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Laboratory Studies on the Effectiveness of Thermal Treatment of Selected Compositions of Waste from Organic Chemistry Industry

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1. Introduction

Thermal processing is one of the methods of disposal of industrial waste. This process reduces volume and weight of those waste, and also allows to avoid their landfilling. However, by-products of thermal processing are: volatile components (flue gas and fly ash) and solids (slag, ash also called furnace waste), which are a source of contamination of the environment [2,4,12,13].

During development of the project of thermal processing of particular waste, various aspects of efficiency of the process should be considered, which should meet, among others, technological and economic conditions [19,20]. The aim of waste utilisation is recovery of their usable energy, maximum possible reduction of harmful substances produced during this process and decrease of their volume. It is connected with the pre-selection of waste.

Laboratory installation for thermal treatment of waste was designed and made at the Department of Water and Sludge Technology and Waste Utilisation of Koszalin University of Technology. It was used for studies on incineration process of pre-selected industrial and municipal waste. Also studies on the process of co-incineration of sewage sludge in mixtures with different types of waste were conducted [5,11,18]. Studied waste also included waste from organic chemistry industry such as plastics, rubber and petrochemical waste, which include paints and varnishes.

The paper presents the results of laboratory studies on the efficiency of incineration of different compositions of mixtures of waste from organic chemistry industry in terms of percentage reduction of their weight. Studies were conducted using different percentages of each waste in mixtures with sewage sludge, as the possibility of co-incineration of sewage sludge and studied waste.

2. Methodology of studies

2.1. Materials

The following materials were selected for the studies:

- polymer waste
  - rubber waste (waste tires) – industrial waste,
  - paint waste – industrial waste,
  - plastic waste – industrial waste, municipal waste,
- sewage sludge – municipal waste.

Waste tires were used as rubber waste. During studies only an external layer of tires was used, which is made of natural or artificial vulcanized caoutchouc – polymer (elastomer) [8,16]. In the case of paint waste, residues of oil-alkyd enamel, that is solvent alkyd-oil paint, one of the most common paints used for decoration and protection of surfaces, was used in the studies. Such waste may be classified as coating type polymers (polymer suspension). Plastomers, commonly recognized as representative sample of plastic materials in municipal waste, were plastics during studies. Sewage sludge used in the studies was taken from "Jamno" Wastewater Treatment Plant, which is an object operated by the local water supply and sewage treatment company in Koszalin. Sewage sludge has been dried to a water content of about 10% because the hydrated sewage sludge was characterized by high value of this parameter (W^r = ~50%), which negatively affects the efficiency of combustion process.

Materials, before incineration were ground to particle diameter < 1,25 mm in order to unify their size.

Technical analysis of the materials used for studies was conducted as a initial stage. It consisted of: determination of combustible parts (u,% – organic matter) and non-combustible (n,% – minerals and water).

The basic parameters characterizing solid fuels are: water content (W), ash content (A), volatiles content (V), and the heat of combustion (Q_s). The sum combustible organic matter, ash and water content is 100% [10]. Analysis was performer according to following standards: PN-ISO 1213-2:1999; PN-80/G-04511; PN-ISO 1171:2002; PN-80/G-04512; PN-G-04516:1998; PN-ISO 1928:2002.

Additionally, qualitative analysis of the studied materials was conducted using MiniPal PW4025 XRF spectrometer, which uses X-ray fluorescence for identification of elements.

2.2. Study range

Studies on the of effectiveness of weight reduction of waste mass in the process of their thermal processing were conducted on laboratory installation. The main element of that installation is a laboratory, single zone, tube furnace with horizontal heating system of a maximum continuous operating temperature 1473K. The combustion process was carried out in atmospheric air, which was fed into the furnace using diaphragm pump, through a table rotameter, which measures the air flow intensity within the range of 0.5–8.5 $dm^3 \cdot min^{-1}$.

Process studies were conducted under following constant parameters of incineration:

T – temperature in the incineration zone of the furnace, °K – 1173.15 (900°C),

λ – excess air coefficient – 1.1 (air flow rate 4 $dm^3 \cdot min^{-1}$),

m – index of the sample material mass in relation to the volume of the furnace chamber, $kg \cdot m^{-3}$ – 1.3 (sample mass – 0.03 g).

Constants values of those parameters were determined on the base of previous studies of incineration process of various materials (municipal waste, sewage sludge and dust coal), using the same installation and also analysis of the influence of changes of mentioned parameters on concentration of pollutants in flue gases [5,11,18].

Studies presented in this work were divided into 4 stages:

I. Combustion of individual waste materials selected for the studies, as a comparative basis for the subsequent stages;

II. Combustion of 1^{st} composition of waste – individual waste mixed with another, one type of waste;

III. Combustion of 2nd composition of waste – individual waste mixed with other two types of waste,
IV. Combustion of 3rd composition of waste – individual waste mixed with other three types of waste.

All compositions of waste selected for the given stages of studies are presented in the Table 1. Table 2 presents mass proportions of mixtures compositions of waste in each stage (at the constant sample mass – 0.03 g).

Table 1. Compositions of waste in individual stages of studies
Tabela 1. Kompozycje odpadów w poszczególnych etapach badań

Stage	Studied waste	Additional waste	
I	paint	–	
	rubber	–	
	plastics	–	
	sewage sludge	–	
II	paint	rubber	
		sewage sludge	
		plastics	
	rubber	sewage sludge	
		plastics	
	plastics	sewage sludge	
III	paint	rubber	sewage sludge
		rubber	plastics
		sewage sludge	plastics
	rubber	paint	sewage sludge
		paint	plastics
		sewage sludge	plastics
	plastics	rubber	sewage sludge
		rubber	paint
		sewage sludge	paint
	sewage sludge	rubber	paint
		rubber	plastics
		paint	plastics

Table 1. cont.
Tabela 1. cd.

Stage	Studied waste	Additional waste		
IV	paint	rubber	sewage sludge	plastics
	rubber	paint	sewage sludge	plastics
	plastics	paint	rubber	sewage sludge
	sewage sludge	paint	rubber	plastics

Table 2. Percentage and mass proportions of waste mixtures in individual stages of studies at fixed sample mass – 0.03 g
Tabela 2. Procentowe i masowe proporcje mieszanin odpadów w poszczególnych etapach badań przy założeniu stałej masy próby – 0,03 g

Percentage and mass share in a sample				
Stage	Studied waste	Additional waste		
I	100%, 0.03 g	–		
II	50%, 0.015 g	50%, 0.015 g		
III	50%, 0.015 g	25%, 0.0075 g	25%, 0.0075 g	
IV	50%, 0.015 g	16,7%, 0.005 g	16,7%, 0.005 g	16,7%, 0.005 g

Output parameter in each stage of studies was a percentage index Δm, % – sample loss of mass during combustion process of the selected compositions of waste. This parameter was calculated using following formula $\Delta m = \frac{m^0 - m}{m^0} \cdot 100\%$, where:
m^0, m – are, respectively, mass of the sample before and after incineration of waste.

However, attention cannot be paid only on the effectiveness of thermal processing in terms of reduction of their volume, because in the case of such type of installation, emissions of environmentally harmful flue gases, which are produced during combustion of waste, must be also taken into account.

Therefore, during all stages of studies described in this paper, the stream of exhaust gases from the furnace reactor was subjected to the analysis with exhaust gas analyzer MADUR GA-21 *plus*. Following gases were measured:
c_{SO2} –concentration of sulfur oxide (IV), mg · m^{-3},
c_{NOx} –concentration of nitrogen oxides, mg · m^{-3},
c_{CO} –concentration of carbon oxide (II), mg · m^{-3}.

In order to facilitate orientation and ability to compare the results, all concentrations of pollutants in exhaust gas were converted to standard contractual conditions of combustion at 11% of O_2 content in the exhaust.

3. Description and analysis of results

3.1. Technical analysis of the materials used for studies

Results of full technical analysis are presented in Table 3. According to standards, values of parameters characterizing the materials are specified for the analytic state (a) when the moisture is in equilibrium with the ambient humidity.

Analysis of the results in Table 3 shows much lower ash content A^a in waste plastic, as compared to other tested materials. It is connected with the content of mineral (non-combustible) substances in the fuel. Results of volatile V^a and combustible substances contents in the analyzed materials show that studied waste paints had the lowest values of those parameters, even in comparison with waste rubber and plastics, although they are also polymers.

This comparative analysis is mainly connected with the content of organic matter in discussed materials, that is analysis of elementary elements, such as carbon, hydrogen, nitrogen and sulfur. On the basis of literature data concerning the qualitative analysis of fuels (waste fuels) [9,14,17], it may be concluded that the waste plastics, despite low content of nitrogen n^a and sulfur s^a, contain significant amounts of elemental carbon c^a, which causes much higher organic matter content, which are also volatile. This amount is comparable eg. with sewage sludge. Low content of organic elements in the waste paint clearly shows a much lower content of volatile substances in that material.

Table 3. Results of technical analysis of materials used in laboratory studies
Tabela 3. Zestawienie zbiorcze wyników analizy technicznej materiałów wykorzystanych do badań laboratoryjnych

Granulation, mm	Volatiles content V^a, %	Water content W^a, %	Ash content A^a, %	Combustible parts u, %	Non-combustible parts n, %	Heat of combustion Q_s^a, MJ · kg^{-1}
Waste paints						
0.35–1.25	17.0	0.8	59.4	39.8	60.2	24.91
Waste rubber						
0.35–1.25	56.2	6.2	16.2	77.6	22.4	31.84
Waste plastics						
0.5–1.25	60.2	0.5	5.8	93.7	6.3	42.02
Sewage sludge (dry)						
0.125–1.25	54.3	10.6	32.0	57.4	42.6	13.57

On the other hand sewage sludge contains a much bigger amounts of volatile substances only due to a significant percentage of elementary elements: sulfur s^a and nitrogen n^a [21]. Energetic properties of waste (heat of combustion Q_S) also result from the content of organic matter. The low content of the elemental carbon c^a in the sewage sludge [21] causes much lower calorific value, in comparison with waste polymer – Table 3. This is confirmed by Bień and Wystalska [3]. According to their studies heat of combustion of the digested sludge, containing 50% of combustible parts, is about 11 MJ · kg^{-1}.

Analysis of water content in the waste polymer shows the comparability of those materials, because most plastics are water resistant. This is the reason of low value of W^a in such waste.

3.2. Studies on reduction of waste mass

Figures 1 and 2 show a graphical interpretation of average values of *Δm* parameter for each studied waste in certain compositions. Tables 4 and 5, however, present basic descriptive statistics calculated for that parameter.

Analysis of the results at first allows to observe that values of mass loss of waste samples vary considerably, although all studied waste, apart from sewage sludge, are by-products of organic chemistry industry. *Δm* parameter changes its value from 42% in the case of waste paint to observed 96% during incineration of waste plastic.

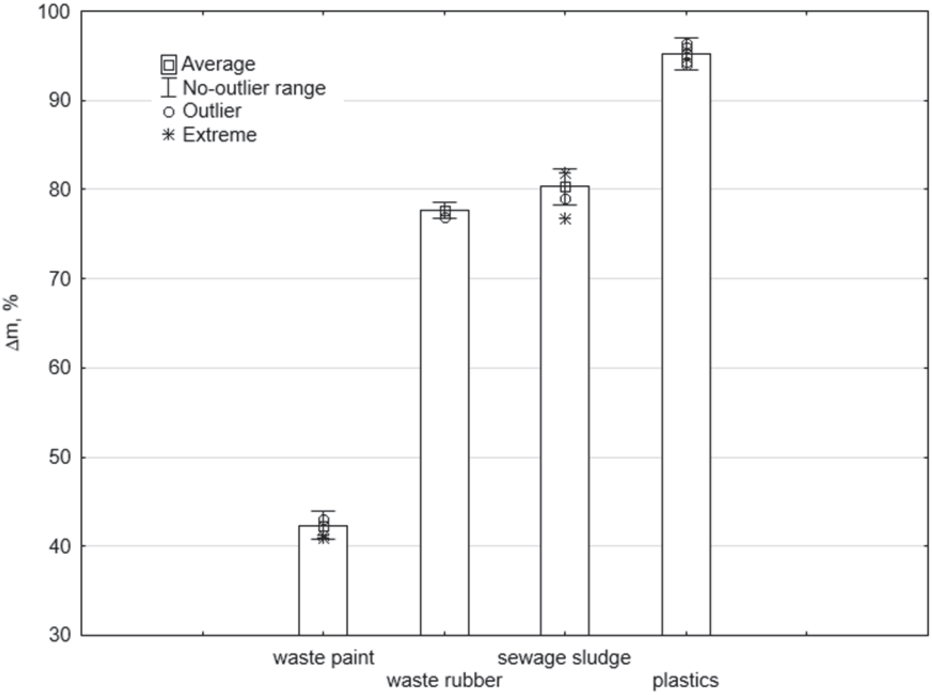

Fig. 1. Values of *Δm* parameter during incineration of studied waste (stage I)
Rys. 1. Wartości parametru *Δm* w procesie spalania badanych odpadów (I etap badań)

Table 4. Basic descriptive statistics calculated for *Δm* parameter after incineration of studied waste (stage I)
Tabela 4. Podstawowe statystyki opisowe parametru *Δm* dot. procesu spalania badanych odpadów (I etap)

	N of valid	% of valid	Average	Median	Minimum	Maximum	Standard deviation.
waste paint	25	100,0	42,3	42,6	41,0	43,0	0,8
waste rubber	25	100,0	77,6	78,0	77,0	78,0	0,5
sewage sludge	25	100,0	80,3	80,0	76,8	81,9	1,0
waste plastics	25	100,0	95,2	96,0	94,0	96,3	0,9

Due to the fact that waste plastics are characterized by the highest mass loss in the combustion process (which is directly related to the low value of the ash content index A^a – about 6% for waste plastics),their addition to studied compositions resulted in an increase of *Δm* index for all studied mixtures. Of course, the highest values of mass loss index were observed at the highest (50%) share of plastic waste in the mixture – the second stage of studies. In this case, addition of waste plastic to waste paint (very high residue after combustion of such waste) caused as much as approx. 60% increase in the value of *Δm* index, while the same addition to composition with rubber waste and sewage sludge caused much lower (approximately 20%) increase of the value of the *Δm* parameter, which in the case of incineration of only waste rubber and sewage sludge (I stage of the study) was similar and amounted to respectively 78% and 80% – Figure 1.

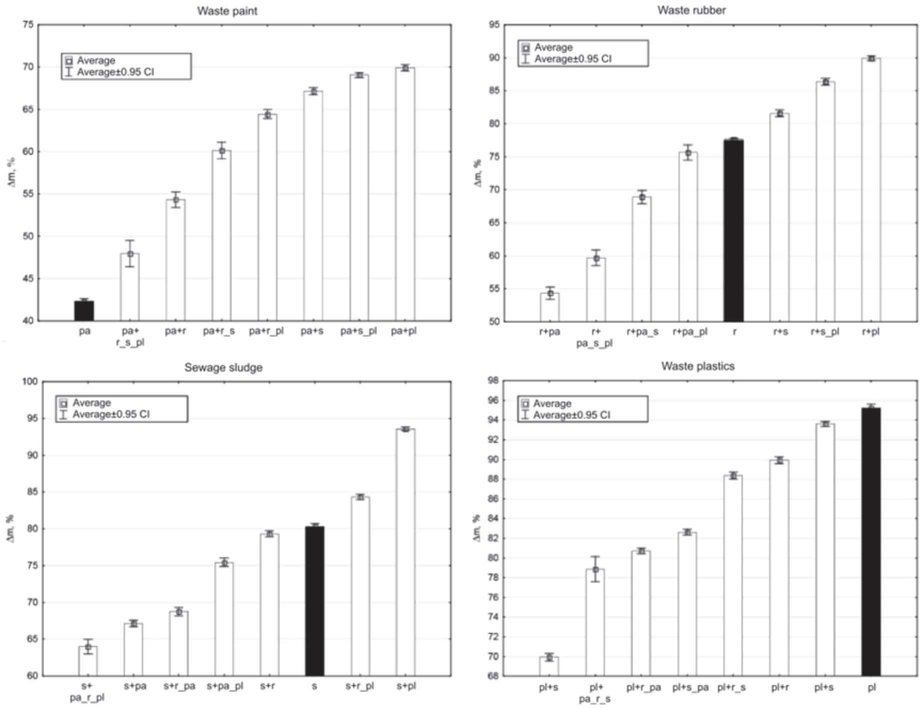

Fig. 2. Variability of *Δm* parameter during incineration of studied waste compositions; pa – waste paint, r – waste rubber; pl – waste plastics, s – sewage sludge

Rys. 2. Zmienność parametru *Δm* w procesie spalania badanych kompozycji odpadów; pa – odpady farbiarskie, r – odpady gumowe, pl – odpady z tworzyw sztucznych, s – osady ściekowe

The fact that a much lower value of mass loss of waste paint during combustion process compared to other studied materials was also the cause of low values of that parameter in the cases when waste paint was added to mixture compositions. It may be evidently observed in Figure 2. The addition of 50% of paint waste to studied mixtures caused following *Δm* parameter values: about 55% of the mixture with waste rubber (30% drop) and more than 65% in the composition with waste plastic and sewage sludge (respectively 27% and 17% drop).

Table 5. Basic descriptive statistics calculated for *Δm* parameter after incineration of studied compositions of waste (stage II–IV)

Tabela 5. Podstawowe statystyki opisowe parametru *Δm* dot. procesu spalania badanych kompozycji odpadów (etapy II–IV)

Waste compositions	N of valid	% of valid	Average	Median	Minimum	Maximum	Standard deviation.
f+g	25	100.0	54.3	55.0	46.1	59.5	2.3
f+o	25	100.0	67.1	67.0	65.0	68.1	1.0
f+tsz	25	100.0	69.9	70.0	69.0	71.0	0.9
g+f	25	100.0	54.3	55.0	46.1	59.5	2.3
g+o	25	100.0	81.6	82.0	78.5	83.0	1.3
g+tsz	25	100.0	89.9	90.0	89.0	91.0	0.9
o+f	25	100.0	67.1	67.0	65.0	68.1	1.0
o+g	25	100.0	79.3	79.0	78.0	81.0	1.0
o+tsz	25	100.0	93.6	94.0	93.0	95.0	0.6
tsz+f	25	100.0	69.9	70.0	69.0	71.0	0.9
tsz+g	25	100.0	89.9	90.0	89.0	91.0	0.9
tsz+o	25	100.0	93.6	94.0	93.0	95.0	0.6
f+g_o	25	100.0	60.1	61.0	55.1	63.7	2.4
f+g_tsz	25	100.0	64.4	65.0	62.0	66.0	1.3
f+o_tsz	25	100.0	69.1	69.0	68.0	70.0	0.8
g+f_o	25	100.0	68.9	69.6	64.5	72.1	2.4
g+f_tsz	25	100.0	75.6	75.0	73.0	83.0	2.8
g+o_tsz	25	100.0	86.4	86.0	85.0	88.0	1.2
o+g_f	25	100.0	68.8	69.0	66.0	70.5	1.4
o+g_tsz	25	100.0	84.3	85.0	83.0	85.2	0.8
o+f_tsz	25	100.0	75.4	76.0	73.0	77.0	1.4
tsz+g_o	25	100.0	88.4	89.0	87.0	89.0	0.9
tsz+g_f	25	100.0	80.7	81.0	80.0	82.0	0.7
tsz+o_f	25	100.0	82.6	82.0	82.0	84.0	0.7
f+g_o_tsz	25	100.0	48.0	47.0	44.0	58.2	3.8
g+f_o_tsz	25	100.0	59.7	60.0	56.0	64.1	2.8
o+f_g_tsz	25	100.0	64.0	64.0	59.3	67.0	2.4
tsz+f_g_o	25	100.0	78.9	78.0	75.0	84.1	3.1

Similar values were achieved for the decrease of efficiency of the combustion of mixtures, when waste paint was added in the III and IV stage of the study. Addition of those waste was respectively 25% and 16%. For example, in such case a decrease of incineration efficiency was 17% for 25% of waste paint added to the mixture with plastic waste and sewage sludge and mixtures with sewage sludge and waste rubber, and a 25% decrease of the Δm parameter when 16.7% of waste paint was added to composition with sewage sludge, waste rubber and waste plastic products. Considering the elemental analysis of waste paint (content of non-combustible parts was much higher than value of that parameter, for example in sewage sludge), such low mass loss during incineration process of those waste is not surprising.

Analyzing the results of the incineration process of compositions of selected waste with sewage sludge, slight changes of mass loss after the combustion process in the case of a mixture of waste rubber with sewage sludge should be noted. The average value of Δm parameter of those mixtures is about 80%, and only addition of waste plastics caused an increase in the combustion mass efficiency to approximately 86%.

To sum up analysis of results of laboratory studies on the effectiveness of waste disposal, it should be noted that the biggest reduction was found for thermal processing of plastic waste and its composition with sewage sludge and waste rubber. However the least preferred is addition of waste paint into mixtures of incinerated waste.

3.3. Studies on changes of pollutants concentration in exhaust gases

The results of the measurement of concentrations of selected exhaust gases produced during incineration of investigated waste compositions are shown in Figures 3 and 4.

a) b)

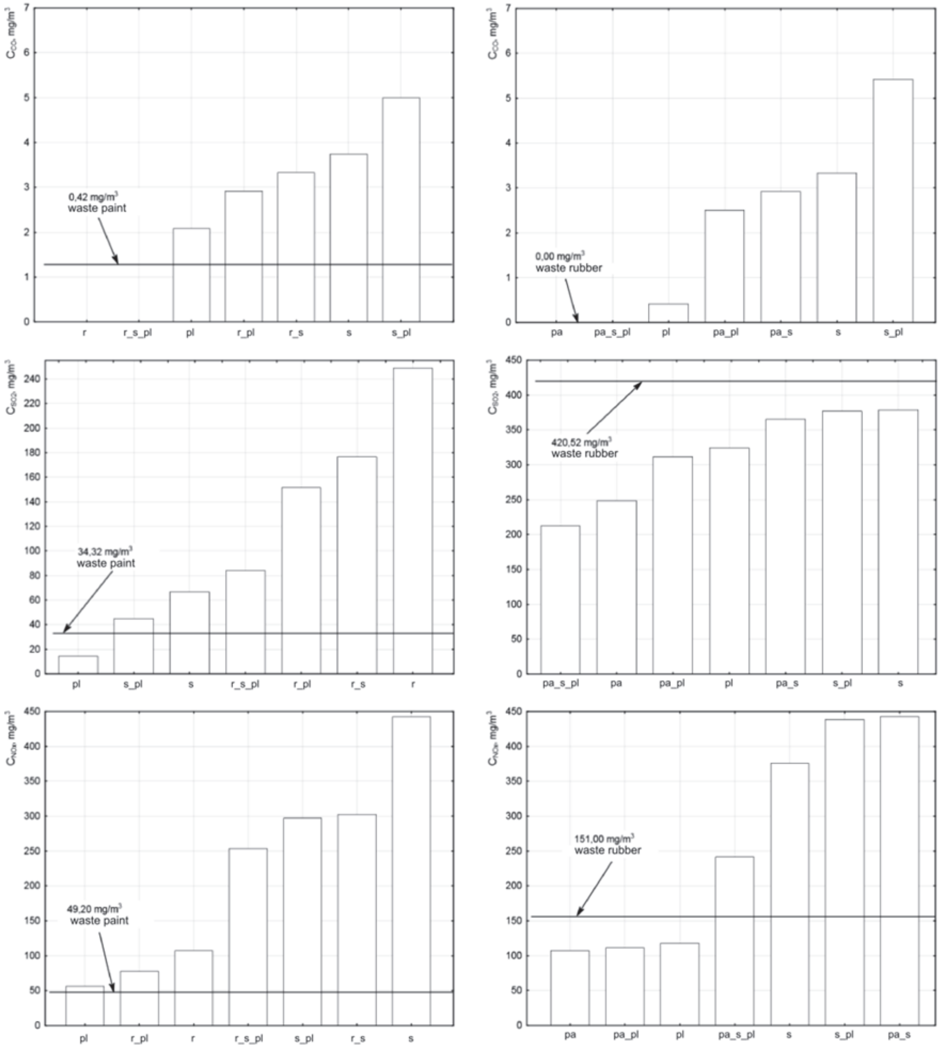

Fig. 3. Variability of the concentrations of selected exhaust gases produced during incineration of examined compositions: a) waste paint, b) waste rubber; additional waste: pa – waste paint, r – waste rubber, pl – waste plastic, s – sludge

Rys. 3. Zmienność stężeń wybranych gazów spalinowych powstałych w procesie spalania badanych kompozycji: a) odpadów farbiarskich, b) odpadów gumowych; dodatkowe odpady: pa – odpady farbiarskie, r – odpady gumowe, pl – odpady z tworzyw sztucznych, s – osady ściekowe

a) b)

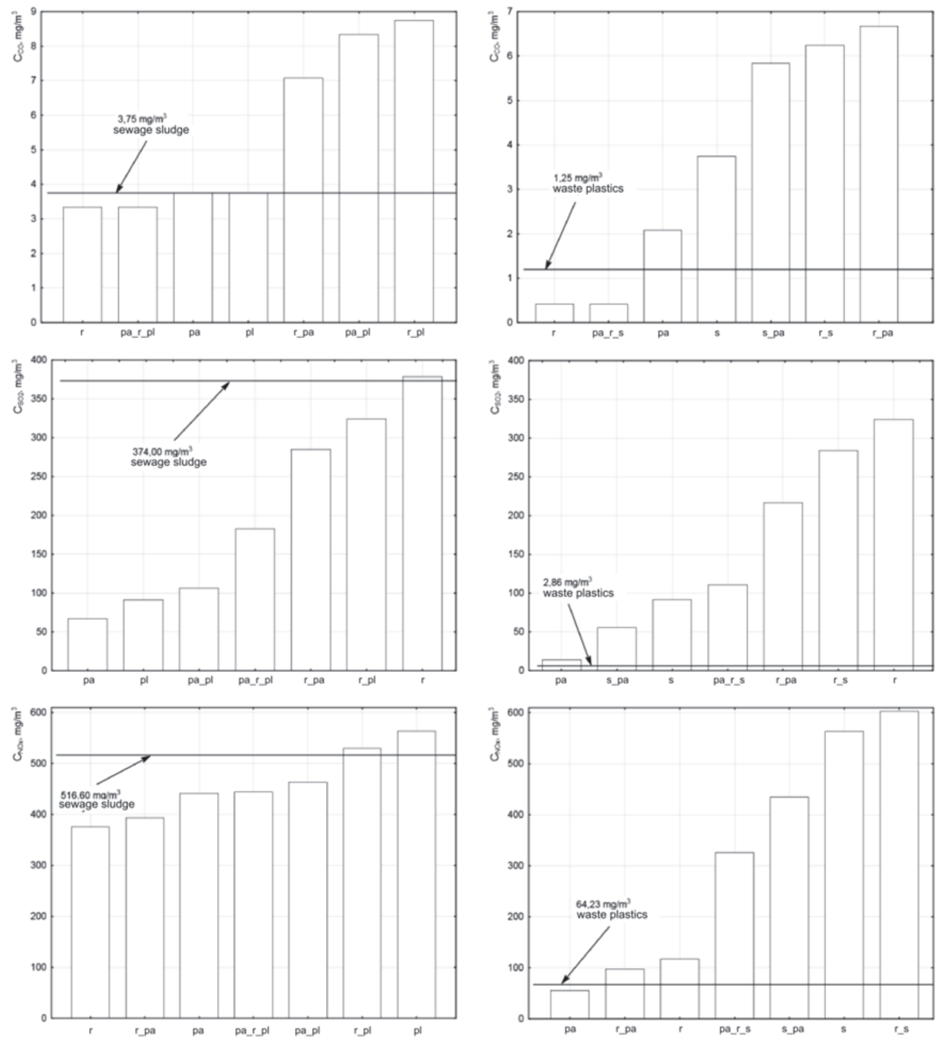

Fig. 4. **V**ariability of the concentrations of selected exhaust gases produced during incineration of examined compositions: a) sewage sludge, b) waste plastics; additional waste: pa – waste paint, r – waste rubber, pl – waste plastic, s – sludge

Rys. 4. Zmienność stężeń wybranych gazów spalinowych powstałych w procesie spalania badanych kompozycji: a) osadów ściekowych, b) odpadów z tworzyw sztucznych; dodatkowe odpady: pa – odpady farbiarskie, r – odpady gumowe, pl – odpady z tworzyw sztucznych, s – osady ściekowe

Analysis of the results shows that high temperature of incineration process of studied waste compositions and sufficient excess air during the process resulted in minimal concentrations of carbon monoxide in all stages of research. In contrast, the negative effect of the thermal processing of examined mixtures of waste are: high concentrations of sulfur dioxide in case of incineration of waste rubber (400 mg · m^{-3}) and high concentrations of nitrogen oxides observed during sewage sludge incineration (500 mg · m^{-3}). Addition of those materials to mixtures with other waste caused a significant increase in the concentrations of SO_2 and NO_x. For example, the lowest value of c_{SO2} was observed in the case of incineration of plastic waste only. Addition of 50% of waste rubber and sewage sludge mixture to the composition with waste plastic caused increase of SO_2 concentration up to 280 mg · m^{-3}.

Of course such dependence is a result of significant content of fuel sulfur in the waste rubber and sewage sludge. This is confirmed by a qualitative analysis of the examined test materials which were performed using MiniPal PW4025 XRF spectrometer. Sample spectra obtained from XRF spectrograph with clearly labeled sulfur energy lines are shown in Figure 5. Spectra clearly show that rubber and sewage sludge contain significantly more elemental sulfur than waste plastics.

Significant differences in concentrations of sulfur and nitrogen oxides during incineration process of selected materials, observed during experiments, are caused mainly by the type of combusted material. Presence of SO_2 in the flue gases is almost entirely caused by oxidation of sulfur contained in fuel, admixtures and additives. Similar situation is in the case of NO_x, but here we have additional source, along with nitrogen contained in the fuel, also the nitrogen from the air is oxidized. Incineration of waste plastic was associated with production of relatively low values of c_{NOx} (mainly thermal oxides), as "pure" polymer does not contain elemental nitrogen. Nevertheless, fuel NO_x may be produced, due to application of antistatics to plastics. Those additional substances contain elemental nitrogen and are added in order to eliminate the phenomenon of electrification of surface of the plastic [22]. Chemicals which improve the properties of plastics usually significantly hinder their disposal and especially their thermal decomposition, causing an increase in the emission of harmful gases, eg. NO_x.

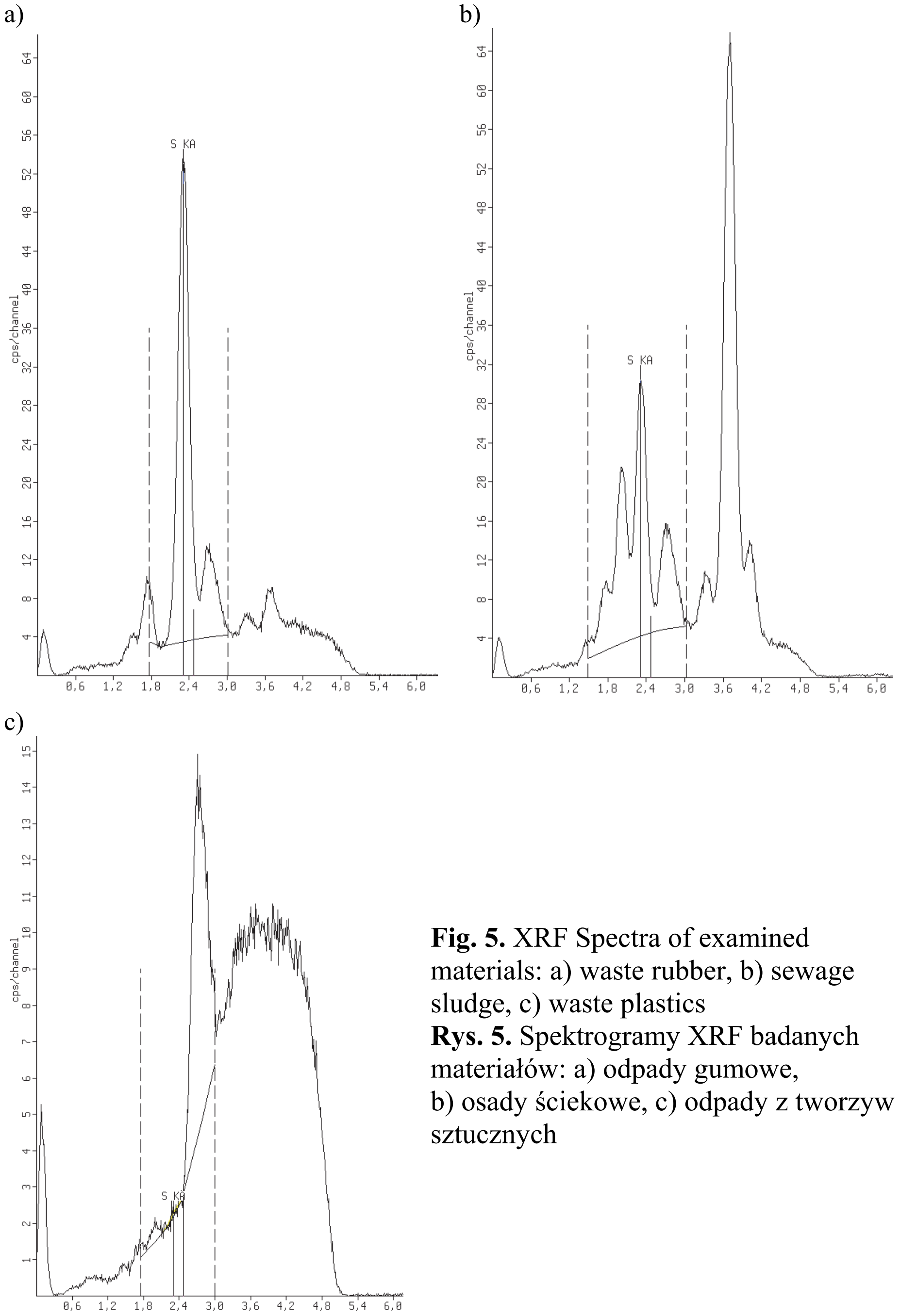

Fig. 5. XRF Spectra of examined materials: a) waste rubber, b) sewage sludge, c) waste plastics
Rys. 5. Spektrogramy XRF badanych materiałów: a) odpady gumowe, b) osady ściekowe, c) odpady z tworzyw sztucznych

Studies on literature results of elementary analysis of fuels clearly show, that sewage sludge is characterized by high content of fuel sulfur (approx. 1,4%) [1,3,5]. Authors of many publications [16,23] also indicate that in the case of waste rubber high concentrations of sulfur and nitrogen as fuel elements are determined. Average content of elemental sulfur in rubber waste can be up to 1.5%. Rubber is a product of vulcanization of natural or synthetic cautchuc with addition of 1–5% of sulfur to accelerators. It also contains plasticizers, fillers, pigments and other additives [8,23].

4. Conclusions

The final analysis of all laboratory studies presented in this paper has shown that waste plastics which have the biggest mass loss and lowest values of concentrations of exhaust gases produced during incineration of those waste, are characterized by the highest degree of efficiency of thermal decomposition process. But also other aspect must be taken into account – the fact that during the thermal treatment of such type of waste other toxic products (PCDDs, PCDFs, hydrogen cyanide, ammonia) may be produced [15,19,20,22]. Their analysis was not included within the range of studies presented in this paper. Therefore, it is necessary to design waste incineration installations which will include complex nodes of flue gases treatment [6,7,10,25]. Such type of installations should be designed on the base of the morphology of municipal waste, energy balance of incinerator feed, in order to make the process efficient and proper, not only for energetical, but also ecological reasons [19]. This will require a certain composition of waste feed into the furnace of thermal waste processing plant.

References

1. **Barz M.:** *Sewage sludge from wastewater treatment as energy source*. International Journal of Renewable Energy. 4(1) (2009).
2. **Bielińska E.J., Futa B., Baran S., Pawłowski L.:** *Eco-energy anthropopressure in the agricultural landscape*. Problemy Ekorozwoju – Problems of Sustainable Development. 9(2), 99–111 (2014).
3. **Bień J.B., Wystalska K.:** *Przekształcanie osadów ściekowych w procesach termicznych*. Wydawnictwo Seidel-Przywecki. Warszawa 2009.

4. **Czop M., Kajda-Szcześniak M.:** *Environemental impact of straw based fuel combustion*. Archives of Environmental Protection. 39(4), 71–80 (2013).
5. **Dąbrowski J., Piecuch T.:** *Badania laboratoryjne nad możliwością współspalania osadów ściekowych wraz z odpadami gumowymi*. Inżynieria Ekologiczna. 25, 55–66 (2011).
6. **Gomez-Garcia M.A., Pitchon V., Kiennemann A.:** *Pollution by nitrogen oxides: an approach to NO_x abatement by using sorbing catalytic materials*. Environment International. 31, 445–467 (2005).
7. **Goo J.H., Irfan M.F., Kim S.D., Hong S.Ch.:** *Effects of NO_2 and SO_2 on selective catalytic reduction of nitrogen oxides by ammonia*. Chemosphere. 67, 718–723 (2007).
8. **Jasiewicz M.:** *Sposoby granulowania i recyklingu zużytych opon. Kompleksowe zarządzanie gospodarką odpadami.* Praca zbiorowa pod red. T. Marcinkowskiego. Wydawnictwo PZITS Oddz. Wielkopolski. Poznań 2009.
9. **Kijo-Kleczkowska A., Otwinowski H., Środa K.:** *Specificity combustion of sewage sludge.* Archives of Waste Management Environmental Protection. 16(4), 93–102 (2014).
10. **Kordylewski W., Jakubiak M., Hardy T.:** *Pilot Plant Studies on NO_x Removal Via NO Ozonation and Absorption.* Archives of Environmental Protection. 39(3), 93–106 (2013).
11. **Lis J.:** *Badania efektywności spalania wybranych kompozycji mieszanin odpadów*. Praca magisterska. Promotor: prof. dr hab. inż. Tadeusz Piecuch. Politechnika Koszalińska. Koszalin 2013.
12. **Liu H.:** *Biofuel's Sustainable Development under the Trilemma of Energy, Environment and Economy*. Problemy Ekorozwoju – Problems of Sustainable Development. 10(1), 55–59 (2015).
13. **Lorenz U.:** *Skutki spalania węgla kamiennego dla środowiska przyrodniczego i możliwości ich ograniczenia*. Mat. Szkoły Eksploatacji Podziemnej. Sympozja i Konferencje nr 64. Wydawnictwo Instytutu GSMiE PAN. Kraków 2005.
14. **Marcisz M.:** *Zawartość siarki całkowitej w złożach monokliny Zofiówki (SW część Górnośląskiego Zagłębia Węglowego)*. Gospodarka Surowcami Mineralnymi – Mineral Resources Management. 29(3), 61–77 (2013).
15. **McKay G.:** *Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review.* Chemical Engineering Journal. 86(3), 343–368 (2002).
16. **Mianowski A., Radko T., Koszorek A.:** *Współspalanie miału węglowego i zużytych opon*. Zeszyty Naukowe Wydziału Budownictwa i Inżynierii Środowiska Politechniki Koszalińskiej. Koszalin 2007.

17. **Misiak J.:** *Jakość węgla eksploatowanych pokładów w LW „Bogdanka” S.A. (Lubelskie Zagłębie Węglowe)***.** Gospodarka Surowcami Mineralnymi – Mineral Resources Management. 28(4), 137–149 (2012).
18. **Piecuch T., Dąbrowski J., Dąbrowski T.:** *Laboratory Investigations on Possibility of Thermal Utilisation of Post-production Waste Polyester.* Rocznik Ochrona Środowiska (Annual Set The Environment Protection). 11, 87–101 (2009).
19. **Piecuch T., Dąbrowski J.:** *Projekt koncepcyjno-technologiczny Zakładu Termicznego Przekształcania Odpadów Komunalnych dla Regionu Środkowopomorskiego.* Rocznik Ochrona Środowiska (Annual Set The Environment Protection). 16, Monografia, 136 (2014).
20. **Piecuch T., Dąbrowski J.:** *Projekt koncepcyjny budowy Zakładu Termicznej Utylizacji Odpadów dla Gminy Połczyn-Zdrój*. Rocznik Ochrona Środowiska (Annual Set The Environment Protection). 16, 196–222 (2014).
21. **Rajczyk R., Bień J., Palka H., Pogodziński A., Smorąg H.:** *Co-Combustion of Municipal Sewage Sludge and Hard Coal on Fluidized Bed Boiler WF-6.* Archives of Environmental Protection. 40(3), 101–113 (2014).
22. **Saechtling H.:** *Tworzywa sztuczne. Poradnik*. Wydawnictwa Naukowo-Techniczne. Warszawa 2007.
23. **Skalmowski K.:** *Poradnik gospodarowania odpadami*. Wyd. Verlag-Dashöfer, Warszawa, 2007.
24. **Sobiecki M.:** *Rozwój systemu gospodarki odpadami po oponach samochodowych w Polsce.* Kompleksowe zarządzanie gospodarką odpadami. Praca zbiorowa pod red. T. Marcinkowskiego. Wydawnictwo PZITS Oddz. Wielkopolski. Poznań 2009.
25. **Wielgosiński G.:** *Instalacje Termicznego Przekształcania Odpadów Komunalnych w kontekście RIPOK – wybór technologii i koncepcji Rozwiązania problemu*. Wydawnictwo Nowa Energia. 1(37), 17–24 (2014).

Laboratoryjne badania nad skutecznością termicznego przekształcania wybranych kompozycji odpadów przemysłu chemii organicznej

Streszczenie

W pracy przedstawiono wyniki badań laboratoryjnych nad skutecznością spalania różnych kompozycji mieszanin odpadów przemysłu chemii organicznej w aspekcie procentowej obniżki ich masy. Badania te przeprowadzono przy założeniu różnych procentowych udziałów poszczególnych odpadów w mieszankach wraz z osadami ściekowymi jako możliwość współspalania ich z tymi odpadami.

Do badań wyodrębniono następujące materiały:

- odpady polimerowe
  - odpady gumowe (zużyte opony) – odpadowe przemysłowe.
  - odpady farbiarskie – odpady przemysłowe,
  - odpady z tworzyw sztucznych – odpady przemysłowe, komunalne,
- osady ściekowe – odpady komunalne,

Podsumowując analizę wyników laboratoryjnych badań nad efektywnością termicznego przekształcania badanych odpadów, należy stwierdzić, że największą skutecznością związaną z redukcją pozostałości po tej utylizacji charakteryzowało się termiczne przekształcenie odpadów z tworzyw sztucznych oraz ich kompozycji z osadami ściekowymi i odpadami gumowymi. Natomiast najmniej korzystny jest udział w spalanych mieszankach odpadów farbiarskich.

W trakcie wszystkich etapów badań opisanych w niniejszej pracy, równocześnie strumień gazów spalinowych wydostający się z reaktora pieca, poddawany był analizie za pomocą analizatora spalin typu MADUR GA-21 *plus*. Mierzonymi parametrami były stężenia tlenku siarki(IV), tlenków azotu i tlenku węgla(II).

Ostateczna analiza wszystkich opisanych badań pozwoliła stwierdzić, że odpady z tworzyw sztucznych posiadając największy masowy ubytek i najmniejsze wartości stężeń gazów spalinowych powstałych w procesie spalania tych odpadów, charakteryzują się największym stopniem efektywności tego procesu. Ale dodatkowo należy brać pod uwagę to, że w czasie termicznego przekształcania tego rodzaju odpadów powstają dodatkowe produkty toksyczne, zarówno gazowe, ciekłe jak i stałe, których analizy nie założono w zakresie badań niniejszej pracy.

Dlatego niezbędne jest projektowanie instalacji termicznej utylizacji odpadów (wraz z kompleksowymi węzłami oczyszczania spalin). Tego rodzaju instalacje należy projektować w oparciu o morfologie odpadów komunalnych oraz bilans energetyczny wsadu do pieca spalarni, tak aby proces ten był efektywny i właściwy, nie tylko ze względów energetycznych, ale i ekologicznych. Będzie to wymagało określonej kompozycji wsadu do komory pieca zakładu termicznego przekształcania odpadów.

Słowa kluczowe:
odpady, osady ściekowe, termiczne przekształcanie, skuteczność spalania

Keywords:
waste, sewage sludge, thermal processing, effectiveness of incineration