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ENGINEERING AND PHYSICAL BASES AND ENVIRONMENTAL SAFETY OF PLASMO-CHEMICAL DISPOSAL OF HAZARDOUS MEDICAL WASTE

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ABSTRACT

The unrestrained growth in the amount and rate of production of hazardous medical waste in the context of the Russian-Ukrainian war critically exacerbates the environmental situation in Ukraine. At the same time, existing traditional methods and technological means are not able to ensure their complete environmentally safe processing and disposal. The paper considers an alternative high-temperature technology for plasma-chemical pyrolysis of medical waste at 1,100−1,250°C, which is implemented in the form of a Plazmon-3 mobile plasma pyrolysis unit, designed and built based on the PUN-1 domestic universal plasma generator. The paper also describes the design, principle of operation, engineering and physical principles underlying the creation of the Plazmon-3, designed to dispose of any type and category of medical waste by destroying it under the action of a high-temperature plasma torch generated by the PUN-1 DC plasma generator, as well as its main operational characteristics. Air, nitrogen, argon, helium, and other gases can be used as plasma-forming gases for the installation. The paper describes the advantages of using high-temperature plasma-chemical pyrolysis for the disposal of hazardous medical and other wastes, which make this technology, in terms of its environmental safety, beyond competition and, unlike its smoke-emitting counterparts, capable of destroying medical waste directly at the point of its generation without forming environmentally hazardous residues and emissions.

Keywords: medical waste, incineration, plasma-chemical pyrolysis, military medical waste, plasma generator, mobile plasma arc unit

INTRODUCTION

As a result of the unrestrained growth and widespread use of disposable medical materials in the context of the Russian-Ukrainian war in Ukraine, the volume and rate of production of hazardous medical waste (HMW) are critically increasing. At the same time, today all medical waste in Ukraine is classified

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as hazardous, and the term ‘medical waste’ defines the full range of all categories and types of medical waste. According to the Order of the Ministry of Health of Ukraine of 8 June 8 2015 No 325 and other legal provisions/recommendations, medical waste in Ukraine is classified into four categories:
– A – epidemically safe medical waste,
– B – epidemically hazardous medical waste,
– C – toxicologically hazardous medical waste,
– D – radiologically hazardous medical waste.

At the same time, the current technological imperfection of the medical waste management system threatens human health and critically aggravates the environmental crisis.

The most common method of medical waste disposal in almost all countries of the world is incineration in the open air or in incinerators. However, due to the lack of modern high-performance and environmentally friendly technologies for the treatment and disposal of medical waste, up to 95% of medical waste ends up in authorised and unauthorised landfills and dumpsites, posing severe chemical, toxic, biomedical, carcinogenic, mutagenic, irritant, radiation, actively caustic, sensitising, flammable, explosive risks and many other health effects on Ukrainian citizens. At the same time, the improper handling of hazardous medical waste and its uncontrolled distribution can lead to infection of medical personnel and the public through skin, respiratory, and digestive tract infections.

The morphological composition of medical waste is unpredictable and depends heavily on the specifics and characteristics of the medical facilities that generate it, as well as on many other factors.

AIM AND METHODOLOGY

The purpose of this paper is to analyse the advantages and disadvantages of using high-temperature plasma--chemical pyrolysis for the disposal of hazardous medical and other wastes.

The following scientific methods were used for the analysis: comparison and generalization of statistical data on waste disposal in Ukraine in recent years. After such analysis, appropriate conclusions were drawn.

RESULTS OF THE STUDY

Analysis of the environmental hazards of the processes adopted in the updated medical waste management system in Ukraine

The process of open-air incineration of medical devices usually has a temperature of no higher than 500−700°C. Such low temperatures are insufficient for complete environmentally safe thermal utilisation and complete destruction of medical devices. This is because such low-temperature conditions produce new, equally dangerous, persistent chemical compounds – dioxins, furans, hydrochloric acid and other toxicants – that are released into the environment and further accumulate in food cycles.

The further combustion of such residues using additional chambers specially installed in incinerators often does not have the desired effect in terms of the norms and requirements of the current legislation of Ukraine, updated in accordance with European standards.

In view of this situation, the Ministry of Health of Ukraine, by its Order No 1602 of 2022, made important changes to the State Sanitary and Epidemiological Rules and Regulations on Medical Waste Management; changes aimed at reducing hazardous risks and blocking the pathways for hazardous substances and materials to enter household landfills/dumps.

The new regulations require all medical waste, except food waste, to be collected separately and then transferred for reuse and recycling.

Another important environmental innovation is the prohibition against chemically disinfecting infected hazardous medical devices, which eliminates the operation of dangerous soaking and rinsing of waste.

There is also a new provision requiring the appointment of specialists responsible for waste management in health care facilities (HCFs) who are obliged to develop standardised schemes for the management of medical waste, to regulate all actions in the management of medical waste in HCFs, from its generation to its disposal or transportation, and to be responsible for the implementation of these schemes.

However, the problem of providing modern technologies for the complete environmentally friendly and safe disposal of medical waste remains beyond the scope of the aforementioned Ukrainian Order No. 1602. In this case, special attention should be paid to the technological aspect of the disposal of waste from infectious and tuberculosis departments, veterinary waste and waste with biological weapons risks, as well as medical waste infected with dangerous diseases (AIDS, hepatitis, etc.). At the same time, despite the considerable cumbersomeness and overload of the medical waste management system, most methods and means of disinfection/disinfection of medical waste still require their additional final incineration with subsequent transportation of unburned ash residues to landfills and landfills. At the same time, the new technologies being introduced for the utilisation of medical waste until its complete environmentally safe destruction should fully cover the disposal of the entire range of hazardous medical waste produced by the more than 70,000 Ukrainian hospitals, clinics and other medical facilities and institutions.

Chemical disinfection/decontamination of various medical wastes before their official transfer to licensed companies for disposal also poses dangerous risks. In this case, there are additional environmental risks to the health of medical and transport personnel as a result of the joint synergistic effects of methylene blue disinfectant together with chemical disinfectants. To solve this problem, it is necessary to create new high-temperature technologies that can radically manage medical waste with fully guaranteed environmental protection during the restoration of community territories.

In Ukraine, relatively expensive incinerators have been used to incinerate hospital biological waste that, according to the World Health Organization (WHO), can dispose of hazardous medical waste in accordance with the most stringent requirements of the new European standards. It is believed that such incinerators can be operated within a radius of 50–100 m of hospitals or residential buildings.

For example, the French Muller S.R.50M incinerator (Fig. 1) for the incineration of organic solid waste completely destroys microorganisms and if any emission parameter exceeds the relevant European standard, the operation of the insinuator is automatically blocked. The incineration depth of infected medical waste reaches 95%, and the remaining 5% of the ash residue can be transported to a landfill. With an average specific heat of waste combustion of 3,500 $kcal \cdot kg^{-1}$ by high-temperature pyrolysis combustion at temperatures up to 850°C in the pyrolysis chamber, followed by afterburning of pyrolysis gases at 1,100–1,250°C in an additional chamber without the formation of ‘black smoke’ and fine dust, the productivity of Muller incinerators is 50–60 $kg \cdot h^{-1}$.

The Muller S.R.50M incinerator destroys combustible medical waste, including epidemiologically hazardous waste, any combustible organic waste, hazardous biological waste from veterinary, livestock, poultry, meat processing, expired pharmaceuticals and pharmaceutical waste, radioactive waste and prohibited pesticides are excluded.

However, it should be noted that medical waste with such a caloric content is not common. At the same time, the Muller S.R.50M incinerator has rather bulky dimensions and high material consumption with its insignificant non-industrial capacity.

In addition, the principal technological temperature limitation of any incinerator is that to deepen the ‘burnout’ of environmentally hazardous substances newly formed in the combustion of medical waste, an additional amount of ‘cold’ air is required to be directed into the combustion chamber, which reduces the temperature in the combustion chamber to 400–500°C, which, among other things, does not ensure the guaranteed destruction of pathogenic extremophilic microorganisms.

Fig. 1. General view of the Muller S.R.50M incinerator made in France

Source: own photo.

The use of other non-combustion (non-fire) means, such as autoclaves and hydroclaves, for the sterilisation of waste by direct and indirect heating still requires further mandatory additional incineration in fire ovens of the medical waste treated in this way.

The same situation applies to very expensive microwave disinfection methods – medical waste sterilised by this method is also transported along with municipal waste to landfills or incinerated.

Against this background, plasma arc technology is the only technology capable of easily creating temperatures of up to 10,000°C and more in a medical waste combustion chamber. Commercially attractive technologies for the plasma-chemical pyrolysis of medical waste already exist and are easily scalable for both local and industrial scale utilisation, recycling and destruction of all types of medical waste without prior sorting. All these and other advantages make plasma-mode technologies unrivalled in terms of environmental safety when treating hazardous toxic waste, and, unlike their smoke-emitting counterparts, plasma-mode incineration and pyrolysis technologies destroy medical waste without the formation of environmentally hazardous residues.

The term 'plasma-chemical pyrolysis' defines the physicochemical process of decomposition of organic compounds carried out in low-temperature plasma with average molecular energies in the range of up to 50 eV. In this case, the plasma-chemical pyrolysis of hydrocarbons can take place directly in an electric arc (electro--cracking) or in a plasma jet of hydrogen and other gases.

Cooling/hardening of pyrolysis gas products with temperatures up to 3,700°C is most often carried out in heat exchangers. The products of the plasma-chemical process are also often cooled by water jets or jets of other liquid or gas coolants. At the same time, quenching of hydrocarbon plasma-chemical pyrolysis products with hydrocarbons increases the number of commercial products and improves the flexibility of regulating their chemical composition at lower energy costs. Therefore, the improvement of existing and development of new technological plasma-arc means of medical waste processing and utilisation is an extremely relevant practical scientific and technological problem. Compared to incinerators, plasma arc incineration maintains the temperature in the reactor's reaction zone at 1,200–3,000°C. At such temperature values in the reaction combustion zone, it is impossible for reactions to occur that result in the formation of highly toxic dioxins, phosgenes, polyhalogenated biphenyls or furans containing halogens (Paton, Cherenets, Marinsky, Korzhik & Petrov, 2005a, 2005b; Zhdanok & Mosse, 2008; Mosse, Savchenko, Savchyn & Levashov, 2012).

When plasma arc technology is used for medical waste disposal, the amount of toxic dioxins and furans is significantly less than the accepted emission standards and does not require sorting/separation of hazardous waste. At the same time, pathogenic microorganisms are completely destroyed.

Today, plasma arc technologies are environmentally acceptable industrial technologies that can create and maintain high temperatures of 1,100–1,300°C, high chemical reactivity and energy density for high-speed heat treatment, processing or disposal of medical and other solid, liquid and gaseous waste in milliseconds. In order to improve the economic and environmental performance for the plasma arc unit's own needs, it is possible to produce high-energy synthesis gas in the form of a mixture of carbon monoxide and hydrogen.

Consequently, the traditional incineration of medical, biomedical and chemical waste in the open air and in closed incinerators has dangerous environmental consequences over long periods of time. During long-term operation, the incinerators themselves become sources of environmentally hazardous pollution. Therefore, the development and creation of new economically and environmentally feasible technologies for the environmentally friendly and safe disposal of all types of medical waste has become a critical necessity. Today, many companies around the world, including Pyrolysis Systems Inc. (Canada), Siemens (Germany), Plasma Energy Applied Technology Inc. (USA), Plasmapole (France) and others, are developing high--temperature plasma arc systems for various purposes.

Global technological and environmental experience, and the current state of plasma technologies for medical waste disposal

Plasma is a mixture of neutral and high-energy charged particles with high kinetic energy. Ionised charged plasma particles are capable of entering into recombination reactions with detached electrons and in this process release significant energy in the form of ultraviolet radiation. The kinetic energy of the particles is converted into thermal energy, which is sufficient for the destruction of chemicals. Due to the presence of charged and excited particles in the plasma, the plasma environment becomes highly reactive and capable of catalysing homogeneous and heterogeneous chemical reactions.

In the case of plasma-chemical pyrolysis, solid medical waste containing carbon is gasified to form gas--aerosol mixtures that are subjected to cooling and purification. The purified mixture can be used to generate heat or electricity and to produce various fuels such as ethanol, hydrogen, and combustible synthesis gas in the form of a mixture of hydrogen and carbon monoxide. The inorganic materials are melted by plasma torches and separated in the form of a glassy, chemically resistant slag.

The significant heat generated in plasma-chemical reactors and combustible synthetic gases can be used in the plasma-pyrolysis cycle itself to save external energy resources, thus increasing the economic performance of the technology/plant. At the same time, the impact of plasma-chemical pyrolysis on the environment in terms of its environmental safety and its environmental manufacturability is superior to other methods and technologies for medical waste management.

Today, plasma arc heating technologies are already in use around the clock at various enterprises around the world. For example, six plasma torches with a total capacity of 2.5 MW are in constant operation at the Defiance plant in the United States to process more than 280 t of scrap metal per shift.

Historically, the first demonstration of a prototype electric arc incinerator in 1987 was carried out by Westinghouse Environmental Services in the United States. About a year later, in 1988, the Hungarian Institute of Electrical Industry developed a new pilot plasma reactor for the destruction of chemical waste (Krajcsovics, Pocsy, Emho & Puskas, 1988). A year later, in 1989, Retech Corporation of California and the U.S. Department of Energy initiated a joint program for the destruction of various wastes using plasma arc technologies (Cretenot, Vanrenterghem, Labrot & Pineau, 1990).

In 1994, the first rotary plasma furnace for the treatment of chlorinated organic compounds was created, with an organic contaminant destruction efficiency of up to 99.9% and very high dioxin and furan destruction characteristics at the level of $(5–9)\times10^{-3}$ $ng\cdot m^{-3}$, which is much lower than the global environmental standards.

For many years, various companies around the world have been investigating plasma-arc treatment processes for many hundreds of different types of waste on an industrial scale. In this process, solid household and medical waste, ash, tires, coal and sludge waste, polychlorinated biphenyl, hazardous ash and sludge, paints, solvents, various materials from landfills, as well as low-level radioactive waste, etc. have been effectively treated and utilised.

CSIRO/Siddons Ramset Ltd's PLASCON™, Retech, Westinghouse Plasma Company, Plasma Energy Corporation and other companies continue to develop large-scale plasma waste disposal systems.

In plasma-chemical pyrolysis processes, the main compounds formed from carbonaceous matter are methane, carbon monoxide, hydrogen, carbon dioxide, and water molecules. Plasma-chemical pyrolysis combines the thermochemical features of plasma with the process of pyrolysis using high-temperature plasma arcs in oxygen-deficient environments to completely degrade hazardous substances in waste into simpler molecules. At the same time, an important feature of plasma pyrolysis compared to the traditional incineration of solid combustible medical waste (CMW) is that preliminary sorting of chlorinated waste is greatly simplified or becomes unnecessary.

Compared to existing technologies, the thermal plasma treatment of medical and other waste has the following advantages:

1. At high temperatures, plasmo-chemical destruction reactions of hazardous molecules and heavily polluting molecular complexes occur, as well as melting with subsequent solidification and vitrification of the inorganic component of medical waste, which significantly reduces the volume of waste and hermetic coke pollution in the form of chemically resistant slag formations that are difficult to destroy.
2. The high energy density of 200 $GJ \cdot m^{-3}$ in the plasma torch makes it possible to create high-performance mobile and stationary installations with lower capital costs. The compact dimensions and high energy density significantly reduce the time to start up and shut down the plants.
3. The use of an electric arc as an energy source makes it possible to separate the heat generation process from the oxygen oxidation process, and it is independent of the oxidiser or air consumption. The use of high-temperature electric arcs also reduces the consumption of various plasma-forming gases.
4. The powerful ultraviolet radiation of the plasma arc significantly accelerates the destruction of waste, which is especially effective in the pyrolysis of organic chlorides. The high temperatures (Nema & Ganeshprasand, 2002) in the reaction zone minimise the duration of heat treatment of waste and achieve high productivity in its processing/recycling. Various automated means of monitoring and controlling the plant can be used for the highly efficient control of plasma-chemical processes.
5. The economic efficiency of plasmo-chemical means of processing various wastes can be increased by synthesising various commercial products with high added value for both external and internal needs.
6. The Plazmon-3 facility can completely destroy and utilise almost all categories of hospital waste: cotton products, various plastics, cellulose-polymer bandages, polyvinyl chloride blood bags, gloves and catheters made of polyurethane or silicone rubber, polyethylene and polymethyl methacrylate materials, glass and others, and as a result of exposure to powerful ultraviolet radiation, completely destroy pathogenic microorganisms, infected biomedical waste, and pathological waste and tissues. At the same time, medical waste is treated in the reactor without detailed sorting and without any segregation or pre-treatment.
7. The high-temperature plasma environment also completely destroys all types of bacteria, as evidenced by the results of bacterial tests for the presence of *Bacillus stearothermophilus* and *Bacillus subtilis* microorganisms in the smoke residues, which were specially grown in the laboratory on stainless steel strips and then passed through the high-temperature plasma environment in the primary chamber.

To organise a continuous plasma pyrolysis process, the temperature in the plasma chemical reactor should be maintained at 1,100–1,300°C. Moreover, each local volume of gas obtained in the process of waste processing should be in the specified temperature zone for less than or equal to 2 s (Vashchenko, Korduba, al Saeed Hafez, Nehoda & Tsybytovskyi, 2023). Under such temperature conditions, toxicants are completely decomposed, and the chlorine present in hydrochloric acid (HCl) easily forms salts in the purification processes.

To block the re-formation of toxicants, plasma pyrolysis products need to be cooled quickly. Especially intensively environmentally hazardous pyrolysis products are formed in the temperature range of 200–65°C with a maximum at a temperature of approximately 300°C. In order to bind chlorine into stable chemical compounds, the cooling process of plasma pyrolysis products is completed by passing them through a lime solution (milk of lime) or a soda solution (Zhovtianskyi et al., 2018).

Figure 2 shows a block diagram of the Plazmon-3 mobile plasma-chemical pyrolysis unit. It should be noted that this unit can also be used for the treatment of radio-pharmaceutical waste (Stockholm Convention on Persistent Organic Pollutants [SSCPOP], 2008).

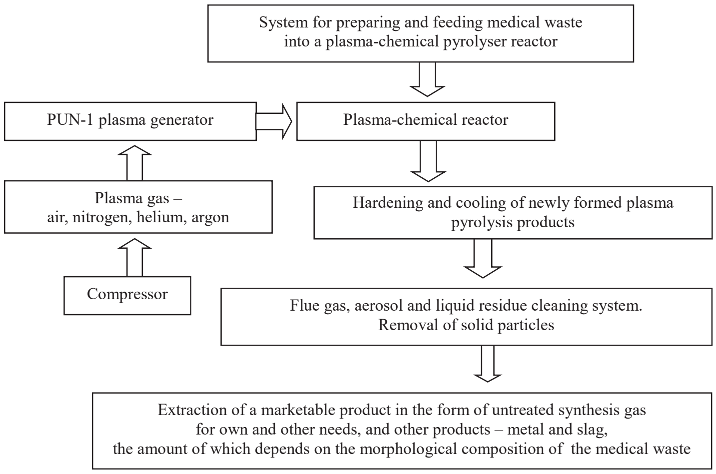

Fig. 2. Block diagram of the Plazmon-3 plasma arc pyrolysis unit with a capacity of 2–3 t·day^{-1} at a waste moisture content of –20%

Source: own work.

One of the main basic principles of the development and creation of mobile plasma plants is to ensure their maximum autonomy with the possibility of power supply from both stationary and autonomous mobile diesel generators. The Plazmon-3 mobile autonomous unit is fully assembled in a 20-foot sea container and can be transported to places of medical waste generation/accumulation.

The prototype of the Plazmon-3 unit was the experimental pilot Plazmon-1 unit (SSCPOP, 2008; Fig. 3). One of the main basic principles of the development and creation of mobile plasma plants is to ensure their maximum autonomy with the possibility of power supply from both stationary and autonomous mobile diesel generators. The Plazmon-3 mobile autonomous unit is, therefore, fully assembled in a 20-foot sea container and can be transported to places of medical waste generation/accumulation.

The main components of each plasma arc system are: plasma generator, power supply and cooling units for the plasma generator, plasma chemical reactor, compressor for supplying compressed plasma-forming gases to the plasma generator, system for preparing medical waste and feeding it to the reactor, cooling/hardening system for products generated in the process of plasma arc incineration of waste, system communication unit, control panel, unburned residue storage unit, final flue gas and aerosol products cleaning system, other auxiliary, control and management systems.

The Plazmon-1,2,3 experimental units were created based on a PUN-1 domestic direct-current plasma generator with air as the plasma gas. The PUN-1 plasma generator was developed at the E.O. Paton Institute of Electric Welding. The main tactical and technical characteristics of the Plazmon-3 unit are presented in Table 1.

Fig. 3. General view of the pilot experimental Plazmon-1 plasma arc unit

Source: own photo.

Table 1. Plazmon-3 specifications

Parameter	Unit	Value
Electric power of the PUN-1 plasma generator	kW	≤ 90
Temperature at the outlet of the plasma generator nozzle	°C	≤ 6 000
Temperature of the air jet into the reactive combustion zone (RCZ)	°C	≤ 1 500–3 500
Combustion temperature in RCZ depending on the composition and humidity of medical waste	°C	1 150–2 000
Plasma air velocity at the compressor outlet	$m \cdot s^{-1}$	50–90
Velocity of the air plasma jet at the inlet to the RCZ	$m \cdot s^{-1}$	20–100
Time of existence of pyrolysis products in the reactor before they start cooling	c	≤ 2
Degree of molecular destruction of waste	%	99.95
Temperature of the flue mixture at the outlet of the chimney	°C	76–90
Air consumption for cooling (quenching) of cool flame combustion products	m^3	≈ 150
Total amount of gases generated as a result of coalbed methane combustion that are supplied for cooling and cleaning	$m^3 \cdot h^{-1}$	≤ 1 000
Content of pollutants in the treated gas and aerosol flue residues emitted into the atmosphere	–	at the MAC level
Specific energy consumption	$kWh \cdot kg^{-1}$	1–2
Amount of heat generated from waste	$kWh \cdot kg^{-1}$ $kcal \cdot kg^{-1}$	1–2 1–3
Productivity at the entrance	$t \cdot day^{-1}$	2–3
Installation weight	kg	≤ 1 000
Installation dimensions	m	≤ 3 × 2 × 1.5

Source: own work.

The modular design of the plant makes it possible to arrange the plant for different process variants in order to adapt it to different types and categories of waste-solid, liquid, gas and aerosol, etc.

The technical documentation for the Plazmon-3 plant contains information on the structure of the medical waste disposal plant, the general principles of operation, operating and maintenance rules, as well as instructions for starting the plant and changing its operating modes. Compliance with the instructions, rules and regulations contained in this documentation ensures safe operation of the facility.

Mobile plasma arc pyrolysis unit

In recent years, due to the technological criticality of the situation with medical waste disposal in different countries, mobile plasma arc pyrolysis units have been of technological and environmental interest.

The layout of the technological flowchart, general view and design features of the Plazmon-3 mobile plasma pyrolysis unit for the disposal of medical waste, developed and manufactured in Ukraine, are shown in Figure 4 (Vashchenko et al., 2019).

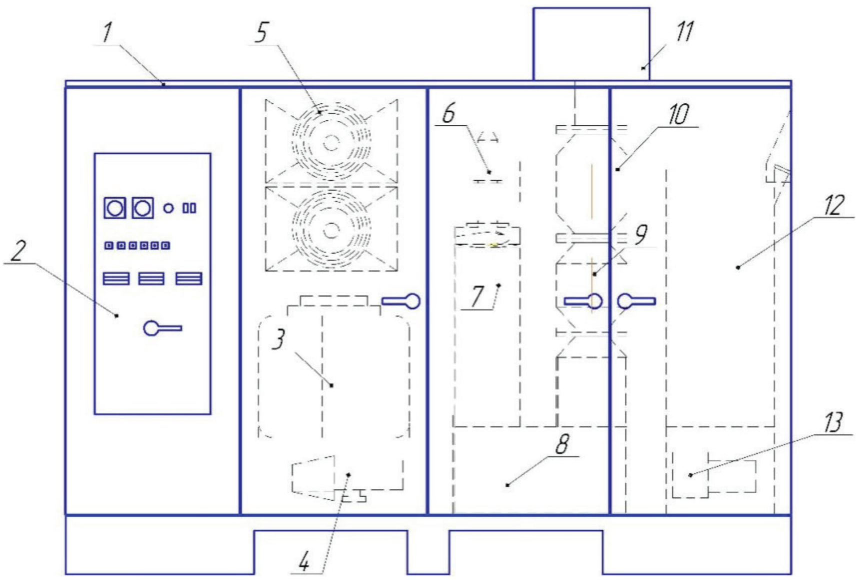

Fig. 4. Layout of the Plazmon-2 unit: *1* – frame-supporting structure; *2* – power unit and control panel; *3* – plasma generator cooling system tank; *4* – plasma generator cooling system circulation pump; *5* – plasma generator cooling system heat exchangers; *6* – plasma generator; *7* – high-temperature waste destruction reactor; *8* – container for collecting residual waste products; *9* – catalyst filter; *10* – muffler; *11* – finishing H14 high--temperature HEPA filter, *12* – temperature sensor, *13* – level sensor

Source: Vashchenko et al. (2019).

The experience gained in the development and creation of the Plazmon-1,2,3 prototype global experimental and industrial plasma arc installations shows their high efficiency in the use and destruction of various medical wastes of any category.

The plasma-chemical pyrolysis technology eliminates almost all the disadvantages of other currently available medical waste disposal technologies and is a comprehensive solution for their safe disposal with a conversion of organic matter into gas of more than 99% and does not require the segregation of chlorinated hydrocarbons. After the waste is incinerated, toxic gases are present in a very small amount at the outlet of the plant, in accordance with regulatory environmental requirements. At the same time, the high temperature and UV radiation of the plasma jet completely destroy bacteria/microorganisms. Therefore, plasma technology can greatly simplify many of the numerous processes of medical waste management.

CONCLUSIONS

1. Electric arc plasma-chemical pyrolysis meets all the technical requirements for the treatment of hazardous medical waste and is easy to maintain in the reactor's reactive oxygen-free environment. It is also possible to change the plasma-forming gas and, thereby, to change the chemical characteristics of the processes taking place in the reactive environment of the plasma-arc reactor.
2. The synthesis gas obtained through plasma arc pyrolysis can be burned for the plant's own needs in its reaction zone, saving electricity from external sources.
3. The results of a comparative analysis of the currently available technologies for the disposal of municipal, medical and other industrial wastes demonstrate the advantages of plasma-arc pyrolysis while also making it uncompetitive for the disposal of hazardous toxic waste. Unlike smoke analogues, its emissions of toxic dioxins and furans into the environment are significantly lower than the accepted standards, and do not require the separation of hazardous waste. At the same time, pathogenic microorganisms are completely destroyed.
4. It would be expedient and profitable to develop and manufacture autonomous mobile modular plasma pyrolysis plants with a capacity of 50–100 kW based on domestic PUN-1 plasma generators with optimal gas consumption for plasma formation. At the same time, the air consumption is 2–15 $m^3 \cdot h^{-1}$, with a minimum consumption of industrial water for cooling the plasma generator in the range of 150–200 $g \cdot s^{-1}$ at an efficiency of up to 70%, and at an optimum temperature of the plasma jet at the outlet of the plasma torch nozzle in the range of 4,300–5,000°C, which is confirmed by experimental measurements.
5. The productivity of the Plazmon-3 unit is 0.5–1.0 $t \cdot MW \cdot h^{-1}$, depending on the composition of the waste and its moisture content, the morphological and physicochemical composition of which has unpredictable seasonal changes, and the nature and purpose of the sources of its generation. The mobility of the facilities makes it possible to destroy medical waste at its place of generation or accumulation, which largely eliminates the need for detailed waste sorting, drying and transportation.

Authors' contributions

Conceptualisation: V.V., I.K. and S.T.; methodology: N.M., Y.T. and N.N.; software: S.T.; validation: V.V. and I.K.; formal analysis: V.V.; investigation: I.K., N.M. and N.N.; resources: Y.T.; data curation: S.T., Y.T. and I.K.; writing – original draft preparation: V.V. and N.M.; writing – review and editing: Y.T.; visualisation: S.T., N.N. and N.M.; supervision: Y.T.; project administration: V.V. and I.K.; funding acquisition: I.K. and S.T.

All authors have read and agreed to the published version of the manuscript.

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PODSTAWY INŻYNIERYJNE I FIZYCZNE ORAZ BEZPIECZEŃSTWO ŚRODOWISKOWE UTYLIZACJI PLAZMOWO-CHEMICZNEJ NIEBEZPIECZNYCH ODPADÓW MEDYCZNYCH

STRESZCZENIE

Nieograniczony wzrost ilości i tempa produkcji niebezpiecznych odpadów medycznych w kontekście wojny rosyjsko-ukraińskiej krytycznie pogarsza sytuację środowiskową na Ukrainie. Jednocześnie istniejące tradycyjne metody i środki technologiczne nie są w stanie zapewnić ich całkowicie bezpiecznego dla środowiska przetwarzania i usuwania. W artykule rozważono alternatywną technologię wysokotemperaturową do pirolizy plazmowo-chemicznej odpadów medycznych w temperaturze 1100−1250°C, która jest realizowana w postaci mobilnego urządzenia do pirolizy plazmowej Plazmon-3, zaprojektowanego i zbudowanego według wzoru krajowego uniwersalnego generatora plazmowego

PUN-1. W artykule opisano również konstrukcję, zasadę działania, inżynierię i zasady fizyczne leżące u podstaw zbudowania urządzenia Plazmon-3, przeznaczonego do utylizacji dowolnego rodzaju i kategorii odpadów medycznych poprzez ich zniszczenie wskutek działania palnika plazmowego o wysokiej temperaturze prądu stałego generowanego przez generator plazmowy PUN-1. Opisano także główne cechy operacyjne urządzenia Plazmon-3. Jako gazy plazmotwórcze w instalacji można stosować powietrze, azot, argon, hel i inne gazy. W artykule opisano zalety stosowania wysokotemperaturowej pirolizy plazmowo-chemicznej do utylizacji niebezpiecznych odpadów medycznych i innych, które sprawiają, że technologia ta pod względem bezpieczeństwa dla środowiska naturalnego przewyższa konkurencję i w przeciwieństwie do swoich odpowiedników emitujących dym jest w stanie niszczyć odpady medyczne bezpośrednio w miejscu ich wytwarzania, bez tworzenia niebezpiecznych pozostałości i emisji.

Słowa kluczowe: odpady medyczne, spalanie, piroliza plazmowo-chemiczna, wojskowe odpady medyczne, generator plazmy, mobilna jednostka łuku plazmowego