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THE IMPACT OF HAZARDOUS WASTE INCINERATION ON THE ENVIRONMENT

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Abstract

The aim pursued in this paper is to estimate the impact produced on the surrounding environment by a furnace for the incineration of hazardous waste. For this purpose, the analysis bulletins of the main pollutants responsible for this were studied, the methods by which they are neutralized before being eliminated in the environment. The parameters considered the most dangerous for human health and the environment were analyzed: total dust, total organic compounds (TOC), sulfur oxides (SOx), nitrogen oxides (NOx), dioxins and furans, as well as heavy metals. Although we were able to ascertain that there was exceeding of the daily average, depending on the origin of the incinerated waste, during the 24 hours the average value allowed by the legislation in force was not exceeded.

Key words: *combustion furnace, hazardous waste, incineration, industrial emissions, limit value*

INTRODUCTION

In Romania, waste incineration has become a major concern in recent years, because it represents an efficient way to reduce the negative impact of waste on the environment [17]. Modern incinerators can significantly reduce dioxin and furan emissions to levels below the limits set by the European Union, through the use of advanced filters and temperature control [3], as well as heavy metals and nitrogen oxides, through methods of capturing and filtering these dangerous pollutants [6]. Also, this method prevents soil and groundwater pollution and can generate energy, compared to waste storage.

According to Directive 2000/76/EC, a waste co-incineration plant is any plant, whether stationary or not, the main purpose of which is to obtain energy or material products and where waste is incinerated, as a rule or as additional fuel, or in which waste is thermally treated for disposal. In Annex II of this directive, conditions are stipulated regarding the determination of emission limit values. These special emission limit values refer to combustion plants where waste is co-incinerated. Through this method, the hazardous waste resulting from a certain sector can reach the position of fuel for another branch of activity [1]. Gas incineration is a technology that uses gas to heat and burn waste. The advantages include cleaner combustion and increased energy efficiency [2]. Disadvantages of this method include higher operating costs and the need for pre-treated waste to ensure efficient combustion. [18] Operating conditions, technical requirements and restrictive emission limit values are established for incineration and co-incineration plants, which should prevent negative effects on the environment and public health risks respectively, or, as far as possible, to limit them [4].

When building a waste co-incineration facility, the following characteristics must be taken into account:

- the technical construction of the combustion plant (temperature, residence time of the fuel in the combustion chamber, resistant to corrosion, the possibility of regulating the supply of waste);
- a sewage gas treatment facility to ensure compliance with the more restrictive emission limit values (dedusting, desulfurization, denitrification) [5];
- a waste water treatment facility and the possibility of waste disposal [8] (filter ash,

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slag, added additives, sludge) resulting from co-incineration.

Solid waste is received for co-incineration, as a rule, in closed delivery places (bunkers), specially designed. These teaching places are equipped with dust removal facilities. Transport to the boiler hopper or directly to the waste combustion chamber [11] (partly together with the regular fuel) takes place in closed transport systems. And the existing drop-off points along the transport system must be dusted off. The installation must be designed and operated in such a way that no fugitive emissions occur. Wastes that can be co-incinerated in LCP (Large Combustion Plant) installations can be the following: sewage sludge, waste from historical pollution (e.g. fuel oil, sludge, contaminated soil), paint sludge, protein meal from meat and blood derived from the disposal of animal carcasses, prepared and treated urban waste.

The combustion plant must be constructed and operated in such a way that even under adverse conditions the flue gas temperature must reach a minimum of 850°C for two seconds. If hazardous waste is co-incinerated with a content of halogenated organic substances, calculated as derivatives of (salts of) chlorine, greater than 1 percent of their weight, then the temperature must be raised to 1,100°C [12]. The plant must be equipped with an automatic waste dosing interruption system for cases where the temperature drops below 850°C and below 1,100°C respectively (eg during plant start-up and shutdown processes). Gasification and pyrolysis represent alternative thermal treatments that limit the amount of combustion air to transform waste into process gas, increase the amount of recyclable inorganics, and reduce the amount of flue gas cleaning. In this context, the goal of this study was to quantify the impact produced on the surrounding environment by a furnace for the incineration of hazardous waste.

MATERIALS AND METHODS

The basic activity of the company under study is the treatment and disposal of hazardous waste, with a capacity of over 10 tons/day. The company goal was and is to obtain an activity that corresponds in terms of emissions with Law 278/2013. In order to reach this target, the incineration plant is provided with high-performance gas analyzers, which monitor the plant emission parameters [13].

The incineration plant consists of the following equipment: feed sluice, rotary furnace, ash chamber, burner 1, ash conveyor with scrapers, combustion station 1, burner 2, combustion station 2 with emergency chimney, cooling tower, combustion gas stationary chamber, pressure boiler, steam drum, sodium bicarbonate silo, activated carbon silo, bag filter 1, bag filter 2, scrubber, pump group, demineralized water tank 30 m^3, turbine, exhauster, final chimney, water cooling towers, condenser, gas analyzer, control cabin, compressor.

The technological flow starts once the waste enters the incineration platform. Each type of waste corresponds to a sheet, in which the composition and concentration of the substances that compose it are presented. The waste is weighed and sent to the landfill. After they have been unloaded in the warehouse, samples are taken from each type of waste to check if what is written on the sheet corresponds to what is in the packaging. The determinations are made in the specialized laboratory by personnel trained to do this type of chemical analysis [14.] After the results of the analyzes have come out, the waste is taken from the waste warehouse and stored in the pre-treatment hall, where the batches are prepared for incineration depending on the concentration of dangerous substances and the determined calorific value [7] [12]. The waste batches are then sent to the incineration plant hall, respectively to the untreated waste bunker. From here, the waste is picked up with the help of the overhead crane and fed into the shredder, where it is chopped up to the size of 30 mm and reaches the chopped waste storage hopper. Then, the waste is picked up with the help of the crane and scale crane and is passed into the feed hopper of the incineration plant. Chemically compatible waste is first chopped through a shredder, in order to obtain a mixture as homogeneous as possible, given their large amount, between

300 and 600 tons. We try not to exceed the concentration of 2-5% of halogens and 1-% of sulfur [5] for each batch, as well as a calorific value as close as possible to 18 MJ/Kg. In the case that, due to various situations, the waste does not have or exceeds these elements, alternative solutions are sought, such as liquid injections or mixture in the feed.

From the feed bunker, the waste reaches the rotary kiln, where the burning (incineration) of the waste takes place. Waste incineration occurs at a temperature between 850-1,100^oC. The waste destruction efficiency at this temperature is 99.99%. The ash resulting from the incineration reaches the ash chamber, in a funnel with a valve; when the bunker is full, the valve opens and the ash reaches the conveyor with scrapers, with the help of which it is discharged into a container. The gases resulting from the burning of waste reach post combustion 1, then post combustion 2, where they are burned at temperatures between 1,100-1,300^oC. The dwell time in the two post combustion is between 3 and 6 seconds. These two combustion chambers, post combustion 1 and 2, are used for the complete destruction of corrosive and toxic gases, as well as the organic compounds found in the combustion gases (HCl, HF, CO, Dioxins and Furans). From combustion station 2, the gases reach the cooling tower, where they are cooled from a temperature of 1,100-1,300^oC to a temperature of 850^oC. The temperature of the gases is maintained until they enter the boiler membrane. Here, the temperature starts to drop, reaching 600^oC - the temperature of the flue gases entering the boiler. In the boiler, the gases are cooled to 200^oC and steam is formed, which then reaches the steam drum and then the membrane drying circuit up to a temperature of 370^oC. Having this temperature and a pressure of 21.5 bar, the steam is sent to the turbogenerator. The capacity of the turbogenerator is 650 Kw/h. The steam comes out of the turbogenerator (turbine) with a pressure of 1.5 bar, reaches the condenser, where it condenses. The condensate reaches the treated water tank, from where it returns to the boiler's cooling circuit [12]. After the boiler, the combustion gases are subjected to chemical treatment in the circuit. The first stage of treatment is carried out with sodium bicarbonate $NaHCO_3$, the second stage of chemical treatment is with activated carbon [15]. Further on, the gases reach the two bag filters, where they are filtered. The dust particles are evacuated from the filters with the help of screw conveyors, the dust reaching a heat exchanger, where it is cooled to a temperature of 40-60^0C. From the heat exchanger, the dust is evacuated and packed with the help of cellular dispensers in 1 m^3 big-bags. The filtered gases reach further into the scrubber, where the gases are washed with a 30% NaOH alkaline solution. After the scrubber, the gases reach the exhauster, and then they are discharged to the chimney [10]. The exhaust chimney has a height of 30 m. On the chimney there are probes that are connected to the analyzer, with the help of which emissions into the atmosphere are continuously monitored. The monitored parameters must comply with Law 278/2013, regarding industrial emissions (transposition of Directive 2010/75/EU) [9].

In order to be able to estimate the neutralization capacity of the resulting gases, we have centralized the analysis reports of the main dangerous pollutants that can result from such an installation within 24 hours: total dust, total organic compounds (TOC), sulfur oxides (SOx), nitrogen oxides (NOx), dioxins and furans, as well as heavy metals.

RESULTS AND DISCUSSIONS

All parameters monitored by the analyzer are calculated at a temperature of 273.15 degrees K and a pressure of 101.3 KPa, at an oxygen content of the waste gas of 11%.

The total dusts monitored in a normal working day must have a maximum daily average value of 10 mg/Nmc. The total dust is removed with the help of the two post-combustion chambers 1, post-combustion 2 and the Scrubber with NaOH solution and stored in the filter bags. Fine filtering takes place in the sequins, that is, here the powders will be taken out. If average values exceeded by dust are found, the speed of the exhauster is reduced, so that they are retained in the filters. Thus, these values will decrease (Table 1).

Table 1. Values of total powder concentration during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total powders [mg/Nmc]	4.8	3.5	3.7	4.2	4.9	5.1	5.6	6.8	7.3	9.1	12	11
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Total powders [mg/Nmc]	9.6	10.2	8.3	7.7	5.5	4.7	4.5	5.3	5.9	6.2	8.1	7.6
Average value over 24 hours	**6.73**											

Source: internal documents of the company.

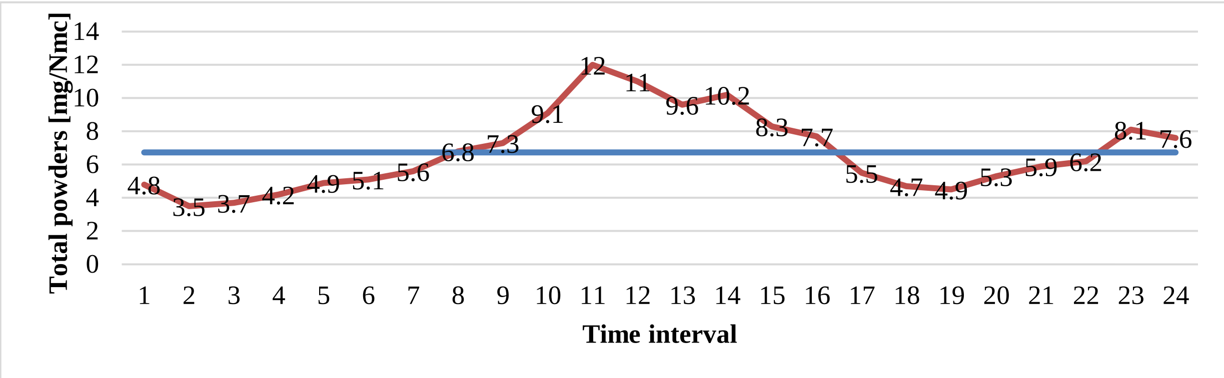

Fig. 1. Variation of total powder concentration during one day
Source: Elaborated by authors.

As we can see from Figure 1, during the time 08:00 and 16:00 it is noted exceeding of total powder values - with a percent of maximum 78.3% compared to daily average, powders eliminated with the help of the two postcombution chambers 1 and 2 and Scruber with solution of NaOH and stored in the filter sacks. Thus, these increased concentration of total powders are decreased with the help of solution of NaOH. Because the average value during 24 hours is of 6.73 mg/Nmc, this means the maximum daily average value was not exceeded - that is of 10 mg/Nmc [9].

The total organic compounds (TOC) in a normal working day must have a maximum daily average value of 10 mg/Nmc. When total organic compounds (TOC) increases, this means that CO and CO_2 at the analyzer will also increase. When they grow, increase the NaOH concentration by 5% per hour in the Scrubber. After these compounds accumulate in the filters, they are disposed of in the garbage (Table 2).

Table 2. Values of total organic compounds concentrations (TOC) during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total organic compounds [mg/Nmc]	3.8	2.2	4.1	3.5	4.3	3.9	4.5	5.6	6.2	5.9	8.6	10.2
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Total organic compounds [mg/Nmc]	13	11	10.4	9.8	8.9	7.7	6.9	6.3	5.7	6.2	6.4	6.8
Average value over 24 hours	**6.74**											

Source: internal documents of the company.

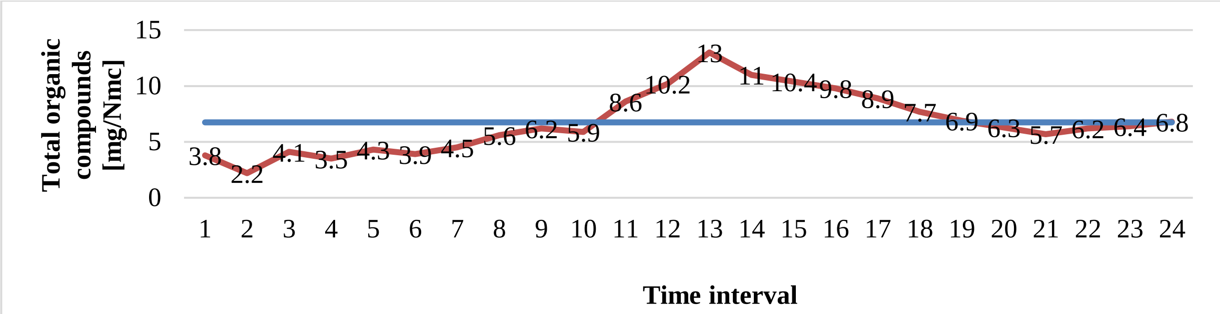

Fig. 2. Variation of total organic compounds concentration (TOC) during one day
Source: Elaborated by authors

In Figure 2, in the time period 11:00 and 18:00, it is noted an exceeding of the values of total organic values with a percent of maximum 92.87% of daily average, exceeding due to introducing in the furnace of animal waste. These increased concentration of total organic compounds were decreased with the help of solution of NaOH. As the average value during 24 hours is of 6.74 mg/Nmc, this means that it did not exceed the maximum daily average value, which is of 10 mg/Nmc, according to legislation [9]. In furnace **SO_x** and **NO_x** are formed, that will go to Scruber, where will be eliminated. In case exceeded values of NO_x and SO_x are seen, NaOH concentration is increased (caustic soda) in Scruber. The increase of dosage concentrations are of 5% to an hour for the solution of liquid reduction NaOH (caustic soda) and of 10% to an hour for solid reduction compounds ($NaHCO_3$-sodiu bicarbonate) and active coal.

Sulphur oxides (SO_x) in a normal working day must have a medium daily average value of 50 mg /Nmc (Table 3) [9].

Table 3. Values of sulphur oxides concentrations during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Sulphur oxides [mg/Nmc]	24	28	32	36	40	48	59	62	55	49	43	38
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Sulphur oxides [mg/Nmc]	35	38	33	29	37	34	41	30	26	30	27	25
Average value over 24 hours	**37.45**											

Source: internal documents of the company.

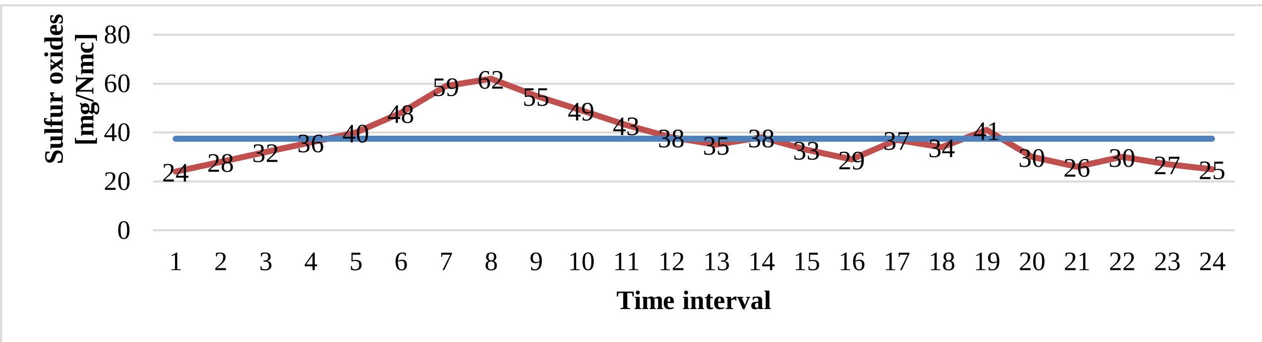

Fig. 3. Variation of sulphur oxides concentrations during one day
Source: Elaborated by authors.

In Figure 3, in the period of time 05:00-12:00 we note increased values of SO_x concentrations with a percent of maximum 65.55% compared to daily average, due to introduction in the furnace of some waste with an increase concentration of sulphur (for example: paints, tires, gum). These increased values of SO_x will be reduced in Scruber according to above dosage concentrations. As the average value during 24 hours is of 37.45mg/Nmc, this means that the maximum daily average value of 50 mg/Nmc was not exceeded, so we comply with the parameters foreseen by law [9].

Nitrogen oxides (NO_x) in a normal working day must have daily average value of maximum 200 mg/Nmc (Table 4) [9].

Table 4.Values of nitrogen oxides concentration during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Nitrogen oxides [mg/Nmc]	79	84	91	99	108	130	143	161	184	210	226	212
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Nitrogen oxides [mg/Nmc]	201	193	181	163	144	132	121	138	146	129	112	107
Average value over 24 hours	**145.58**											

Source: internal documents of the company.

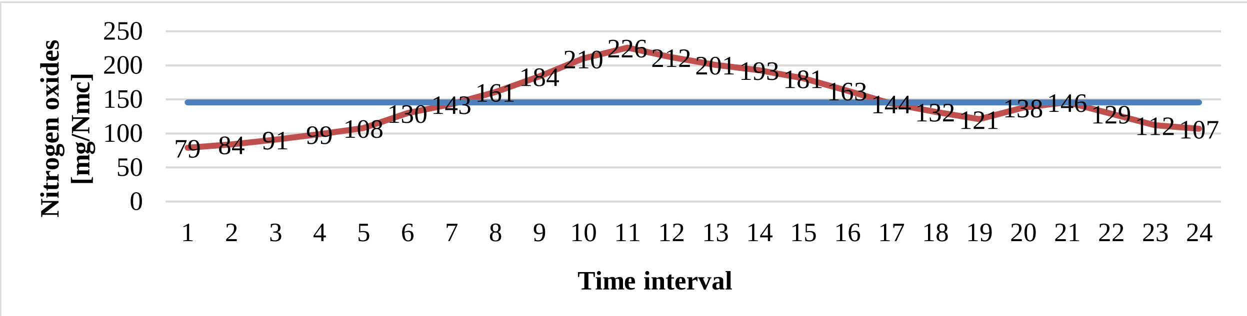

Fig. 4. Variation of nitrogen oxides concentration during one day
Source: Elaborated by authors

In Figure 4, in the period of time 08:00-16:00 we note increased values of concentration of NO_x with a maximum percent of 55.24% compared to daily average, due to introducing in the furnace of some waste with increased composition of nitrogen (de ex. Solvents based on nitrogen, paints that have a nitrosolvent composition (pesticides, herbicides) [16]. These increased values of NO_x will be increased in Scruber according to above dosage concentrations. As average value during 24 hours is of 145.58 mg/Nmc, this means maximum daily average value was not exceeded, of 200 mg/Nmc [9].

Dioxins and furans in a normal working day must have a maximum daily average value of 0.1 mg/Nmc. Dioxins and furans are dangerous gases, which form many compounds when the temperature in the furnace is suddenly decreased from 1,500^{0}C to 450^{0}C and a pressure increase of more than 4 Bars. To reduce the appearance of these dangerous gases, the temperature in the oven must be as constant as possible (Table 5).

Table 5. Values of dioxins and furans concentration during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Dioxins and furans [mg/Nmc]	0.003	0.0012	0.005	0.008	0.01	0.03	0.06	0.09	0.12	0.13	0.09	0.07
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Dioxins and furans [mg/Nmc]	0.05	0.02	0.009	0.007	0.003	0.001	0.005	0.008	0.006	0.04	0.009	0.05
Average value over 24 hours	**0.034**											

Source: internal documents of the company.

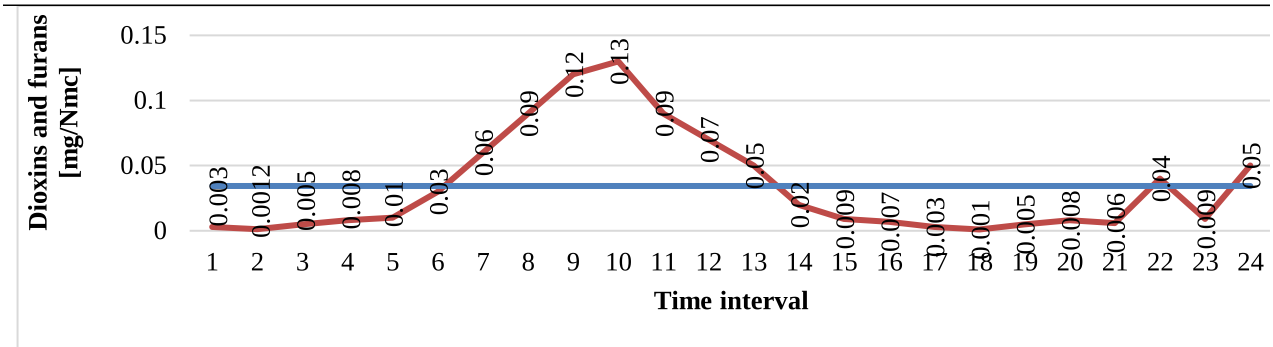

Fig. 5. Variation of dioxins and furans concentration during one day
Source: Elaborated by authors.

In Figure 5 we can note in the period of time 07:00-13:00 increased values of dioxins and furans concentration, with a percent of maximum 82.35% compared to daily average, due to sudden decrease of temperature in the furnace from the value of 1,400^{0}C to 450^{0}C and an increase of pressure higher of 4 Bars.

Once returning to temperature to the value of 950^{0}C, dioxins and furans concentration will decrease. As the average value during 24 hours is of 0.034 mg/Nmc, this means that maximum daily average value was not decreased, of 0.1 mg/Nmc [9]. Thus, we comply with the values foreseen in the legislation.

Heavy metals accumulate in water from Scruber, and when they reach the chimney it means that the concentration of lime, soda and active coal concentration must be increased in order to decrease their value to the chimney. Increasing the lime, soda and coal concentrations will increase also the quantity of heavy metals accumulated in water from Scruber and the quantity of heavy metals eliminated in the air will decrease (Table 6).

Heavy metals monitored are: Cobalt+Chrom+Arsen+Lead+Stibiu+Copper+ Mangan+Nikel+Vanadium. In a normal working day the concentration of heavy metals must have daily average value of maximum 0.50 mg/Nmc [9].

Table 6. Values of heavy metals concentration during one day

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Heavy metals[mg/Nmc]	0.2	0.27	0.25	0.29	0.33	0.37	0.41	0.45	0.64	0.71	0.55	0.48
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Heavy metals[mg/Nmc]	0.42	0.33	0.27	0.25	0.23	0.29	0.32	0.36	0.34	0.37	0.31	0.35
Average value over 24 hours	**0.366**											

Source: internal documents of the company.

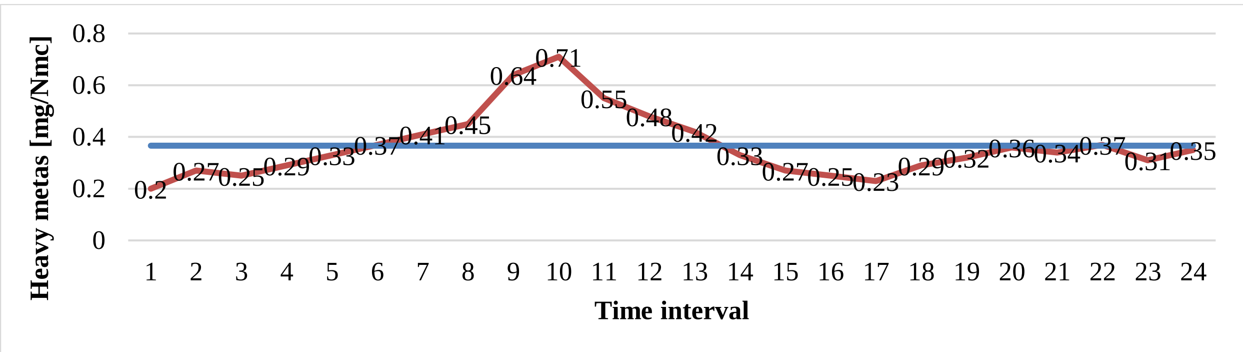

Fig. 6. Variation of heavy metals concentration during one day
Source: Elaborated by authors.

In Figure 6, in the time interval 06:00-13:00 we observe increased values of the concentration of heavy metals with a maximum percentage of 93.99% compared to the daily average, due to the introduction into the furnace of some waste with increased concentrations of heavy metals that will be decreased by increasing the concentrations of lime, soda and coal in the Scrubber. Since the average value during 24 hours is 0.366 mg/Nmc, this means that the maximum daily average value of 0.50 mg/Nmc was not exceeded [9].

CONCLUSIONS

Incinerators have the ability to reduce waste in a very large percentage, in a relatively short time - especially if it is solid waste. Incinerators make waste disappear permanently, while the spaces allocated to warehouses favor the accumulation of odors that poison the environment.

The amount of solid material resulting from burning represents only 15-20% of the initial weight of the waste, this leads to the reduction of land areas required for storage and their use for other purposes. Also, the thermal treatment process reduces to zero the danger of infesting the water table through possible infiltration of the resulting leachate into the deposits and reduces methane emissions by abolishing the deposits [18].

The company analyzed in our study has its own treatment plant with three stages: the biological stage, the mechanical stage and the reverse osmosis stage, for the treatment of domestic and technological wastewater from the incinerator and from the company activity.

In order to avoid soil pollution, the temporary storage of all raw materials (waste to be incinerated), auxiliary materials, products (resulting waste to be recovered / disposed of) is done only in sealed containers resistant to the type of substance stored and appropriately labeled located in places specially arranged (waste deposit to be incinerated) provided with concrete platforms and retention tanks, cold rooms, as appropriate.

Following the study carried out in this work, we can conclude that the incinerator emissions fall within the limits of law 278/2013, because the average daily concentrations of the emission parameters evaluated in the analysis bulletins fall within the legal norms.

We can see that the methods of neutralization of the main pollutants discharged into the environment are effective.

Depending on the origin of the incinerated waste, there was exceeding of the average, but during the 24 hours the average allowed value was not exceeded.

Incineration must be a solution of last resort, after the options of reduction, reuse and recycling have been taken into account and must be integrated into a wider waste management strategy. The role of incineration in the context of circular economy and sustainability is important. The objective is to minimize waste, reuse resources and recycle as much as possible. Incineration, although at first sight it seems to contradict these principles, can actually play a complementary role: by transforming waste that cannot be recycled into energy or heat, incineration contributes to reducing dependence on fossil resources and promoting an economy with low emissions of carbon.

Other alternative methods of disposing the hazardous waste are: *controlled storing in environmentally friendly landfills* (this method can prevent direct contamination of the environment, but if the insulating materials deteriorate, soil and groundwater contamination and methane generation may result); *solidification and stabilization* (this consists of mixing these wastes with substances such as cement; the risk of contamination is lower, but in the long term this stabilization may diminish); *neutralization of waste with chemicals* (heavy metals can be precipitated from solutions, acids can be neutralized with bases) - this method can however generate toxic by-products; *bioremediation (*inoculation of bacteria or fungi that break down the waste) - this is a lengthy process and is greatly influenced by temperature and humidity; *nitrification* (melting the waste at very high temperature and turning it into a solid, glass-like material) - this is an energy-intensive process; *pyrolysis and gasification* (these are only effective for chemical and organic waste and can generate toxic gases).

Certainly, all these methods have advantages and disadvantages. Incineration coupled with controlled landfilling can reduce the volume of these wastes immediately, but can generate pollution in the long term if managed improperly. Vitrification and bioremediation - can be slow and expensive, but are more sustainable methods.

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