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Thermal methods in chemical weapon destruction and computer modeling of plasma technology

Kimyasal silahların bertarafında termal yöntemler ve plazma teknolojisinin bilgisayar modellemesi

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Thermal Methods in Chemical Weapon Destruction and Computer Modeling of Plasma Technology

Highlights

- *The emission limit values of the flue gases released from industrial facilities in our country have been determined by the "Regulation on Control of Industrial Air Pollution, dated 03.07.2009 and numbered 27277"*
- *In the study, the contents of the gas released from the disposal of six different chemical compounds were compared with this regulation.*
- *it is not possible to directly release the analyzed gas into the atmosphere, both without oxidant addition and with oxidant addition, as it is far above the legal values. It is possible to reduce acidic compounds such as HCl and H_2S in the gas by 99.9 % with an aqueous scrubber.*

Graphical Abstract

In this study, information is given about the general disposal process of chemical weapons as well as plasma disposal and simulation.

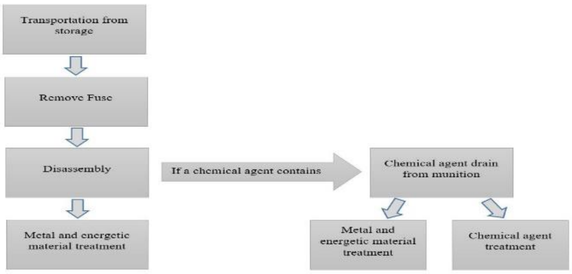

Figure. Disposal process of munitions

Aim

Modeling of chemical weapons destruction process and their byproducts using a computer program.

Design & Methodology

Gasification of 3 different chemical agents and 3 different explosive materials in the plasma gasification unit and the content of the released gas were simulated with the help of a package program.

Originality

Evaluation of compliance with environmental laws in the disposal of not only explosives but also chemical agents with plasma technology.

Findings

The most striking value is seen in HCN. Since these values do not comply with the legal limits, they must be subjected to additional chemical processes (oxidation, catalytic oxidation, etc.).

Conclusion

This study is an important source for possible chemical weapons disposal facilities to be established in our country and it provides the opportunity to compare the relationship of these data with environmental legislation by giving numerical information about the content of gases that will emerge in the disposal of this ammunition with the plasma method.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Kimyasal Silahların Bertarafında Termal Yöntemler ve Plazma Teknolojisinin Bilgisayar Modellemesi

Araştırma Makalesi / Research Article

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ÖZ

Kimyasal silahların bertarafı oldukça karmaşık bir konu olup, metal ve enerjik (patlayıcı) kısımları mühimmattan ayrıldıktan sonra termal ya da nontermal yöntemlerle bertaraf edilebilmektedir. Termal yöntemler yakma, süper kritik oksidasyon, erimiş metal teknolojisi ve plazma gazlaştırmadır. Plazma gazlaştırma teknolojisi, 2000 ºC'den çok daha yüksek sıcaklıklarda çalıştırıldığından kimyasal bileşiklerin bağ yapıları kırılır ve daha az ağır metal içeren gazlar açığa çıkar. Diğer termal yöntemlere göre daha çevreci bir bertaraf yöntemi olan bu yöntem çalışmanın konusunu oluşturmaktadır. Kükürt Mustard, Nitrojen Mustard ve Tabun gibi kimyasal ajanlar ile TNT, RDX ve PETN patlayıcılarının plazma teknolojisi ile gazlaştırılması VMGSim© yazılımı ile modellenmiş ve açığa çıkan sentez gazının içerikleri incelenmiştir. Bu çalışmada incelenen hem kimyasal maddeler hem de patlayıcılar, kimyasal mühimmatlarda en sık kullanılan kimyasallar oldukları için seçilmiştir. Ayrıca reaktöre giren hava, oksijen ve buhar miktarının, bu kimyasallar gazlaştırılırken, açığa çıkan yanma ürünlerinin bileşimine etkisi araştırılmıştır.

Anahtar Kelimeler: Kimyasal silah, bertaraf yöntemleri, plazma teknolojisi, gazlaştırma, termal bertaraf yöntemleri, bilgisayar modellemesi.

Thermal Methods in Chemical Weapon Destruction And Computer Modeling of Plasma Technology

ABSTRACT

Disposal of chemical weapons is a very complex issue, and this ammunition can be disposed of by nonthermal or thermal methods after separating from metal and energetic parts. Thermal methods are incineration, supercritical oxidation, and plasma gasification technology. Since the plasma gasification technology is operated at temperatures much higher than 2000 ºC, the bond structures of chemical compounds are broken and gases containing fewer heavy metals are released. This method, which is a more environmentally friendly disposal method compared to other thermal methods, is the subject of the study. The gasification of chemical agents such as Sulfur Mustard, Nitrogen Mustard, and Tabun, and explosives TNT (trinitrotoluen), RDX (Royal Demolition Explosive), and PETN (Pentaerythritol tetranitrate) with plasma technology was modeled with VMGSim© software, and the contents of the synthesis gas released were examined. Both chemical agents and explosives studied in this study were chosen because they are the most commonly used chemicals in chemical munitions. Besides, the effect of the amount of air, oxygen, and steam entering the reactor on the composition of the combustion products released while these chemicals are gasified has been investigated.

Keywords : Chemical munitions, disposal methods, plasma technology, gasification, thermal disposal methods, computer modelling.

1. INTRODUCTION

The first modern and large-scale uses of chemical weapons date back to the First World War, but there were also primitive uses as a result of various coincidences and discoveries before history. Looking at their recent use, it is seen that such weapons are preferred by countries as an alternative to conventional weapons or as a means of action or sabotage by terrorist groups. The chemical weapon attacks were carried out by a terrorist group in Japan between 1994 and 1995, which caused 19 people to die, showed the whole world that chemicals can be used for terrorism purposes, and caused great repercussions. Similarly, because of the chemical weapons attacks in Syria in August 2013, more than 1500 people lost their lives [1]. Countless chemical weapons attacks have been carried out in our neighboring countries as the internal turmoil in Syria continues, and terrorist groups such as ISIS have increased their activities. The most striking of these attacks are Khan Sheikhun on 7.04.2018 [2], Kharbit Masasnah on 7.07.2017 and 4.08.2017, Qalib Al-Thawr, and Al-Salamiyah on 9.08.2018, Yarmouk on 22.10.2017, Al-Balil on 8.11.2017, Souran Aleppo on 24.11.2018 [3]. Apart from these attacks, the Salisbury [4] and Amesbury [5] incidents in England and the event in Malaysia [6] are the most important events in our recent history. A chemical agent is a substance with hazardous qualities that is used to cause purposeful death or harm. Chemical weapons also include explosives, chemical agents and other equipment specifically designed to weaponize poisonous substances. [7]. In the same convention,

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periods and conditions are determined for the detection and disposal of these weapons and production facilities. However, our country does not have these weapons or chemical weapons production facilities to produce these weapons. In this respect, studies on the disposal of chemical weapons are limited in our country. Chemical agents are used for killing, injuring, neutralizing people, polluting and destroying plant and animal food sources, food stocks, destroying economically important targets, and causing chaos and panic. These are toxic chemicals in solid, liquid, and gaseous forms [8]. When chemical warfare agents are categorized according to their toxic properties, they are listed as nerve agents, blister agents, blood agents, choking agents, capacity disrupting agents, and riot control agents [9]. Acute exposure to nerve agents can cause rapid death. The nerve agents were

developed in Germany. Although there are many varieties, the most well-known nerve agents are, sarin, soman, tabun, and cyclosarin. In addition to the nerve agent G agents, V agents were first developed by the British in the 1950s. Although little information is known about the development of Novichocks ("A-series") by the Union of the Soviet Socialists. Iraq is the first State to used nerve agents in the Iran-Iraq War in 1986 [10].

A category of compounds known as blistering agents is utilized in warfare. Iperite, also known as mustard gas, is the most commonly referenced chemical. The present name for this category of compounds comes from the bubbles that developed in people exposed to iperite during a conflict in the First World War. Its chief side effects are the production of fluid-filled bubbles on the skin, eyes, and respiratory tract. The stated agent's liquid form has a high rate of absorption through the skin, whereas the vapor form has strong systemic effects on respiration [11].

Blood poisoning agents are usually in gas or vapor form and are taken into the body by the respiratory tract. The effects of highly volatile blood poisoning agents appear in a short time. Exposure to high doses of blood poisoning agents can result in death within 5-8 minutes. The most common blood poisoning agents are Hydrogen Cyanide, Cyanogen Chloride, Potassium Cyanide, Sodium Cyanide, Arsin, Carbon Monoxide [8].

Choking agent exposure, including chlorine gas, causes upper respiratory symptoms. Chlorine gas also interacts with the airway Transient Receptor Potential channels, causing delayed low respiratory symptoms. Conjunctival injections, and abrasions can be seen in the eyes. Chlorine gas can cause toxic pneumonia, pulmonary edema, and acute respiratory distress syndrome (ARDS) [12].

This class contains items that cause disorders similar to psychosis and serious mental illness. They affect the central nervous system and cause behavioral disorders through stimulation or depression. The most known agents in this group are fentanyl, lysergic acid diethylamide (LSD), and quinuclidinol benzilate (BZ). In cases of poisoning with LSD, respiratory and cardiac functions should be examined, if the patient is not in a coma, vomiting, activated charcoal and cathartic should be applied. Diazepam is recommended against anxiety. If there is psychosis, 5hydroxytryptophan (5-HTP) and carbidopa should be given. In poisoning with BZ, the patient is removed from the contaminated environment and physostigmine is used as a specific antidote [13]. These are the substances that are used by the security forces, especially in demonstrations, in chaos, and in self-defense situations, that disrupt the capacity of the aggressor and render the person ineffective. Components used as riot control agents include oleoresin capsicum, ochlorobenzylidene malononitrile, and 2-chloroacetophenone [14].

In this study, after giving basic information about ammunition containing chemical agents, thermal disposal methods of ammunition were examined. The most innovative and outstanding of these methods is the plasma gasification method. Since there is no chemical weapons disposal facility in our country, plasma gasification is not performed. The study is very important in terms of showing that the disposal process with plasma gasification process meets the legal requirements. And it will guide the possible weapons disposal facilities to be established in our country.

2. DISPOSAL METHODS

There are many different sorts of waste, including industrial and organic wastes as well as non-hazardous and hazardous wastes. There are 940 methods for handling these pollutants, according to a study on the best practices for waste treatment released by the European Commission (2006) [15]. Due to the dangerous chemicals they carry, ammunition that contains chemical agents is categorized as hazardous waste. The method of disposal of ammunition varies according to the presence of a chemical (chemical agent) in the ammunition that, when exposed, pollutes the environment or makes it fatal. To prevent unwanted explosions of the munition taken from storage, the fuze and other trigger parts are removed and sent to the mechanical dismantling band. If there is a chemical agent in the munition, the ammunition is separated and drawn from the chemical agent. Although the chemical agent is extracted from it, metal parts are disposed of or decontaminated on a separate line since metal parts are contaminated with these chemicals. On the other hand, in chemicalfree ammunition, the ammunition is disposed of with the energetic (explosive) part, or by separating this part, on the other line. (Figure 1) Dismantling of explosive ammunition is a complex process that involves a series of operations divided into several stages. The removed material can be reused or destroyed. Causes of ammunition dismantling; Dismantling of outdated/unusable items that are damaged due to poor storage or during transportation. Maximum care is taken in the dismantling of unexploded ammunition damaged due to an accident [16].

The purpose of the dismantling process is to remove the energetic (explosive) material from the ammunition. Some disassembly techniques include:

- Reverse engineering by removing plugs, filler plugs, or base plates,
- Using a mechanical hole punch to pierce a munition,
- Ammunition crushing or crushing machines,
- Cutting using a saw.

The drilling method is to pierce the bullet jacket of the drill head and extract the explosives inside the bullet. Typically, up to 95 % of the filler can be purged with this method, as complete compression of the explosive is not allowed with the drill [17].

authorized processing center or disposed of in an on-site explosion-reinforced rotary kiln. The liquid mustard agent is transferred to a liquid injection incinerator for incineration. Metal parts that may contain residual mustard material are processed in the metal part incinerator [19].

The heat degradation of organic chemicals into simpler inorganic, harmless components, particularly carbon dioxide and water, is known as incineration. Other acid gases produced by burning include hydrogen fluoride, phosphorus pentoxide, nitrogen dioxide, and hydrogen chloride. Scrubbers may easily hold these discharged acid gases [20].

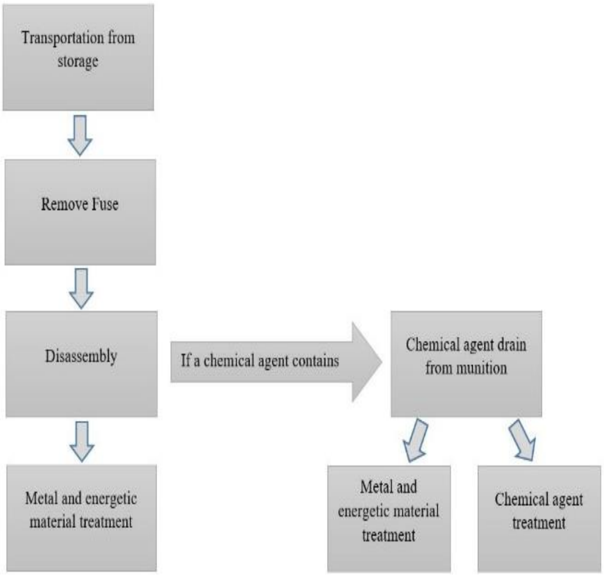

Figure 1. Disposal Process of Munitions

The traditional process for munitions involves reverse assembly or reverse engineering with special equipment such as automatic robots. Separation of bullets from cartridges, dehumidification, and removal of explosives from projectiles can be carried out with reverse engineering. After the ammunition containing a chemical agent is separated from the metal and energetic part, it is disposed Of By Non-Thermal Or Thermal Methods [18].

2.1. Thermal Dısposal Methods

Chemical weapons disposal methods are examined in two parts: thermal and non-thermal. Nonthermal methods are neutralization, hydrolysis, biodegradation, and electrochemical oxidation. Thermal methods are incineration, supercritical water oxidation, and plasma gasification. In this study, only thermal methods will be discussed.

2.1.1. Incıneratıon

After dismantling, metal ammunition bodies and mustard agents are thermally treated in incinerators. Disposal takes place in a two-story structure designed to prevent any leakage of mustard material. Mustard agents and explosive parts are separated from metal parts in this structure. The explosive portion can be sent off-site to an

2.1.2. Supercrıtıcal Water Oxıdatıon (Cswo)

It is described as supercritical when the temperature and pressure values of a single component fluid reach the critical point. The oxidation of organics with air or oxygen at a high concentration of water at a temperature and pressure over the critical point values of 22 MPa and 374 °C is known as supercritical water oxidation. Density increases dissolving, just as it does with liquids. Non-polar organic compounds dissolve faster when the dielectric constant is low. The rate of thermal response increases as the temperature rises. These characteristics create a reactor environment in which the mixture moves quickly, organics dissolve quickly and react quickly with oxygen, and salts precipitate [21].

Water has special physical-chemical properties under these conditions that make it an excellent oxidation reaction medium, resulting in high reaction rates and conservations close to unity in short residence times and tiny reactor volumes. Furthermore, because the oxidation reactions are exotermic, the CSWO process can accomplish autogenic operation and even heat production. However, when scaling up from a laboratory system, the energy cost of heating the waste externally becomes prohibitive [22].

2.1.3. Molten Metal Technlogy

Floating organic molecules in a bath with metals like iron, cobalt, and copper at a temperature of 1650 °C allows organic compounds to be thermally decomposed into more harmless components while inorganic chemicals are dissolved and trapped in the slag. This approach was developed by Elkem Technology and Molten Metal Technology. A current is passed between the electrodes of the metals in the furnace to heat them. The chemicals that must be disposed of are dumped into the bottom of the molten metal pool. Hazardous chemicals are thereby broken down into atoms and molecules, which are then dispersed throughout the metal solution. It collects and separates liquid inorganic slag, then efficiently oxidizes and supplies the gases to the filter system [23].

2.1.4. Plasma Gasıfıcatıon

Plasma; is defined as the fourth state of matter, which is electrically neutral, consisting of neutral particles, ions, and electrons. Plasma technology aims to create an uninterrupted electric arc bypassing the electric current through a gas in a process, a process considered as electrical decay. Due to the electrical resistivity in the system, it causes an ionized flow of gas or plasma that separates electrons from the gas molecules, resulting in considerable heat. Gas molecules split into atoms and when the temperature rises to 3000 ° C, gas molecules lose electrons and become ionized. In this case, the gas has a viscosity at atmospheric pressure like that of liquids, and its free electrical charges give the gas a relatively high electrical conductivity close to that of metals. The remaining metal materials and heavy metals are also used in road and asphalt construction [24]. Studies have shown that the elastic modulus of electric arc furnace (EAF) slag is quite high compared to natural aggregate. When used as a base material on roads with low traffic volume, it significantly reduces road costs, and it has been shown to heal itself [25-26]. An explosion chamber can be used to neutralize explosive components with a powerful ignition (explosion or detonation), and then the residue and gas generated in the chamber are processed in a high-temperature plasma [27].

All components of chemical munitions can be treated with plasma pyrolysis reactors (i.e., chemical agent, fuses, bursters, propellant, metal casings, and packing materials). By energetic initiation (detonation or deflagration), an explosion chamber can be used to deactivate explosive components, and the ensuing debris and gas can subsequently be treated in a high-temperature plasma [28].

3. METHOD

In this study, thermal methods of chemical weapons disposal, especially the plasma gasification method, were studied. In the last part of the study, the products released as a result of the disposal of chemical weapons and explosives with known mass fraction contents in the plasma gasification unit were modeled with a package program named VMGSim© 10.0 and the results were interpreted. This study was modeled with VMGSim 10.0 software. This program is software used in the design and operation of many facilities, modeling combustion furnaces, plasma gasifiers, absorbers, and other important process equipment. Thanks to VMGSim©, costly stages such as experimental study and prototype production can be modeled and possible results can be predicted with close to zero cost [29]. As mentioned, the parts that make up the ammunition contain chemical agents, explosive substances, and metal parts. It is very important to dispose of each component. In this study, the disposal of metal parts was not taken into account. The disposal of three different chemical agents (Sulfur mustard, nitrogen mustard, and Tabun) and three different explosives (TNT (Trinitrotoluen), RDX (Royal Demolition Explosive), and PETN (Pentaerythritol tetranitrate)) were modeled in a plasma gasification reactor and the obtained results were discussed.

In the sofware, the plasma gasification reactor was selected, and the contents of each chemical were introduced to the system separately as mass fractions. The elemental contents of chemical agents and explosives were given in Table 1 and Table 2, respectively.

As can be seen from both tables, explosive materials consist of C, O, H, and N elements, while such chemical agents contain elements such as P, S, and Cl that are harmful to human health and cannot be released into the environment without treatment. Some parameters required for calculations are shown in Table 3.

After all the necessary parameters were introduced to the system, mass flow rates for each chemical were entered into the system to make the calculation. These mass flow rates were shown in Table 4 for chemical agents and in Table 5 for explosives.

Three chemical agents, sulfur mustard, nitrogen mustard, and Tabun agents, as well as TNT, RDX, and PETN explosives, were modeled for gasification software using the VMGSim© in scenarios with 100 kg fixed feed and 50 kg plasma gas input, and the results were studied.

Chemical warfare agents were gasified in the first trial using 100 kg of feeds and 50 kg of plasma gas (air was utilized as plasma gas), as well as steam (H2O) to speed up the reactions in the reactor. The crucial issue is that without this addition, no result was obtained, and the steams required for combustion are listed in Table 4. According to the same table, Sulfur Mustard and Nitrogen Mustard have no oxygen in their molecular structure, but Tabun has 19,75 percent oxygen. As a result, when there was insufficient oxygen in the surroundings, the processes could not be completed, necessitating the addition of oxygen from the outside, which was provided by steam additive.

Table 1. Mass Contents of Chemical Warfare Agents

	Name of Chemical	Chemical Formula	C %	O %	H %	N %	P %	S %	Cl %
1	Sulfur Mustard	$C_4H_8Cl_2S$	30.20	0	5.00	0	0	20.15	44.65
2	Nitrogen Mustard	$C_6H_{12}Cl_3N$	21.36	0	7.10	8.30	0	0	63.20
3	Tabun	$C_5H_{11}N_2O_2P$	37.00	19.75	6.80	17.30	19.15	0	0

Table 2. Mass Contents of-Expolosives.

	Name of Chemical	Chemical Formula	C %	O %	H %	N %
1	Tri Nitro Toluen (TNT)	$C_7H_5N_3O_6$	37.00	42.30	2.20	18.50
2	RDX	$C_3H_6N_6O_6$	16.21	43.24	2.70	37.85
3	PETN	$C_5H_8N_4O_{12}$	18.99	60.76	2.53	17.72

Table 3. Specifications Of The Inside Of The Reactor

Pressure (kPa)	101,33
Reactor Bottom Temperature (^{0}C)	3000
Delta Pressure (kPa) (Adiabatic)	0
Reactor Top Temperature (^{0}C)	1500
Ambient Temperature (^{0}C)	25
Torch Plasma Duty (kW)	100

Table 4. Inlet Mass Flow Rates to Plasma Reactor for CWA's

	Name of Chemical	Chemical Formula	Feed (kg)	Torch Air in (kg)	Steam (kg)	Oxidant (kg)	Coke in (kg)
1	Sulfur Mustard	$C_4H_8Cl_2S$	100	50	33	0	0
2	Nirogen Mustard	$C_6H_{12}Cl_3N$	100	50	18	0	0
3	Tabun	$C_5H_{11}N_2O_2P$	100	50	46	0	0

Table 5. Inlet Mass Flow Rates to The Plasma Reactor For Explosives

	Name Of Chemical	Chemical Formula	Feed (kg)	Torch Air in (kg)	Steam (kg)	Oxidant (kg)	Coke in (kg)
1	TNT	$C_7H_5N_3O_6$	100	50	0	25	0
2	RDX	$C_3H_6N_6O_6$	100	50	0	25	20
3	PETN	$C_5H_8N_4O_{12}$	100	50	0	25	15

4. RESULTS AND DISCUSSION

The mass compositions of the synthesis gas released as a result of the modeling taken from the program were calculated for both 3 chemical warfare agents and 3 different explosive chemicals. These results are shown in detail in Table 6, and Table 7.

Table 6. Composition Of Gas Released After Plasma Gasification of CWAs

Name of Chemical Formula	**Sulfur Mustard $C_4H_8Cl_2S$**	**Nitrogen Mustard $C_6H_{12}Cl_3N$**	**Tabun $C_5H_{11}N_2O_2P$**
H_2O %	0	0	0
H_2S %	10.533	0	0
H %	3.433	4.077	7.157
HCl %	25.093	38.689	0
HCN %	0	0.953	2.194
CH_4 %	0.001	0.002	0.004
N %	20.959	26.041	32.605
NH_3 %	0	1.502	3.457
CO %	36.827	28.526	54.195
CO_2 %	1.092	0.211	0.387
COS %	2.063	0	0

Explosives, according to Table 2, have a chemical structure that has more than 42.00 percent oxygen. However, because the amount of carbon in explosives is minimal, unlike the CWA, it was realized that the reactions could not be completed and the products could not develop without introducing a coke (carbon) into the system. When the first modeling for CWAs was looked at, it was discovered that the synthesis gas contained around 36.8% carbon monoxide for sulfur mustard, 28,50% carbon monoxide for nitrogen mustard, and 54.20% carbon monoxide for tabun as can be seen Table 6.

Table 6 and Table 7 show the compositions of the products discovered. Both chemical groups received oxidant to ensure complete combustion, and the amount of oxidant required for complete combustion of CWAs is larger, as shown in Tables 8 and 9. (The percentages for CWA's are 350, 350, and 570 percent, respectively; the percentages for explosives are 47, 35, and 25 percent.)

It can be concluded that there was no total combustion in the reactor. Although explosives do not produce as much carbon monoxide as CWA, roughly 23.90% of carbon monoxide is emitted for TNT and 10% for RDX as can be seen Table 7.

In the first models, it was determined that there is a large amount of carbon monoxide in the synthesis gas. This suggested that there was no complete combustion as there was not enough oxygen in the reactor. It has been tried to obtain the products of complete combustion as much as possible by providing oxidant input to the reactor for both 3 different chemical agents and 3 different explosives. The rate of those entering the plasma reactor for CWA is given in Table 8, and the rate of those entering the reactor for explosives is given in Table 9.

CWAs, on the other hand, use air as an oxidant, whereas explosives need oxygen. Nonetheless, explosions' extra oxygen lessens the requirement for oxidants. The amount of nitrogen released in the oxidant-added gaseous products has also grown as a result of the nitrogen in the oxidant-air utilized for CWAs. When looking at Tabun's mass composition, When the bulk composition of Tabun, a chemical warfare agent, is examined, it is discovered to contain approximately 19% phosphorus. However, no phosphorus component is emitted when the synthesis gas created during plasma gasification is investigated.

The important point here is oxidant air (79 N2 %, 21% O2) for chemical warfare agents, whereas only oxygen (O2) for explosives. The results of plasma gasification modeling of CWAs with the help of the software are given in Table 10 and those of explosives in Table 11.

When the program is studied in detail, it is discovered that the slag out of the reactor contains all of the P2O5 (phosphorus pentoxide) generated as a result of gasification (43.88 kg). Because phosphorus pentoxide is a white crystalline solid, it has accumulated in the slag outflow after gassing.

The emission limit values of the flue gases released from industrial facilities in our country have been determined by the "Regulation on Control of Industrial Air Pollution, dated 03.07.2009 and numbered 27277" [30]. In the study, the contents of the gas released from the disposal of six different chemical compounds were compared in Table 12 in terms of compliance with this regulation. As can be seen from Table 12, it is not possible to directly release the analyzed gas into the atmosphere, both without oxidant addition and with oxidant addition, as it is far above the legal values. It is possible to reduce acidic compounds such as HCl and H2S in the gas by 99.9 % with an aqueous scrubber [31]. When the After Scrubber sections in the table are examined, it is understood that the H2S released from Sulfur Mustard is still above these values. In this respect, a second washing process is recommended to reduce these values. The most striking value in the table is seen in HCN. Since these values do not comply with the legal limits, they must be subjected to additional chemical processes (oxidation [32], catalytic oxidation [33], etc.). It should not be forgotten that these processes will cause an increase in the installation and operating costs of the facility. With the use of scrubbers after the plasma gasification process, all harmful content except H2S and HCN has been reduced to values below the legal limits. These two compounds will also be reduced to legal limits when subjected to the recommended chemical treatment.

Table 7. Composition Of Gas Released After Plasma Gasification of Explosives

	Name of Chemical	Chemical Formula	H_2O %	HCN %	H %	N %	CO %	CO_2 %	NH_3 %
1	Tri Nitro Toluen (TNT)	$C_7H_5N_3O_6$	5.456	2.040	0	28.788	23.892	36.611	3.213
2	RDX	$C_3H_6N_6O_6$	1.764	3.745	0	32.285	9.868	46.437	5.900
3	PETN	$C_5H_8N_4O_{12}$	6.802	1.799	0	26.248	0.534	61.782	2.835

Table 8. Inlet Oxidant Added Mass Flow Rates to The Plasma Reactor For CWAs

	Name of Chemical	Chemical Formula	Feed (kg)	Torch Air in (kg)	Steam (kg)	Oxidant (kg)	Coke in (kg)
1	Sulfur Mustard	$C_4H_8Cl_2S$	100	50	33	350	0
2	Nitrogen Mustard	$C_6H_{12}Cl_3N$	100	50	18	350	0
3	Tabun	$C_5H_{11}N_2O_2P$	100	50	46	570	0

Table 9. Plasma Reactor Intake Oxidant Added Mass Flow Rates for Explosives

	Name of Chemical	Chemical Formula	Feed (kg)	Torch Air in (kg)	Steam (kg)	Oxidant (kg)	Coke in (kg)
1	TNT	$C_7H_5N_3O_6$	100	50	0	47	0
2	RDX	$C_3H_6N_6O_6$	100	50	0	35	20
3	PETN	$C_5H_8N_4O_{12}$	100	50	0	25	15

Table 10. Composition of Gas Released After Plasma Gasification Process After Oxidant addition to CWA's

	Name of Chemical	Chemical Formula	H_2O %	H_2S %	H %	HCl %	HC N %	CH_4 %	N %	NH_3 %	CO %	CO_2 %	CO S %
1	Sulfur Mustard	$C_4H_8Cl_2S$	10.53 5	3.61 6	0	8.615	0	0	57. 567	0	16.7 09	2.249	0.70 8
2	Nitrogen Mustard	$C_6H_{12}Cl_3N$	11.81 7	0	0	12.54 8	0.30 9	0	60. 276	0.487	0.07 5	14.48 8	0
3	Tabun	$C_5H_{11}N_2O_2P$	13.47 6	0	0	0	0.46 2	0	67. 418	0.728	0.18 5	17.73	0

Table 11. Composition Of The Gas released after the addition of oxidant and Plasma Gasification of Explosives

	Name of Chemical	Chemical Formula	H_2O %	HCN %	H %	N %	CO %	CO_2 %	NH_3 %
1	Tri Nitro Toluen (TNT)	$C_7H_5N_3O_6$	4.847	1.812	0	25.573	1.673	63.241	2.855
2	RDX	$C_3H_6N_6O_6$	1.678	3.562	0	30.711	0.847	57.59	5612
3	PETN	$C_5H_8N_4O_{12}$	6.802	1.799	0	26.248	0.534	61.782	2.835

Table 12. Comparison of Results with Legal Limit Values

	Compound	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
Sulfur Mustard	H_2S	52863.2	52.8632	26261.6	26.2616	5 mg/Nm^3
	HCI	87470	87,47	64740	64.74	100 mg/Nm3
	HCN	0	0	0	0	5 mg/Nm^3
	NH_3	0	0	0	0	200 mg/Nm^3
	CO	67.39 kg/h	67.39 kg/h	11.99 kg/h	11.99 kg/h	500 kg/h
	COS	14809	14.809	7354,3	7.3543	100 mg/Nm^3
Nitrogen Mustard	**Compound**	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
	H_2S	0	0	0	0	5 mg/Nm^3
	HCI	576446.1	576.4461	94040	94.04	100 mg/Nm3
	HCN	6547110	6547.11	1305300	1305.3	5 mg/Nm^3
	NH_3	10964.6	10.9646	2452.8	2.4528	200 mg/Nm^3
	CO	47.92 kg/h	47.92kg/h	0.39kg/h	0.39 kg/h	500 kg/h
	COS	0	0	0	0	100 mg/Nm^3
Tabun	**Compound**	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
	H_2S	0	0	0	0	5 mg/Nm^3
	HCI	0	0	0	0	100 mg/Nm3
	HCN	4252530	4252.53	1834000	1834	5 mg/Nm^3
	NH_3	8015.4	8.0154	3460	3.46	200 mg/Nm^3
	CO	82.44 kg/h	82.44 kg/h	1.34 kg/h	1.34 kg/h	500 kg/h
	COS	0	0	0	0	100 mg/Nm^3
TNT	**Compound**	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
	HCN	8889780	8889.78	9953940	9953.94	5 mg/Nm^3
	CO	41.81 kg/h	41.81 kg/h	3.30 kg/h	3.30kg/h	500 kg/h
	NH_3	16768.1	16.7681	19301	19.301	200 mg/Nm^3
RDX	**Compound**	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
	HCN	17882610	17882.61	19002000	19002	5 mg/Nm^3
	CO	19.24 kg/h	19.24 kg/h	1.74 kg/h	1.74 kg/h	500 kg/h
	NH_3	33733.3	33.7333	35830	35.83	200 mg/Nm^3
PETN	**Compound**	**No oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Oxidant added mg/Nm^3**	**After Scrubber mg/Nm^3**	**Legal Limit**
	HCN	10250040	10250.04	10250000	10250	5 mg/Nm^3
	CO	1.01 kg/h	1.01 kg/h	1.01 kg/h	1.01 kg/h	500 kg/h
	NH_3	19330.4	19.3304	19330.4	19.3304	200 mg/Nm^3

5. CONCLUSION

It varies depending on whether the ammunition to be disposed of contains chemical agents or not. If the ammunition contains various chemical agents, it is disposed of by the methods mentioned in working on a separate line, while if it does not contain chemical agents, it is disposed of via the other line with relatively easier methods. Although chemical weapons can be disposed of by non-thermal and thermal methods, only thermal methods are mentioned in this study, especially plasma gasification.

The Chemical Weapons Convention prohibits the use, transfer, and storing of chemical weapons created and deployed during World War I and afterwards employed by terrorist organizations and some states. This convention resulted in the abolition of 99 percent of designated chemical weapons. Although this is a welcome development, the increased use of chemical weapons by non-state actors, particularly DAESH, as well as events in Syria, Afghanistan, and even Ukraine, necessitates that we maintain our knowledge of how to dispose of these weapons up to date. Despite the fact that the number of chemical weapons on the globe has dropped, the threat has not. The most frequently utilized thermal methods for the disposal of chemical agents and weapons are examined and given in this paper, which begins with a brief overview of chemical agents.

Plasma Gasification (Pyrolysis), one of the thermal methods, is an innovative technology, and it is a very environmentally friendly method as it produces minimum waste. Gaseous chemicals can be subjected to filtration and can easily give results under environmental laws. With this technology, both chemical agents, explosive parts and metal parts can be disposed of.

Our country has never used, stored, or transferred chemical weapons in any period of its history. For this reason, there is no study in our country on both this ammunition and the disposal methods of these munitions. The plasma gasification method is also an important method used in the disposal of hazardous materials both in the world and in our country. In this respect, this study is both an important source for possible chemical weapons disposal facilities to be established in our country and it provides the opportunity to compare the relationship of these data with environmental legislation by giving numerical information about the content of gases that will emerge in the disposal of this ammunition with the plasma method.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Murat ŞAHİN: Performed the experiments and analysed the results. Wrote the manuscript.

Caner DERELİ: Performed the experiments and analysed the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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