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Thermal Treatment of Municipal Waste in Poland on Example of RDF Pyrolysis

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Abstract : In the face of the constant tightening of environmental regulations, alternative sources of fuels and energy are being increasingly sought. The European Union strives to introduce waste-free or low-waste closed-loop technologies using material and energy recovery to manage natural resources in a rational manner. Therefore, European regulations require member states to progressively restrict the amount of landfill waste. In Poland, these requirements have been included in the Act on waste and the Act on order and cleanliness in the commune. In addition, since 1 January 2016, it has been forbidden to store waste with a calorific value exceeding 6 MJ/kg, which is why in recent years there has been an increase in interest in the thermal transformation of municipal waste. Therefore, the article presents the current shape of waste management in Poland, and also introduces the dominant form of RDF management in the cement industry. Nevertheless, the capacity of cement plants is limited, and the energy use of fuels from waste encounters difficulties related to a significant reduction in pollutant emissions, which is why the use of modern installations for the thermal conversion of waste such as pyrolysis and gasification is increasingly considered. Taking into account the promising energy properties of secondary fuels obtained during the pyrolysis process, the chemical composition of gas from RDF pyrolysis was modeled for a pilot installation operating in Poland using CHEMKIN-PRO software. Determination of the combustible components allowed the calorific value of pyrolytic gas to be estimated, ranging from 28.2 - 28.7 MJ/m^3. The obtained calorific value is much higher than the average calorific value of RDF (11-18MJ/kg) [1], which encourages wider use of the waste pyrolysis process in order to obtain secondary fuels with promising energy parameters. It will contribute to a further reduction in the amount of deposited waste, and thus to creating environmentally-friendly closed-loop waste management.

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1 Introduction

The main legal act regulating the principles of municipal waste management in Poland is the Waste Act of December 14, 2012. The amendment to the said act, which entered into force on 6 February 2015, modified the definition of a regional municipal waste treatment installation (in polish: RIPOK), opening it to new technologies. In the current definition, the use of other technologies not used to date in regional installations is allowed, for example pyrolysis, gasification or the plasma process, regardless of the fact that the process is qualified as thermal transformation. In addition, the legislator foresaw the possibility of removing a regional installation that does not meet the requirements of environmental protection or other measures provided for it from the resolution on the implementation of the Voivodeship Waste Management Plan (VWMP) Furthermore, the entry into force of the law on order and cleanliness in municipalities (01/01/2012), giving Polish municipalities 18 months to prepare for implementation of the new system, seems important from the point of view of proper waste management. Since 1 July 2013, the said municipalities have been responsible for the collection of municipal waste, as well as the collection of fees from residents. The above legal act contributed to an increase in the importance of selective municipal waste collection and its recycling. Observing the changes in the share of individual forms of waste management in previous years (Figure 1), a gradual decrease in the amount of waste deposited in

Poland can be noticed (except for 2012, where a slight increase was recorded), in favor of other forms of their use, especially recycling and thermal transformation. The last-mentioned form has a great chance of developing because according to Annex 4 to the Regulation of the Minister of the Economy regarding the admission of waste for landfills of 16 July 2015, since 1 January 2016, a ban on depositing waste with a calorific value exceeding 6 MJ/kg of dry matter at landfill sites has been in force in Poland. The aim of the above-mentioned solution is to maximize the use of the highest calorific waste, which will allow the landfilling of only waste whose energetic use would be unprofitable. Therefore, it seems appropriate to consider the use of these wastes in developing innovative waste treatment installations. At the same time, the Waste Act of December 14, 2012 defined thermal transformation as: *combustion of waste by its oxidation*, other waste thermal treatment processes other than those indicated in the literature, including pyrolysis, gasification and the plasma process, as long as the substances resulting from the above-mentioned processes are subsequently incinerated.

These Polish legal acts on waste management have contributed to an increase in waste recovery, including its recycling, while opening up to new technologies of thermal transformation, giving the opportunity to recover energy from waste and increasing the level of environmental protection [3–5].

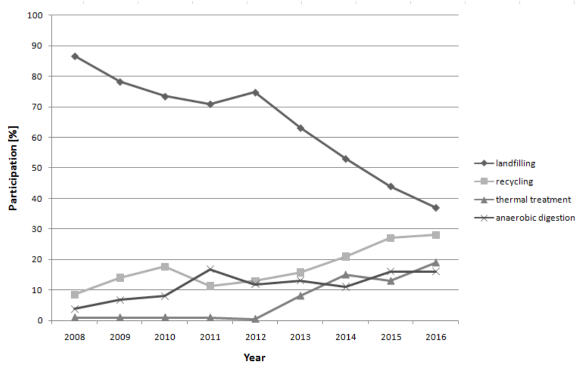


Figure 1 The share of forms of municipal waste management in Poland in 2008-2016 (Eurostat)

As an EU member state, Poland strives to achieve the community waste management requirements. These requirements relate to gradual implementation of the Zero Waste and Closed-loop Economy plans. A good indicator of changes for the better in Polish waste management is the amount of waste disposed of by landfilling per capita (Figure 2). Comparing the approach of Poland and other EU countries to landfilling, one can notice a disproportion between the amount of deposited wastes per capita. Although the amount of the above-mentioned municipal waste in Poland per person was higher in 2012-2015, there is a downward trend. In 2016, in this country, the amount of waste managed by landfilling per inhabitant was lower than in the EU. In addition, at the end of 2012, there were 527 active controlled landfills in Poland, accepting municipal waste, with a total area of nearly 2,198 ha. During the analyzed year, 61 landfills of this type were closed, with an area of almost 132 ha. At the end of 2016, there were 320 active controlled landfills receiving municipal waste, occupying a total area of over 1800 ha. In 2016, 36 such facilities were closed, with an area of nearly 80 ha. Over 200 waste landfills were closed within the analyzed period of five years, which confirms that Poland implements European regulations on waste management to national law on an ongoing basis, and then meticulously fulfills them, achieving the required environmental effects.

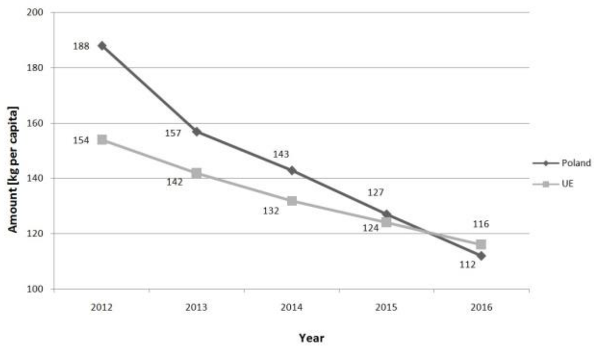


Figure 2 Municipal waste neutralized by landfilling in Poland and the EU per capita (Eurostat)

Poland has committed itself to achieving the required recycling targets, up to 30% in 2018 and 50% in 2020 respectively. In addition, from this year a commitment was made to prohibit municipal landfills containing more than 35% biodegradable mass compared to the volume produced in 1995. The above actions constitute elements of the National Waste Management Plan for 2015-2022, including mainly: limiting the amount of waste generated and increasing public awareness of proper waste handling, achieving the assumed recovery and recycling goals for individual types of waste, adopting a system of selective waste collection in all households in Poland, discontinuing the landfilling of biodegradable waste.

The aspect regarding the increase in public awareness of waste management seems to be particularly important. Recently, the Polish government, through new legal regulations, has been trying to change citizens' bad habits. One of them is the regulation of the Minister of Development and Finance regarding the requirements for solid fuel boilers, from 1 July 2018 prohibiting the sale of boilers that do not comply with emission class 5, in accordance with standard PN-EN 303–5:2012. The said legal act excludes the use of boilers having a so-called "Emergency grate" enabling waste incineration. In addition, this regulation is an element of limiting the phenomenon of low emission, contributing to the formation of smog. This phenomenon deprives many people of health and even life every year, which is why proper education of children and youth is equally important. Another significant legislative change was introducing the Act of 12 October 2017 amending the act on the management of packaging and packaging waste as well as some other acts (Journal of Laws, item 2056), imposing from 1.01.2018 a recycling fee for each plastic bag offered when shopping. The aforementioned fee is to discourage Poles from buying plastic bags in favor of reusable bags which serve for years and do not generate additional quantities of plastic waste. The above activities combined with high levels of raw material and energy recovery will contribute to creating effective closed-loop waste management that cares for the environment, as well as reasonably managing natural resources [4,7–12].

2 Characteristics of RDF

RDF is a specific type of alternative fuel (Figure 3), characterized by high calorific value (average 16-18 $MJ.kg^{-1}$) [13] as well as homogeneous particle size. The production process of this fuel involves separation of combustible parts from the overflow fraction of municipal waste (paper, plastics, textiles, wood, rubber) by sorting them, as well as subjecting them to a multi-stage process of grinding and then briquetting [14–18].

Figure 3 *View of the RDF fuel [own elaboration]*

Currently in Poland, RDF is most often used as an alternative fuel in the cement industry. This is due to the specific temperature conditions prevailing in the rotary kiln for burning clinker, as well as the possibility of dispensing fuel into its various zones, which allows the use of various forms of fuel - liquid, lumpy or silty. In addition, combustion in the said installation meets the requirements of the European Directive, ordering maintaining the appropriate temperature of exhaust gas (> 1370 K) for at least 2 seconds, minimizing the negative impact on the environment. As a result, alternative fuels have been applied in Polish cement plants for 15 years, using, in addition to RDF, also used tires and agricultural biomass. In 2008, the percentage of these fuels in Poland accounted for 26% and was higher than in the European Union (21%) and in the world (11%). Currently, the share of alternative fuels in the Polish cement industry accounts for 50% (and a maximum of 80% in the Chełm Cement Plant), which is largely due to the EU climate policy, introducing carbon dioxide emission limits. Polish producers, instead of participating in the emissions trading system, invest in emission reduction technologies, increasingly more often using alternative fuels for cement production.

The MBT/MBS reject fraction (RDF) processed in plants can be used in the co-combustion process with coal dust, both in the main burner of the rotary kiln and in the secondary burner, in the process of initial decarbonisation. In the second case, there are no problems related to ensuring proper combustion conditions, hence it is possible to use up to 100% of alternative fuel from waste, whereas in the main burner of the furnace it is necessary to ensure the appropriate temperature difference in the sintering zone (> 400 K), between the temperature of the clinker being burned and the exhaust gas temperature. Ensuring this temperature regime is possible with a calorific value of RDF greater than 22 $MJ.kg^{-1}$. A lower calorific value of the said fuel contributes to a decrease in efficiency and an increase in heat consumption. Taking into account the average calorific value of RDF at the level of approx. 16-18 $MJ.kg^{-1}$ [1], determined by a high moisture content (biomass share), it can be concluded that obtaining high calorific fuel from waste will not be a simple task. The Polish experience shows that alternative fuel with a calorific value of 13 $MJ.kg^{-1}$ allows about 10% of coal dust to be replaced, while RDF with a calorific value of 18 $MJ.kg^{-1}$, allows the replacement of already about 20% of traditional coal fuel [15,18–23].

3 Thermal conversion technologies

In recent years, the technology of thermal transformation of waste has become increasingly more important in Poland, which is why it seems that the development of innovative technologies for thermal conversion of waste will contribute to further reducing the amount of landfill waste, and thus creating environmentally friendly management of recyclable waste. The modern waste management system should include energy recovery, without which it is impossible to balance the management of many waste groups. Chemical energy contained in the majority of waste can be used for power engineering purposes like production of electricity [24] and heat in various technological variants of thermo-technical conversion, e.g. pyrolysis (Figure 4) [3, 4,6,25–27].

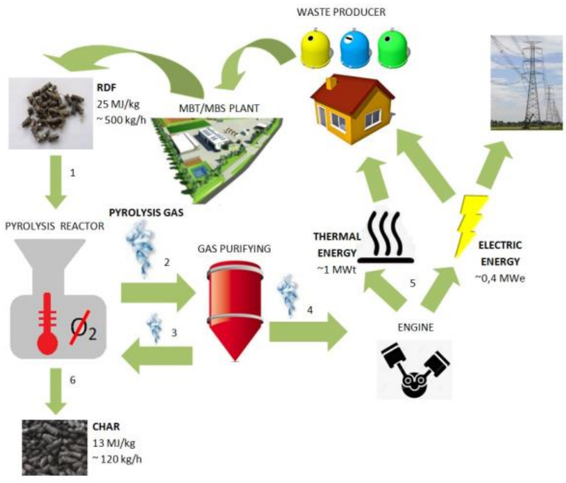


Figure 4 Modern Waste Management in Poland

Currently, there are 157 regional municipal waste treatment installations (RIPOK/MBT) in Poland, with a total capacity of 10 799 100 Mg/year, and a further increase in their capacity is planned, ultimately in 2020 to 12 414 133 Mg/year, which gives 179 MBT installations - the most in Europe. However, currently only 8 modern installations for the thermal transformation of municipal waste operate in the country: Bialystok (120 000 Mg/year), Bydgoszcz (180 000 Mg/year), Konin (96 000 Mg/year), Cracow (220 000 Mg/year), Poznan (210 000 Mg/year), Warsaw (60 000 Mg/year), Szczecin (150 000 Mg/year) and Rzeszów (100 000 Mg/year). Summing up the processing capacity of the above incineration plants, a promising efficiency of over a million Mg per year is obtained. Taking into account the National Waste Management Plan (NWMP) for the years 2016-2020, significant power surpluses of MBT installations in many voivodships are noticed, while at the same time noticeable amounts of RDF (currently almost 2 500 000 Mg/year). In addition to the use of this fuel in cement plants, it can also be used in power and heating. Unfortunately, in this case there are problems related to the adaptation of currently used installations for the co-incineration of waste, especially in the area of poor exhaust gas treatment systems. Due to the fact that cement plants can use only about 1 million Mg of alternative fuel from waste during a year, other effective methods of its management should be sought, therefore this article compares three methods for the thermal conversion of RDF: combustion, pyrolysis and gasification [3,28].

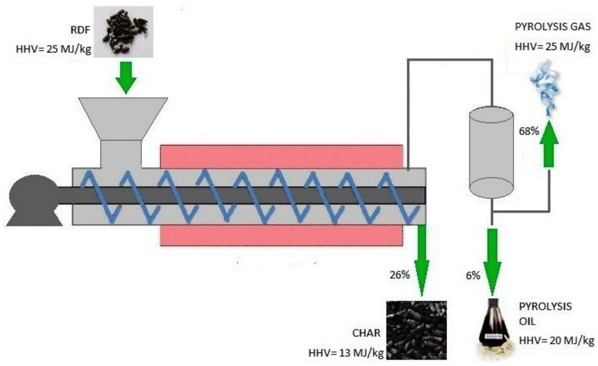


Figure 5 Scheme of RDF Pyrolysis (Polish pilot plant)

Pyrolysis and gasification allow the recovery of chemical energy in the form of secondary fuels or provide raw materials to carry out other processes (Figure 5), while combustion allows the recovery of electricity and heat. It seems that improvement in the total energy recovery from waste, by combining the efficiency of installations currently operating in Poland, using the rotary kilns of cement plants and new installations for pyrolysis and gasification, e.g. located in MBT (RIPOK) plants, will allow the role of landfilling in Polish waste management to be limited further. Firstly, it will ensure compliance with the increasingly demanding European regulations, and secondly, it will contribute to the rational use of natural resources, while at the same time increasing the level of environmental protection.

4 Results and discussion

Pyrolysis was selected for further analysis, as it shows the greatest flexibility of obtained products among the methods of thermal conversion of waste. Using the licensed CHEMKIN-PRO software, the chemical composition of gas from RDF pyrolysis was modeled for a pilot plant operating in Poland. Determination of the combustible components allowed the calorific value of the pyrolytic gas to be estimated for the changing conditions of the process, i.e. the temperature and residence time. A detailed chemical mechanism developed by the CRECK Modeling Group [38] was implemented for the calculations. The mechanism is dedicated to the chemical analysis of processes occurring during the thermal conversion of fuel [39–46] and includes 137 compounds and 4533 chemical reactions. Figure 6 shows a simplified scheme of the calculations.

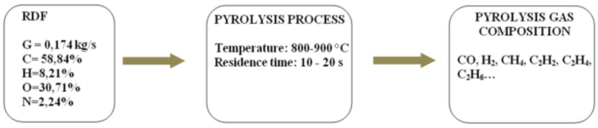
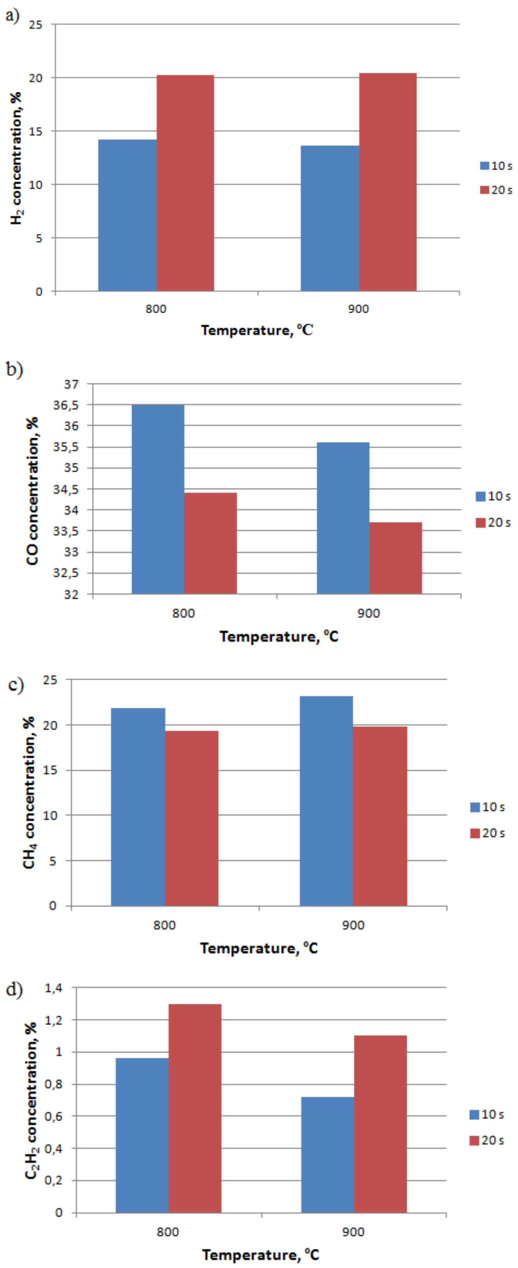


Figure 6 The scheme of calculations

The contributions of selected combustible gas components obtained as part of the calculations, namely: CO, H_2, CH_4, C_2H_2, C_2H_4 and C_6H_6 are summarized in Figures 7-8 as a function of the pyrolysis temperature and residence time.



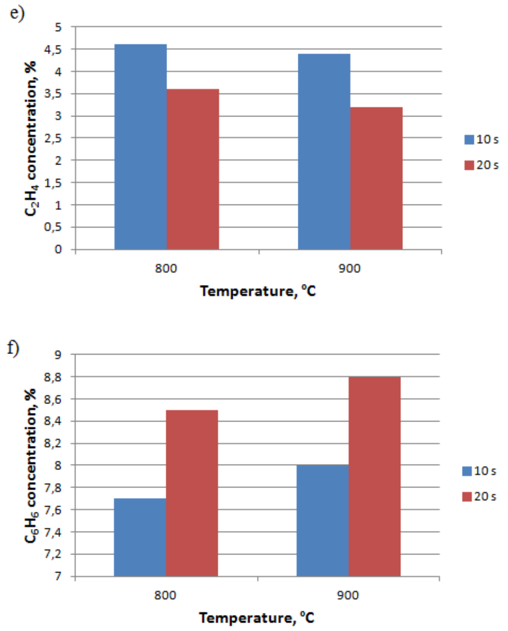
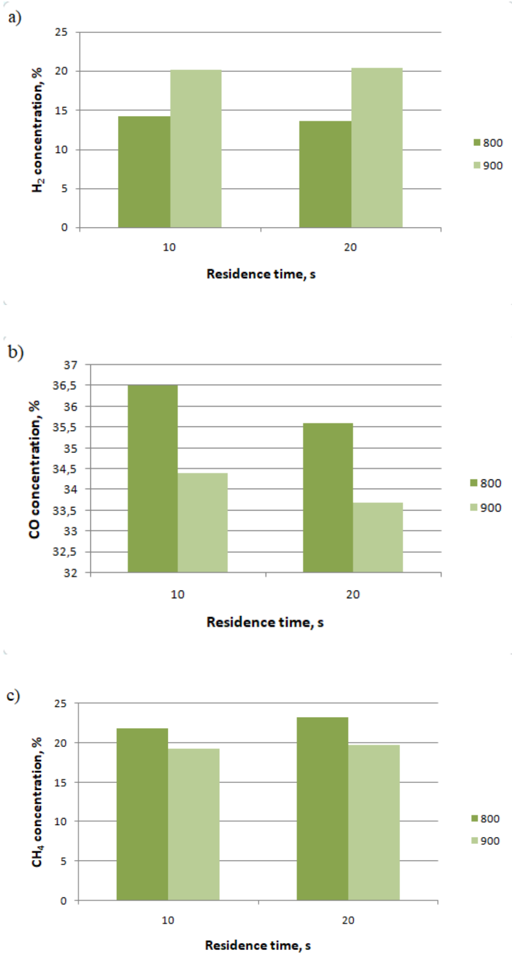


Figure 7 Influence of temperature on concentration in pyrolysis gas: a) H_2 b) CO c) CH_4 d) C_2H_2 e) C_2H_4 f) C_6H_6



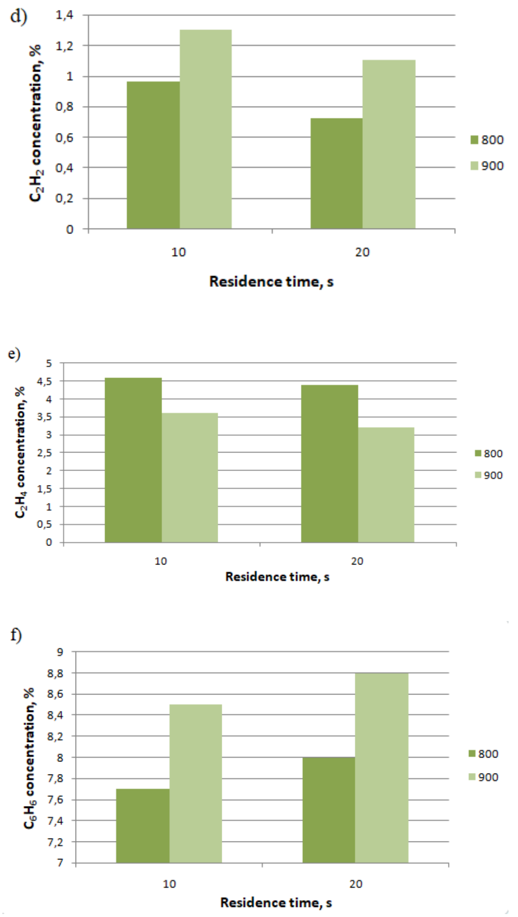


Figure 8 Influence of the residence time on concentration in gas from pyrolysis: a) H_2 b) CO c) CH_4 d) C_2H_2 e) C_2H_4 f) C_6H_6

Analyzing the obtained results, one can observe an increase in the content of combustible components of pyrolysis gas, i.e. hydrogen, acetylene and benzene, as well as a decrease in the content of carbon monoxide, methane and ethene, as the temperature rises between 800-900°C. On the other hand, a change in the residence time in the range of 10-20 sec contributed to a slight increase in the concentration of methane and benzene as well as a slight decrease in the concentration of carbon monoxide, acetylene and ethene.

Based on the calculated chemical composition of the pyrolysis gas, its calorific value was estimated. The calculated calorific value for the analyzed variants ranged from 28.2-28.7 $MJ.m^{-3}$. The obtained calorific value of pyrolytic gas is much higher than the average heating value of gas from RDF fuels (16-20$MJ.kg^{-1}$) from literature data. It seems that the reason for the above the discrepancy is the significant share of heavy hydrocarbons in the gas composition calculated for the Polish installation. The said fraction can constitute up to 30% of the volume of the pyrolytic gas, affecting changes in the elemental composition, and also significantly increasing its calorific value. In addition, the studies by (Efika et al. 2015) [47] show that an increase in temperature in the range 800-900°C caused a decrease in the gas combustion value from 24.8 $MJ.m^{-3}$ to 21.3 $MJ.m^{-3}$, also while reducing the concentration of higher hydrocarbons. Analyzing the aforementioned cases, it can be stated that with increasing concentrations of combustible components of pyrolysis gas, which are characterized by high heating values, the total calorific value of the gas also increases, which encourages wider use of the said secondary fuel for energy purposes.

5 Conclusions

In recent years, new trends in waste management have been observed in Poland, emphasizing the gradual reduction of the amount of waste stored, while developing installations for energy recovery, the so-called "Waste to Energy" (WtE). In the European Union, there is a gradual effort to eliminate landfilling in favor of a circular economy based on recycling and energy recovery from waste. As a result of thermal processes, it is possible to produce electricity and heat, but also to obtain new secondary fuels such as pyrolytic gas, suitable for energy use. CHEMKIN-PRO software helps choose the optimal parameters of these processes and select fuels with the expected properties. Therefore, the authors of this article undertook the task to estimate the calorific value of gas from RDF pyrolysis. The results obtained during numerical calculations allowed approximate calorific value of the pyrolysis gas (28.2-28.7 $MJ.m^{-3}$) to be determined. High-calorific pyrolysis gas may contribute to the reduction of natural gas consumption, and thus to the diversification of fuel and energy sources in Poland. Therefore, it is worth developing installations for the pyrolysis of RDF fuel, reducing the amount of landfilled waste, while gaining an attractive source of energy, so the development of pyrolysis technology seems to be the right direction.

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