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# AMMONIA EMISSION FROM SEWAGE SLUDGE INCINERATION PROCESS

## EMISJA AMONIAKU Z PROCESU SPALANIA OSADÓW ŚCIEKOWYCH

**Abstract:** In quantitative terms, sludge produced in the process of municipal wastewater treatment represents a small part of the total waste generated in municipal sources - its quantity represents only a few percent of the generated mass of municipal waste. However, the threats it brings, do not allow it to be neglected while designing the wastewater treatment process. At the same time, with increasing requirements regarding the quality of sewage discharged into the environment, there is an increase in the amount of sludge produced in wastewater treatment processes. In recent years, the share of thermal treatment of municipal sewage sludge has risen sharply - about 12 modern sludge incineration plants have been built and construction of new ones is considered. During more than a four-year operation of the sewage sludge incineration plant in the Combined Sewage Treatment Plant in Lodz (GOS) a large ammonia emission from the combustion process was observed. So, a decision was taken to examine this process. The paper presents results of ammonia emission from the combustion of sewage sludge from GOS as a function of temperature.

**Keywords:** ammonia, ammonia emission, sewage sludge, emission from combustion

## Introduction

Municipal sewage sludge is a 'waste' produced in sewage treatment plants in digesters or other installations for treatment of both municipal sewage and wastewater whose composition is similar to that of municipal sewage. Currently, this sludge in quantitative terms represents a small percentage of all 'wastes' generated in the municipal utilities. However, from year to year there is a noticeable increase of its amount caused by a continuous development of municipal sewage disposal and treatment systems [1]. Figures 1 and 2 illustrate changes that occurred in the last 15 years both in the quantities of treated sewage and amounts of resulting sewage sludge.

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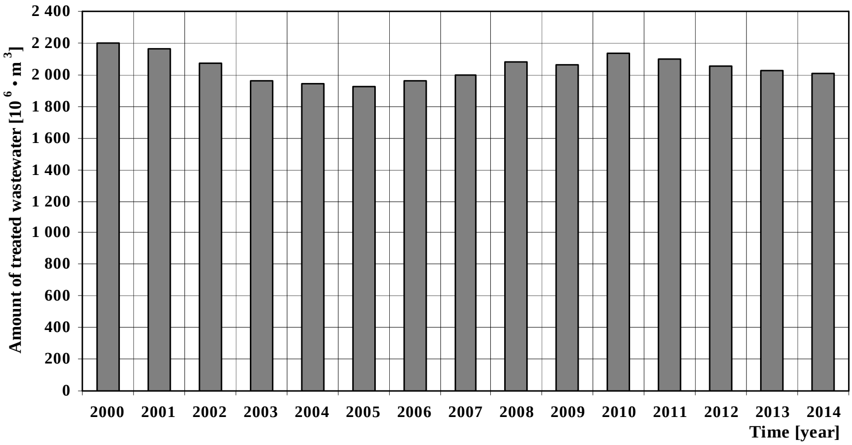


Fig. 1. Changes in the amount of treated wastewater in Poland in the years 2000-2014 according to data of the Central Statistical Office [2]

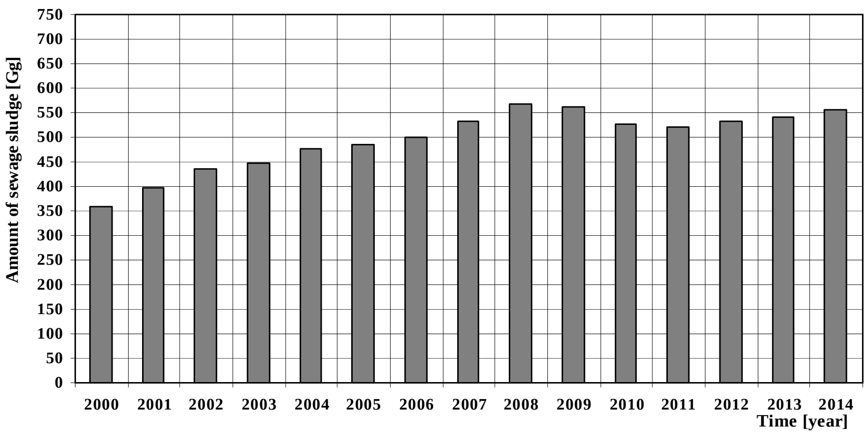


Fig. 2. The increase in the amount of sewage sludge generated in Poland in the years 2000-2014 according to data of the Central Statistical Office [2]

Proper management of sludge is one of the key elements of the national waste management, both in respect of production scale and ability to generate all kinds of negative effects. Its formation is one of the most important elements determining the shape of the investment associated with sewage treatment. The amount of sludge produced depends on the composition of wastewater and methods of treatment [3]. Due to the presence of numerous organic compounds and biogenic substances municipal sewage sludge can be a valuable source of nutrients essential for plant growth, which indicates the possibility of its use in nature. However, due to the presence of heavy metals and many other toxic substances (phenols and chlorophenols, pesticides, hexachlorobenzene, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and nitrosamines) as well as pathogens which limit the use of sewage sludge as fertilizers, the most reasonable way of dealing with municipal sewage sludge is to apply thermal methods [4].

In recent years the share of thermal treatment of municipal sewage sludge has increased sharply because, for instance in Poland, 12 modern sludge incinerators have been built (and more are under consideration). The purpose of combustion of sewage sludge is not only its disposal, but also reduction of the associated risks. Sewage sludge in relation to other waste has a characteristic chemical composition and very high moisture content. This high hydration is the main reason why the sludge before undergoing thermal transformation (incineration) should be fully or partially dried. Unfortunately, during the drying process and then combustion, many chemical substances some of which are toxic, carcinogenic, etc., are emitted to the atmosphere [5-11]. Therefore, a key role for the environmental safety of waste incineration plants is to reduce these emissions.

## Ammonia emission from thermal treatment of sewage sludge

The subject of research was the installation for thermal treatment of sewage sludge in the Combined Sewage Treatment Plant of Lodz Agglomeration at 66 Sanitariuszek Str. It was launched in 2011. The installation was built by Veolia Water Systems. It is one of the largest installations for thermal sewage sludge treatment in Poland (similar ones are in Krakow and Plock). Its capacity is about 82,000 Mg sewage sludge per year (approx. 18,040 Mg d.m.). The installation works on a continuous basis, that is 24 hours a day. This gives an annual operating time of approx. 8,000 h/year. Its primary task is the disposal of ‘waste’ formed in the sewage treatment process, *i.e.* dehydrated, fermented sewage sludge and screenings. The installation consists of two independent combustion lines connected by a common water/steam system. Combustion technology is based on the fluidized bed technique (Fig. 3).

During more than a four-year operation large ammonia emission from the incineration process was observed. This phenomenon has not been described in the available literature yet. Therefore, it was decided to examine this process in detail. The paper presents results of studies on ammonia emission from the process of sewage sludge incineration in GOS in Lodz as a function of temperature.

Nitrogen as a biogenic compound is necessary for a proper functioning of living organisms. The main source of mineral nitrogen is gaseous nitrogen which constitutes nearly 80% of the earth’s atmosphere. It can be converted into ammonia by some specialized bacteria in the binding process. Substantial amounts of nitrogen can be found in municipal sewage, primarily in the form of urea which is a product of protein metabolism from food consumed by humans and is converted into ammonia form in the sewage system. The presence of ammonia salts, nitrites and nitrates usually indicates water contamination. Even at low concentrations ammonia and nitrites are toxic to aquatic organisms. Depending on conditions, ammonia can accumulate or be converted via nitrites to nitrates (nitrification processes) caused by bacteria in the presence of oxygen. A reverse process is the decomposition of nitrites to ammonia (denitrification) which proceeds also in the presence of bacteria in anaerobic conditions [3].

The Sewage Sludge Incineration System (SSIS) consists of two parallel production lines combined by a common boiler water system. Digested and dewatered sludge is transported to SSIS and collected in storage silos. Because dry matter content in the sludge prior to the drying process is approx. 20-22% in nominal conditions, in order to ensure proper utilization of thermal power of the incineration plant the sewage sludge is pre-dried before incineration.

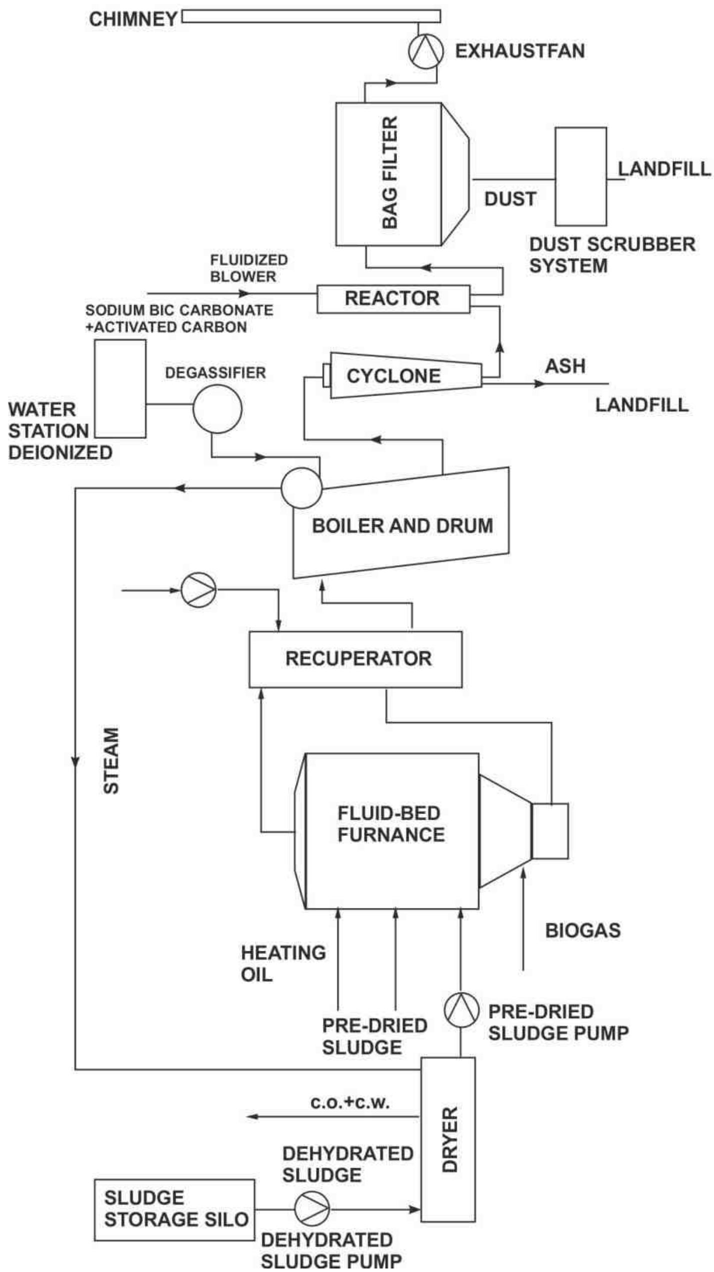


Fig. 3. Schematic diagram of Sewage Sludge Incineration System in GOS Lodz Ltd.

Through a pumping system the waste is supplied to two disc dryers with indirect steam drying. After pre-drying the sludge is injected to a fluid-bed furnace. A sand bed is a mixture of quartz sand of different granulation. The state of fluidization, *i.e.* suspension, is maintained by blowing heated air under the sand bed. As a result of complex physicochemical reactions, liquids take the form of vapors and organic solids are gasified in a small amount of oxygen. The resulting energy is absorbed by sand. The released gases are burnt in the upper part of the furnace at min. 850°C. The required residence time of flue gas in the furnace is at least 2 seconds. After leaving the furnace the exhaust gas is directed to a multi-stage flue gas cleaning system. The first step includes cooling of the exhaust gas in the recuperator. It heats air required for the fluidization process. The next stage in which heat is recovered, is the production of steam. In a tubular boiler water takes up energy from exhaust gases and steam is produced in a drum located at the top of the boiler to be used further in sludge pre-drying. Next, the exhaust gases are purified, first in a cyclone and then in a bag filter. Chemical removal of acid compounds and mercury consists in injecting dry, freshly ground sodium bicarbonate and activated carbon into the stream of gases. The mixture is retained in the last element of the system, *i.e.*, in a bag filter. Dust, as a hazardous waste, is subjected to washing in order to decrease the amount of salt compounds. Ashes from the purification of exhaust gases are transported by specialized vehicles to a landfill site.

Since during operations of the incineration plant an increased emission of ammonia from sludge combustion is observed, for analyses presented below a system monitoring the incineration process was used. The presented results are discussed on the basis of 'raw' data of exhaust gases, *i.e.* not converted to 11% of oxygen. Curves shown in Figures 4, 5 and 6 present the emission during a month of operation for two production lines.

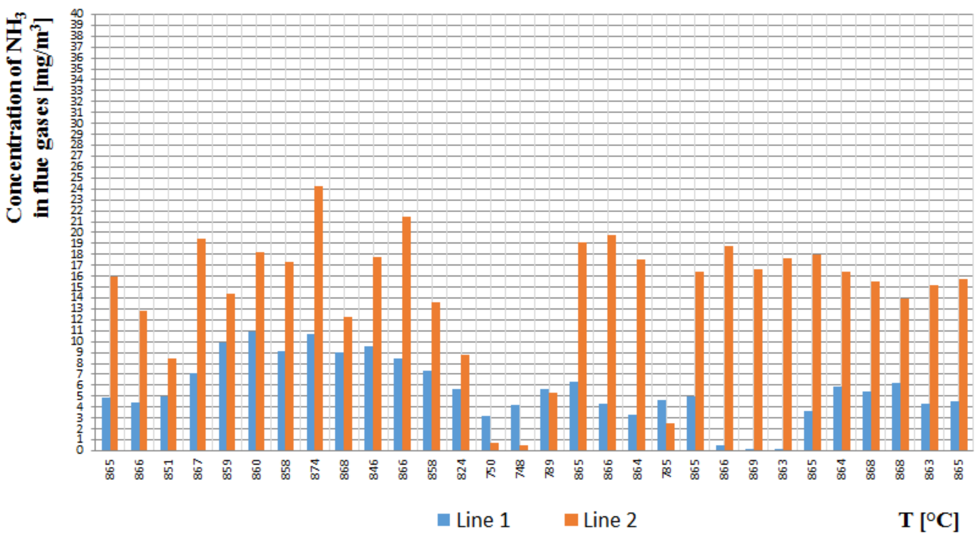


Fig. 4. Ammonia emission from a sewage sludge incineration plant - concentrations of $NH_3$ in flue gases in function of temperature measured in April 2014

Since in Figures 4, 5 and 6 a very high level of emissions can be observed, it was decided to analyze the operation of power supply system of the furnace. During thermal process fumes are emitted from the pre-dried sludge. Partly, they condense and are discharged to the sewage system in the form of a lecheate, while the other part is directed to the furnace temperature zone of 850°C. Table 1 summarizes results of the analysis which was carried out for the leachate discharged to the sewage system because a considerable amount of total and ammonia nitrogen was found in it (in the period from February to November the measurements were taken twice a month).

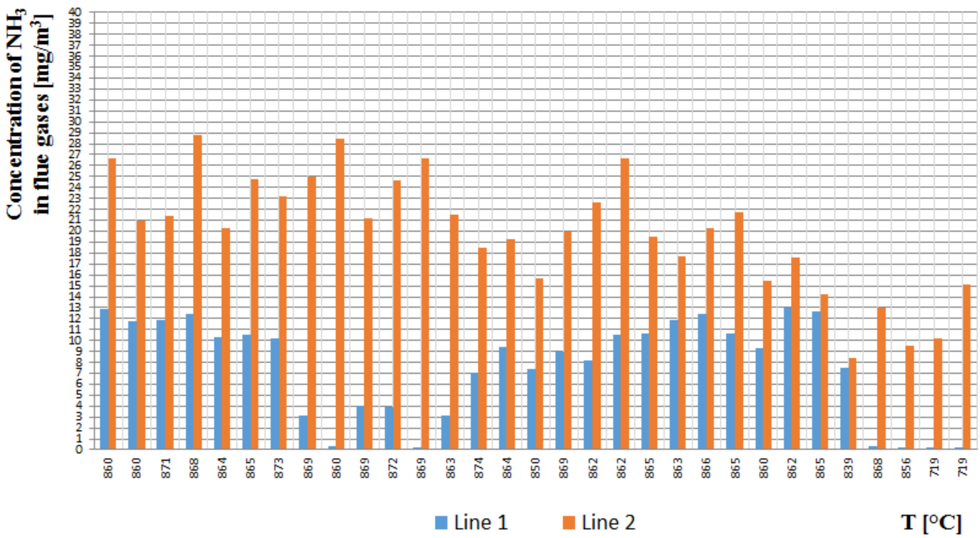


Fig. 5. Ammonia emission from a sewage sludge incineration plant - concentrations of $NH_3$ in flue gases in function of temperature measured in October 2014

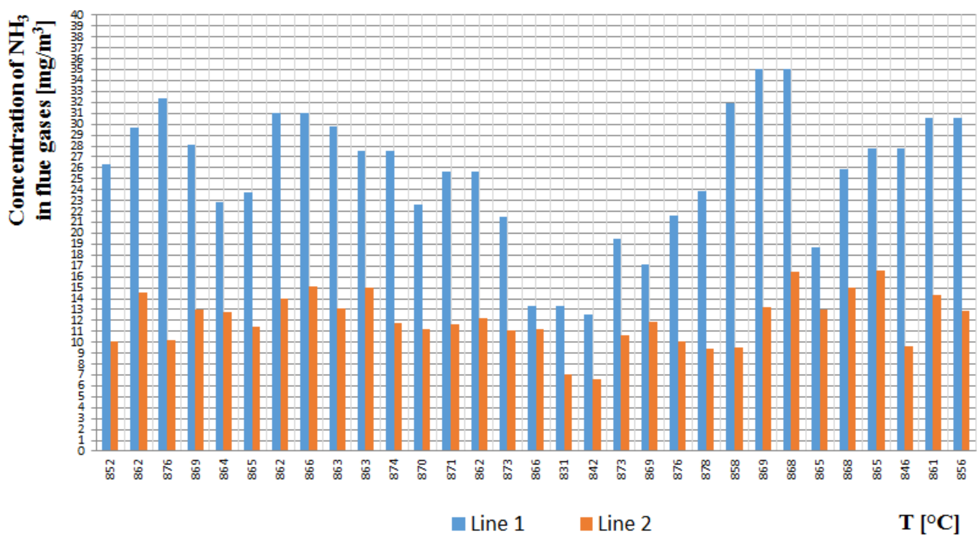


Fig. 6. Ammonia emission from a sewage sludge incineration plant - concentrations of $NH_3$ in flue gases in function of temperature measured in December 2014

Table 1

The content of total and ammonia nitrogen in the leachate from the dryers

| **Sampling period** | **Total nitrogen [mg/dm$^3$]** | **Ammonia nitrogen [mg/dm$^3$]** |
|---|---|---|
| January | 1760 | 1472 |
| February | 1046 | 658 |
| February | 535 | 520 |
| March | 1140 | 1084 |
| March | 1148 | 1550 |
| April | 541 | 676 |
| April | 873 | 232 |
| May | 796 | 1101 |
| May | 599 | 570 |
| May | 677 | 622 |
| June | 296 | 301 |
| June | 1173 | 1104 |
| July | 1106 | 1009 |
| July | 1257 | 1229 |
| August | 586 | 685 |
| August | 1528 | 1167 |
| September | 735 | 698 |
| September | 558 | 489 |
| October | 376 | 353 |
| October | 519 | 511 |
| November | 553 | 528 |
| November | 760 | 113 |
| December | 549 | 540 |

Table 2 gives values obtained when testing the dewatered sludge to be pre-dried and the mixed sludge from all presses (*i.e.* the sludge stored in silos in the SSIS).

Table 2

The content of total and ammonia nitrogen in the sludge

| **Sampling period** | **Total nitrogen [mg/kg]** | **Ammonia nitrogen [mg/kg]** |
|---|---|---|
| January | 42171 | 8837 |
| February | 40041 | 8326 |
| March | 47407 | 11208 |
| April | 26000 | 10000 |
| May | 43000 | 9000 |
| June | 49000 | 8000 |
| July | 37000 | 8000 |
| August | 35200 | 9400 |
| September | 35900 | 7300 |
| October | 37900 | 7000 |
| November | 31700 | 7020 |
| December | 28300 | 8900 |

It follows from Table 2 that sewage sludge contains large amount of nitrogen, including ammonia nitrogen, which is partially removed during sludge drying, and partly can be released in the combustion process [12-16]. It should be kept in mind that the mechanism of $NH_3$ formation during the combustion process is possible but rather unlikely probably because of the mechanism of pollutant formation in the incineration process [11].

## Laboratory tests

The phenomenon observed at a technical scale was verified by studies on the process of sludge incineration in laboratory conditions, owing to which the effect of combustion temperature on $NH_3$ emissions was determined. The experiment was performed using a laboratory resistance furnace with a horizontal working chamber PR-45/1350-M. A built-in PRT 911 regulator was used to maintain the desired temperature during the measurement. For testing, the pre-dried sludge freshly taken from the SSIS GOS Lodz was used. The test included the combustion of a sludge sample at a predetermined temperature. The resulting flue gas was passed through two wet scrubbers connected in series to absorb the released ammonia. Schematic diagram of the experimental set-up is shown in Figure 7.

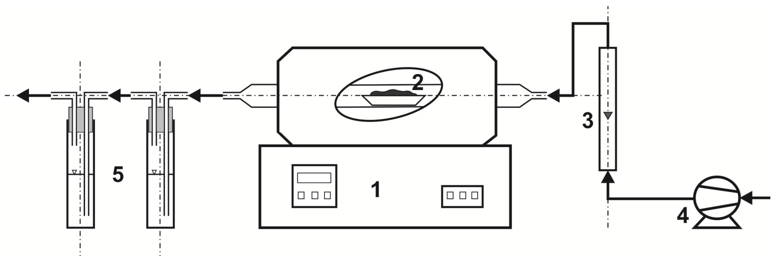


Fig. 7. Schematic diagram of the experimental set-up: 1 - electrical furnace with quartz tube, 2 - examined sample, 3 - rotameter, 4 - air pump, 5 - glass scrubber

The experimental set-up (Fig. 7) consisted of a electrical furnace with a quartz tube reactor with controlled temperature, air pump with a air flow meter (rotameter) and two consecutive glass water-filled scrubbers.

The sludge sample was placed in the quartz tubular reactor. Process temperature was set using a regulator. Once it was reached, the sludge sample weighing approx. 2 g was fed to the combustion zone. Air for combustion was supplied by a blower. The air flow rate was established using a rotameter. It was approximately 4 $dm^3$/min. The resulting gases were introduced to two scrubbers arranged in series, each containing 150 $dm^3$ of distilled water. Combustion time was 5 minutes. Ammonia content in the scrubbers was determined by the Nessler method and results of the measurements are given in Tables 3 to 5.

Table 3

The emission of $NH_3$ during sewage sludge combustion - series 1

| **Process temperature** | **Scrubber 1 [1]** | **Scrubber 2 [2]** | **Σ of [1] + [2]** | **Σ of [1] + [2] converted to d.m.** | **Dry matter** |
|---|---|---|---|---|---|
| [°C] | [mg] | [mg] | [mg] | [-] | [%] |
| 200 | 0.154 | 0.050 | 0.204 | 0.72 | 28.18 |
| 300 | 0.264 | 0.011 | 0.276 | 0.98 | |
| 400 | 0.389 | 0.013 | 0.403 | 1.43 | |
| 500 | 0.499 | 0.054 | 0.553 | 1.96 | |
| 600 | 0.527 | 0.043 | 0.570 | 2.02 | |
| 700 | 0.332 | 0.042 | 0.374 | 1.33 | |
| 800 | 0.210 | 0.008 | 0.218 | 0.73 | 30.07 |
| 900 | 0.138 | 0.006 | 0.144 | 0.48 | |

Table 4

The emission of $NH_3$ during sewage sludge combustion - series 2

| **Process temperature** | **Scrubber 1 [1]** | **Scrubber 2 [2]** | **Σ of [1] + [2]** | **Σ of [1] + [2] converted to d.m.** | **Dry matter** |
|---|---|---|---|---|---|
| [°C] | [mg] | [mg] | [mg] | [-] | [%] |
| 200 | 0.170 | 0.047 | 0.217 | 0.77 | 28.18 |
| 300 | 0.290 | 0.037 | 0.327 | 1.16 | |
| 400 | 0.431 | 0.004 | 0.436 | 1.55 | |
| 500 | 0.468 | 0.074 | 0.542 | 1.92 | |
| 600 | 0.572 | 0.036 | 0.608 | 2.16 | |
| 700 | 0.352 | 0.062 | 0.414 | 1.47 | |
| 800 | 0.217 | 0.007 | 0.224 | 0.74 | 30.07 |
| 900 | 0.131 | 0.003 | 0.134 | 0.45 | |

Table 5

The emission of $NH_3$ during sewage sludge combustion - series 3

| **Process temperature** | **Scrubber 1 [1]** | **Scrubber 2 [2]** | **Σ of [1] + [2]** | **Σ of [1] + [2] converted to d.m.** | **Dry matter** |
|---|---|---|---|---|---|
| [°C] | [mg] | [mg] | [mg] | [-] | [%] |
| 200 | 0.152 | 0.051 | 0.203 | 0.72 | 28.18 |
| 300 | 0.304 | 0.019 | 0.322 | 1.14 | |
| 400 | 0.389 | 0.009 | 0.398 | 1.41 | |
| 500 | 0.508 | 0.065 | 0.572 | 2.03 | |
| 600 | 0.564 | 0.033 | 0.597 | 2.12 | |
| 700 | 0.349 | 0.010 | 0.358 | 1.27 | |
| 800 | 0.212 | 0.011 | 0.223 | 0.74 | 30.07 |
| 900 | 0.136 | 0.009 | 0.146 | 0.48 | |

The tested material was a pre-dried sludge obtained from GOS Lodz. The tests were performed approximately every month to check reproducibility of the results obtained (Fig. 8). The laboratory tests demonstrate clearly that during thermal decomposition (combustion) of sewage sludge gaseous ammonia is released. Figure 8 shows reproducibility of the results obtained in different measurement series, including a pronounced peak of emission in the temperature range 500-600°C.

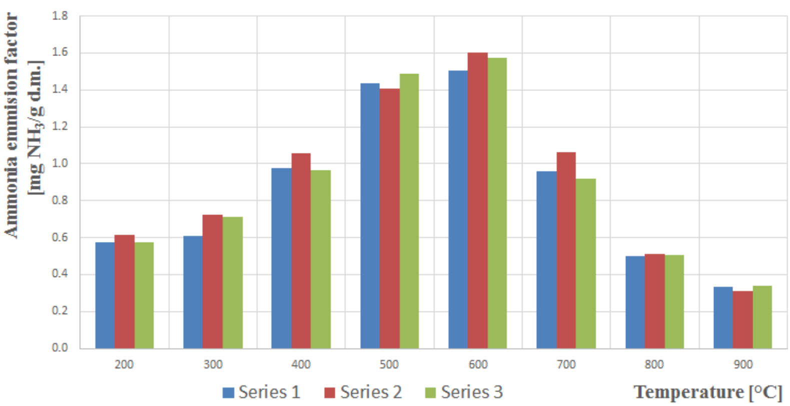


Fig. 8. Ammonia emission factor (per combusted sludge mass) as a function of combustion temperature

As can be seen, the emission of ammonia occurs already at 200°C, which is most likely due to the presence of free ammonia in the incinerated sludge, and grows to approx. 600°C where it reaches a pronounced maximum to decrease later with increasing temperature, which may indicate an ongoing decomposition of the gaseous ammonia (oxidation to nitric oxide) or binding it by acid gases (*e.g.* HCl, $SO_2$) also emanating during the combustion process.

## Conclusions

The study shows that sewage sludge from GOS Lodz contains significant amount of ammonia. Curves plotted on the basis of data from the continuous monitoring of emissions from the sewage sludge incinerator, results of the measurements made by the laboratory of the treatment plant and laboratory tests confirm the above thesis. Comparing the curves plotted on the basis of data collected from the monitoring and obtained in laboratory tests, it can be concluded that ammonia emission increases with temperature in the secondary combustion chamber. During shutdown of the furnace, *i.e.* when sludge is not fed and temperature in the secondary combustion chamber decreases, the emission of ammonia declines. From laboratory tests it follows that the emission of ammonia is the highest at about 600°C. It also demonstrates that the pre-dried sludge contains ammonia. Differences in the emission results from the mass of sludge processed. Samples tested in the laboratory weighted approx. 2 g, while in the furnace about 5.5 Mg/h pre-dried sludge is processed. Thus, it can be stated that ammonia ‘wanders’ in the sewage treatment system from the stage of biological treatment, through fermentation, to thermal treatment of the sludge. When analyzing this ‘journey’ several sources of ammonia emission were found, especially in the SSIS. The main ones are sludge dryers and the furnace. Ammonia contained in the pre-dried sludge is broken into two streams. One is supplied to the furnace (results of flue gas monitoring), while the other one is directed to the sewage system (results of analysis of leachate from the dryers). The digested sludge, which is subjected to thermal processing, first ‘wanders’ through a multi-stage treatment system. High content of ammonia in the raw sludge is clearly reflected in the final system of the incineration plant, in the emission of pollutants.

Although the combustion of municipal sewage sludge is today a widely used technology of its disposal [4, 17], it appears that despite numerous studies conducted previously by many researchers, the emission of ammonia from sludge combustion has not been described in the rich literature yet.

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