

Laboratory Investigations on Possibility of Thermal Utilisation of Post-production Waste Polyester¹

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1. Introduction

For many years amount of plastic waste has been increasing. They are produced in all fields of economy, industry and everyday life. Due to diversity, volume and long degradation period, their landfilling is not favourable. That is why it is very important to re-use or utilize plastics in one of types of recycling [1, 2, 15, 17]:

- raw material, when plastic waste are processed to the form of raw material, they had been produced from,
- material, when plastic waste are processed to the form of new products,
- energetic, when plastic waste is incinerated with recycling of energy.

Division of Water Sludge Technology and Waste Utilization for many years has investigated issues of thermal utilization of waste [3÷14]. Investigations in the Division are carried out on many groups of waste. Waste polyester from production of polyester clothing haberdashery is one of the types of investigated waste. At the moment waste polyester coming from production is stored on municipal landfill. This is the reason why the Division became interested in investigations on incineration of waste polyester or its co-incineration together with fine coal or other wastes [3, 4].

Results of investigations on the possibility of thermal utilization of waste polyester in the process of incineration are presented in this paper. The

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aim of this research was to determine optimal temperature of the process and value of the excess air factor, at which concentrations of pollutants in flue gas fulfil emission standards for waste incineration installations [16]. The paper also presents proposal of technological installation for burning waste polyester or its co-burning with other wastes. This installation assures full protection of air against the harmful components of flue gas.

2. Materials and methods

2.1. Range of investigations

Investigations consisted of:

- determination of properties of investigated material (particle fraction distribution, bulk density, calorific value),
- investigation of the incineration process of waste polyester.

The laboratory investigations of the incineration process were carried out in the following conditions: temperature $T=600\div 1200^{\circ}\text{C}$, the excess air factor $\lambda=1.3\div 2.1$, incineration time $t=1$ min. Mass of the sample, in relation to volume of incineration chamber was 5.8 and 1.2 kg/m^3 of the chamber.

Measurements of calorific value Q_s were carried out using calorimeter according to Polish Standards PN-81/G-04513. Concentrations of carbon monoxide CO, sulphur dioxide SO_2 , sum of nitrogen oxides NO_x , carbon dioxide CO_2 and oxygen O_2 were measured in flue gases.

The excess air factor λ was determined through analysis of flue gas. λ was calculated on the basis of CO_2 content, using following equation:

$$\lambda = \frac{\text{CO}_{2\text{max}}}{\text{CO}_{2\text{p}}} = \frac{20.95}{20.95 - \text{CO}_{2\text{p}}} \quad (1)$$

The inflow of air for the process was regulated in order to keep the excess air factor λ within the range values applied for solid fuels in installations with hand-fired grates ($\lambda=1.3\div 1.6$) and with mechanical grates ($\lambda=1.6\div 2.1$) [14, 15].

Received results were compared with admissible values given in Polish Standards for emission standards from installations [16].

2.2. Materials used in investigations

Waste polyester used in investigations comes from production process of raw material for production of buttons from polyester resin ESTROMAL. This type of polyester is characterised by high mechanical and thermal

resistance, and elevated resistance to chemical reagents. The content of moisture in waste polyester was 2.5%, energetic properties determined by calorific value was 28.6 MJ/kg. Particle fractions distribution of studied waste polyester is presented in Table 1 and Fig. 1, in the form of fractional composition curve.

Table 1. Particle fractions distribution of studied waste polyester

Tabela 1. Analiza ziarnowa odpadów użytych do badań

Particles diameter, d, [mm]	Mass, m, [g]	Output, γ , [%]
<0.25	1.59	0.54
0.63÷0.25	3.84	1.30
0.8÷0.63	2.50	0.84
1.0÷0.8	3.87	1.31
2.0÷1.0	41.81	14.12
4.0÷2.0	123.48	41.70
6.3÷4.0	104.20	35.19
>6.3	14.81	5.00
Total	296.09	100.00

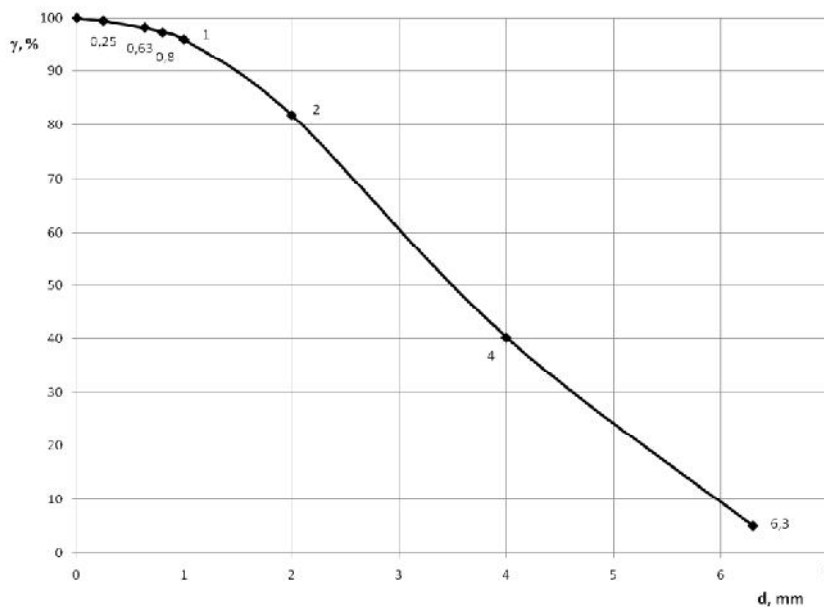


Fig. 1. Fractional composition curve of waste polyester

Rys. 1. Krzywa składu ziarnowego odpadów poliestrowych

2.3. Experimental stand

Measurements of calorific value of investigated material were carried out using microprocessor calorimeter KL-11 „Mikado” (Fig. 2). The calorimeter is designed for measurement of calorific value of solid or inexplusive fuels and flammable organic substances.



Fig. 2. „Mikado” KL-11 Calorimeter
Rys. 2. Kalorymetr KL-11 „Mikado”

The measurement consists in total incineration of the sample in the atmosphere of oxygen under pressure in a calorimetric bomb, plunged in water. Increase of water temperature is measured. Calorific value is calculated automatically and presented on the calorimeter’s digital display.

Investigations of incineration process were carried out in the experimental stand presented in Fig. 3 and as diagram in Fig. 4. The main components of the stand are: pipe furnace (1) and combustion gas analyser (5).

PRC 20 HM is a laboratory monozonal pipe furnace with horizontal heating of maximum temperature of continuous work 1200°C. The accuracy of temperature control is $\pm 5^{\circ}\text{C}$. Microprocessor temperature programmer MRT-4 is a part of furnace which measures, controls and programmes temperatures of heating installation.



Fig. 3. Experimental stand for investigations of waste incineration process
Rys. 3. Instalacja do badania procesu spalania odpadów

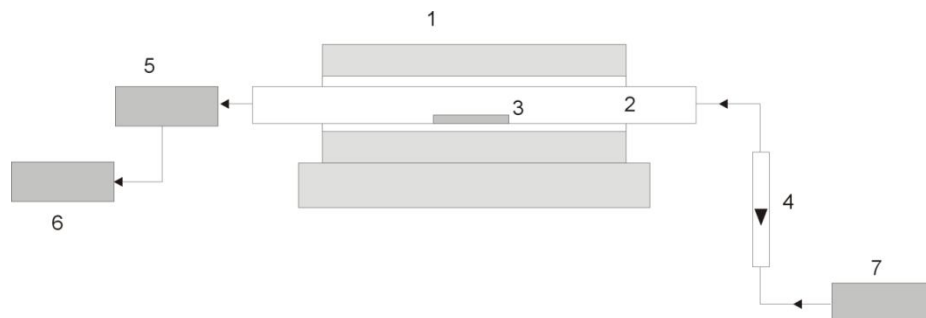


Fig. 4. Diagram of experimental stand for investigations of waste incineration process;
1 – pipe furnace, 2 – reactor, 3 – ceramic dish, 4 – rotameter, 5 – combustion gas analyser, 6 – computer, 7 – small diaphragmatic pump

Rys. 4. Schemat stanowiska badawczego do procesu spalania odpadów; 1 – piec rurowy, 2 – reaktor, 3 – kuweta ceramiczna, 4 – rotametr, 5 – analizator spalin, 6 – komputer, 7 – pompka przeponowa

The process of incineration was carried out in a reactor – quartz pipe which dimensions are: $\phi 25 \times 2.5 \times 710$ mm (2). Samples of incinerated waste polyester were spread evenly in porcelain dish (3), and then placed in the quartz pipe of furnace (2). Combustion zone, 200 mm long, is located in the central part of the pipe. The process was carried out in the atmosphere of air, which

was introduced by a small diaphragmatic pump (7) through a rotameter (4) which measures flow rate.

Stream of flue gases from furnace reactor was analysed using combustion gas analyser MADUR GA-21 plus. The analyser is a versatile device, which measures concentration of gases with electrochemical and infrared sensors. Analyser used in investigations was equipped in electrochemical sensors of: O₂, CO, NO, SO₂, NO₂ and IR sensor of CO₂. Results of measurements are gathered through the whole measuring cycle in EEPROM memory and then processed with using a computer (6).

3. Results and discussion

During the initial stage of investigations the mass of sample in reference to the volume of the incineration chamber was 5.8 kg/m³. This is the maximum single batch of sample which may be incinerated in the laboratory furnace. Results obtained at this amount of batch are presented in Table 2.

Table 2. Changes of concentrations of combustion gases against incineration temperature T and excess air factor λ at constant sample mass in reference to volume of incineration chamber 5.8 kg/m³

Tabela 2. Zmiany stężeń gazów spalinowych w zależności od temperatury spalania T i współczynnika nadmiaru powietrza λ przy stałej masie próbki w odniesieniu do objętości komory spalania wynoszącej 5,8 kg/m³ komory

T, [°C]	600			700					
λ	1.3	1.7	2.1	1.3	1.7	2.1			
CO, [mg/m ³]	5860.49	5513.64	5227.87	5121.00	4982.29	4819.11			
NO _x , [mg/m ³]	34.51	37.76	37.58	42.02	45.74	53.02			
SO ₂ , [mg/m ³]	208.64	202.58	150.15	54.34	51.33	49.31			
T, [°C]	800			900					
λ	1.3	1.7	2.1	1.3	1.7	2.1			
CO, [mg/m ³]	4563.75	4088.75	3517.50	2476.43	1961.46	1825.43			
NO _x , [mg/m ³]	44.69	55.96	70.72	76.87	83.38	86.13			
SO ₂ , [mg/m ³]	35.18	30.89	27.74	19.39	18.59	17.16			
T, [°C]	1000			1100			1200		
λ	1.3	1.7	2.1	1.3	1.7	2.1	1.3	1.7	2.1
CO, [mg/m ³]	–	–	–	–	–	–	–	–	–
NO _x , [mg/m ³]	–	–	–	–	–	–	–	–	–
SO ₂ , [mg/m ³]	–	–	–	–	–	–	–	–	–

Analysis of results proves, that concentration of nitrogen oxides increases, and concentrations of sulphur dioxide and carbon monoxide decrease

along with process temperature increase. For example for $\lambda=1.7$ concentration of NO_x increased 120.8%, concentration of SO_2 decreased 90.8%, and CO 64.4%. While the increase of excess air factor does not cause significant changes as in the case of the temperature. E.g. for temperature 600°C decrease of concentration of SO_2 and CO is: 10.6% and 10.7%, whereas increase of concentration of NO_x was 12.0%. For 900°C concentrations drop of SO_2 and CO were: 11.5% and 26.3%, whereas growth of NO_x concentration was 12%.

It is clear visible, that concentration of CO is still very high in spite of high temperature of the process. Additionally large quantities of soot were formed (about 0.3 g/g of incinerated polyester). Soot makes measurements of flue gases very difficult, almost impossible. Therefore decision was made to stop investigations and to reduce quantity of incinerated waste. Farther investigations of the incineration process were carried out with the sample mass in reference to the volume of the incineration chamber 1.2 kg/m^3 . At this quantity of batch, amount of formed soot was much smaller (between ten to a hundred times smaller, depending on values of other process parameters).

Results of investigations of incineration process of waste polyester, conducted at the mass of sample in reference to the volume of the chamber 1.2 kg/m^3 are presented in Table 3 and in figures 5÷7.

Table 3. Changes of concentrations of combustion gases against incineration temperature T and excess air factor λ at constant sample mass in reference to volume of incineration chamber 1.2 kg/m^3

Tabela 3. Zmiany stężeń gazów spalinowych w zależności od temperatury spalania T i współczynnika nadmiaru powietrza λ przy stałej masie próbki w odniesieniu do objętości komory spalania wynoszącej $1,2 \text{ kg/m}^3$ komory

T, [°C]	600			700					
λ	1.3	1.7	2.1	1.3	1.7	2.1			
CO_2 , [mg/m ³]	4016.67	2897.73	1658.30	3689.00	1441.67	1454.17			
NO_x , [mg/m ³]	11.95	12.81	13.67	18.48	22.02	26.51			
SO_2 , [mg/m ³]	86.03	67.93	59.20	41.47	34.03	26.88			
T, [°C]	800			900					
λ	1.3	1.7	2.1	1.3	1.7	2.1			
CO_2 , [mg/m ³]	394.00	352.12	229.50	16.12	8.33	7.54			
NO_x , [mg/m ³]	31.16	34.03	35.46	51.25	57.37	58.57			
SO_2 , [mg/m ³]	12.01	8.58	5.58	5.72	5.72	2.86			
T, [°C]	1000			1100			1200		
λ	1.3	1.7	2.1	1.3	1.7	2.1	1.3	1.7	2.1
CO_2 , [mg/m ³]	6.375	5.31	5.31	3.18	2.125	2.12	3.18	2.12	1.25
NO_x , [mg/m ³]	59.24	62.73	66.21	62.73	67.95	73.18	67.95	73.18	80.15
SO_2 , [mg/m ³]	5.72	5.72	2.86	4.86	2.86	2.86	2.86	0.00	0.00

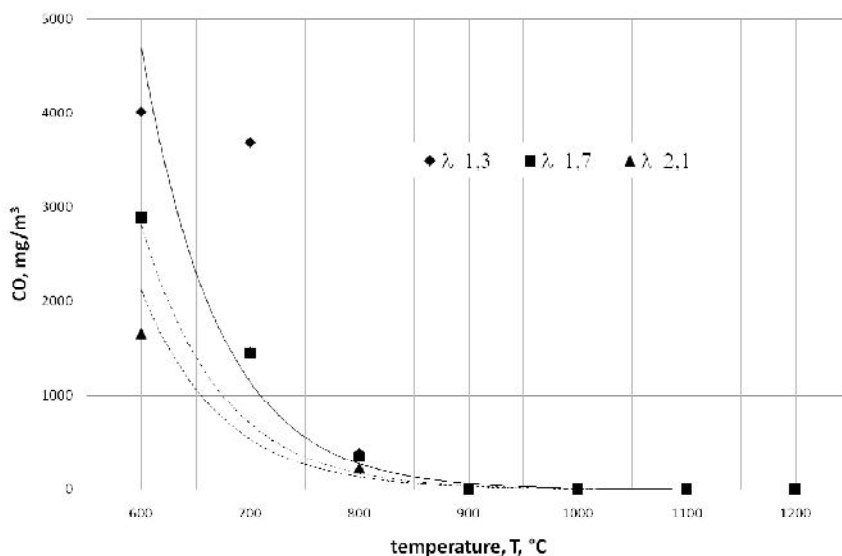


Fig. 5. Influence of temperature T on concentration of CO in dependence on λ
 Rys. 5. Wpływ temperatury T na stężenie CO w zależności od współczynnika λ

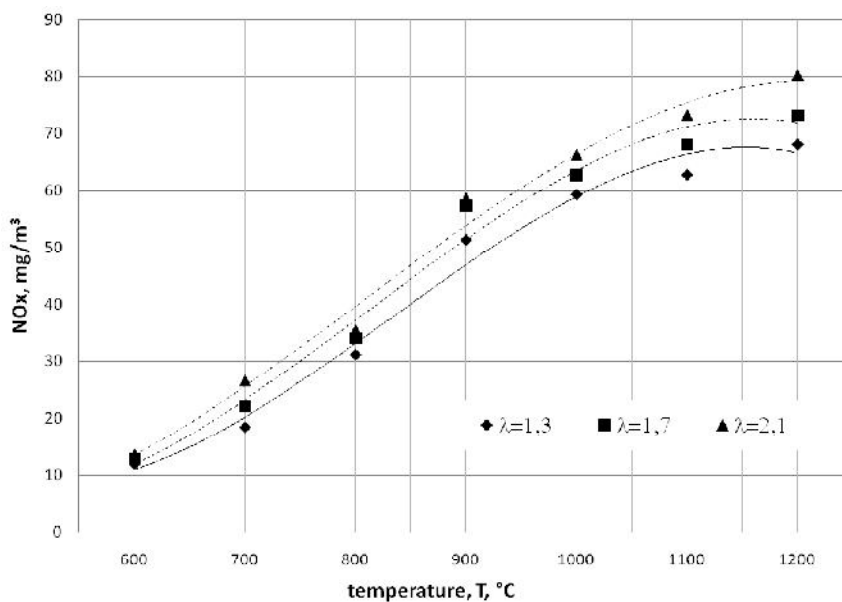


Fig. 6. Influence of temperature T on concentration of NO_x in dependence on λ
 Rys. 6. Wpływ temperatury T na stężenie NO_x w zależności od współczynnika λ

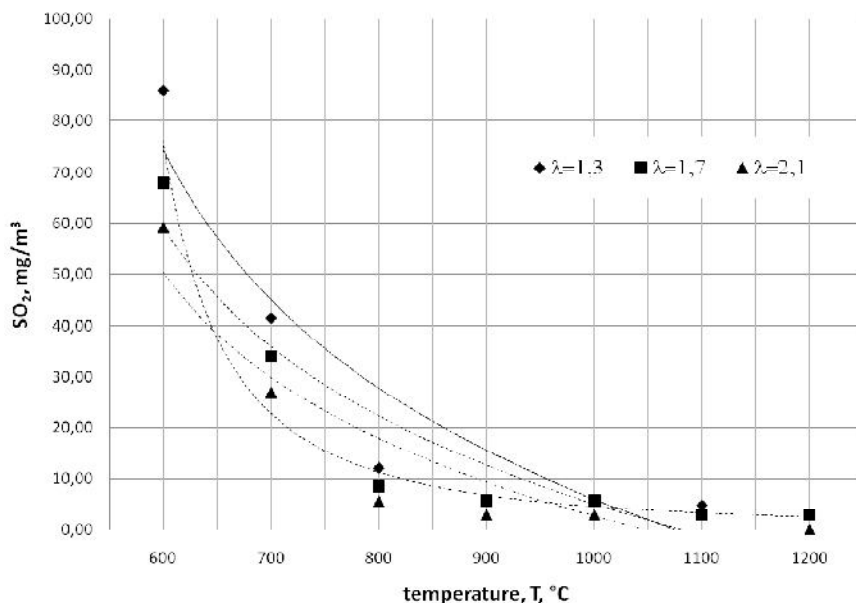


Fig. 7. Influence of temperature T on concentration of SO_2 in dependence on λ
Rys. 7. Wpływ temperatury T na stężenie SO_2 w zależności od współczynnika λ

On the base of conducted results analysis it must be stated that both temperature and excess air factor have substantial impact on quality of flue gases after the process. Increase of temperature causes increase of nitrogen oxides concentration (for $\lambda = 1.7 - 471.2\%$), drop of sulphur dioxide concentration (for $\lambda = 1.7 - 95.7\%$) and carbon monoxide concentration (for $\lambda = 1.7 - 99.9\%$). In case of changes of excess air factor λ changes of determined gases are following: for temperature 600°C decrease of SO_2 and CO is 31.2% and 58.7% , while increase of NO_x concentration was 14.3% . For temperature of 1200°C changes were respectively 100% , 60.8% and 17.9% .

Observing the courses of CO concentrations changes presented in Fig. 5 and courses of SO_2 concentrations changes shown in Fig. 7, dramatic falls of concentrations of both gases along with the growth of incineration temperature to about 850°C are clearly noticeable. Increase of the temperature beyond 850°C and change of excess air factor λ do not influence significantly on decrease of concentration of both gases in combustion gas. In case of NO_x (Fig. 6) increase of their concentration is even in the whole examined range of temperature and λ coefficient changes.

Comparison of obtained results of investigations with admissible values determined by emission standards from installations for incineration and co-

incineration of wastes (enclosure no. 5 in Decree [16]) shows, that in the whole examined range of temperatures and excess air factor λ , only concentration of NO_x were not bigger than admissible value. While in case of other gases emission standards from installations for incineration and co-incineration of wastes are fulfilled: for SO_2 above temperature about 650°C and for CO above 900°C . It means that installation for incineration of waste polyester should allow obtaining temperature over 900°C in the furnace chamber. It also should be equipped with technology for flue gases treatment especially when other types of waste will be co-incinerated together with waste polyester [2, 3].

4. Preliminary project of installation for waste polyester incineration

Schematic project of technology for waste incineration or co-incineration is presented in Fig. 8. Individual appliances are designated as nodes with letter W and consecutive number of next appliance (W1, W2, W3...).

The first node of installation is grate furnace W1. Flue gases from node W1 flow to node W2 – post combustion chamber. This is the first stage of flue gases treatment. Here hydrocarbons, carbon monoxide and part of solid phase (soot) contained in the flue gas are post combusted. Temperature in post combustion chamber should be over 1200°C , and combustion gases should stay there longer than 2.5 seconds. Obviously this is practically very difficult to achieve. At the flow velocity 10 to 12 m/s (assuming continuity of the stream), time of flue gas stay in node knot W2 will be about 0.2 second.

Next combustion gases flow to node W3 – heat exchanger. Here heat from combustion gas is recovered. This node entitles to state that this is utilisation of waste polyester, not only incineration.

After heat exchanger W3 flue gas goes to bag filters W4a. Temperature of filtered gas should not be greater than 240°C . Too high temperature of flue gas would damage filter bags. For full protection installation should also be equipped with electrostatic precipitator – node W4b.

Next two nodes are of installation are two columns with spray of $\text{Ca}(\text{OH})_2$ (node W5) and NaOH (node W6) for reduction of sulphur dioxide, hydrogen chloride and hydrogen fluoride. In node W5 also part of heavy metals may be removed.

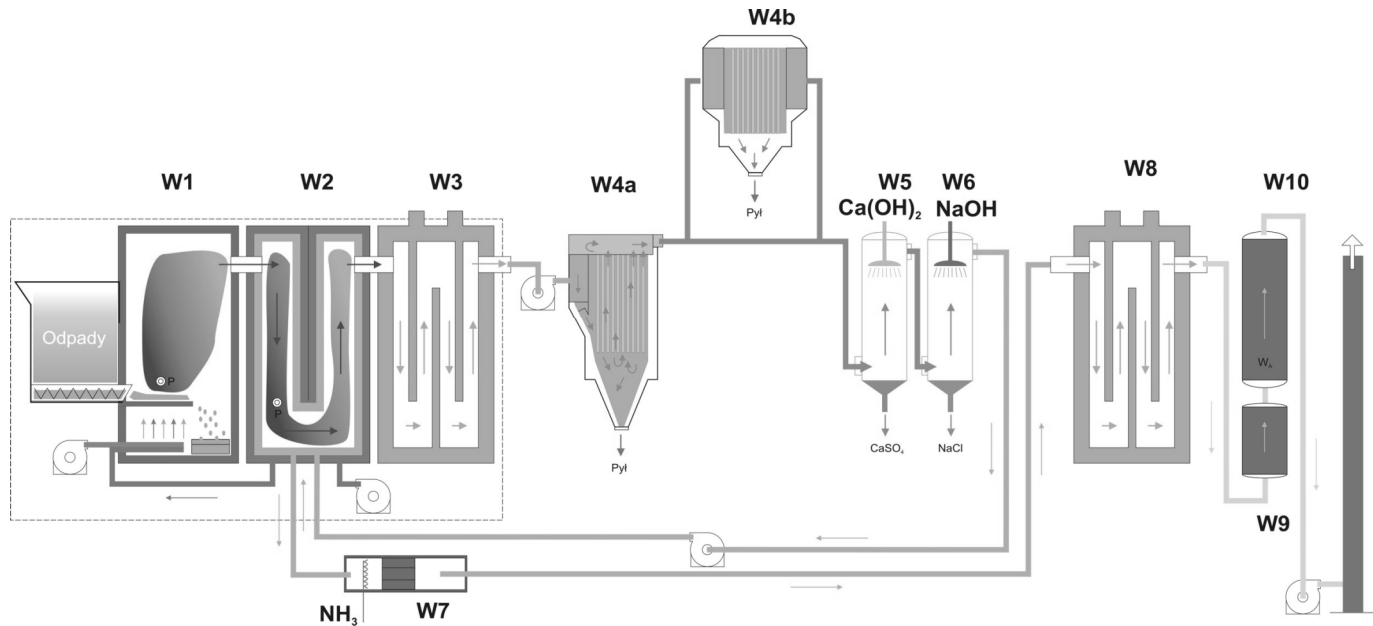


Fig. 8. Technological diagram of preliminary project of waste incineration installation; W1 – waste incineration chamber, W2 – post combustion chamber, W3 – heat exchanger, W4a – bag filter, W4b – electrostatic precipitator, W5 – reduction of SO₂, W6 – reduction of HCl and HF, W7 – reduction of NO_x, W8 – heat exchanger, W9 – reduction of mercury, W10 – column with active carbon

Rys. 8. Schemat technologiczny maszynowy spalarni; W1 – komora spalania odpadów, W2 – komora dopalania, W3 – wymiennik ciepła, W4a – filtr workowy, W4b – elektrofiltr, W5 – instalacja uławiania SO₂, W6 – instalacja uławiania HCl i HF, W7 – instalacja redukcji NO_x, W8 – wymiennik ciepła, W9 – instalacja neutralizacji par rtęci, W10 – instalacja doczyszczania spalin na węglu aktywnym

Pre-treated flue gas after node W6 will be too cool to go straight to reduction of NO_x . In order to obtain high efficiency of the process, temperature at least about 350°C (if catalysts are applied) is required. That is why flue gas after node W6 goes to heat exchanger – node W2. It is equipped with double thermal overcoat, which is a novelty of this technology. Heated flue gas is directed to node W7 – reduction of nitrogen oxides to nitrogen N_2 with application of ammonia NH_3 .

After reduction of nitrogen oxides to free nitrogen flue gas should undergo reduction of mercury (node W9). Reduction of mercury is achieved by taking advantage of special propriety of mercury – creation of alloys with noble metals, so-called amalgams. A column equipped with barriers created from scales (gills) of platinum or gold is used for removal of mercury. But it is a huge investment cost. The column may be installed before heat exchanger W8 (quicker reaction, but bigger investment costs) or after (more difficult reaction, because of lower temperature, but smaller cost of node W9).

Flue gas after node W7 will be directed to heat exchanger W8, and then to node of sorption on active carbon (node W10). Temperature of flue gas after heat exchanger and before active carbon should be lower than 120°C . After sorption flue gas goes to the chimney.

Such installation during normal work is also a source of secondary waste and wastewater:

- secondary waste, so-called slag after node W1,
- soot and fly ash from bag filters (node W4a),
- mixture of water and plaster after node W5; requires dewatering,
- wastewater from node W6,
- used active carbon – secondary waste from node W10.

Full project of such installation also requires neutralisation and utilisation of secondary wastes as well as treatment of wastewater, choosing proper methods, depending on their amount. Appropriate investigation should be conducted, but after installation is started.

5. Conclusions

Results of investigations show that utilisation of waste polyester in the process of incineration is possible. In order to fulfil requirements determined by emission standards for installations for wastes incineration, temperature of process should be higher than 900°C . Additionally in the case of co-incineration of waste polyester together with other types of wastes, flue gas treatment installation is required. Preliminary project of such installation proposed in the

paper fully meets such requirements. It assures full protection of atmosphere against harmful combustion gas components.

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Badania laboratoryjne nad możliwością termicznej utylizacji poprodukcyjnych odpadów poliestrowych

Streszczenie

Od wielu lat obserwuje się nieustanny wzrost ilości odpadów tworzyw sztucznych. Pochodzą one z różnych dziedzin przemysłu, gospodarki i życia codziennego.

Katedra Techniki Wodno-Mułowej i Utylizacji Odpadów Politechniki Koszalińskiej od wielu lat zajmuje się problematyką termicznej utylizacji odpadów [3÷14]. Badania w Katedrze prowadzone są nad wieloma grupami odpadów. Jedną z nich są odpady poliestrowe pochodzących z zakładu produkującego galanterię odzieżową.

W artykule przedstawiono wyniki badań laboratoryjnych nad możliwością termicznej utylizacji odpadów poliestrowych w procesie spalania. Celem badań było ustalenie optymalnej temperatury procesu oraz współczynnika nadmiaru powietrza, przy których stężenia zanieczyszczeń w gazach odlotowych będą spełniały standardy emisyjne dla instalacji do spalania odpadów. Zaproponowano również układ technologiczny, który pozwala na spalanie odpadów poliestrowych, również z dodatkiem innych odpadów. Układ ten zapewnia pełną ochronę powietrza przed szkodliwymi składnikami spalin.

Laboratoryjne badania procesu spalania prowadzono w następujących warunkach: temperatura $T = 600\div 1200^{\circ}\text{C}$, współczynnik nadmiaru powietrza $\lambda = 1,3\div 2,1$, czas spalania $t = 1$ min. Masa próbki, określona w odniesieniu od objętości komory spalania, wynosiła $5,8$ i $1,2$ kg/m^3 komory.

Porównując uzyskane wyniki badań z wartościami dopuszczalnymi określonymi poprzez standardy emisyjne z instalacji spalania i współspalania odpadów (załącznik nr 5 Rozporządzenia [16]) można zauważyć, że w całym badanym zakresie temperatur i współczynnika λ tylko stężenie NO_x nie przekroczyło wartości dopuszczalnej. Natomiast dla pozostałych gazów standardy emisyjne z instalacji spalania i współspalania odpadów spełnione są: dla SO_2 powyżej temperatury około

650°C, a dla CO powyżej 900°C. W związku z tym konieczne jest zaprojektowanie instalacji pozwalającej na uzyskanie temperatury w komorze paleniskowej powyżej 900°C oraz instalacji oczyszczającej spaliny. Szczególnie gdy wraz z odpadami poliestrowymi współspalane będą innego rodzaju odpady [2, 3].

Istnieje możliwość termicznej utylizacji odpadów poliestrowych w procesie spalania. Aby jednak spełnione były standardy emisyjne dla instalacji do spalania odpadów, temperatura procesu powinna być wyższa niż 900°C. Dodatkowo w przypadku współspalania odpadów poliestrowych z innymi odpadami konieczne będzie również zastosowanie dodatkowej instalacji oczyszczania spalin. Zaproponowany układ technologiczny spełnia te wymagania. Zapewnia on pełną ochronę powietrza przed szkodliwymi składnikami spalin.

