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Przemysław RAJCA
Czestochowa University of Technology, Faculty of Production Engineering
and Materials Technology, Chair of Industrial Furnaces and Environmental Protection
al. Armii Krajowej 19, 42-200 Częstochowa
e-mail: rajca.przemyslaw@wip.pcz.pl

Innovative Technologies in the Development of Alternative RDF Fuel

Innowacyjne technologie w zagospodarowaniu paliwa alternatywnego RDF

Innovative solutions are being developed in many areas of human activity, including environmental protection. Innovations that help reduce the negative impact of processes and products on the environment are referred to as "eco-innovation". The increasingly restrictive European legislation on waste management, which is also implemented into the national regulations, aims to increase waste recovery and thus to improve the state of the environment. The legislation is oriented towards the development of a circular economy based on the maximal utilization of waste through material and energy recovery while ensuring efficient management of natural resources. The amount of waste collected for storage is being reduced in Poland as it represents the least desirable form of waste development, whereas the volume of waste returned to recycling and thermal treatment is increasing. Due to the fact that innovations are regarded as a factor that impacts on the pace of economic development, the present paper discusses the innovative solutions of thermal waste treatment, with particular focus on incineration, pyrolysis and gasification. The process of pyrolysis of waste in the form of an alternative RDF fuel is an interesting alternative, allowing for obtaining syngas with high calorific value (21.7 MJ/kg) and significant energy efficiency at the level of 75%, which offers a huge potential for electricity recovery. Furthermore, the high calorific value of pyrolysis gas encourages its use as a fuel in heating installations, both in the heating and metallurgical sectors, currently using coal gas with lower calorific value (about 16.5 MJ/kg). Furthermore, pyrolysis gas obtained from waste is likely to contribute to the reduction of natural gas consumption, thus leading to diversification of fuel and energy sources in Poland. The innovative solutions for thermal waste disposal presented in this paper are likely to limit the use of landfills and they contribute to the increase of the level of environmental protection.

Keywords: innovations, waste management, energy recovery

Introduction

The necessity to introduce innovative solutions that represent the driving force for the economy has been emphasized in recent years in Poland. This results from the fact that with these solutions, Polish entrepreneurs, who offer innovative products or services, are likely to become competitive in the market and find new customers. This, in turn, contributes to the increase in revenues in enterprises, which significantly stimulate the economic development of the state. The concept of innovation is defined as the implementation of new or significantly improved products, services or processes into business practice, including the implementation of new marketing or organizational methods which redefine the way the company operates and its relations with the business environment. Innovative solutions can be implemented in many areas, including waste management. The development of modern installations for energy recovery from waste and limitation of its storage contribute to reduced consumption of fossil fuels and minimization of the negative impact of waste on the environment. These processes, combining creativity with environmental sensitivity, are termed eco-innovations. Eco-innovations are aimed to develop new products and processes without leading to negative changes in the environment. The most common types of eco-innovations presented in the literature include:

- technological innovations, such as products and production processes,
- social eco-innovations, e.g. behaviours, consumption habits,
- organizational eco-innovations, e.g. eco-audits,
- institutional eco-innovations, concerning formal groups, e.g. cooperation platforms involved in environmental activities,
- marketing eco-innovations, e.g. eco-packaging.

Changes which are occurring in the business environment, growing customer expectations and the successive tightening of environmental protection regulations, contribute to the introduction of new methods to manage production and the environment that allow for rational management of raw materials and waste [1, 2].

1. Waste management in Poland

1.1. Changes in waste management: statistical analysis

The rapid pace of the development of modern civilization leads to increased consumption, and, consequently, to greater amount of generated waste. Figure 1 presents changes in the amount of municipal waste collected in Poland over recent years based on statistical data.

As can be seen from the Figure, a gradual increase in the amount of municipal waste collected in Poland has been observed since 2013. With this tendency, the opportunities for managing the growing amount of waste should be taken into consideration. Also in Poland, more and more rigorous European regulations enforce the introduction of ecological changes in waste management [3-8].

Figure 2 shows the percentage of individual forms of municipal waste management in Poland in 2012-2016. Analysis of the data presented in Figure 2 reveals a significant decrease in the percentage of storage of waste in relation to other forms of waste management. Compared to 2012, almost half of municipal waste was stored in 2016, whereas more than twice as much waste was recycled, which shows new tendencies in Polish waste management. It is also worth noting that the interest in thermal treatment is increasing.

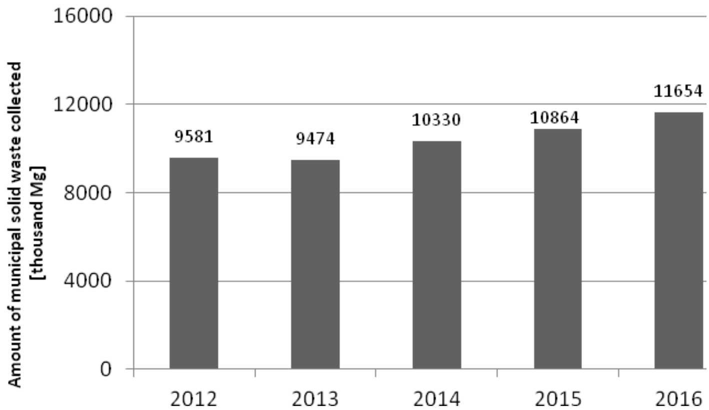

Fig. 1. Amount of municipal waste collected in Poland in 2012-2016 [3-7]

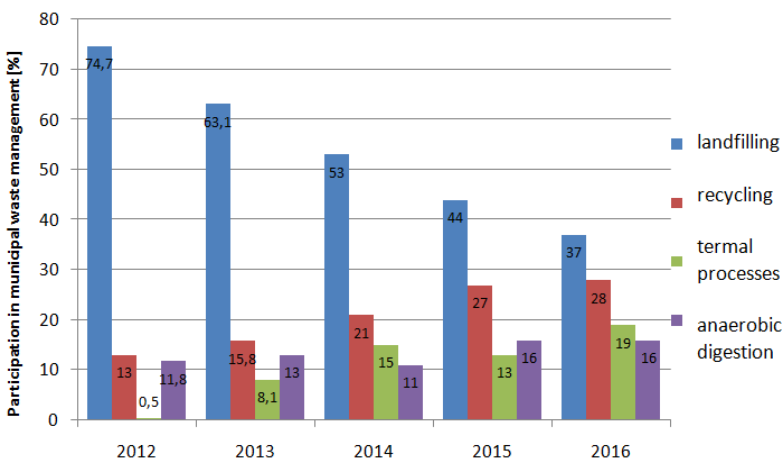

Fig. 2. Percentage of individual forms of municipal waste management in Poland in 2012-2016 [3-7]

In 2016, it accounted for almost a fifth, which demonstrates that the technology is gaining more and more popularity and it is worth developing while maintaining the requirements of environmental protection. Furthermore, the percentage of composting and fermentation has slightly increased in recent years or remains at a similar level. The above mentioned trends, limiting the percentage of waste storage compared to other forms of waste management, confirm the fact that Poland is gradually fulfilling European obligations while minimizing the negative impact of waste on the environment [3-7].

1.2. Legal regulations

According to the Annex No. 4 to the Ordinance of the Minister of Economy on the admission to waste storage in landfills of 16 July 2015 (Journal of Laws 2015, item 1277), storage of waste with calorific value above 6 MJ/kg has been forbidden since 1 January 2016. The introduction of this regulation enables the most effective use of waste with the highest calorific value, for which this form of management is profitable. Therefore, it is worth considering the opportunities for processing of this type of waste in innovative energy recovery installations. Furthermore, the Act amending the Waste Act and some other acts of 15 January 2015 (Journal of Laws 2015, item 122) modified the definition of the Regional Municipal Waste Treatment Facility (in polish: Regionalna Instalacja Przetwarzania Odpadów Komunalnych - RIPOK). The changes concerned the possibility to extend the list of technologies admitted by the legislation to the use in regional installations (thermal treatment, mechanical and biological treatment, composting and storage). In the new version, the phrase "and ensuring thermal waste treatment" was removed, which allowed for the use of other technologies in RIPOKs, for example pyrolysis, gasification or plasma processes, regardless of whether they are categorized as thermal waste treatment. The aim of the amendments was, firstly, to define effective waste recovery, including recycling (while separating the biodegradable fraction), and, secondly, to maximally reduce waste going to landfills. The European legislation provides for successive tightening of regulations on waste management, including:

- The Communication from the Commission to the European Parliament, the Council of Europe, the European Economic and Social Committee and the Committee of the Regions "Towards a circular economy: A zero waste program for Europe" of 2 December 2015, which imposed a ban on landfilling recyclable waste from 2025 and a total ban on landfilling from 2050.
- Government's position of 12 January 2016 to the Communication "Closing the loop - An EU action plan for the Circular Economy".
- Conclusions of the EU Council of 20 June 2016 to the Communication "Closing the loop", which promote waste prevention, re-use and recycling, and the development of the market for secondary raw materials.

The above-mentioned initiatives are aimed to protect natural resources by using wise waste management, including material and energy recovery, which can bring both economic and environmental benefits [8-10].

2. Opportunities for waste management

More and more restrictive regulations on landfill reduction forced the EU member states to seek more environmentally-friendly methods of waste management. In addition to material recovery, waste can be used to recover energy from waste (WtE), with waste becoming an alternative fuel or a raw material for the production of another fuel. Consequently, in the Polish legislation, the Waste Act of 14 December 2012 defined thermal waste treatment as:

– waste incineration by oxidation,
– waste thermal treatment processes other than those indicated in the literature, including pyrolysis, gasification and plasma processes, if the substances generated in these processes are eventually incinerated.

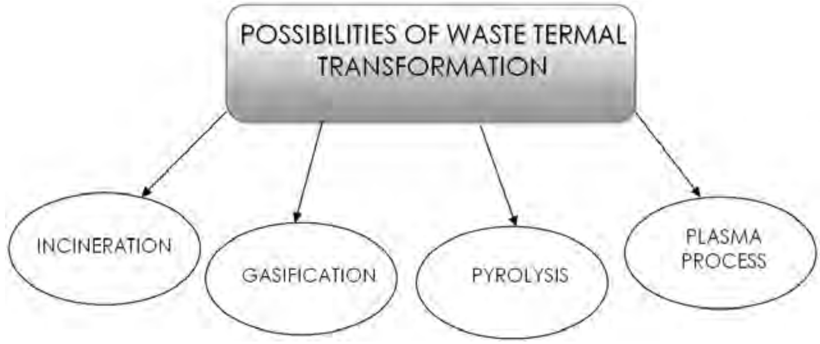

Fig. 3. Possibilities of thermal waste treatment [11]

Figure 3 shows the options of thermal waste treatment and describes three basic methods used in Poland [11].

2.1. Waste incineration

Similar to most management technologies, waste incineration is aimed to reduce the volume of waste and to destroy the potentially harmful compounds. Incineration processes also allow for the recovery of energy and certain chemical substances from waste. In recent years, the incineration sector has been rapidly developing, which results from the introduction of emission limits. An example of installations that meet the above requirements is the rotary kilns in cement plants. The operating temperature in such devices ranges from 500°C (gasifier) to 1450°C (high temperature clinker melting chamber), whereas the process time is usually from 30 to 90 minutes, thus allowing for adequate completion of waste burning and also complying with the Directive 2000/76/EC of the European Parliament and of the Council which stipulates that the temperature of waste incineration has to be raised to 1100°C for at least two seconds. The Polish cement industry is considered one of the most modern in Europe, which results from implementation of many innovative solutions. Initially, the solutions focused on reducing energy consumption during the process by replacing the wet method of clinker burning with the energy-efficient dry method. In addition, it contributed to the increased cement production and reduction in CO_2 emissions (by approx. 360 kg CO_2/Mg) and limitation of the emissions of harmful dusts. Currently, in the face of depletion of cost-effective methods of reduction in energy intensity of the process, solutions are being sought to decrease fuel and energy consumption and to minimize the negative impact on the environment. An example of such initiatives is the use of waste-based fuels and raw materials. Innovative installations allow for the use of ca. 1.2 million Mg of alternative fuels per year, including ca. 1.1 million Mg of fuel from waste, termed refuse derived fuel (RDF). This high percentage of alternative fuels used in the clinker burning process (ca. 50%, with a maximum of 80%) contributed to limitation of the use of conventional coal fuel by ca. 800 Mg/year. Unfortunately, with the high biomass content in RDF and the significant moisture content, heating value of these fuels is reduced and therefore their use is limited. This inspires the search for new methods of management of alternative fuels that offer new opportunities for their use [12-14].

2.2. Gasification

One of the methods of effective management of RDFs is their gasification. This process consists in conversion of any carbon fuel into a gaseous form in the presence of an oxidizing agent, e.g. air, oxygen, water vapour, etc. Gasification is usually performed at temperatures close to 1000°C, while its products usually include hydrogen and carbon monoxide, as well as methane, carbon dioxide, nitrogen and water vapour. Table 1 presents an example of composition of a gas from gasification of RDF fuel.

Table 1. **Chemical composition of syngas from RDF fuel gasification [15]**

Air flow, Nm^3/h	12	15	18
CO, %	21.61	17.69	19.35
CH_4, %	1.52	0.97	1.14
CO_2, %	4.02	4.25	3.09
H_2, %	10.19	10.46	9.44
Calorific value, MJ/Nm^3	4.37	3.71	3.87

The above data show that the highest calorific value of syngas (4.37 MJ/Nm^3) and content of carbon monoxide (21.61%) were achieved for air flow of 12 Nm^3/h. However, the highest hydrogen content was found for air flow of 15 Nm^3/h. Furthermore, an increase in RDF consumption was observed during the experiment with the increase in air flow during the gasification process [15, 16].

The calorific value of the obtained syngas usually ranges depending on the gasifier used, from ca. 5 MJ/m^3 (for air and water vapour) to 10 MJ/m^3 (for pure oxygen), which encourages further use of this gas. Syngas can be burnt in gas engines to generate electricity, used for synthesis of liquid hydrocarbons to produce fuels or for methanol synthesis. A relatively low calorific value of this gas translates into an insignificant interest in its use as gas fuel in heating boilers. Nevertheless, it is worth considering co-combustion of syngas with other gaseous fuels, and opportunities for supplying syngas to the installations for RDF drying, which can additionally increase heating value of the fuel. Installations for RDF gasification are currently used in the power and heat industry and waste incineration plants because waste incineration in such plants is associated with higher emissions of harmful compounds to the atmosphere and serious challenges that result from different conditions of the incineration process. These problems include premature degradation of the installation and the need for major modifications, which is uneconomic. Consequently, the potential of the gasification for energy recovery from waste is considered an innovative installation that reduces the harmful impact of waste on the environment [12, 16-18].

2.3. Pyrolysis

Pyrolysis is an endothermic process of thermal transformation of carbon-rich substances occurring in an anaerobic environment or containing negligibly small amounts of this element, occurring at temperatures below 1000°C. The products of the said process are:

- pyrolysis gas, containing mainly: H_2, CH_4, C_2H_6, CO, CO_2 as well as H_2S, NH_3, HCl and HF,
- pyrolysis coke, containing mainly carbon and metals and other inert substances,
- pyrolytic liquid, containing a mixture of tars, oils and water, as well as simple aldehydes, organic acids and dissolved alcohols [13,16].

Table 2 presents composition of syngas obtained from the RDF pyrolysis depending on the process temperature.

Table 2. **Composition of gas from RDF pyrolysis [19]**

Temperature °C	Light hydrocarbons %	CO %	CO_2 %	H_2 %	N_2 %
400	3.5	4.9	42.5	0.0	49.1
500	25.5	11.0	30.0	0.1	33.4
600	18.7	9.6	32.4	0.2	39.1
700	6.1	20.2	57.5	0.0	16.2

Analysis of the above data reveals significant amounts of carbon dioxide, with small amounts of hydrogen in the syngas composition. Low rate of release of CO and light hydrocarbons at lower temperatures (400°C) and its increase at the temperature of 500°C were also found. Furthermore, the content of light hydrocarbons decreased with the increase in temperature to 600 and 700°C, with a simultaneous decrease followed by a rapid rise in the CO content. Calorific value of pyrolysis gas usually falls within the range from 5 to 15 MJ/Nm^3 in the case of municipal waste and 15 to 30 MJ/Nm^3 for the RDF fuel [13, 19-24].

Figure 4 presents a diagram of the installation for conducting the RDF pyrolysis process. The installation presented in Figure 4, developed for the research purposes by Metal Expert, was built in the Waste Disposal Plant in Elbląg, Poland. It is an innovative technology for energy recovery from waste allowing for obtaining a pyrolysis gas with high calorific value (21.7 MJ/m^3) at high efficiency of 75%, which demonstrates a huge potential for electricity conversion. With the increasingly strict European regulations on the reduction of emissions from incineration of any types of fuels, including refuse derived fuels, pyrolysis seems to offer an interesting substitute [25].

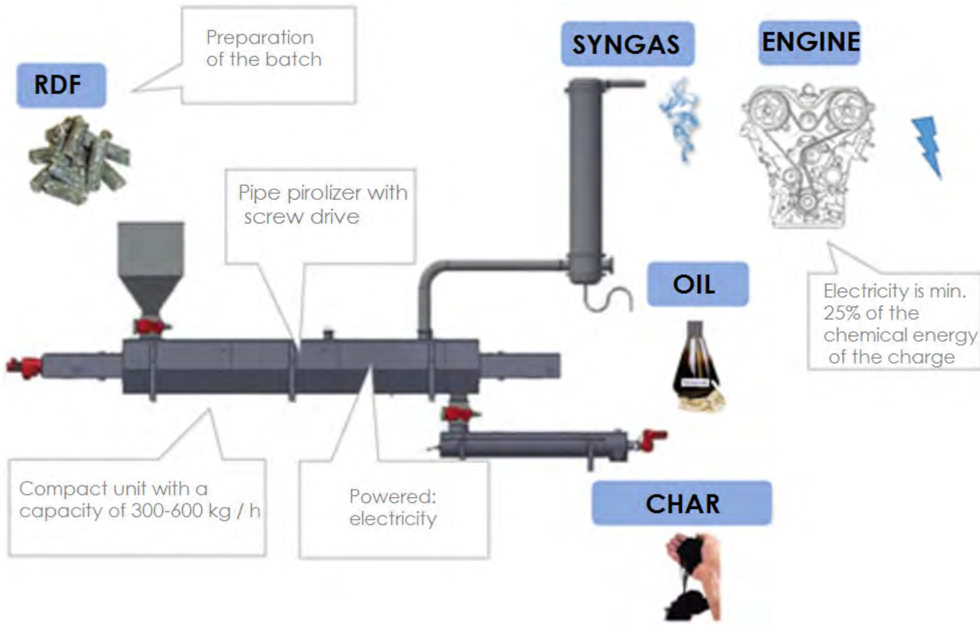

Fig. 4. Diagram of installation for RDF pyrolysis process [16]

Conclusions

The rapid pace of the development of modern civilization leads to the increasing amount of generated waste. Analysis of the data on the amount of municipal waste collected in Poland over recent years shows an upward tendency. Furthermore, the amount of waste collected for storage is gradually reducing as it represents the least desirable method of waste management, with the increasing emphasis on recycling and thermal treatment technologies. These trends lead to gradual meeting of Community requirements regarding waste management. Furthermore, searching for good alternatives to storage contributes to the development of other forms of waste management. The interest in thermal waste treatment in Poland has been increasing in recent years and, since waste incineration in conventional installations increases the emissions of harmful compounds into the environment, innovative solutions for energy recovery from waste are being developed. Such installations include rotary kilns for clinker burning in the cement industry, which, with appropriate process conditions, do not contribute to the increase in pollutant emissions, which translates into reducing the negative impact of waste on the environment, using the existing industrial infrastructure. Another method that meets eco-innovative requirements is waste gasification. Since a new fuel (synthesis gas suitable for further use) is obtained during gasification, this method represents an interesting alternative to incineration, further reducing the environmental impact. Another innovative solution that is likely to gain importance in the upcoming years is pyrolysis of waste. A research plant for conducting RDF pyrolysis process has been operated in the Waste Treatment Plant in Elbląg, Poland. This technology allows for generating a pyrolytic gas with a high calorific value (21.7 MJ/kg) and high energy efficiency, at the level of 75%, which offers a huge potential for electricity recovery while increasing the level of environmental safety. Furthermore, the high calorific value of syngas encourages its use as a fuel in heating devices, both in the heating and metallurgical sectors, currently using coal gas with lower calorific value (about 16.5 MJ/kg). The pyrolysis gas obtained from waste is likely to contribute to the reduction of natural gas consumption, thus leading to diversification of fuel and energy sources in Poland and substantial economic benefits.

Therefore, the implementation of innovative solutions is also possible with regard to waste management. The stimulus for such initiatives is the increasingly restrictive European regulations that force the implementation of technologies limiting the negative impact on the environment while bringing additional economic benefits of the reduction in the use of conventional fuels.

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Streszczenie

Innowacyjne rozwiązania dotyczą wielu dziedzin, m.in. ochrony środowiska. Innowacje przyczyniające się do zmniejszenia negatywnego wpływu procesów oraz produktów na środowisko określa się mianem „ekoinnowacji”. Coraz bardziej restrykcyjne europejskie przepisy dotyczące gospodarki odpadami, które są następnie wdrażane w ustawodawstwie krajowym, mają na celu zwiększenie odzysku odpadów, a tym samym poprawę stanu środowiska. Dążą one do wprowadzenia gospodarki o obiegu zamkniętym, opierającej się na maksymalnym wykorzystaniu odpadów poprzez odzysk materiałowy i energetyczny, przy racjonalnym gospodarowaniu zasobami naturalnymi. W ostatnich latach w Polsce zmniejszono udział magazynowania, które jest najmniej pożądaną formą ich zagospodarowania, a jednocześnie zwiększono udział głównie recyklingu i przekształcenia termicznego. Ze względu na fakt, iż innowacje są uważane za decydujący czynnik w tempie rozwoju gospodarczego, w niniejszym artykule skupiono się na innowacyjnych możliwościach termicznej utylizacji odpadów ze szczególnym uwzględnieniem: spalania, pirolizy i gazyfikacji. Na uwagę zasługuje proces pirolizy odpadów w postaci paliwa alternatywnego RDF, pozwalający na uzyskanie syngazu o wysokiej wartości opałowej (21,7 MJ/kg,) a także znaczącej wydajności energii, na poziomie 75%, co daje ogromny potencjał do odzysku energii elektrycznej. Ponadto, wysoka kaloryczność gazu pirolitycznego zachęca do wykorzystywania go jako paliwo w urządzeniach grzewczych, zarówno w ciepłownictwie, jak i w przemyśle hutniczym, stosującym obecnie gaz koksowniczy o mniejszej wartości opałowej (ok. 16,5 MJ/kg). Dodatkowo, syngaz otrzymany z odpadów może się również przyczynić do ograniczenia zużycia gazu ziemnego, co pozwoli na dywersyfikację źródeł paliw i energii w Polsce. Wskazane w niniejszym artykule innowacyjne możliwości termicznej utylizacji odpadów po pierwsze ograniczą wykorzystanie składowisk, a po drugie przyczynią się do podniesienia poziomu ochrony środowiska.

Słowa kluczowe: **innowacje, gospodarka odpadami, odzysk energii**