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## GASEOUS POLLUTANT EMISSIONS FROM BURNING ANIMAL BY-PRODUCTS

Gaseous emissions during thermal animal waste treatment in a meat production plant have been determined. A dry flue gas system with a multisectional bag filter was installed at a meat production plant. Animal waste was incinerated in a rotary kiln, the capacity of the plant was 700 kg/h. The average thirty-minute (1352 samples) emission values of volatile dust, total organic carbon (TOC), hydrogen chloride (HCl), hydrogen fluoride (HF), sulfur dioxide (SO<sub>2</sub>), nitrogen oxide (NO), nitrogen dioxide (NO<sub>2</sub>) and carbon oxide (CO) were obtained during a study period of 1 month. Specific samples were collected to determine dioxin, furane, heavy metal, mercury, cadmium and thallium concentrations. Histograms of the obtained results were prepared, and the results were compared with the permissible emission levels defined by the European Union. Additionally, justification was provided when the observed values exceeded the levels defined by the European Union.

### 1. INTRODUCTION

Waste management, i.e., the collection, transport, recovery and disposal of waste is one of the most important engineering tasks for protecting the environment. The significance of waste management has been increasing due to increase of generated waste all over the world.

Particularly, it is important to dispose animal waste because it poses a sanitary hazard. Many technologies can be used for animal waste disposal, including gasification, pyrolysis and incineration, which allows the energetic use of such waste and has a lower environmental cost. The thermal recycling of meat and bone meal (MBM) [1], poultry litter [2] and animal post-slaughter waste [3–5] by means of combustion, pyrolysis and gasification has been investigated using numerous types of reactors, including fluidized-bed and fixed-bed reactors. Co-combustion of MBM has been tested to analyze the effect of adding MBM to coal, peat or chicken litter during combustion processes

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[6–11]. In the majority of studies, co-combustion of MBM with coal was conducted in fluidised-bed reactors with a continuous feed with a screw feeder. The measured levels of emissions of PCDD/Fs, SO<sub>2</sub>, NO<sub>x</sub>, CO, and SO<sub>2</sub> were below the limits established by international regulations. The thermal treatment system tested herein was installed in a large existing meat-processing plant. The basic element of the system was a rotary kiln, in which waste and residues from the processing of meat and cold cuts were incinerated. Most similar systems were tested only at a laboratory scale. In nearly all published analyses and tests for the thermal processing of animal waste fixed- or fluidized-bed reactors were investigated.

The results of studies conducted in a large meat production plant have been presented in this paper. A rotary kiln was installed in the plant to thermally treat animal waste generated during the manufacturing process. Studies were conducted over 1 month to quantify the release of pollutants into the atmosphere from a dry flue gas treatment system at the studied plant. The average (1352 samples) emissions of various pollutants over 30 min (thirty-minute average) were determined and compared with the applicable limits defined by the European Union. Samples were also collected to determine dioxin, furane, heavy metal, mercury, cadmium and thallium concentrations in the gas.

## 2. DESCRIPTIONS OF THE WASTE TREATMENT AND MEASURING SYSTEMS

### 2.1. THERMAL WASTE TREATMENT PLANT WITH A DRY FLUE GAS TREATMENT SYSTEM

Figure 1 shows the structure of the meat waste management system after upgrading the plant by erecting a thermal treatment plant for post-production waste. Due to the proximity of the production and processing lines and the incineration plant, the animal waste was delivered to the incineration plant for thermal treatment through interdepartmental transfer. Simultaneously, the time between waste generation and disposal was minimized.

The plant meets the requirements for the thermal treatment of animal waste. The temperature in the afterburner chamber was continuously maintained above 850 °C, and the required residence time of the flue gases in the afterburner chamber was 2 s. Due to the homogeneity of the post-production waste, it was easy to maintain appropriate parameters during the combustion process and to maintain efficiency in the flue gas treatment systems.

One advantage of the localization of the thermal waste treatment plant at the meat processing plant is the possibility of using the heat generated during the thermal waste treatment process. The saturated steam generated in the recovery boiler is fed directly

into the existing boiler room before traveling to the existing heat exchangers and pipelines. Thus, the saturated steam and hot water are used to supply the production and processing lines and the central heating, ventilation and utility water systems. Consequently, the load incurred by the local steam boiler room is lower, and the natural gas consumption is lower as well. The decreased (reduced) natural gas flux reduces the amounts of pollutants and carbon dioxide (CO<sub>2</sub>) emitted into the atmosphere. Consequently, a “reduced emissions” effect is obtained.

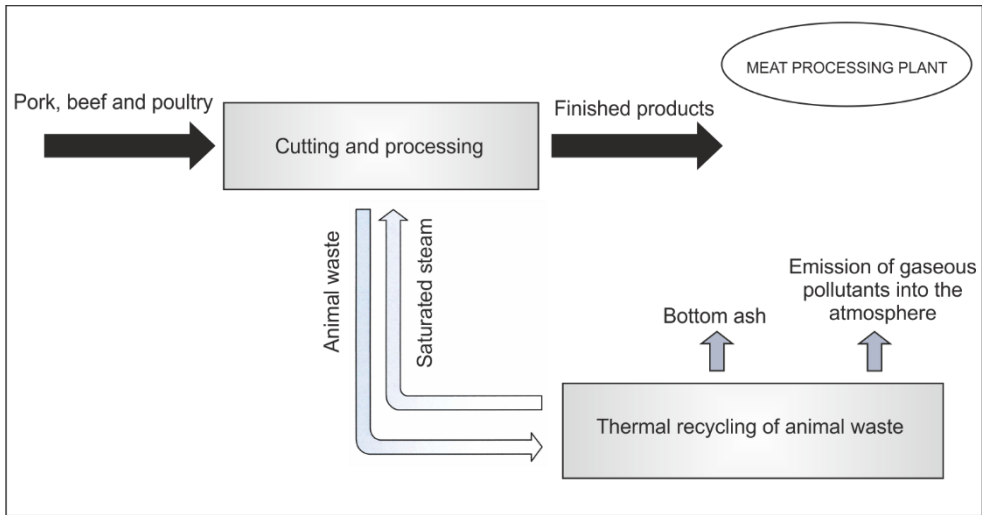


Fig. 1. Structure of the meat waste management system after upgrading the plant

One additional advantage of location of the thermal waste treatment system in the plant is that it eliminates the need to transport waste to external (regional) treatment plants which reduces the consumption of diesel, oil and fuel for external transport. In addition, the slag and ashes (the solids that remain after incineration) generated after meat incineration can be processed into mineral fertilizers because of their nature and structure. These ashes form a perfect material for eco phosphate (monocalcium phosphate), which is an ecologically friendly phosphorus fertilizer.

The examined thermal animal waste treatment plant (Fig. 2) consisted of the following elements:

*Waste load.* The automatic loading system prevented waste from being loaded as follows:

- during start-up, when the required temperatures in the rotary kiln and the after-burner chamber are too low,
- during operation, when the rotary kiln temperatures exceed the maximum allowable values, or when the permissible level of pollution emissions is exceeded.

If a load was too heavy, the incineration process was intensified in the initial part of the rotary kiln which temporarily reduced the excessive amounts of  $O_2$  in the rotary kiln and afterburner chamber.

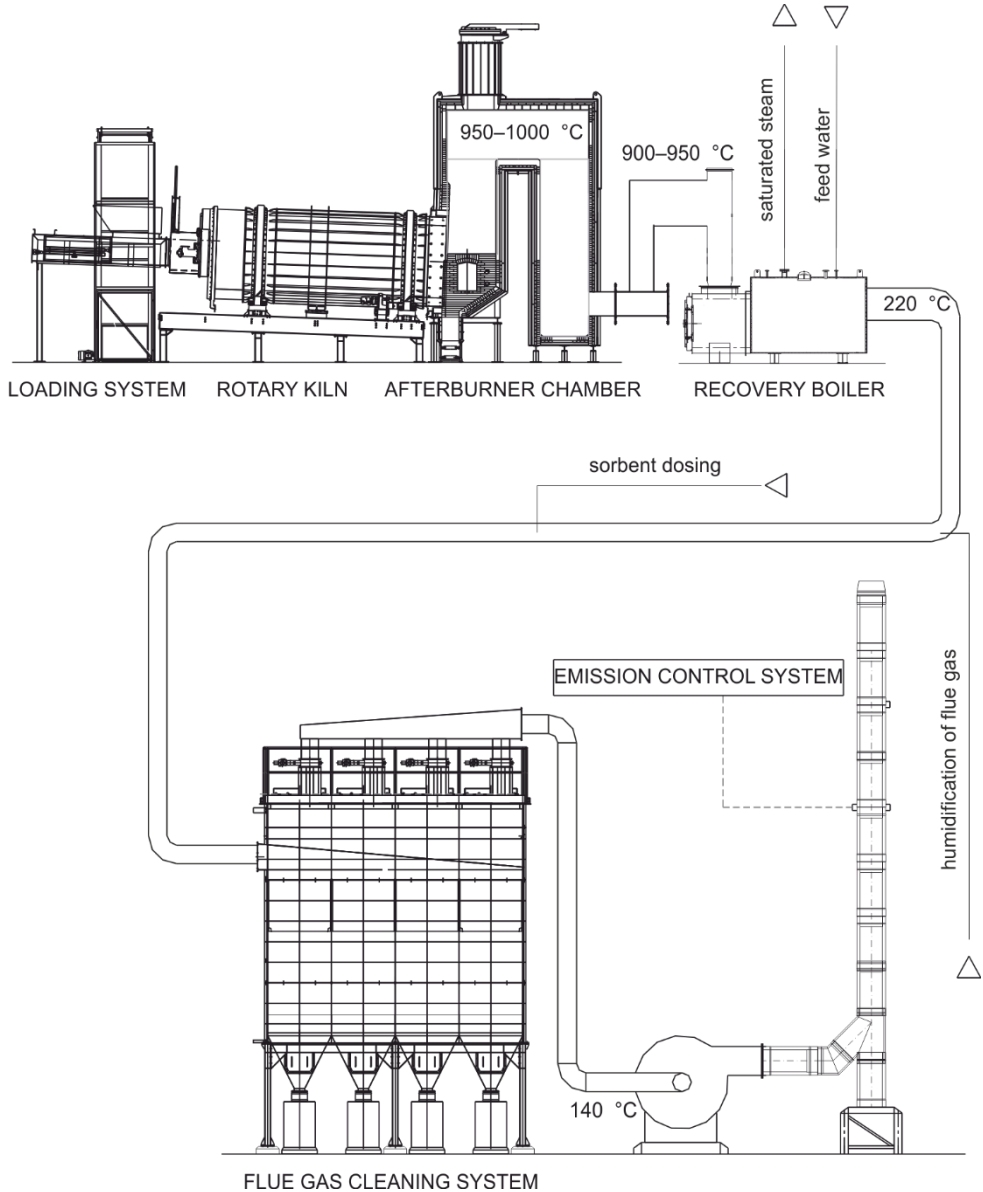


Fig. 2. Schematic of the waste thermal treatment plant with a heat recovery unit and dry flue gas treatment system

*Rotary kiln.* The rotational speed was adjusted within 1–10 revolutions per hour, with a capacity of 700 kg/h. The kiln could also be operated in cycles. The appropriate rotational speed determined the plant capacity and the level of bottom ash burning and influenced the volatile dust and carbon oxide (CO) emissions. The waste incinerated inside the kiln moved according to the direction of the flue gas flow. The rotary chamber was equipped with a gas burner which could be used to heat the kiln during start-up and maintain the required temperature during plant operation. During the thermal waste treatment process, a vacuum of 40 Pa was maintained inside the rotary kiln, which was 7 m long with a diameter of 2 m.

*Afterburner chamber or thermoreactor.* During the thermal waste treatment process, the waste in the rotary kiln was decomposed into solid and gaseous products. The gaseous products were moved to the afterburner chamber, where high-temperature thermal destruction of the organic substances occurred and the resulting substances were oxidized to form the combustion end products. Due to its dimensions, the chamber ensured an appropriate flue gas holding time (2.5 s) and temperature (above 1100 °C). The volume of the thermoreactor was 20.0 m<sup>3</sup>, and the actual flux of flue gases flowing through thermoreactor was approximately 28 800 m<sup>3</sup>/h. The temperature in the afterburner chamber was adjusted automatically by the modulating gas burner or auxiliary air. The emergency stack was an integral part of the afterburner chamber. A flap, which normally closed, was located at the stack outlet and could be opened immediately in specific emergency situations. In addition, the afterburner chamber was equipped with an automatic bottom ash removal system. A high temperature and an appropriate flue gas holding time ensured thermal decomposition of dioxins and furanes. Additionally, when the excessive oxygen in the flue gas was optimized (8–9%), the CO and volatile organic substance emissions were reduced significantly.

*Recovery boiler.* After leaving the thermoreactor flue, gas at 1100–1200 °C flowed through the heat recovery unit where saturated steam was produced under a pressure of ca. 8 bar. By releasing heat, the flue gas was cooled to 220 °C. The heat exchange surface of the recovery boiler was 180 m<sup>2</sup>. A large heat exchange surface ensured fast flue gas cooling and lower dioxin and furane re-emissions (*de novo* synthesis). The total recovery length of the boiler was 6.7 m, and its diameter – 1.8 m.

*Moistening and sorbent dosing system.* After leaving the recovery length of the boiler, the flue gas was moistened and flux adsorption occurred. The flux adsorption process included direct, dry injection of a highly effective reagent into the flue gas. At this plant, the Sorbacal ACSP reagent was used, consisting mainly of calcium hydroxide and dusty active carbon. Flux adsorption and the use of a fabric filter based on Teflon membranes was a very effective method for removing dioxins, furanes, acidic gaseous pollutants, volatile dusts and heavy metals. The exhausted sorbent was a hazardous

waste and was transported to a hazardous waste landfill. The tested plant produced approximately 170 kg/h of dust.

*Bag filter.* Filtration area surface  $F$  was 200 m<sup>2</sup>. The flue gas flowed from the inlet collector to the initial dust-laden gas chamber, where thicker and heavier dust fractions were separated due to expansion. The uniform distribution of the flue gas flux throughout the chamber allowed dust to settle on the external surfaces of the filtration bags. The treated gas flowed inside the bag and was moved through the treated gas chamber to the outlet collector with shut-off throttles. The dust retained on the bags and the used sorbent were periodically removed by injecting short pulses of compressed air into the bag. The dust and used sorbent fell into a hopper before transferring to a container with a feeding screw. The dust removal process was controlled with a microprocessor and depended on the filter resistance and pulse interval.

## 2.2. CONTINUOUS FLUE GAS MONITORING SYSTEM

*Measuring method, measured substances and sample collection.* The extraction measuring method was used to measure the concentrations of the gaseous pollutants. The entire measurement route from the probe up to the analyzer was heated along with the analyzers. The flue gas flux, dust, pressure and temperature were measured directly in the flue gas duct. The stack was fit with a stainless steel testing tube. The samples were collected and pre-filtered in the heated ceramic filter provided in the measuring probe. Next, the samples were transferred through the heated hose to the room with the measuring cabinet, sample preparation system and the set of analyzers.

Table 1

Data measured with the continuous flue gas measurement system

Measured parameter	Measuring device	Producer	Measurement range	Error [%]
Total dust, mg/Nm <sup>3</sup>	D-RX 250	DURAG	0–10	2.0
Total organic carbon, mg/Nm <sup>3</sup>	JUM 3-700	J.U.M.	0–160	1.0
Hydrogen chloride, mg/Nm <sup>3</sup>	CX-4000	GASMET	0–50	2.0
Hydrogen fluoride, mg/Nm <sup>3</sup>			0–10	2.0
Sulfur dioxide, mg/Nm <sup>3</sup>			0–2000	2.0
Carbon oxide, mg/Nm <sup>3</sup>			0–700	2.0
Nitrogen oxide, mg/Nm <sup>3</sup>			0–1000	2.0
Carbon dioxide, %			0–20	2.0
Oxide, %			AMS-3220	AMS-DIELHEIM
Humidity, %	CX-4000	GASMET	0–30	2.0
Flue gas flux, m <sup>3</sup> /h	D-RX 250	DURAG	0–10000	2.0
Flue gas temperature, °C			0–200	2.0
Static pressure, mbar			0–1600	0.25

*Analyzers.* Table 1 presents the values measured in the continuous flue gas monitoring system with their ranges and measurement errors. The average flux of flue gas passing through the analyzer during the tests oscillated between 8000 and 9000 m<sup>3</sup>/h, with an average temperature of 186 °C.

The following analyzers were used during the examinations:

- CX-4000. An essential multicomponent analyzer based on the Fourier transform infrared (FT-IR) method. FTIR is based on the ability of the polyatomic gas particles to absorb infrared radiation. The method enables one simultaneous, direct determination of the concentrations of most compounds (including CO, CO<sub>2</sub>, nitrogen dioxide (NO<sub>2</sub>), nitrogen oxide (NO), dinitrogen oxide (N<sub>2</sub>O), sulfur dioxide (SO<sub>2</sub>), hydrogen fluoride (HF), hydrogen chloride (HCl) and H<sub>2</sub>O).

- AMS-3220 was used to measure the concentration of oxygen in the flue gas. This device consisted of a zirconic sensor with a flow control module and an electronic system for controlling the sensor and reading and converting the signal into oxygen concentrations. The zirconic sensor was installed so that the sample flowed through the measurement portion and the reference portion was exposed to the ambient air.

- JUM, model: 3-700 was utilized to measure the total organic compounds by the continuous flame ionization detection (FID) method, being a reliable method for quantifying high molecular weight hydrocarbons and traces of other pollutants in relatively pure gases. In the FID method, the hydrocarbon particles in the measuring gas are ionized within the flame.

All of the instruments listed above were protected against condensation using the automatic air blowing devices provided for the measuring systems. In addition, the measuring cabinet was equipped with the computer used to analyze the data sent from the analyzers and conditioning system. An uninterrupted power supply was provided to protect the computer against power supply loss.

*Flow, dust concentration, flue gas temperature and pressure changes.* An integrated D-RX 250 probe was used to measure the flow, dust concentrations, temperatures and pressures. The D-RX 250 probe is a multiparameter probe frequently applied in dry gaseous pollutant removal methods and dust removal methods. The D-RX 250 probe measured the following parameters:

- flue gas flow by using the differential pressure,
- dust concentration by measuring the charge carried by the dust particles using the triboelectric method,
- flue gas temperature using the Pt100 sensor,
- flue gas pressure.

The stack was equipped with a system for collecting and transporting gas samples and for measuring dust and other reference parameters.

### 3. RESULTS OF TESTS

#### 3.1. AVERAGE THIRTY-MINUTE EMISSION VALUES AND THEIR PERMISSIBLE LEVELS

Figure 3 shows the average thirty-minute concentrations of  $\text{NO}_x$ , and Fig. 4 presents an empirical distribution (histogram) based on the experimental and statistical results.

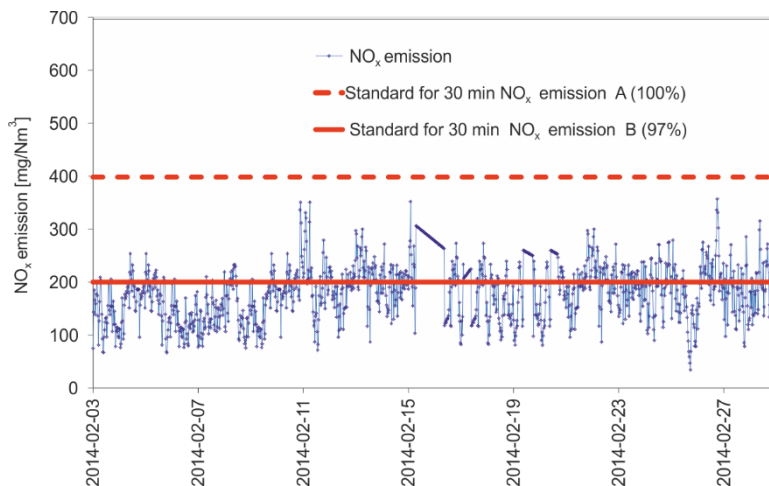


Fig. 3. Standard and measured thirty-minute averaged  $\text{NO}_x$  emissions

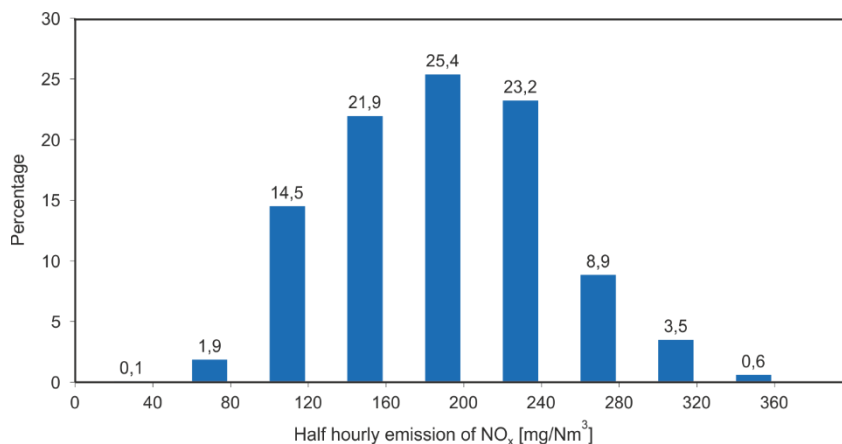


Fig. 4. Average thirty-minute  $\text{NO}_x$  emissions

Emission standards [12] mention two permissible values of  $\text{NO}_x$ , which are converted into  $\text{NO}_2$  and the A and B standards as follows: 100% of the average thirty-minute concentrations of the examined substances must be below the A standard of



400 mg/Nm<sup>3</sup>, or 97% of the average thirty-minute concentrations of the examined substance must be below the B standard of 200 mg/Nm<sup>3</sup> during a given calendar year.

The conducted experiments showed that the NO<sub>x</sub> concentrations often exceeded 200 mg/Nm<sup>3</sup> (B standard) but never exceeded 400 mg/Nm<sup>3</sup> (A standard). Notably, the urea solution was not added to the flue gas during the experiment, and the maximum NO<sub>x</sub> emissions reached 357 mg/Nm<sup>3</sup>. The average CO<sub>2</sub> concentration obtained during the monthly examinations was 180 mg/Nm<sup>3</sup>, 63.8% of the analyzed concentrations were below the B standard, and 36.2% of the values were between 200 mg/Nm<sup>3</sup> and 357 mg/Nm<sup>3</sup>. Thus, all of the measured values were below the A standard. To meet the B standard, a selective non-catalytic nitrogen oxide (NO<sub>x</sub>) reduction (SNCR) system should be applied involving the addition of an aqueous urea solution to the flue gas in the duct connecting the afterburner chamber and recovery boiler (HRSG).

Choosing an appropriate urea injection location is important for efficient reducing NO<sub>x</sub>. The NO<sub>x</sub> reduction process is the most efficient across a narrow temperature range of 920–1050 °C. The examined plant meets this criterion. The average effectiveness of the SCNR with urea injection in the “temperature window” is 40–60%. Injecting ammonia at a temperature higher than the temperature of the flue gas (1050 °C) increases the formation of NO<sub>x</sub>. If the above process is completed below 920 °C, ammonia is produced in the flue gas.

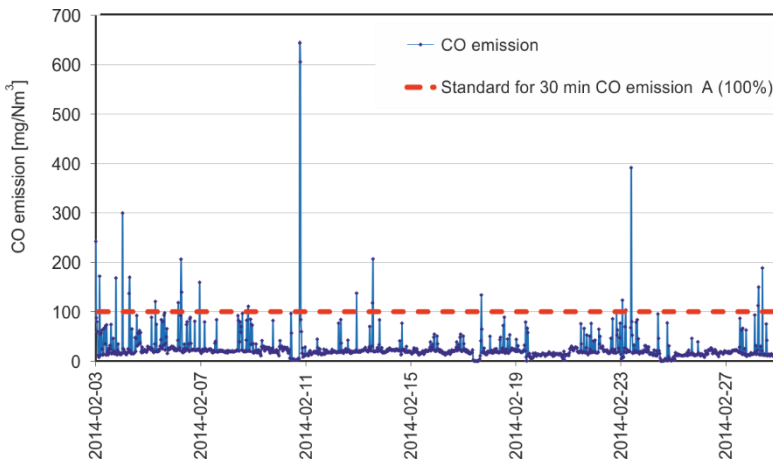


Fig. 5. Standard and measured thirty-minute averaged CO emissions

The CO concentrations measured in the flue gas are shown in Fig. 5. The standard value for CO emissions is a thirty-minute average of 100 mg/Nm<sup>3</sup>, with no A or B standards. The concentrations of CO in the flue gas often exceeded 100 mg/Nm<sup>3</sup>. The highest CO emission level was 644 mg/Nm<sup>3</sup>. In most cases, the limit values were exceeded in connection with the operation of the cyclic rotary kiln [13]. The operational cycle consisted of a rotation phase and a standstill phase. The duration of the standstill phase was

adjusted based on the conditions under which the incineration process occurred and the physiochemical properties of the incinerated waste. During the rotation phase, the top layer of the incinerated waste moved down towards the afterburner chamber before a new layer of incinerated waste was exposed. During the standstill phase, the new layer of waste was incinerated, and slag with appropriate chemical and physical properties could be obtained. The incineration process was intensified due to rotations of the afterburner chamber which temporarily reduced the excessive  $O_2$  concentrations in the rotary kiln and afterburner chamber.

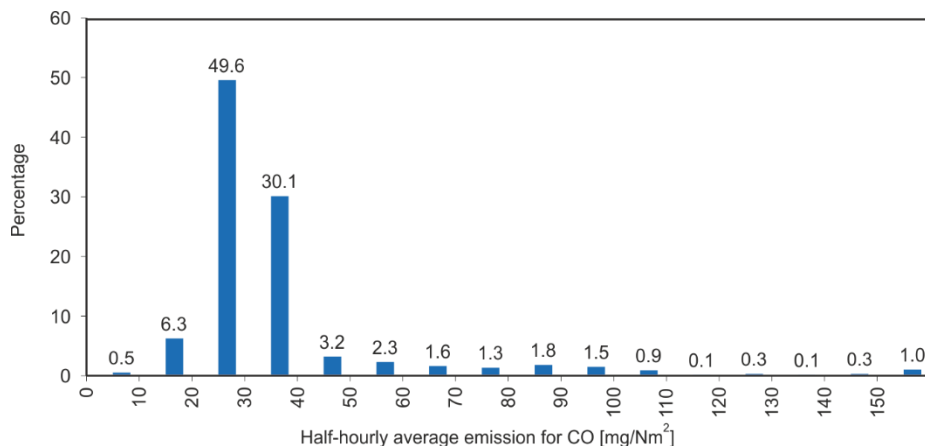


Fig. 6. Observed thirty-minute averaged CO emissions

Oxygen shortages were apparent after approximately 25 s of drum rotation and lasted approximately 100 s. A controlled stream of air was injected into the afterburner chamber to compensate for the excess decrease in  $O_2$  in the flue gas. If the injected air stream was too large, the excess  $O_2$  in the flue gas may become overregulated. Combustion under such rapidly changing conditions could cause momentary and significant variations in CO emissions. The highest CO concentrations analyzed (Fig. 6), i.e., 49.6%, were from 20 mg/Nm<sup>3</sup> to 30 mg/Nm<sup>3</sup>. In addition, 30.1% of the emissions had CO concentrations of 30–40 mg/Nm<sup>3</sup>. Furthermore, in most of the emissions (97.2%) CO concentration did not exceed 100 mg/Nm<sup>3</sup>.

During balanced and stable operations, the CO emissions were very low. The average CO concentration obtained during the experiment was 26 mg/Nm<sup>3</sup>. The limit values were exceeded in 2.8% of the examined cases, which could be prevented by maintaining appropriate CO concentrations in the afterburner chamber. In the rotary kiln, the excess CO in the flue gas should exceed 8% [13] but not 10%. In addition, appropriate CO emissions could be obtained by reducing the number of the rotary kiln operational cycles by extending the durations of the operation and standstill phases.

*Volatile dust and HCl emissions.* Limiting dust emissions has an enormous influence on clean air and the protection of human health. Dusts, particularly PM10 and PM2.5, are pollutants emitted during solid fuel combustion and are particularly dangerous. Elemental carbon, which is included in dust particles (unburnt carbon contained in volatile dust), also promotes the formation of dioxins, furanes and polycyclic aromatic hydrocarbons. This phenomenon also occurs during so-called “de novo synthesis”, when flue gases leaving the after combustion chamber are cooled not rapidly enough to the appropriate temperature of less than 260 °C. Examinations of dust emission (Fig. 7) indicated that several of the thirty--minute average values were significantly higher than those of the B standards (97%). The number and size of loads also played an important role in this result. However, the filtration bags installed at the plant had been used for several years and needed replacing. The A standard (100%) was met during the examined period. The highest average thirty-minute volatile dust emissions reached 28 mg/Nm<sup>3</sup>.

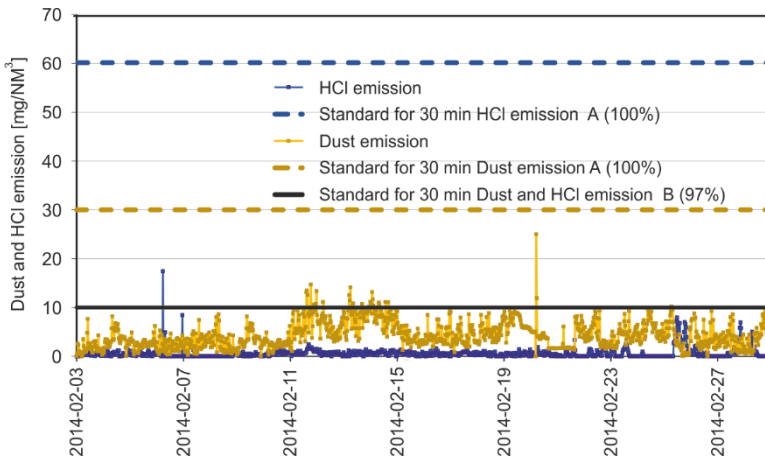


Fig. 7. Standard and measured thirty-minute averages of the volatile dust and hydrogen chloride concentrations

During stable and balanced operation and when the specified number and size of loads were maintained, the dust emissions were significantly lower than those in the B standard. From 03/02/2014 to 11/02/2014, the emission values were not exceeded at the plant. Throughout the study, 98.1% of the examined cases had dust emissions of 0–10 mg/Nm<sup>3</sup> (Fig. 8). Only 1.9% of the examined concentrations of dust emitted into the atmosphere exceeded the B standard. The average measured volatile dust concentration was 4 mg/Nm<sup>3</sup>.

The HCl concentrations were also measured during the study (Fig. 7). The maximum average thirty-minute concentration was 19 mg/Nm<sup>3</sup>. However, this concentration was only reached once and resulted from the failure of the sorbent dosing system. The

A emission standard was met because none of the examined samples exceeded  $60 \text{ mg/Nm}^3$ . More than 99.4% of the examined cases had HCl emissions  $0\text{--}10 \text{ mg/Nm}^3$ . This result is confirmed by the emissions histogram (Fig. 8), which proves that the HCl emissions were easily maintained below the B standard.

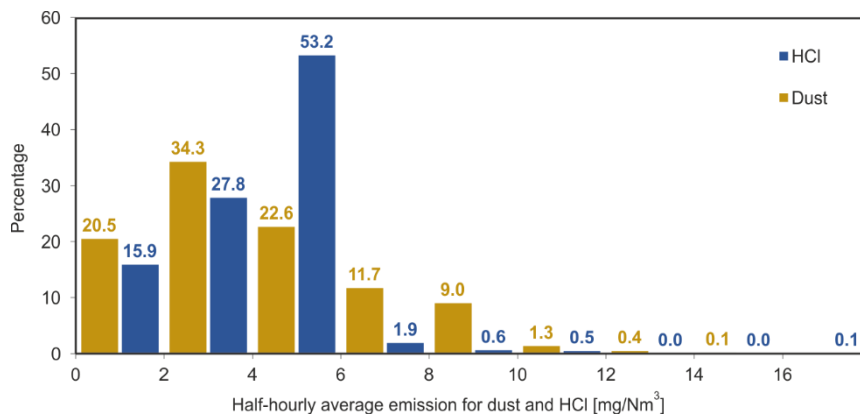


Fig. 8. Estimated thirty-minute average SO<sub>2</sub> and HCl emissions

In summary, the emission standards for volatile dust and HCl were met because the actual pollutant emissions were below the A and B standards. According to the applicable regulations, meeting one of the above-mentioned standards is sufficient. In this system, the commercially available Sorbocal ACSP reagent was used which consists of calcium hydroxide and dusty active carbon (15%). Apart from the removal of dioxins, furanes and HCl, Sorbocal ACSP is also used to remove SO<sub>2</sub>, sulfur trioxide (SO<sub>3</sub>), HF and heavy metals. Sorbocal ACSP is a dry, grey, ready-to-use powder, and its effectiveness depends on the flue gas humidity and temperature where it is dosed.

The dosing location of Sorbocal ACSP is shown in Fig. 2. A flue gas moistening system was installed before the sorbent dosing system. The highest effectiveness of sulfur dioxide removal (over 70%) when using the calcium reagents was achieved when the sorbent was injected into the flue gas at 350 °C [14]. In this case, the humidity of flue gas was not important. However, when using bag filters, the maximum flue gas working temperature was 240 °C. To achieve maximum removal of SO<sub>2</sub> from the flue gas, Sorbocal ACSP should be dosed at 150 °C. In addition, the humidity of the gas is very important at this temperature. Higher temperatures result in greater effectiveness of desulfurization. At the humidity of flue gas of 25% and temperature of 150 °C, the desulfurization process reached 72%. The temperature and humidity of flue gas at the sorbent dosing location were also measured during the examinations, and the average flue gas temperature was 200 °C. The humidity of the flue gas was 15%, and the desulfurization efficiency was 25%. Thus, to remove 1 kg of SO<sub>2</sub>, ca. 3.4 kg of Sorbocal ACSP was used. After completing the experiments, the Investor received guidelines for

lowering the flue gas temperature to 150 °C and increasing its humidity to 25% at the sorbent injection location. Thus, approximately 4 kg of Sorbacal ACSP was used to remove 1 kg of SO<sub>2</sub>.

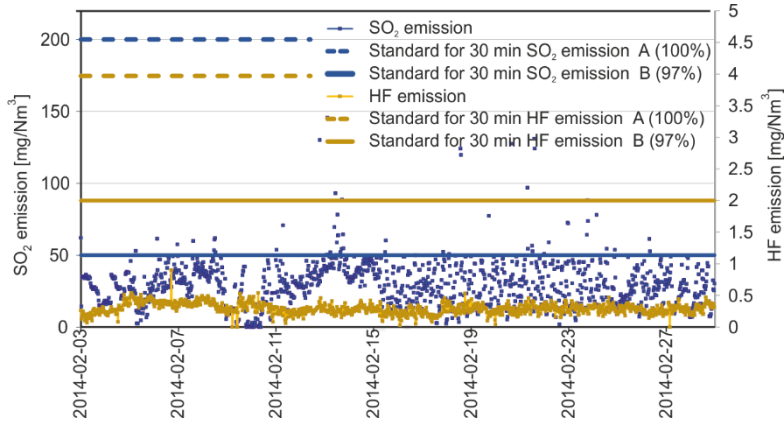


Fig. 9. Standard and measured thirty-minute averaged SO<sub>2</sub> and HF concentrations

The observations show that the SO<sub>2</sub> concentrations (Fig. 9) fluctuated from 0 mg/Nm<sup>3</sup> up to 162 mg/Nm<sup>3</sup> and never exceeded 200 mg/Nm<sup>3</sup> (A standard). In addition, only in 4.3% of the samples SO<sub>2</sub> concentrations exceeded 50 mg/Nm<sup>3</sup> (B standard) (Fig. 10). Thus, the B standard was not met because the number of samples exceeding the B standard was slightly higher than 3%. According to applicable regulations, meeting one of the above-mentioned standards is sufficient, thus no attempts were made to meet the B standard emissions. To meet the B standard, more sorbent would need to be added to the flue gas, which would increase the operation cost.

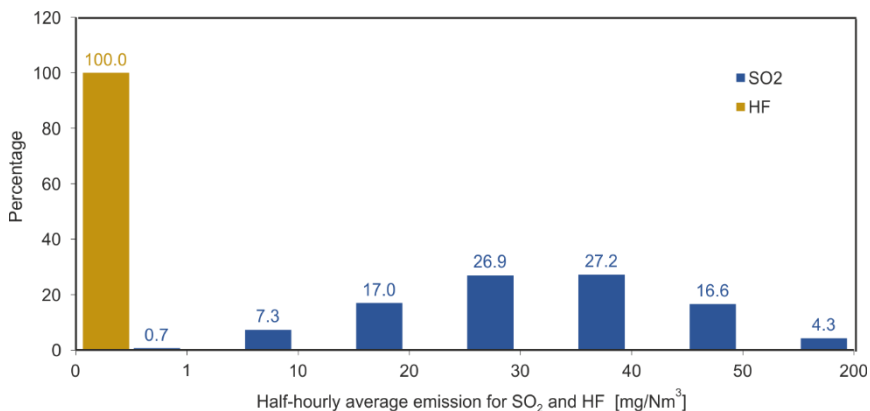


Fig. 10. Observed thirty-minute averaged emissions of SO<sub>2</sub> and HF

However, the HF concentrations throughout the entire examination period (Fig. 9) were very low. All of the examined average thirty-minute values met the A and B standards, and none of the HF concentrations (Fig. 10) exceeded  $1.0 \text{ mg/Nm}^3$ .

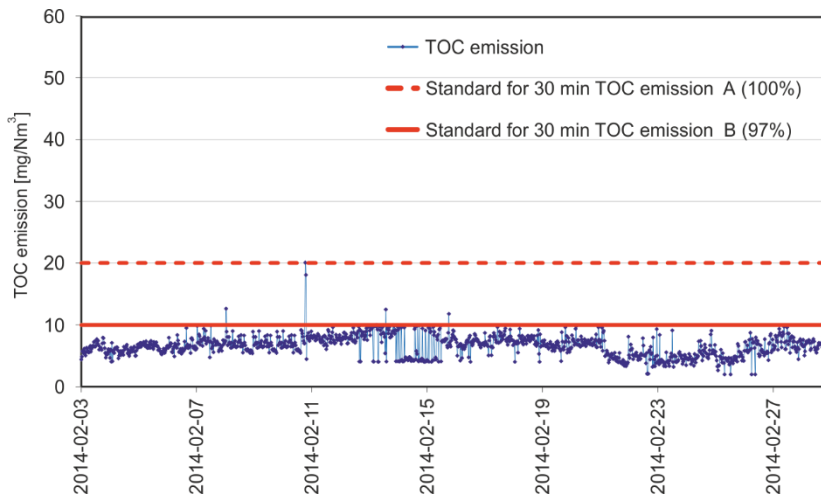


Fig. 11. Standard and measured thirty-minute averaged total organic carbon

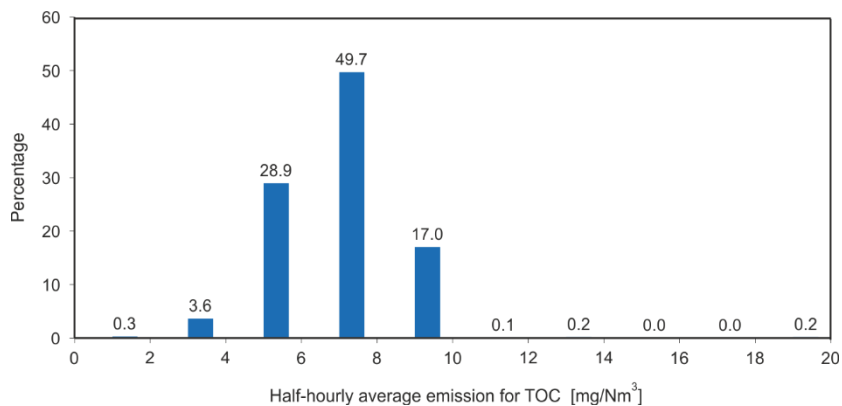


Fig. 12. Thirty-minute averaged TOC emissions

Animal waste incineration also results in the emissions of gases and vaporous organic substances, referred to as TOC. Flue gas may contain various organic substances and compounds such as aliphatic hydrocarbons (pentane, hexane), aromatic hydrocarbons (benzene, toluene, ethylbenzene, etc.), aldehydes and alcohols. To reduce the TOC emissions, the examined technology was equipped with an afterburner chamber with the temperature of the flue gas not lower than  $1100 \text{ }^\circ\text{C}$ . In addition, the supply of air ensured that the appropriate excessive oxygen level was maintained in the flue

gas (over 8%) and that all organic compounds in the flue gas were burnt. The examined plant showed very low TOC emissions. Two emission peaks (Fig. 11) occurred during the examination period but it did not influence the ability of the system to meet emission standards. More than 82% of the emitted average thirty-minute concentrations (Fig. 12) did not exceed  $8 \text{ mg/Nm}^3$ , and 17% were below  $10 \text{ mg/Nm}^3$ . Thus, the B emission standard ( $10.0 \text{ mg/Nm}^3$ ) was met, with 99.5% of the examined cases falling below the B standard. In addition, none of the examined samples exceeded the A emission standard ( $20.0 \text{ mg/Nm}^3$ ). Only 5 concentrations exceeded the B standard, which represented 0.5% of all examined cases.

### 3.2. DIOXIN, FURANE, HEAVY METAL, MERCURY, CADMIUM AND THALLIUM EMISSIONS

Dioxin and furane [15] emissions can be significantly lowered using primary methods including using of appropriate configurations of the technological system, designs and structures and an optimum incineration process. The most important primary methods aim to avoid chloride in waste because traces of chloride and organic matter in increased temperature zones ( $200\text{--}700 \text{ }^\circ\text{C}$ ) result in the formation of dioxins and furanes. However, it is nearly impossible to avoid the presence of chloride in waste. The following primary methods were used in the examined technology:

- using an appropriate afterburner chamber structure and volume,
- maintaining a flue gas temperature higher than  $1100 \text{ }^\circ\text{C}$  throughout the entire afterburner chamber volume,
- using an appropriate heat recovery unit to ensure fast cooling of flue gas,
- optimizing the combustion process by maintaining the appropriate oxygen level in the afterburner chamber to minimize the formation of carbon oxides (CO). Higher CO concentrations in flue gas result in higher dioxin concentrations.

In the examined plant, also the flux adsorption process was applied (secondary method) which included adding active carbon mixed with calcium to the flowing flue gas and subsequently dedusting the gases in the fabric filter.

The dioxin and furane concentrations were periodically measured. Samples were analysed within 7 h by the certified laboratory at Cracow. The PCDDs and PCDFs (dioxins and furanes) concentration was  $0.016 \text{ ng/Nm}^3$  being lower than the permissible value of  $0.1 \text{ ng/Nm}^3$ . The total heavy metal concentration was  $0.018 \text{ mg/Nm}^3$ , which did not exceed the maximum emission standard of  $0.5 \text{ mg/Nm}^3$ . The concentration of mercury in the flue gas was  $0.0044 \text{ mg/Nm}^3$ , which was significantly lower than the standard value of  $0.05 \text{ mg/Nm}^3$ . Furthermore, the total measured cadmium and thallium concentration was  $0.0014 \text{ mg/Nm}^3$ , which was more than 30 times lower than the permissible value of  $0.05 \text{ mg/Nm}^3$ .

#### 4. CONCLUSIONS

This paper presents the results of the analyses of the thermal treatment of animal waste. Analyses were conducted at a large meat and ham production plant. The standard values for pollutant emissions defined by the European Union directive were compared with the actual values measured at the plant.

The results indicated that it was difficult to meet the standard thirty-minute averaged values of NO<sub>x</sub> and SO<sub>2</sub>. The B emission standards (97%) were not met for NO<sub>x</sub> and SO<sub>2</sub> during the study. However, the CO, HCl, volatile dust, TOC and HF concentrations were within the A and B standards.

In all of the above cases, the measured pollutant concentrations (except for NO<sub>x</sub>) did not exceed the B and A standards for long periods (a few days). When such systems are used with diligence, they result in emissions well below the A and B standards. Thus they should be handled to prevent overloading, i.e., not exceeding the maximum permissible frequencies and load sizes in the rotary kiln. Legally, either the A or B standard must be met. Thus, all of the above-mentioned pollutant emissions were below the applicable legal standards.

The average permissible dioxins, furane, heavy metal, mercury, cadmium and thallium (sample collection period: 7 h) emissions were much lower than the permissible values.

This study proves that the thermal treatment of animal waste in a rotary kiln with a dry flue gas treatment system can meet the defined pollution emission requirements for airborne pollutants. The study confirms the results of similar tests conducted mainly at the laboratory scale.

#### REFERENCES

- [1] CASCAROSA E., GEA G., ARAUZO J., *Thermochemical processing of meat and bone meal. A review*, Renew. Sust. Energ. Rev., 2012, 16 (1), 942.
- [2] LYNCH D., HENIHAN A.M., BOWEN B., LYNCH D., McDONNELL K., KWAPINSKI W., LEAHY J.J., *Utilisation of poultry litter as an energy feedstock*, Biomass Bioenerg., 2013, 49, 197.
- [3] POSKROBKO S., *Identification and stabilization of combusting animal waste with active participation of bone material. Emission of SO<sub>2</sub> and HCl*, Fuel Process. Technol., 2013, 113, 20.
- [4] HASSEN-TRABELSI A.B., KRAIEM T., NAOU S., BELAYOUNI H., *Pyrolysis of waste animal fats in a fixed-bed reactor: production and characterization of bio-oil and bio-char*, Waste Manage., 2013, 34 (1), 210.
- [5] STAROŃ P., KOWALSKI Z., KRUPA-ŻUCZEK K., WZOREK Z., *Thermal utilization of mixtures of bone waste*, Pol. J. Chem. Technol., 2010, 12 (4), 26.
- [6] BECK J., BRANDENSTEIN J., UNTERBERGER S., HEIN K.R.G., *Effects of sewage sludge and meat and bone meal co-combustion on SCR catalysts*, Appl. Catal. B: Environ., 2004, 49, 15.
- [7] CUMMINS E., McDONNELL K.P., WARD S.M., *Dispersion modelling and measurement of emissions from the co-combustion of meat and bone meal with peat in a fluidised bed*, Bioresour. Technol., 2006, 97 (7), 903.



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- [8] MILLER B.G., FALCONE MILLER S., FEDOROWICZ E.M., HARLAN D.W., DETWILER L.A., ROSSMAN M.L., *Pilot-scale fluidized-bed combustor testing co-firing animal-tissue biomass with coal as a carcass disposal option*, *Energ. Fuel.*, 2006, 20 (5), 1828.
- [9] BUJAK J., *Experimental study of the energy efficiency of an incinerator for medical waste*, *Appl. Energy*, 2009, 86 (11), 2386.
- [10] COUTAND M., CYR M., DEYDIER E., GUILLET R., CLASTRES P., *Characteristics of industrial and laboratory meat and bone ashes and their potential applications*, *J. Hazard. Mater.*, 2008, 150, 522.
- [11] CUMMINS E., McDONNELL K.P., WARD S.M., *Dispersion modeling and measurement of emissions from the co-combustion of meat and bone meal with peat in a fluidised bed*, *Biores. Technol.*, 2006, 97, 903.
- [12] European Union. Directive 2010/75/EU of the European Parliament and of the council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Brussels, 24 November 2010.
- [13] BUJAK J., SITARZ P., *Reduction of NO<sub>x</sub> and CO emissions through the optimization of incineration parameters in a rotary kiln*, *Environ. Prot. Eng.*, 2016, 42 (1), 85.
- [14] WIELGOSIŃSKI G., ZAWADZKA A., *Analysis of the effectiveness of various reactants in the process of removing HCl from the flue gas dry method in incinerators for medical waste*, 11th Scientific-Technical Conference POL-EMIS 2012, Air protection, Sienna–Czarna Góra, 13–16.06.2012 (in Polish).
- [15] WIELGOSIŃSKI G., *Dioxin emissions from thermal processes and methods of its limitations*, Polish Academy of Sciences, Branch in Łódź. Committee on the Environment, 2009 (in Polish).