MICROWAVE THERMAL OXIDATION OF GAS EMISSIONS RESULTING FROM THE RISKY MEDICAL WASTE INCINERATION

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Articolul prezintă o aplicație în tehnica microundelor bazată pe utilizarea unor materiale ceramice puternic absorbante de microunde, care dezvoltă un efect de oxidare (post-ardere) termică a emisiilor poluante (CO, SO_2, NO_x, componente organice volatile COV) rezultate în urma incinerării deşeurilor medicale periculoase.

Sunt prezentate aspecte teoretice şi experimentale ale comportării în câmp de microunde a acestor materiale în diverse variante, nivelurile maxime de temperatură obținute pentru asigurarea regimului termic de oxidare a emisiilor poluante şi panta de creştere a temperaturii pentru diferite niveluri de putere în microunde.

De asemenea sunt prezentate date privind stabilitatea mecanică a materialelor susceptoare de microunde, în condițiile temperaturilor maxime dezvoltate de acestea.

The paper presents an application of the microwave technique based on the use of microwave highly absorbing ceramic materials that develop an effect of thermal post-combustion (oxidation) of the pollutant emissions (CO, SO_2, NO_x, volatile organic compounds VOC) resulting after the incineration of the risky medical waste.

Theoretical and experimental aspects concerning the behavior of these materials tested in different variants in the microwave field, the maximum temperature levels achieved to ensure the thermal regime for the oxidation of the polluting emissions and the positive temperature slope for the different levels of power in microwaves are presented.

Data on the mechanical stability of the microwave susceptor materials in the conditions of maximum temperatures developed by them are also presented.

Keywords: microwave filter, incineration process, risky medical waste, polluting emissions, thermal oxidation

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1. Introduction

Nowadays, the problem of wastes has become more and more severe due to the increase in their amount and their negative impact on the environment.

An important waste category is represented by the medical (solid) waste materials that belong to the high contamination risk category, such as medical single use syringes and devices, anatomical parts and anatomopathological rests, infectious waste, chemical and pharmaceutical waste, medical dressing (bandages), plastic or rubber gloves, perfusion bags.

The source of these waste materials is represented by the hospitals and clinics - typical units from the point of view of the generated waste materials. A percentage of 10 – 25 % of the total waste produced by the medical units is considered risky waste; the rest of it is considered non-hazardous and can be assimilated to municipal waste. Both the amount and the types of medical waste can vary with some factors (the dimension of the medical unit, the type of activity, the number of patients and the period of the year).

According to the regulations in force, risky waste is collected in containers according to certain technical regulations. The package is a yellow carton box, visibly marked with the international biological hazard symbol. The box is lined with a resistant polyethylene layer and has a final closing system on top. The single use box will be eliminated together with its content.

The risky waste ultimate elimination method will ensure a fast and complete destruction of the potentially harmful factors for the people and the environment. Therefore, the method used for the ultimate elimination of this kind of waste is incineration in special installations, named incinerators.

The incinerator will ensure a high combustion temperature in order to obtain waste neutralization by means of the polluting gas retaining and purification equipment. The incinerator will also comply with the international rules and standards relating to the polluting gas emissions into the atmosphere and of the secondary products resulting from the incineration process [1].

At present, the treatment of the medical waste materials, incineration especially, is performed through classical methods that are hazardous for the hospitals and for the people and the surrounding areas due to the polluting emissions (CO, SO_2, NO_x, volatile organic compounds - VOC) generated during this process.

If the hospitals do not have their own incinerators, highly contaminating medical waste material can seriously affect the health of the personnel involved in the waste material collection and transport.

The transport of these medical wastes into or out of the hospitals or clinics increases the risk of environment contamination due to the possible contamination of the transport means that, in their turn, become powerful sources of street contamination.

All these aspects have determined us to initiate a research with the ultimate goal of developing a method for incinerating the highly contaminating medical wastes. The efficient non-polluting incinerator that has been developed can be used at the very place of the waste production. This incinerator is based on the utilization of the microwave energy both for the incineration of waste and retention of resulting emissions by means of a special filter.

2. Theoretical considerations

The ability of a material to be heated in a microwave field depends on its dielectric properties, characterized by the dielectric complex constant ε^*:

$$\varepsilon^* = \varepsilon' - j\,\varepsilon''. \quad (1)$$

Dielectric permittivity ε' represents the material ability to store electromagnetic energy and the loss factor ε'' to dissipate it. The dielectric constant of a material varies with its temperature, frequency and composition.

Knowing the dielectric properties of the medical waste submitted to incineration is very important to the incineration process, both for the assessment of the incineration parameters and of the microwave power levels of the waste amount.

The quantitative assessment of the dielectric constant of the medical waste submitted to the incineration is a very difficult activity as the waste components cannot be sorted by type and treated separately (e.g., the textile material which was in contact with blood or other biological fluids), each waste component having its own dielectric constant.

For this reason, the assessment of the dielectric constants is made by medical waste categories, where the dielectric constant with the highest value is predominant. From this point of view, risky medical wastes can be divided into two important classes:

- the waste with the dielectric constant ε' (dielectric permittivity) ranging between 50 and 70 is the class of fluid wastes, anatomopathological rests and wet cotton waste;
- the waste with the dielectric constant ε' ranging between 1 and 10 is the class of paper waste, plastic materials and textile waste which was in contact with liquids (blood or other biological fluids).

The dielectric constant values of these two waste categories characterize the behavior of medical waste in microwave field during the incineration process, determining the conversion efficiency of the energy transported by the electromagnetic waves into heat.

The power in microwave absorbed in the material (medical waste) is the highest (maximum) when the dielectric constant value is high. The power P absorbed in the material (medical waste) is proportional to the loss factor ε'', the frequency f [Hz] and the electric field intensity E [V/m]:

$$P = 2\,\pi f \varepsilon_0\, \varepsilon''\, E^2 \tag{2}$$

or:

$$P = 55.63 * 10^{-12} f \varepsilon' \tan\delta\, E^2, \tag{3}$$

where the dielectric loss angle (loss tangent) is:

$$\tan\delta = \varepsilon'' / \varepsilon'. \tag{4}$$

Equation (3) shows that, for a fixed value of the electric field E, the power P in microwave absorbed in the waste mass is proportional to the frequency f (which is practically 2.45 GHz), the dielectric permittivity ε' and loss factor ε'' (through the loss tangent $\tan\delta$), which vary with the materials temperature and humidity in their turn.

The power absorbed in the waste mass heats the entire material mass. The temperature depends on the microwave power level supplied by the microwave generator and the magnetron working time. The higher the heat produced in the waste mass, the greater dielectric constants (this is why it is so important to know the dielectric properties of waste).

When a dielectric material is exposed to a microwave field, it is heated directly by microwaves, while a microwave transparent material is heated only by conduction or convection. The ability to selectively store heat is a strong motivation for using of the microwave heating.

Microwaves penetrate dielectric materials [2]. The penetration depth D_p is a function of the dielectric constant ε' and frequency f, with greater penetration when frequency and complex dielectric constant are low:

$$D_p = \frac{c}{2\pi f \tan\delta \sqrt{\varepsilon'}}, \tag{5}$$

where c is the speed of light in vacuum.

The microwave penetration ensures the transport of energy inside the solid material and the uniform heating.

Other important advantages of microwave heating in comparison with other heating methods are: no electrical connections in the noxious gas stream are required and the gas stream is not heated directly (out of efficiency increase reasons) [3].

3. Experiments

The method presented in this paper is the decentralized incineration of the risky medical waste (at the very place of their production). The incinerator constructive solution is based on the utilization of microwave energy.

The frequency of microwaves utilized both for waste incineration and filtration of noxious gaseous emissions, resulting from incineration, is 2.45 GHz (the frequency utilized in Industrial, Scientific and Medical Applications - ISM) [4].

To this goal, the developed incinerator is made up of two combustion chambers, as in the block diagram in fig. 1.

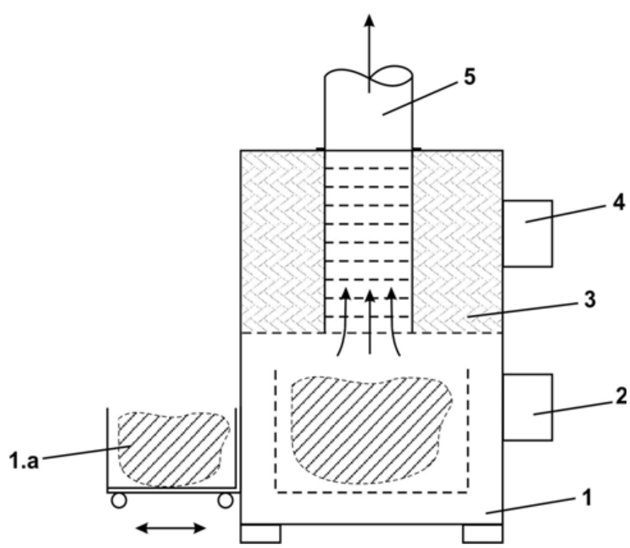

Fig. 1. The block diagram of the microwave incinerator:
1 – primary combustion chamber for waste incineration;
1.a – waste loading system;
2 – microwave generator;
3 – combustion chamber for exhaust gases (filter);
4 – microwave generator;
5 – tubing for filtered gases removal.

The waste incineration takes place in the first combustion chamber (1). This incineration chamber (1) in the form of a parallelepiped is made of stainless steel and includes the following components:

- two microwave sources (2), one of them mounted on the incinerator side wall and the other on the back wall;
- an access door for the waste box loading, frontally mounted;
- an air admission system for the waste burning;
- a microwave absorbent (susceptor) ceramic plate and a thermal ceramic insulation, both placed at the bottom of the chamber;
- a perforated area in the center of the incineration chamber top wall, for the transfer of the gas emissions resulting from the waste incineration to the filter chamber.

This chamber (1) is dimensioned so that to have a resonant frequency around the 2.45 GHz value (in order to ensure a maximum microwave energy transfer to the waste).

For the microwave generators, the incineration chamber is equipped with their anode high voltage transformer (source) and filament voltage transformer (source) [5].

As the plastic materials, especially polyethylene and PET, are microwave less energy absorbent until the melting phase, it was necessary to use a highly microwave absorbent ceramic material which ensures this melting temperature. During the incineration process, the ceramic plate has developed a temperature between 600 and 1000 ^{o}C, ensuring the conditions for incineration of the waste which does not absorb microwave energy.

Besides this role, the ceramic material plays the role of a tray (thermal bed). This bed extends to the entire surface of the chamber bottom and the waste for incineration is placed on the bed surface. This ceramic mass also ensures the necessary temperature for the volatilization of the organic compounds produced by the plastic material waste incineration.

Due to its temperature, the ceramic plate produces the syringe needle annealing and ensures a high temperature of the mixture air - gas emissions which penetrate into the filter chamber, maintaining its high temperature as well.

The ceramic elements of the assembly microwave susceptor ceramic plate - thermal ceramic insulation are fixed together by a temperature resistant ceramic putty.

The combustion chamber (1) is loaded with waste through the loading system (1.a) which is designed so that to prevent unfiltered gas leakages during repeated loading operations. The loading system (1.a) is mounted on the chamber access door.

This loading system is made up of a stainless steel parallelepiped body inside which the waste box is introduced. The body is covered by a lid (door) which prevents the functioning of the incineration chamber microwave sources when it is opened (the loading of the waste box is not dangerous for the human operators).

The transport of the waste box from the loading system to the incineration chamber is performed by means of a translation device (like a drawer) driven by an electric motor.

During operation, the waste introduced into the combustion chamber (1) is submitted to the action of the microwave field, which at first dries the waste (in the case of wet waste) and then incinerates it.

The waste incineration process is controlled by an adjustable air intake (admission), so that the amount of emitted gases has to correspond with the filter clean-up capacity.

The gas combustion chamber (3) filters the gases resulting from the incineration process taking place in the chamber (1). This chamber is also connected to a microwave generator (4) for ensuring the necessary conditions for the gas filtration.

The filter chamber (3) has a cylindrical thermal insulation placed between the microwave susceptor ceramic parts and the inside wall of the cylindrical metallic precinct.

The ceramic material used for the filter thermal insulation is MgO, with low values of the dielectric constants (dielectric permittivity ε', loss factor ε'') and low microwave absorption level.

The filter (3) represents a distinct constructive component of the incinerator. Its role is to reduce the concentration of the gas emissions resulting from the waste incineration process through an oxidation process in the incineration chamber.

The gases passing through this filter – chamber (3) undergo a pyrolysis process, a strong oxidation process, respectively, resulting in an important reduction of the gas concentration.

For manufacturing the filter ceramic parts we have developed a special device. The filter ceramic parts composition has been developed in 3 variants. All the variants include 2 microwave susceptor ceramic materials that differ in their proportion [2].

Microwave susceptor ceramic used materials differ by positive temperature slope and maximum developed temperature. Thus:

- ***the A microwave susceptor material*** has a positive temperature slope up to 750 – 800 ^{o}C, followed by an increase in the microwave energy absorption up to the maximum temperature of about 1100 – 1150 ^{o}C;
- ***the B microwave susceptor material*** has a low positive temperature slope up to 600 – 650 ^{o}C (the absorption level of microwave energy being low), that

continues with a strong microwave absorption, resulting in a maximum temperature reaching about 1900 – 2000 ^oC.

The combination of these 2 microwave susceptor ceramic materials in different proportions ensures the necessary operating temperature of the filter (1200 – 1300 ^oC) and helps in reaching it in a short period of time.

The composition of the 3 variants of the filter ceramic parts is mainly the following:

- the first variant – A susceptor material: 80 %; B susceptor material: 10 %; the rest: miscellaneous materials;
- the second variant – A susceptor material: 70 %; B susceptor material: 20 %; the rest: miscellaneous materials;
- the third variant – A susceptor material: 60 %; B susceptor material: 30 %; the rest: miscellaneous materials.

The filter sintered ceramic parts have undergone an experimental program with the following objectives:

- determination of the positive temperature slope for several microwave power levels;
- determination of the maximum developed temperature;
- determination of the period of time necessary for attaining the maximum temperature;
- verification of mechanical stability maintenance in the course of time (no cracks, fissures, breakthroughs etc. occurrence) of the ceramic part after a certain number of operating cycles.

In order to carry out the experiments, we used an experimental configuration including [6]:

- the multimode-type microwave chamber with the inside walls thermally insulated by means of ceramic fiber for the 1450 ^oC temperature;
- 2 microwave generators of 0 – 850 W adjustable output power, connected to the microwave chamber;
- ceramic materials used to support the parts which are tested inside microwave chamber;
- thermocouple for temperature measuring (PtRd-Pt), fixed on the ceramic part of the filter;
- temperature indicator.

The diagram in fig. 2 presents the results of the experiments.

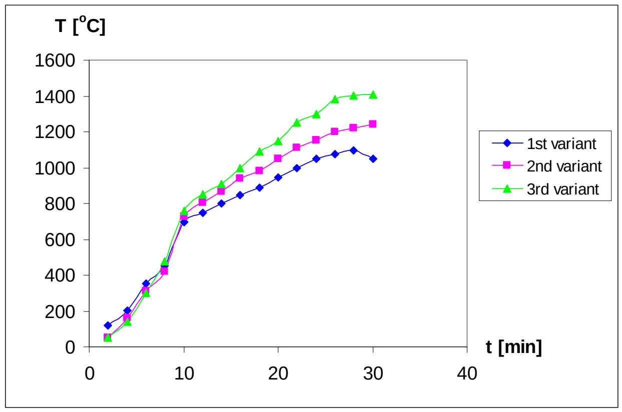

Fig. 2. Variation of the microwave susceptor ceramic material temperature:
- the first variant – A susceptor material: 80 %; B susceptor material: 10 %;
- the second variant – A susceptor material: 70 %; B susceptor material: 20 %;
- the third variant – A susceptor material: 60 %; B susceptor material: 30 %.

By analyzing the obtained experimental results, presented in the figure 2, the third variant of the microwave susceptor ceramic material (A component = 60 % and B component = 30 %) has been chosen for the filter development.

The microwave susceptor ceramic parts have been tested from the mechanical stability point of view for determining whether or not cracks or deformations occur after a number of operating cycles.

The testing program consisted in carrying out 100 heating cycles up to 1400 ^{o}C temperature, maintaining a temperature level of 1400 ^{o}C for 60 minutes and forced cooling up to 200 ^{o}C.

After the testing program has been carried out, the microwave susceptor ceramic parts have exhibited no cracks or fissures.

When they come out of the filter – chamber (3), the gas emission concentration on the tubing (5) is much lower than the admissible levels established by the norms.

In order to determine the emission concentration levels at this type of incinerator, we use a gas analyzer. The probe (well) of the analyzer was mounted on the tubing (5).

The experiments carried out have taken into account monitoring of the gas emission levels in the case of the single - use syringe, medical dressing (bandages), plastic or rubber gloves and perfusion bag usage.

The objective of these tests was to emphasize the role of thermal oxidation of the gas emissions resulting from the incineration process. The oxidation process of these gases takes place at about 1150 – 1400 ^oC, the temperature produced by the microwave susceptor ceramic parts of the filter.

The results obtained from these experiments are shown qualitatively in fig. 3 and quantitatively in tables 1 and 2.

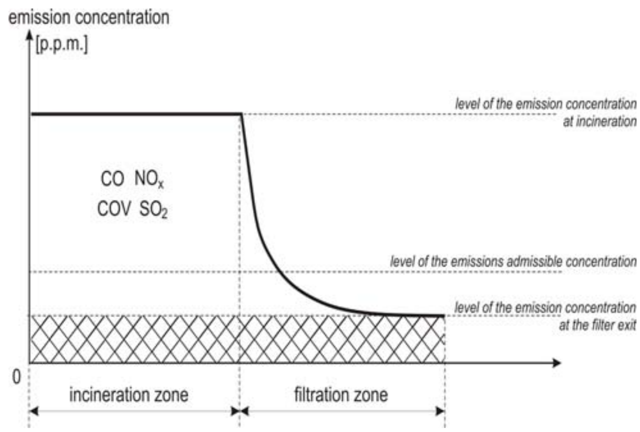

Fig. 3. The emission concentration levels obtained during microwave incineration of medical waste.

Table 1

Gas emission concentration for microwave susceptor ceramic parts of the filter the waste category: medical textile and plastic waste, temperature of 1150 ^oC

The gas emissions type	CO	NO_x	VOC	SO_2	Dioxin
The level of emission concentration at the filter entry	400	1500	77	750	10^{-3}
The level of emission concentration at the filter exit [p.p.m.]	65	300	14	150	-
The level of emission admissible concentration [p.p.m.]	100	400	20	200	10^{-4}

Table 2

Gas emission concentration for microwave susceptor ceramic parts of the filter the waste category: medical textile and plastic waste, temperature of 1400 ^oC

The gas emissions type	CO	NO_x	VOC	SO_2	Dioxin
The level of emission concentration at the filter entry [p.p.m.]	450	1470	80	700	10^{-3}
The level of emission concentration at the filter exit [p.p.m.]	25	100	5	50	-
The level of emission admissible concentration [p.p.m.]	100	400	20	200	10^{-4}

4. Results

The analysis of the chart presented in figure 2 indicates an important reduction in the levels of the gas emission concentration during their passing through the filter. The higher the temperature of the microwave susceptor ceramic material, the more enhanced this reduction, as it can be noticed from tables 1 and 2. This is an evidence of the microwave filter type efficiency.

This filter, in a laboratory testing stage, has another type of microwave susceptor ceramic material which can develop temperatures about 2100 – 2200 ^{o}C. We are considering using these filters in incinerators, as well as in other industrial applications with polluting emissions. This represents an alternative to the electrode filters, with the major advantage of the filter unlimited lifetime.

During the experiments, the following relevant aspects have also resulted:

- at the end of the syringes incineration cycle, in the incinerator there remained only the needles, but they are sterile, the plastic syringe part has entirely disappeared;
- perfusion bags and plastic or rubber gloves have been completely burnt during incineration, disappearing (“evaporating”), too;
- after incineration, the bandages and other medical textile waste have been transformed into a fine, sterile ash, which can be collected from the incinerator and stored like any other non-dangerous waste;
- the filter used in these experiments can have an unlimited lifetime, due to its property of regeneration at the end of each incineration cycle.

5. Conclusions

The obtained results point out that the solution of the non-pollutant incinerator for the elimination of the medical waste is correct and has the following advantages:

- it can be used for the final elimination of the high contamination risk medical waste at the very place where it is produced (surgery and post-surgery units from the hospitals, medical clinics for the treatment of infectious diseases such as hepatitis or AIDS, private clinics etc.);
- minimizes the temporary storage time of the risky waste into the medical unit;
- minimizes the volume of waste resulting from the incineration process;
- eliminates the potential environmental problems by the complete destruction of the pathogen agents and degradation of many noxious organic chemical products, as the ash resulting from the incineration being sterile;
- when it operates, it does not supplementary pollute the environment by pollutant emissions (the measured levels are much lower than the levels allowed by the legislation in force);

- has a low energy consumption in comparison with all the other conventional incineration systems;
- significantly decreases (about 60 %) the medical waste incineration time;
- reduces by 40 % the medical waste incineration costs in comparison with the classical incineration methods;
- does not require special arrangements (water connection, gas connection) for functioning;
- does not require a big investment in comparison with the existing conventional incinerators;
- has small dimension;
- the incineration procedure does not require any auxiliary personnel for the transport or operation (incineration is running at the very place of the waste production).

The above mentioned advantages prove the high performances of the microwave technologies used in the incineration process, in comparison with the traditional technologies.

The main users of the medical waste microwave incineration system are the sanitary units (hospitals, polyclinics, human and veterinary cabinets, dental cabinets etc.). Other potential users are the laboratories from the medical and pharmaceutical research institutes.

The researchers aim at developing incinerator types able to cover diverse types and quantities of medical waste. In this way, the researchers take into account the development of incinerators both for the private medical offices and the surgery units from the hospitals and clinics.

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