kWh·kg$^{-1}$ |
| 1. | Drying | 13.176 | 3.66 | - | - | | |
| 2. | Fuel forming | 0.36 | 0.1 | - | - | | |
| 3. | Combustion | - | - | 14.68 | 4.08 | | |
| | Total | 13.536 | 3.76 | 14.68 | 4.08 | 1.14 | 0.32 |

*Source: own study / Źródło: opracowanie własne*

Table 3. Energy balance for the use of apple marc by methane fermentation and conversion of the fermentation into combustion
*Tab. 3. Bilans energetyczny wykorzystania wysłodków w fermentacji metanowej i przetworzenia pofermentu na cele spalania*

| No | Process | Energy expenditure | | Energy yield | | Energy balance [energy expenditure-energy yield] | |
|---|---|---|---|---|---|---|---|
| | | $MJ \cdot kg^{-1}$ | $kWh \cdot kg^{-1}$ | $MJ \cdot kg^{-1}$ | $kWh \cdot kg^{-1}$ | $MJ \cdot kg^{-1}$ | $kWh \cdot kg^{-1}$ |
| 1. | Combustion of biogas | - | - | 3.27 | 0.91 | | |
| 2. | Separation of post-fermentation pulp | 0.018 | 0.005 | - | - | | |
| 3. | Drying of post-fermentation pulp | 12.34 | 3.43 | - | - | | |
| 4. | Fuel forming | 0.36 | 0.1 | - | - | | |
| 5. | Combustion of post-fermentation pulp | - | - | 14.62 | 4.06 | | |
| | Total | 12.718 | 3.535 | 17.89 | 4.97 | 5.17 | 1.44 |

*Source: own study / Źródło: opracowanie własne*

The energy obtained from the combustion of biogas is defined as 3.27 $MJ \cdot kg^{-1}$ (0.91 kWh/kg) and from the combustion of 14.62 $MJ \cdot kg^{-1}$ (4.06 $kWh \cdot kg^{-1}$).

The energy gain from the conversion of pomace into biogas resulting from fermentation into solid fuel and the combustion of this fuel was 5.17 $MJ \cdot kg^{-1}$ (1.44 $kWh \cdot kg^{-1}$) (Table 3).

## 5. Conclusions

The research shows that apple pomace can be used for energy purposes.

It is proven to be suitable for solid fuel as well as methane fermentation. It is also possible to use the fermentation as a combustion method.

The proposed simulation of the energy balance shows that a higher energy yield is possible during fermentation of marc and combustion of fermentation. IInd variant of marc utilization allows to obtain by 4.03 $MJ \cdot kg^{-1}$ (1.12 $kWh \cdot kg^{-1}$) more than when burning marc. The moisture content of fresh marc has a decisive influence on the obtained result.

The energy efficiency of the marc combustion process can be improved by limiting the drying process, at least to a level of about 15%, as well as by co-combustion with e.g. woodchips.

Due to epidemiological restrictions on food production plants, combustion remains the only solution if marc is to be used to generate energy for the plant's technological needs. The two-step biomass energy recovery process contributes to improving the energy balance and increasing the profitability of the industry. It can be used in conjunction with a biogas plant at a safe distance from the company for sanitary reasons.

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[11] Polskie Normy. PN-74/C-04540/00. Wydawnictwo Normalizacyjne. Warszawa. Oznaczenie zasadowości.

[12] Polskie Normy. PN-75/C-04616/01. Wydawnictwo Normalizacyjne. Warszawa. Oznaczanie suchej masy osadu i substancji organicznych. Woda i ścieki. Badania specjalne osadów. Oznaczanie zawartości wody, suchej masy, substancji organicznych i substancji mineralnych w osadach ściekowych.

[13] Polskie Normy. PN-75/C-04616/04. Wydawnictwo Normalizacyjne. Warszawa. Oznaczenie lotnych kwasów tłuszczowych.

[14] Polskie Normy. PN-90 C-04540/01. Wydawnictwo Normalizacyjne. Warszawa. Woda i ścieki. Badania pH, kwasowości i zasadowości. Oznaczanie pH wód i ścieków o przewodności elektrolitycznej właściwej 10 μS/cm i powyżej metodą elektrometryczną.

[15] Polskie Normy. PN-81/G-04513 Wydawnictwo Normalizacyjne. Warszawa. Paliwa stałe - Oznaczanie ciepła spalania i obliczanie wartości opałowej.

[16] Polskie Normy. PN-ISO 1928. Wydawnictwo Normalizacyjne. Warszawa. Paliwa stałe - Oznaczanie ciepła spalania metodą spalania w bombie kalorymetrycznej i obliczanie wartości opałowej.

[17] Polskie Normy. PN-EN ISO 18134-3. Wydawnictwo Normalizacyjne. Warszawa.

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