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CONSIDERATION REGARDING GASEOUS EMISSIONS INCINERATION OF HOUSEHOLDS WASTE FROM MARAMUREȘ COUNTY, ROMANIA

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Abstract

This study is part of an international project titled "Energy Recovery from Municipal Solid Waste by Thermal Conversion Technologies in Cross-border Regions." Household waste samples for the experiments were collected from a landfill in Maramureș County, Romania. While previous research has outlined optimal incineration conditions for energy recovery, this paper focuses on the environmental impact of incineration, particularly gaseous emissions. Although incineration is an efficient method for waste disposal, it significantly impacts the environment through the release of gaseous emissions, slag, and ash. Effective management of these emissions is crucial to mitigate environmental and health risks, necessitating a detailed understanding of emission characteristics based on waste composition and combustion conditions.
This paper presents a quantitative analysis of key pollutants in the gaseous emissions, including nitrogen oxides (NOx), sulfur dioxide (SO2), particulate matter (PM10), and volatile organic compounds (VOCs), specific to the sampled waste. The analysis was conducted using advanced gas analysis equipment during controlled incineration experiments. The results revealed high concentrations of NO2 and PM10, exceeding the threshold values set by the European Directive 2008/50/EC on air quality standards. To address the pollution from the incineration plant, the study recommends implementing a purification system focused on reducing suspended dust and neutralizing nitrogen oxides. These findings highlight the necessity for stringent emission control measures to minimize the environmental and health impacts associated with waste incineration.

Key words: gaseous emissions, incineration, municipal solid waste, particulate matters

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1. Introduction

Waste potentially represents an enormous loss of resources in the form of both materials and energy. Additionally, the management and disposal of waste can have serious environmental impacts. For instance, landfills occupy valuable land space and can cause air, water, and soil pollution (Anand and Palani, 2022; Mor and Ravindra, 2023; Schiopu and Gavrilescu, 2010). The European Union (EU) has implemented waste management policies aimed at reducing the environmental and health impacts of waste while improving resource efficiency. In 2018, the total waste generated in the EU by all economic activities and households amounted to 5234 million tonnes. The share of different economic activities and households in total waste generation is shown in Table 1 (https://ec.europa.eu/eurostat).

In Romania, household waste constitutes only 2.1% of the total waste, yet the total waste amount is 109.9 million tonnes, and the data show a continuous increase. In the EU, more than half (54.6%) of the

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waste was treated in recovery operations in 2018: recycling (37.9%), backfilling (10.7%), or energy recovery (6.0%). The remaining 45.4% was either landfilled (38.4%), incinerated without energy recovery (0.7%), or otherwise disposed of (6.3%). Some Member States, such as Italy and Belgium, have high recycling rates, while others, including Greece, Bulgaria, Romania, Finland, and Sweden, favor landfill (https://ec.europa.eu/eurostat).

Globally, the problem of waste accumulation is critical, with disposal options becoming increasingly limited and costly. Landfills are not a sustainable solution as they turn into hazardous sites over time. Incineration techniques have been proposed as an alternative for waste disposal due to their potential for energy recovery, making them one of the safest and most cost-effective methods (Hemidat, 2019; Kerdsuwan, 2016). In order to overcome the many inconveniences related to landfills, as an alternative, incineration techniques have been proposed for the disposal of different types of waste (Imai and Okamura, 1991; Kelessidis and Stasinakis, 2012; Zhan et al., 2019).

The potential for recovered energy makes incineration not only the safest, but also one of the most cost-effective disposal methods (NRC, 2000; Ungureanu et al., 2020). Landfill management is expensive and environmentally disadvantageous. Thus, recovering waste by generating heat or electricity is a viable alternative, as municipal solid waste (MSW) is a reliable and long-term energy source (Elnaas, 2015; Ungureanu et al., 2021).

Effective combustion control is demonstrated by destroying all existing compounds in MSW. Effective combustion control involves destroying all existing compounds in MSW, influenced by parameters such as temperature, combustion air, and turbulence. Thermal destruction increases exponentially with temperature, with combustion temperatures of 1000°C and a residence time of 1 second being sufficient for complete destruction. Modern incinerators are equipped with primary and secondary combustion chambers to ensure more complete destruction of residual components (Lima and Bachmann, 2002; Zhang et al., 2020).

Combustion as a municipal solid waste management (MSW) strategy has a number of benefits, including the reduction of the volume and weight of waste and reuse of the energy resulted from waste (Jansson et al., 2009), but at the same time, it releases various types of emissions including lead, mercury, dioxins and furans ("Dioxins and furans" refers collectively to polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), particulate matter, carbon monoxide, nitrogen oxides, acidic gases (i.e., SO_x, HCl), metals (cadmium, lead, mercury, chromium, arsenic, and beryllium), polychlorinated biphenyls (PCBs), and brominated polyaromatic hydrocarbons (PAHS) (Vaverkova et al, 2018). Direct exposure to such toxins poses major risks to the health of facility workers and residents in nearby communities while indirect exposure, through the food chain, poses global risks.

Table 1. Sources of solid wastes generated all over the world, (% share of total waste) (https://ec.europa.eu/eurostat)

Country	***Mining and quarrying***	***Manufacturing***	***Energy***	***Construction and demolition***	***Other economic activities***	***Households***
EU	26.6	10.6	3.4	35.8	15.4	8.2
Belgium	0.1	24.9	1.2	33.5	33.1	7.2
Bulgaria	82.4	2.0	10.0	0.1	3.1	2.4
Czechia	0.2	14.6	1.5	41.7	26.7	15.3
Denmark	0.0	4.7	5.1	56.0	17.8	16.4
Germany	2.2	13.9	2.3	55.5	16.8	9.2
Estonia	29.5	18.8	32.3	9.5	7.6	2.4
France	0.4	6.6	0.4	70.2	13.7	8.7
Croatia	12.0	8.9	1.3	22.7	31.7	23.3
Italy	0.8	16.5	1.3	35.3	28.7	17.5
Latvia	0.1	21.7	2.5	17.5	25.7	32.6
Lithuania	1.6	37.2	2.1	8.8	30.3	20.0
Hungary	1.0	14.3	11.2	33.2	25.4	14.9
Austria	0.1	8.7	0.8	74.4	9.3	6.7
Poland	36.7	17.0	10.7	9.7	20.6	5.3
Portugal	0.2	19.0	1.1	8.8	38.1	32.8
Romania	***88.0***	***3.9***	***3.4***	***0.3***	***2.4***	***2.1***
Slovenia	0.2	20.2	11.8	8.1	51.9	7.8
Slovakia	2.2	27.5	7.9	4.4	39.8	18.2
Sweden	74.7	3.7	1.4	8.9	8.0	3.2
Iceland	0.0	24.4	0.0	3.9	31.5	40.2
Norway	1.2	12.8	1.5	40.0	27.4	17.1
United Kingdom	5.2	4.0	0.2	48.8	32.4	9.4
Montenegro	27.4	3.7	27.6	11.3	8.6	21.4
North Macedonia	14.2	46.6	0.5	3.1	35.6	0.0
Serbia	75.6	2.9	14.7	1.1	2.1	3.6

Source: Eurostat (online data code: env_wasgen)

Dioxins and furans are persistent organic pollutants that are almost invariably formed as undesirable by-products in all heating systems when chlorine-based compounds are present (Altarawneh et al., 2009). These compounds are found in some "plastic" materials (polyvinyl chloride, polypropylene, polyethylene etc.). The occurrence of these compounds in the thermal incineration of municipal solid waste (MSW) is not desirable.

The efficiency of the methods of formation and destruction of these compounds in thermal systems depends on a balance in the gas phase (Altarawneh et al., 2009). For this reason, incineration of waste using the latest technology requires removal of plastic materials and temperatures between 850-1050°C, using two combustion chambers, a primary combustion chamber of municipal solid waste and, a secondary combustion chamber, meant to dissociate the gases resulting from the primary combustion process. For this purpose, the two combustion chambers each have a burner, where the excess air required for combustion can be adjusted as necessary.

It is particularly important to establish the content of the components of the gaseous emission resulting from the incineration process in order to identify the possible effects on the environment, as well as the necessary purification operations. In this sense, the experiments carried out and presented in this work are aimed at the quantitative analysis of some potentially polluting components from the gaseous emission, such as nitrogen oxides, sulphur dioxide, solid particles in suspension, organic compounds. The household waste for which the experiments were carried out were taken from the household waste deposit in Maramureș County, Romania. The flue gas volumetric rate and its composition are essential to determine and monitor the emissions from waste incineration plants (Mungai et al., 2020; Thabit et al., 2020).

Therefore, this study focuses on the incineration of household waste from Maramureș County, Romania, as part of an international project aimed at energy recovery from municipal solid waste using thermal conversion technologies. The primary objective is to quantitatively analyze the gaseous emissions produced during incineration, identify pollutants exceeding European air quality standards, and propose necessary measures for emission control.

By understanding the characteristics of gaseous emissions based on waste composition and combustion conditions, this research aims to provide valuable insights into managing and mitigating the environmental and health risks associated with household waste incineration.

2. Solid waste available for incineration in Maramureș County, Romania

The composition of waste defines its recovery potential and leads to a better factor of recovery of various materials or raw materials and their reintroduction into the circuit, saving natural resources and has a direct impact on the establishment of collection systems. The average composition of household waste in Maramureș for 2016-2020 is presented in Fig. 1 (Maramureș Environmental Protection Agency, 2021). According to the data presented in Fig. 1, an increase in the percentage of biodegradable waste in the composition of municipal solid waste for 2020 as compared to 2016 can be observed, the increase being by 17.80%. Inert waste shows a decrease by 3.40% in 2020 as compared to 2016.

As regards the composition of municipal solid waste reported for 2020, a decrease in paper, plastic and metal contents is observed, a situation created as a result of the increased interest in recycling for these categories of materials.

After a detailed analysis and following the study of the specialized literature (Lee et al., 2017; Thabit et al., 2020, 2022; World Bank, 2000; Zhang et al., 2019), in order to obtain a satisfactory calorific value, and to limit the emissions resulting from the heat treatment, we propose the following methods of managing MSW:

• from the total amount of MSW that is directed to be deposited in the warehouse, the following categories should be eliminated: metals, glass and construction waste, plastic materials;

• also, from the total amount of MSW that is directed to be deposited in the warehouse, the part of bio waste (from gardens, parks, green spaces) that is oriented towards obtaining compost should be eliminated. Bio-waste from tree trimming, maintenance of green spaces and gardens can be subjected to aerobic processes of decomposition of organic matter, and the resulting compost can be an amendment (fertilizer) for green spaces, support material for greenhouses or agricultural crops. The average quantity available for this type of treatment is 12,632.35 tons/year.

Thus, based on the data provided by the National Agency for Environmental Protection Maramureș County (Maramureș Environmental Protection Agency, 2021, 2022), which is an interested party in the project, the amount of waste available for incineration was determined, as an average of the last 2 years (2017; 2018), and this is 53,325.87 tons per year. The distribution by waste categories is presented in Table 2. The amount of municipal solid waste available for thermal treatment was obtained after subtracting the part of recyclable waste, as well as metal, glass and construction waste from the total amount of collected waste. The amount of municipal solid waste and its composition undergo changes depending on the consumption habits of the population, which are constantly changing (Maramureș Environmental Protection Agency, 2021). The values and characteristics of municipal solid waste differ not only from one country to another, but also from one region to another, even from one neighborhood to another in the same city.

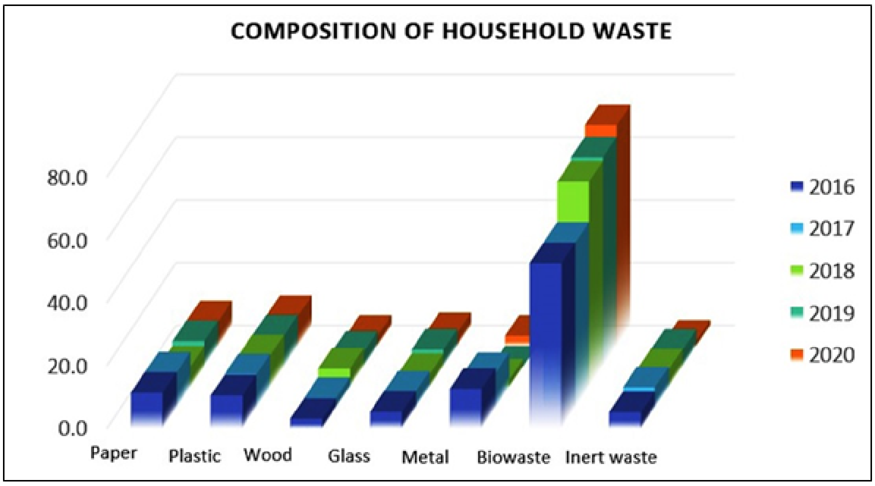

Fig. 1. The average composition of household waste for 2016-2020 (%) (Ungureanu et al., 2020)

Waste management represents a major challenge for Romania, despite the formal progress made following the adoption of the National Waste Management Plan and the Waste Generation Prevention Program in December 2017. Both documents are valid until 2025. Despite recycling and efficient use of resources, circular economy remains poorly developed although the existing potential is significant. In this sense, increasing awareness of the benefits of the circular economy play a primary role alongside the development and branching of the necessary infrastructure (Maramureș Environmental Protection Agency, 2021).

2. Materials and methods

2.1. Characteristics of household waste samples

Five household waste samples, each weighing approximately 5 kg and having similar compositions, were collected from landfills in Maramureș County. These samples were selected without plastic bottles or plastic bags to minimize the formation of dioxins and furans. The average composition of the household waste used in the incineration experiments is depicted in Fig. 2, indicating that food waste is the primary component. Each 5 kg sample was incinerated, and the resulting flue gas was analyzed.

2.2. Equipment used in incineration experiments

The incineration experiments utilized an I8-10S incinerator, which has a combustion chamber volume of 0.1 m³ and includes a secondary chamber to eliminate smoke, odors, and harmful emissions. Waste is introduced into the primary chamber where it is transformed into sterile, environmentally safe material under the action of burners. The primary chamber features a loading hatch that remains closed during the incineration cycle, and ash is manually unloaded at the end of each batch. The secondary chamber, equipped with a fuel burner, purifies the gases resulting from primary combustion by subjecting them to heat treatment at a minimum of 850°C for 0.5 seconds. The incinerator is equipped with high-performance, fully automated burners and continuous ventilation. The I8-10S incinerator is manufactured by INCINER8 Limited in the United Kingdom.

The control panel settings for optimal incinerator operation (Inciner8, 2022) are as follows:

- Preheat the incinerator using burners with lower air settings (main burner air regulator at 3-3.5 atm).
- Turn off the main burner and load a small amount of waste (5-25% of capacity, depending on the type of waste), as shown in Fig. 3.
- Turn on the main burner briefly if the waste has not self-ignited. Typically, the main burner is not needed after preheating if burning flammable waste, and the air settings are increased by adjusting the air regulator on the main burner between 6 and 8 (depending on the type of waste).
- Turn off the main burner and add more air if necessary (by increasing the setting on the air regulator).

After the waste ignites, the temperature will rise to a maximum level (depending on the amount and calorific value of the waste) and then decrease, indicating that most of the waste has been burned. At this point, additional waste can be loaded. The incinerator was preheated, and the maximum combustion temperature exceeded 850°C, as illustrated in Fig. 3(b).

The combustion gases passed through the secondary chamber for heat treatment at a minimum of 850°C (World Bank, 2000). The resulting sterile ash was discarded at the end of each batch. Fuel consumption depends on the nature of the waste (calorific value and burning rate), operating temperature, oxygen amount, and homogeneity of the waste. Each sample had a burning time of 30 minutes at a minimum temperature of 850°C. The average methane gas consumption per sample was approximately 4 m³. Detailed parameters for each sample are provided in Table 3.

Table 2. Wastes available for incineration (average)/year (tons)

In Maramureș County	***2017 (tons)***	***2018 (tons)***	***Average (tons)***	***Waste for incineration/year (tons/year)***	***Percentage in the sample (%)***
Paper waste	6605.63	4761.34	5683.48	5683.48	10.66
Plastic waste	5485.97	5950.30	5718.13	5718.13	10.72
Wood waste	1719.70	3424.27	2571.98	2571.98	4.82
Biowaste	31582.40	30007.16	30794.78	30794.78	57.75
Textile waste	4535.13	3461.43	3998.28	3998.28	7.40
Voluminous waste	4183.87	4934.54	4559.20	4559.20	8.55
Waste for incineration (average)/year	54112.70	52539.04	53325.87	**53325.87**	100.00

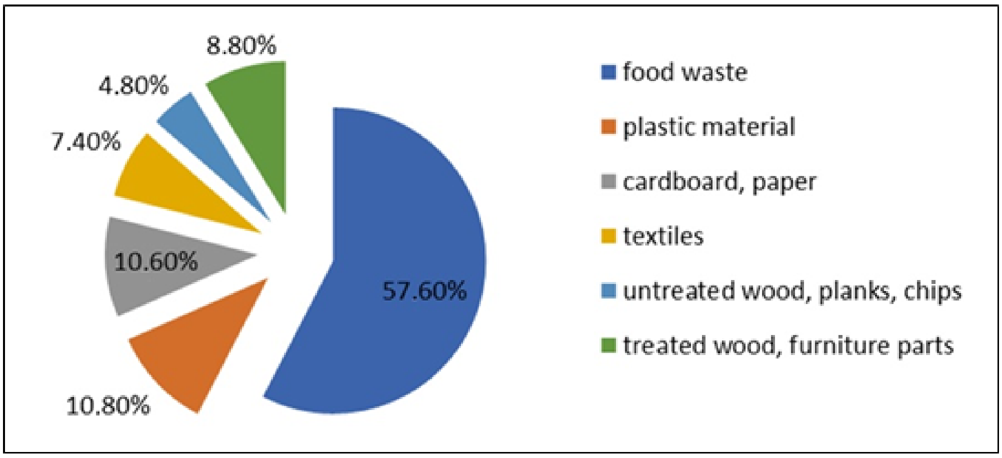

Fig. 2. The average composition of household waste

(a) (b)

Fig. 3. The Inciner I8-10S incinerator: (a) Primary chamber loaded with waste, (b) Sample burning temperature

Table 3. Parameters of incinerated samples

Parameters	***S. no.1***	***S. no.2***	***S. no.3***	***S. no.4***	***S. no.5***	***Average***
Maximum combustion temperature [^{0}C]	891	893	850	869	890	878,6
The resulting ash (solid residue) [g]	200	295	190	165	490	268
The resulting slag (solid residue) [g]	50	75	55	40	0	29
Total solid residue result [g]	250	370	245	205	490	312
Reduction degree of municipal solid waste [%]	95.0	92.6	95.1	95.9	90.2	93.76

Advances in incinerator research and development, coupled with stricter emission limits, have led to most municipal waste incinerators being equipped with flue gas cleaning systems (Lima and Bachmann, 2002; Oleniacz, 2014; Testo 350, 2011).

2.3. Gaseous emissions from incineration experiments

It is well established that the primary compounds in gaseous emissions from household waste incineration that impact human and environmental health include CO_2, CO, NO_x, SO_2, VOCs, particulate matter, furans, dioxins, acid gases, and other substances, depending on the waste composition (Juhasz et al., 2011). In this study, we measured CO, NO_2, SO_2, total VOCs, HCN, and PM_{10} at different combustion temperatures. Emissions were recorded using a MultiRAE LITE gas analyzer (manufactured by JJS Technical Services, USA) and dust emissions with the HAZ-DUST Environmental Particle Air Monitor Model EPAM-5000 (manufactured by SKC Limited, UK). Measurements were taken at 2-minute intervals throughout the burning process at temperatures above 700°C. Between 700-1100°C, in fully oxidative conditions, reactions are nearly complete, and the major gases produced are water, nitrogen, and carbon dioxide.

Regarding air pollution, it is crucial to note that combustion includes rapid reactions (fractions of seconds) occurring in the gas phase. Self-supporting combustion is possible if the waste's heat value and oxygen concentration are sufficient (Quina et al., 2008).

3. Results and discussions

During incineration, the fuel components of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) are oxidized, generating carbon monoxide (CO) from incomplete combustion, carbon dioxide (CO_2), nitrogen oxides (NO_2), sulfur dioxide (SO_2), volatile organic compounds (VOCs), water (H_2O), and particulate matter (PM).

The average emissions for all samples are presented in Table 4 and illustrated in Figs. 4-7. The results were compared with the limit values established by European environmental legislation for air quality.

Table 4. Average values of gaseous emissions from the waste incineration process

Time [min.]	***CO [mg/m^3]***		***NO_2 [µg/m^3]***		***SO_2 [µg/m^3]***		***PM10 [µg/m^3]***		***VOC_{total} [mgC/Nm^3]***		***HCN [mg/m^3]***	***Temp. [^{0}C]***
	AV	***LV****	***AV***	***LV****	***AV***	***LV****	***AV***	***LV****	***AV***	***LV*****	***AV***	
2	3		212		0		0		0		0.2	500
4	0.0		221		0.0		1		0.0		0.0	
6	1.0		221		0.0		25		2.0		0.0	700
8	0.0		207		0.0		100		1.0		0.0	
10	1.0		255		0.0		195		3.0		0.0	763
12	2.0		192		0.0		510		6.0		0.5	
14	0.0		199		0.0		1010		0.0		0.0	775
16	0.0		232		0.0		475		0.0		0.0	
18	0.0		201		0.0		370		0.0		0.0	
20	0.0		222		0.0		290		0.0		0.0	793
22	1.0	10	232	200	0.0	350	515	40	4.0	100	0.0	
24	0.0		232		0.0		610		0.0		0.0	
26	1.0		212		0.0		475		0.0		0.5	800
28	0.0		202		0.0		430		1.0		0.0	
30	0.0		190		306.0		313		0.0		0.0	802
32	0.0		184		0.0		265		0.0		0.0	803
34	0.0		174		0.0		277		1.0		0.0	810
36	0.0		198		0.0		300		0.0		0.0	
38	0.0		458		0.0		448		1.0		0.0	821
40	0.0		461		0.0		518		2.0		0.2	830
42	3.0		474		232.0		870		1.0		1.0	841
44	1.0		481		232.0		710		1.0		0.2	850
46	3.0		187		0.0		0		0.0		0.2	500

AV: Average Values from our determinations; LV: Limit Values from EU air quality standards, Directive 2008/50/EC; LV**: Limit Values from EU air quality standards, Directive 1999/13/EC*

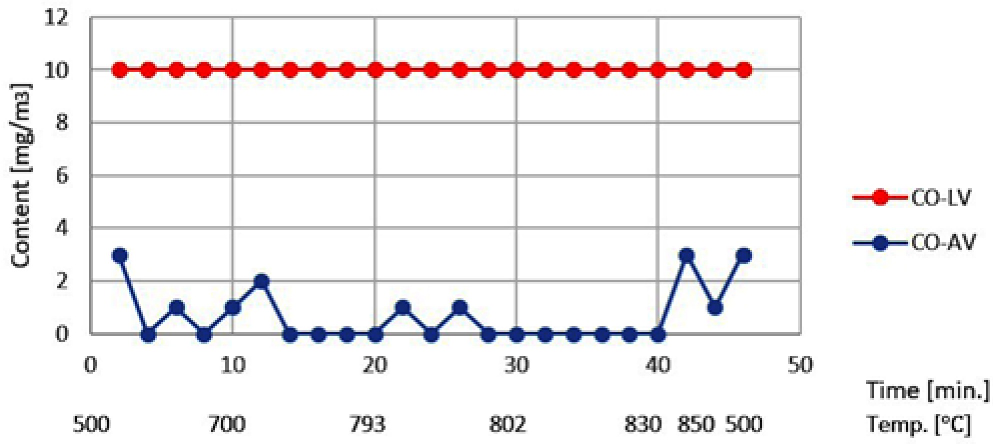

Fig. 4. CO content in incineration gaseous emission

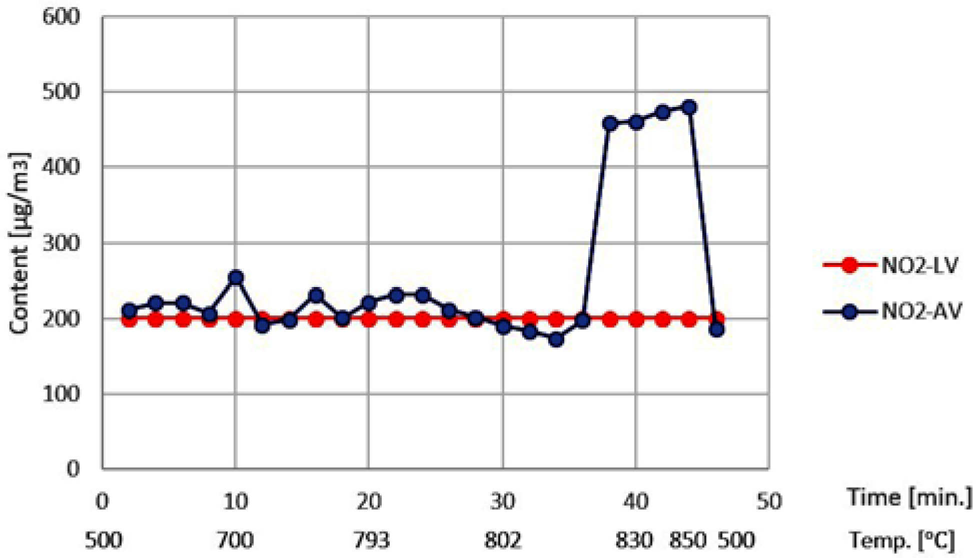

Fig. 5. NO_2 content in incineration gaseous emission

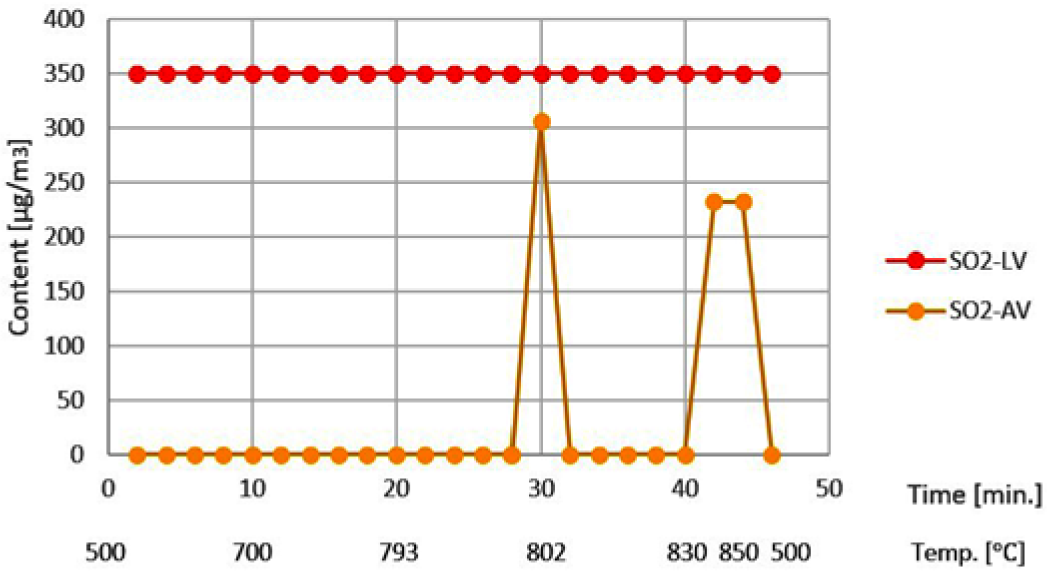

Fig. 6. SO_2 content in incineration gaseous emission

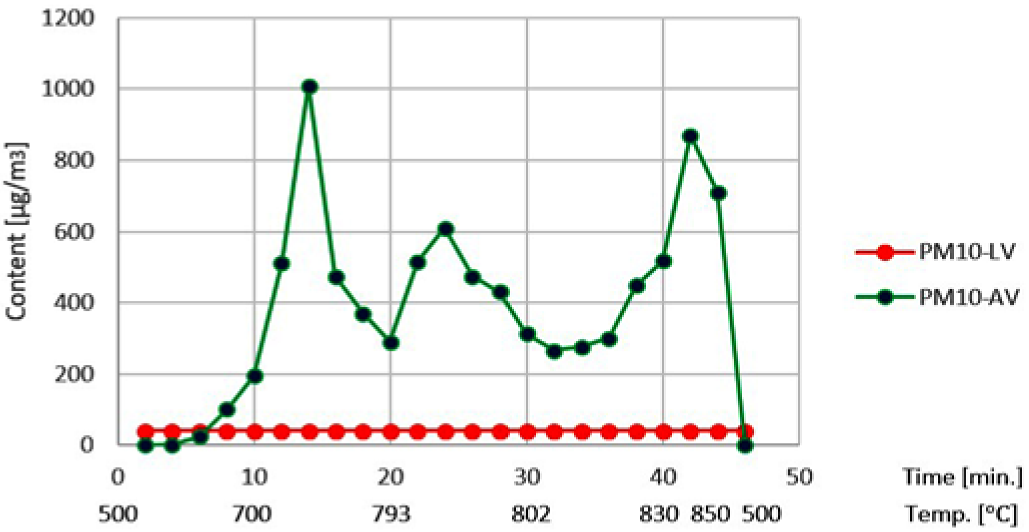

Fig. 7. PM10 content in incineration gaseous emission

Incomplete combustion is inevitable at the beginnings and ends of the burns (Lima and Bachmann, 2002). The maximum value of CO observed was 3 mg/m³, well below the limit value of 10 mg/m³. This indicates that the combustion air quantity is optimal for waste burning at higher temperatures above 800°C. However, once CO reaches the atmosphere, it undergoes an oxidative process under the influence of atmospheric O_2, turning into CO_2. High CO concentrations indicate combustion conditions that can also correlate with high dioxin concentrations.

Nitrogen dioxide (NO_2) can be formed either by the oxygenation of nitrogen in the waste or by the fixation of combustion air nitrogen in a high-temperature flame. The incineration temperature cannot be reduced as European legislation mandates a minimum gas phase combustion temperature of 850°C (Directive 2000/76/EC). Nitrogen in food is primarily found in proteins as amino acids, which are present in various forms such as free amino acids, creatine, choline, creatinine, purines, pyrimidines, and amino sugars. Foods rich in nitrogen include meat, fish, potatoes, milk, eggs, grains, and vegetables. Therefore, the organic nitrogen content in the waste depends on the type of food waste.

In our samples, NO_2 content ranged from 180 µg/m³ to 232 µg/m³ at temperatures below 800°C and from 458 µg/m³ to 480 µg/m³ at temperatures above 800°C. These values exceed the limit value for NO_2 (200 µg/m³) set by Directive 2008/50/EC (Fig. 5). The temperature must be maintained high enough to ensure complete combustion, but not so high as to generate excessive nitrogen oxides. NO_x can be controlled, in part, by combustion-process modification and ammonia or urea injection through selective or nonselective catalytic reduction and wet flue-gas denitrification. To minimize NO_x production, it is recommended to maintain a lower-oxygen condition just above the grates or in the primary chamber of a dual-chamber facility, coupled with a higher excess-oxygen condition at the location of overfire air injection or in the secondary chamber (Wilson and Velis, 2015).

The SO_2 content in the incineration gaseous emissions for our samples, shown in Fig. 6, does not exceed the allowed limit value from EU air quality standards. However, this is highly dependent on the composition of the household waste, especially the type and quantity of food waste. Natural sources of biologically active sulfur include cruciferous vegetables, garlic, onions, green legumes, nuts, seeds, plant milk, animal milk, and eggs, as well as food additives like sodium metabisulfite (E223). Textiles also have high nitrogen and sulfur contents.

Particulate matter (PM_{10}) in the incineration gaseous emissions is one of the most significant pollutants for the environment and health. As shown in Fig. 7 and Table 4, the PM_{10} content (average value = 380 µg/m³) far exceeds the allowed limit value, necessitating strict dust emissions control. Particulate matter consists primarily of entrained non-combustible matter in the flue gas and products of incomplete combustion, including inorganic ash and carbonaceous soot. To limit particulate emissions from waste combustors, effective dust control is necessary, which can also reduce metal content in the emissions. Fine-particle control devices include fabric filters (baghouses), electrostatic precipitators (ESPs), wet scrubbers, and venturi scrubbers. The presence of VOCs in the gaseous emissions from household waste incineration in our samples is insignificant (Table 4).

4. Conclusions

Incinerating waste for energy emerged as a response to the oil crisis of the 1970s, aimed at achieving energy independence and addressing landfill issues. In Romania, the practice of incinerating household waste for electrical and thermal energy production is still nascent. Incineration poses environmental and health risks, particularly related to atmospheric emissions and combustion by-products such as slag and ash.

This paper is part of a broader study on the potential for energy recovery from household waste in Maramureș County, Romania. It aims to quantitatively analyze some potentially polluting components in gaseous emissions at different combustion temperatures.

The incineration experiments were conducted using an I8-10S laboratory incinerator. Quantitative gas analysis was performed with the MultiRAE LITE gas analyzer, and dust emissions were recorded using the HAZ-DUST Environmental Particle Air Monitor Model EPAM-5000. Five household waste samples were tested, composed predominantly of combustible material with over 57% food waste and less than 5% plastic to minimize the formation of dioxins and furans (see subsection 2.1).

The following gaseous emission components were identified: CO, NO_2, SO_2, total VOCs, HCN, and suspended particles, with a focus on PM10. Among these, the average concentrations of nitrogen dioxide (NO_2) and PM_{10} exceeded the threshold values set by EU air quality standards (Directive 2008/50/EC) and Romanian national standards. Measurements were taken at combustion temperatures ranging from 800°C to 850°C.

NO_2 concentrations ranged from 180 μg/m³ to 232 μg/m³ at temperatures below 800°C, and from 458 μg/m³ to 480 μg/m³ at temperatures above 800°C, both exceeding the Directive 2008/50/EC limit of 200 μg/m³. PM_{10} concentrations varied between 200 μg/m³ and 1010 μg/m³, surpassing the Directive's limit of 40 μg/m³. Therefore, for household waste incineration in Maramureș County, a treatment facility for gaseous emissions is essential to remove dust and nitrogen oxides and to monitor these pollutants closely.

For the incineration of household waste to be a viable method for final disposal or energy recovery, strict environmental controls of generated emissions must be enforced. Additionally, a rigorous waste segregation process at the source is crucial, despite the increased cost of this process.

The results presented in this paper are not universally applicable to all household waste types worldwide. Each region's household waste composition, particularly the food waste component, waste proportion, and degree of waste segregation, results in different chemical characteristics of gaseous emissions during incineration.

The development of advanced incineration technologies, effective combustion gas treatment, and safe storage of combustion by-products can make waste-to-energy a sustainable solution for utilizing household waste as an alternative energy source.

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