https://doi.org/10.18321/cpc477

Plasma technology and equipment for medical waste processing

G. Paskalov[1] and A. Mosse[2]*

[1]LLP «Plasma Microsystems» 22002 Linda Dr., Torrance, California, USA
[2]A.V. Luikov Heat and Mass Transfer Institute, National Academy of Sciences of Belarus, 15 P. Brovki str., Minsk, Belarus

ABSTRACT

In the technology of processing medical waste, including waste generated during a pandemic, the main generally accepted methods are thermal, using fuel or plasma furnaces, for combustion in an oxygen-containing environment or for pyrolysis in a reducing atmosphere to produce synthesis gas (H_2 and CO) that can be further used for the chemical industry or as a fuel. Moreover, direct combustion or pyrolysis of the initial solid waste, which ensures the gasification of its organic components, is usually only the first stage of the general technological process. In general, it consists of three stages. At the second stage, the gas products of the first stage are brought to a predetermined composition, at the third stage, the inorganic residue is neutralized - ash, the formation of which is up to 20% of unsorted medical waste. A promising option for the technology under consideration is the use of electric arc plasma installations. Compared to non-plasma furnaces, even those using intensive gas-dynamic operating modes, a number of significant advantages are achieved: a decrease in the volume of the furnace (while maintaining the productivity of raw materials) and a decrease in the volume of exhaust gases by about an order of magnitude with an increase in temperature in the reaction zone of the furnace to 2000–2300 °C.

Keywords: medical waste, plasma-chemical technology, plasma devices, processed products.

1. Introduction

The problems of medical waste disposal until recently, considered of little relevance for many countries, which coincided with the global assessment of its importance. However, since the end of the last century, interest and a variety of approaches to this problem, especially in highly developed countries (USA, Israel, Japan, Germany, etc.), have increased significantly. It is believed that this is due to the strategic trend declared at the interstate level towards a comprehensive «greening» of the environment, as a factor that compensates for its degradation due to industrial development. And also with an increase in the specific danger to the population from the rapidly accumulating volumes of highly toxic and infected waste from hospitals and biomedical industries. And also the medical waste generated during the pandemic. Some countries did not pay attention to medical waste processing due to the small volume of medical waste compared to the industrial, household and other types of waste. For example, according to the data of 2000, about 37 million tons of non-recyclable waste from the chemical industry was accumulated annually, and 200 thousand tons from the petrochemical industry. The need for the annual disposal of hazardous waste of medical origin was approximately 20 tons. However, sanitary and hygienic studies of typical solid medical waste carried out both in Belarus republic and abroad [1], show that their danger to the environment is significantly higher than that of most chemical wastes (with the exception of only those containing substances of the 1st hazard class according to the toxicological classification) and, for example, in the case

**Ответственный автор*
E-mail: alfmosse@gmail.com (A. Mosse)

of solid waste containing cytostatic drugs, antibiotics and others, comparable to the danger of contamination with radioactive waste of high and medium level of activity (>10 Bq/kg).

The problem under consideration is complicated by the fact that the already accumulated and stored solid medical waste, as a rule, is not sorted and in some cases has a very complex composition that cannot be accurately identified. At the same time, the standards adopted for the processing of medical waste in Japan, Italy and other countries [2, 3] require preliminary sorting of them into groups, depending on the composition. So, there are four main groups:

1) ordinary (biochemically stable) and environmentally friendly waste, which can be disposed of in open landfills (together with household waste) even without additional soil backfill.

2) slightly hazardous, but chemically unstable waste, which, due to decomposition during storage, can emit harmful substances, therefore, they must be disposed of in landfills with an anti-seepage lining and with a special system for collecting and processing wastewater.

3) highly hazardous waste requiring special treatment and subsequent disposal (for example, in Japan, all medical waste containing radionuclides is collected and processed by the Japanese Isotope Society).

4) medical syringes, which are recommended to be collected and recycled separately from other waste.

Obviously, in the case of processing unsorted waste, it will be necessary to use the most universal methods, i.e. guaranteeing disinfection and neutralization of any waste components.

2. Technologies and methods of toxic medical waste recycling

In the technology of processing this type of medical waste, the main conventional methods are thermal, in particular, using fuel or plasma furnaces for combustion in an oxygen-containing environment or pyrolysis in a reducing atmosphere to obtain H_2 and CO, which can be further used as synthesis gas for chemical industry or as a fuel mixture. Moreover, direct combustion or pyrolysis of the initial solid waste, providing gasification of its inorganic components, is usually only the first stage of the overall technological process. In general, it consists of three stages. At the second stage, the gas products of the first stage are brought to a given composition (sometimes it is carried out in a special afterburner), at the third stage, the non-gasified inorganic residue (ash, the formation of which, according to [4] is up to 20% of the mass of unsorted medical waste introduced into the furnace). The latter stage can be carried out by melting the ash to obtain a crystalline material to be buried, or by obtaining vitrified ingots having a higher chemical resistance. The vitrification process requires charging with various additives (iron and silicon dioxide), which makes it possible to obtain silicate materials, from which, when stored in ordinary soils, there is practically no leakage of heavy metal ions, and the rate of their leaching does not exceed 10^{-9} to 10^{-10} kg/(m^2s).

The most promising version of this technology, actively developed in the USA, Germany and Japan in the last 4-6 years (Westinghouse, Plasma Energy Corporation (USA), NUKEM and Siemens (Germany), Prometron (Japan) , Laboratory INEL (USA), etc.), is the use of shaft-type electric arc plasma furnaces In this case, compared with non-plasma furnaces, even using intensive gas-dynamic processing (pseudo-fluidized bed, etc.), a number of significant advantages are achieved. Reduction of the furnace volume by 6–8 times (while maintaining the volume of raw materials) and a corresponding decrease in the area of production systems, a decrease in the volume of exhaust gases by about an order of magnitude and an increase in the temperature in the reaction zone of the furnace to 2000–2300 °C, makes it possible to improve the penetration of the ash residue from combustion and to exclude the formation of toxic components in the gas phase – Cl_2, dioxins and polychlorinated biphenyls.

In our laboratory the collection and analysis of information on the qualitative and quantitative composition of biomedical waste has been carried out, technologies for the processing and disposal of biomedical waste by various methods have been considered, a plasma recycling technology has been described, and a model for the process of high-temperature biomedical waste processing has been selected. Also, a thermodynamic analysis of the plasma thermal processing of liquid medical and biological waste and waste generated in pharmacological production was carried out, a model of an experimental installation was developed and plasma system manufactured, a method for conducting experimental research was chosen. Experiments were also carried out to process samples of real liquid waste from the production of medical products obtained during scientific and technical cooperation with medical institutions. The analysis of the obtained gas phase and the analysis of the remainder of the liquid fraction of each of the samples, which remained in the reactor after treatment, were carried out. The obtained optical spectra were decoded. An experiment was carried out, the purpose of which was to refine the treatment of medical waste and analyze the resulting products. A mixture of ethyl and isopropyl alcohols and acetone in various ratios was used as a raw material. This mixture is a real production waste that is generated during the cleaning of containers in pharmacological industries. These are liquids produced by mexibel: TP-1, TP-2, TP-3 and TP-4, from the stage of obtaining the substance of sodium levothyroxine;

During the experiments, with the given parameters of the plasma reactor in operation, the percentage of gases H_2, CO, CO_2, CH_4 was measured using a combined gas analyzer and the temperature of the exhaust gas (T_1 is the temperature at the outlet of the reactor, T_2 is the temperature at the outlet of the afterburner). The operating modes of the reactor and the results of the experiments performed are shown in Fig. 1.

The decoding of the obtained spectra was carried out, during which it was found that the qualitative composition of the liquid fraction is identical to the loaded material. Thus, it can be concluded that the synthesis of secondary toxic substances does not occur in the reactor.

The analysis of the composition of waste gases such as Cl_2, cyanides and undecomposed chlorine-containing organic substances was carried out using a RAID-S2 ion spectrometer. These substances were not found in the exhaust gases. Similar results were obtained and presented in [5], where it is shown that the plasma-thermal technology for waste processing is universal, because it can be used for the disposal of any waste, regardless of their composition and preliminary sorting.

3. Plasma pyrolysis – efficient method for processing of COVID-19 medical waste

COVID-19 has led to a huge increase in medical waste around the world, mostly generated in hospitals, clinics and other healthcare facilities [5]. This poses an additional challenge in the management of medical waste, especially in developing countries. Improper handling of medical waste can cause serious public health problems and have a significant impact on the environment. There are currently three disinfection technologies available for the treatment of COVID-19 medical waste (CMW), namely incineration, chemical and physical recycling. We focus on thermochemical processes, in particular the pyrolysis process for the treatment of medical waste. Pyrolysis is a process that takes advantage of the instability of organic components in medical waste to convert them into valuable products. In addition, the technology is environmentally friendly and more efficient, requires less disposal capacity, causes less pollution and is more cost-effective. The current pandemic situation is generating a large amount of plastic medical waste, which contains components such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and nylon (N). This plastic waste can be converted into valuable energy products such as oil and gas. This study provides information on the handling of KTM,

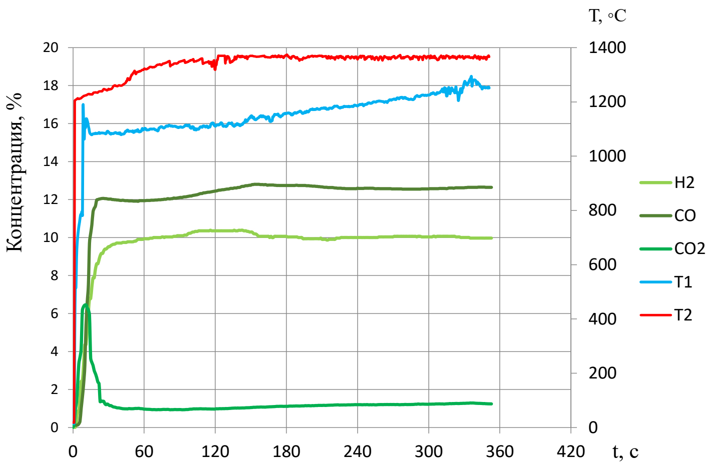

Fig. 1. Experimental Data of TP-1 processing.

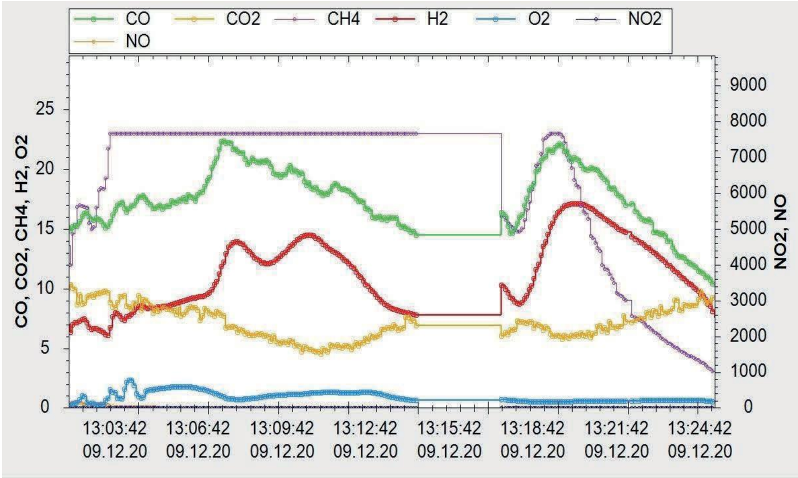

Fig. 2. Chemical composition of off gases at average plasma temperature of 1200 to 1300 °C.

processing methods, the production of valuable products (biofuels) and proper discharge into the open environment. This plastic waste can be converted into valuable energy products such as oil, gas and coal through the pyrolysis process. The origin of the new human coronavirus (SARS-CoV-2) and its potential danger have increased the amount of face masks and medical waste in the environment, requiring urgent measures to prevent and control the pandemic. In works [5–7], the generation of face masks and medical waste in different countries during a pandemic is assessed in order to convince waste management authorities and the scientific community to find ways to eliminate the negative impact that waste disposal has on the environment. Standardization, procedures, guidelines and strict adherence to the management of COVID-19-related medical waste in public habitats and public places must be carefully considered to reduce the risks of a pandemic in hospitals, as proper disposal of medical waste effectively controls sources of infection. Currently, in connection with the coronavirus pandemic, the most acute problem is the safe disposal of masks, gloves and other medical waste. Within the framework of the legislation of most countries, during the collection, disposal, temporary storage of waste in medical institutions, all medical waste must be disposed of using methods that are safe for the environment. To solve this problem, plasma technology is the most optimal technology in terms of safety, productivity and energy efficiency [6]. A set of tests was carried out on a plasma installation to find optimal technological solutions. Parameters such as the composition of exhaust gases, its dependence on temperature in the chambers of plasma-arc reactors/furnaces, specific energy consumption in the technological process, etc. have been determined. The need to obtain these parameters is associated with the further development of installations with a capacity of 50 kg/h and more. Experimentally obtained optimal temperature range is 1200–1300 °C. Chemical composition of the exhaust gases is shown in Fig. 2.

The chemical composition of the gas generated at the high temperature in the furnace chamber is the best in terms of productivity and composition of the gases formed. When the temperature rises to 1200–1300 °C in a plasma-arc furnace, the elemental composition of the exhaust gases is: CO_2 – 4.5%, O_2 – 0.5%, CO – 22%, H_2 – 14.5%, NO – 0 ppm, NO_2 – 0 ppm. According to experimental data, the gas contains no nitrogen oxides and dioxides, and also low carbon dioxide content. The peaks in the graph shown in Fig. 2 are associated with the discrete feeding of packaged waste. Comparison of calculated and experimental data for the process of high-temperature gasification of organic waste shows good convergence.

4. Conclusion

Thus, the goal of the work was achieved, namely: determination of optimal technological parameters: composition of exhaust gases, dependence of exhaust gases on temperature in a plasma-arc furnace, specific energy consumption in the technological process, etc. Temperature conditions for disposal of medical waste before their complete decomposition into simple chemical compounds. At the same time, there are no harmful components in the exhaust gases.

Our experimental studies [8, 9] also made it possible to establish the possibility and feasibility of implementing plasma technology.

References

[1]. Brunner CR, Brown CH (1988) Journal Air Pollution Control Association (JAPCA) 38(10):1297. DOI:10.1080/08940630.1988.10467014

[2]. Briosi GL, Ventola G (1989) La Termotecnica 43(12):49.

[3]. Tanaka M (1989) Kogykenkyu 18(4):45. DOI:10.2134/jeq1989.18145x

[4]. Proceedings of the IInd International Symposium on Plasma Chemistry. Ivanovo, Russia (1995): 387.

[5]. Dharmaraj S, Pandiyan R, Halimatul Munawaroh HS, Chew KW, Chen W-H, Ngamcharussrivichai C (2021) Chemosphere 275:130022. DOI:10.1016/j.chemosphere.2021.130092

[6]. Jacob S, Nitianandam S, Rastogi S, Sakhuja S, Alankar SNSL (2021) Environmental and Health Management of Novel Coronavirus Disease (COVID-19) 207–232. DOI:10.1016/B978-0-323-85780-2.00012-3

[7]. Domarov PV, Anshakov AS, Faleev VA (2021) Journal of Physics: Conference Series 2119:012039. DOI:10.1088/1742-6596/2119/1/012039

[8]. Messerle VE, Mosse AL, Nikonchuk AN, Ustimenko AB (2015) Journal of Engineering Physics and Thermophysics 88(6):1471-1475. DOI:10.1007/s10891-015-1332-1

[9]. Nikanchuk AN, Mosse AL, Sauchyn VV, Lozhachnik AV (2009) VI International Conference Plasma Physics and Plasma Technology. Minsk, Belarus: 684-687.

Технологии и оборудование для плазменной утилизации медицинских отходов

Г. Паскалов[1], А. Моссэ[2]

[1]ТОО «Plasma Microsystems», 22002 Линда Др., Торренс, Калифорния, США
[2]Институт тепло-массообмена им. А.В. Лыкова, НАН Беларуси, ул. П. Бровки, 15, Минск, Беларусь

Аннотация

В технологии переработки медицинских отходов, в том числе отходов, образующихся во время пандемии, основными общепринятыми способами являются термические, с использованием топливных или плазменных печей, для сжигания в кислородсодержащей среде или для пиролиза в восстановительной атмосфере с получением синтез-газа (H_2 и CO), которые в дальнейшем можно использовать в химической промышленности или в качестве топлива. При этом непосредственное сжигание или пиролиз исходных твердых отходов, обеспечивающие газификацию их органических компонентов, обычно является лишь первой стадией общего технологического процесса. В целом он состоит из трех этапов. На втором этапе доводят до заданного состава газообразные продукты первого этапа, на третьем этапе обезвреживают неорганический остаток – золу, образование которой составляет до 20% несортированных медицинских отходов. Перспективным вариантом рассматриваемой технологии является использование электродуговых плазменных установок. По сравнению с неплазменными печами, даже использующими интенсивные газодинамические режимы работы, достигается ряд существенных преимуществ: уменьшение объема печи (при сохранении производительности сырья) и уменьшение объема уходящих газов примерно на порядок при повышении температуры в реакционной зоне печи до 2000–2300 °С.

Ключевые слова: медицинские отходы, плазмохимическая технология, плазменные устройства, переработанные продукты.

Медициналық қалдықтарды плазмалық кәдеге жарату технологиялары мен жабдықтары

Г. Паскалов[1], А. Моссэ[2]

[1]Plasma Microsystems LLP, 22002 Линда Др., Торренс, Калифорния, АҚШ
[2]Жылу және масса алмасу институты, А.В. Лыкова, Беларусь Ұлттық ғылым академиясы, П. Бровки, көш., 15, Минск, Беларусь

Аңдатпа

Пандемия кезінде пайда болған қалдықтарды қоса алғанда, медициналық қалдықтарды өңдеу технологиясында негізгі дәстүрлі әдістер оттегі бар ортада жағу немесе синтездік газды (H_2 және CO) алу үшін қалпына келтіретін атмосферада пиролизді пайдалану үшін термиялық, отын немесе плазмалық пештерді пайдалану болып табылады, кейінірек химия өнеркәсібінде немесе отын ретінде қолданылуы мүмкін. Бұл жағдайда олардың органикалық компоненттерін газдандыруды қамтамасыз ететін бастапқы қатты қалдықтарды тікелей жағу немесе пиролиздеу әдетте жалпы технологиялық процестің бірінші кезеңі болып табылады. Жалпы, ол үш кезеңнен тұрады. Екінші кезеңде бірінші кезеңнің газ тәріздес өнімдері алдын ала белгіленген құрамға келтіріледі, үшінші кезеңде бейорганикалық қалдық бейтараптандырылады – күл, оның түзілуі сұрыпталмаған медициналық қалдықтардың 20% дейін құрайды. Қарастырылып отырған технологияның перспективалы нұсқасы электр доғалық плазмалық қондырғыларды пайдалану болып табылады. Плазмалық емес пештермен салыстырғанда, тіпті интенсивті газ-динамикалық жұмыс режимдерін қолданатындармен салыстырғанда, бірқатар маңызды артықшылықтарға қол жеткізілді: пештің көлемінің төмендеуі (шикізат өнімділігін сақтай отырып) және пайдаланылған газ көлемінің төмендеуі пештің реакция аймағындағы температураның 2000–2300 °C дейін жоғарылауымен газдар шамамен шама ретімен.

Кілт сөздер: медициналық қалдықтар, плазмалық-химиялық технология, плазмалық құрылғылар, өңделген өнімдер.