The Federal Agency on Technical Regulating and Metrology (Rosstandart)

A Russian Federation
Standardization Document

Draft, Public Discussion,
2015

INFORMATION TECHNOLOGY BEST AVAILABLE TECHNIQUES REFERENCE DOCUMENT

Thermal Waste Processing (Waste incineration)

The present draft reference document is not subject to implementation before its approval

MOSCOW
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Introduction

This reference document is divided into 7 sections, containing information on the level of technical and technological development in the field of thermal waste treatment, the implemented best available technologies (hereinafter: BAT) as well as the various aspects of the implementation of them as well as the promising best available techniques. In the attachment to the reference document as a complement to the PNST 22-2014 BEST AVAILABLE TECHNIQUES *terms and definitions* the main special terms and definitions are presented, used when describing the field of thermal waste processing.

The first section presents general information on the field of thermal waste processing: based on the questionnaires presented to the companies, general information on techniques and equipment used at the companies within the various branches of the Russian Federation economy for the thermal processing of waste that contains organic compounds, in order to lower the hazard level and/or a reduction of their mass as well as the geographical position. A short overview of the environmental aspects and the environmental problems that are connected to these within the treated field of activities.

Section two describes the technique and the technological processes, used presently in the field of thermal waste processing in the Russian Federation as well as abroad. It also describes the main environment parameters as well as the main types of existing reactors connected with these techniques and processes, as well as their advantages and disadvantages.

The third section covers thermal waste processing from the viewpoint of its environmental impact. Characteristics for the evaluation of the technologies are presented, including marker pollutants contained in emissions to air, as well as the current emission levels.

The fourth section accounts for the methodology of determination of a certain thermal waste processing technique as BAT, including methods used, allowing for the step-wise consideration of a number of techniques and choosing the best available technique out of these.

The fifth section casts light upon the general technique schemes based on the most widespread methods of thermal waste processing – incineration, pyrolysis, gasification, while also listing the BAT techniques and describing the main technological equipment,

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the various versions of technology processes as well as the technical aspects and the technological performance characteristics of BAT.

Section 6 covers the economic aspects of the introduction of BAT, as well as the economic performance characteristics of BAT – capital and operational expenditures, their structure as well as the gathering and processing of economic information, the evaluation of expenditures as well as the received benefit.

Section 7 dwells upon the newly developed technologies fulfilling the requirements of BAT the level of research and development (at the research and development stage) while also presenting their possible future advantages as well as the possible problems concerned with their implementation.

While composing the present reference document the following documents were considered: the statutes of the Federal Act of the 10 October 2002 no.7FZ On Environmental Protection (including amendments of the 29 December 2014), The Federal Act of the 24 June 1998 no. 89FZ, On Production and Consumption Waste (including amendments until 29 December 2014, the version in force from 1 July 2015 and onwards), the Federal Act of the 30 March 1999 no. 52-FZ On the Sanitary-Epidemiological Well-being of the Population (with amendments until 29 December 2015, the version in force since 1 July 2015, The Federal Act of the 23 November 1995, no. 174 FZ On Environmental Review (with amendments until 29 December 2015, version in force from the 1 July and onwards), The Federal Act of the 4 May 1999, no 96-FZ On Air Protection (with amendments until 29 December 2015).

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Preface

The Aims, the main principals and the order of elaboration of the reference document are established in the Government of the Russian Federation Ordinance On the order of Determination of a Technique as the Best Available Techniques well as the Elaboration, Up-dating and Publishing of the Digital versions of the Best Available Techniques Reference Documents no. 1548 of the 23 December 2015.

1 Status of the Document

The present digital reference document on best available techniques (hereinafter – the reference document) is a standardization document.

2 Information on the Developers

The reference document was elaborated by Working Group no 9 (Thermal Waste Processing (incineration of waste), Created on the bases of the Rosstandart administrative order no. 836 of the 17 July 2015.
The reference document has been presented for approval to the Best Available Techniques Bureau (The BAT Bureau) www.burondt.ru.

3 A Short Description

The present reference document contains a description of the production processes, equipment, technical means and methods used in the field of thermal waste processing, that allow for a reduction of the negative impact on the environment and water consumption, as well as the advance of energy efficiency and resource conservation. From the list of described production processes, equipment, technical means and methods are defined the solutions that constitute best available technique For BAT the corresponding technical characteristics are established.

4 interrelations with International and Regional Analogues

The present reference document was elaborated taking into account the following reference documents of the European Union in the field of best available technologies:

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The EU Reference Document on Best Available Technique: ”European Commission. Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for Waste Incineration. August 2006”;

The EU Reference Document on Best Available Technology " European Commission. Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for Waste Treatment Industries. August 2006"

The Information from the reference documents has been used taking into account the specific situation in the Russian Federation in the field of thermal waste treatment.

5 Data Collection

The information on production processes, equipment as well as technical means and methods used in the field of thermal waste treatment in the Russian Federation was collected in the process of elaboration of the reference document in accordance with the Order for Collection of Data, necessary for the Elaboration of a Digital Reference Document on Best Available Technique and the Analysis of Priority Problems of the Branch, Approved by a Rosstandart Order of the ____________________ (Year) no. __________________________

6. The Interrelation with other BAT Reference Documents.

The interrelation of the present reference document with other reference documents, elaborated in accordance with the Government Instruction of the 31 October no. 2178-r is described in the section "Field of Application".

7. Information on the Approval, Publishing and Enactment

The reference document was approved by a Rosstandart instruction of the ________________(year) no. _____________________________

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The reference document is put into force from the moment of its official publication in the information system of general use – on the official site of the Federal Agency for Technical Regulation and Metrology in the Internet network www.gost.ru .

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Field of Application

The reference document covers the following main field of activity:
Treatment of waste containing organic substances, using thermal methods using the methods of incineration, pyrolysis and gasification.
This field of activity corresponds partly to the code OKPD (All-Russian Classification of Products for Various Fields of Commercial Activity) 38.21.23 Services for the Incineration of unhazardous waste. There is no OKVED (All-Russian Classification of Economic Activities) code, corresponding to this field of activity.
This reference documents also covers the processes that are directly connected to the main kinds of activity, which may have an impact on the emission levels or the scope of environmental pollution:

- the accumulation (storage) and preliminary preparation of the waste to be processed
- Choice and preparation of the used materials and fuel
- Methods for the prevention and reduction of emissions and the formation of waste

- Methods of recycling of secondary energy resources

The reference document does not cover

- Techniques for waste treatment processes, during which thermal impact methods are used, that do not lead to the destruction of the waste under treatment (drying, distillation, etc.);
- Techniques for thermal treatment of waste that are an integral part of the under-process of the process of production of the production of the specific branch at the enterprises.
- Techniques for the thermal recycling of waste, the main goal of which is the use of waste as alternative source of fuel to obtain heat and energy and/or production of products.
- Issues, exclusively concerning the securing of industrial safety or workmen's safety
- Other forms of activities for the treatment of waste by thermal means and in accordance with the corresponding BAT (according to the Russian Federation Government Instruction no. 2178-r of the 31 October 2014) are shown in table 1.

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Table 1

Filed of Activity	Corresponding BREF
Waste treatment	BREF on Waste Treatment
Waste burying disposal	BREF on Production and Consumption Waste Burying Disposal

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Section 1. General Information on the Field of Thermal Waste Treatment

1.1. General Information on the Field of Activities

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In the present section of the reference document, on the basis of the questionnaires, supplied by the companies, techniques and equipment are presented which is used for thermal waste treatment of waste containing organic compounds at companies of various economical branches of the Russian Federation in order to reduce the hazard level of the waste or in order to reduce the mass of the waste. The special treatment of the considered techniques does not depend on the specific characteristics of the economic branch within which the techniques may be used, but is oriented towards the groups of types of waste containing organic substances and that are subjected to thermal treatment.

The sources of organic waste formation are comprised of both household vital functions as well as the production and administrative activities of companies.

Examples of such waste are: Municipal solid waste (MSW); soil, polluted by organic matter; decayed and prohibited pesticides, persistent organic pollutants including polychlorinated biphenyls, oil sludge, waste from the chemical industry's production of chloroorganic substances; waste from the production of mineral fertilisers and chemical plant protection agents , waste from the production of organic syntheses (acids, aldehydes, ketones, alcohols etc.); stockpiles of off-grade rocket fuel, wastewater sludge, medical waste, including infectious; biological waste and many other types of waste [1]. In order to choose an optimal technological and constructive characteristics of the applies thermal installations and equipment, it is necessary to depart from the concrete types of waste that are subject to thermal treatment based on the waste classification shown in table 1.1 [1].

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Table 1.1 – Classification of waste applied for thermal treatment [1]

Aggregate form	**Combustibility of the waste**	**Waste composition**	**Type of neutralizing reagent in the gas treatment system**	**Volatility of the organic component**	**The possibility of distillation of the mineral product of the treatment**	**The temperature of the liquid state of the mineral products of the treatment**
Liquid waste	Combustible waste for which the $\Delta T_{max} \geq 0°C$	Waste, containing only organic and inorganic substances, giving rise to CO_2, H_2O and N_2 under oxidative treatment	As a neutralizing regent alkali-reagents are used (NaOH, Na_2CO_3 KOH, K_2CO_3)	Highly volatile	Fully subliming substances	Substances with the temperature of the liquid melted condition considerably higher than T_{or}
Solid waste	Incombustible waste for which the $\Delta T_{max} < 0°C$	Waste, containing only organic and inorganic substances, giving rise to Nitrogen oxide NO under oxidative treatment	As a neutralizing regent alkali-earth reagents are used ($Ca(OH)_2$, CaO, $CaCo_3$)	Volatile	Practically non-subliming substances	Substances with the temperature of the liquid melted condition close to the working temperature of the treatment process T_{or}
Slurried waste (mud, sludge, sediment)		Waste, containing organic, mineral compounds of S, P, Cl, F and giving rise to gaseous acids or oxides SO_2, P_4O_{10}, HCl and HF under oxidative treatment	As a neutralizing reagent alkali and alkali-earth reagents are used	Low-volatile	Partly subliming substances	Substances with the temperature of the liquid melted condition considerably lower than T_{or}
		Waste, containing organic, mineral compounds of Na and K, and giving rise to mineral salts (NaCl, Na_2SO_2, $Na_4P_2O_7$, Na_2CO_3 and KCl) under oxidative treatment	No neutralization of flue gases	Non-volatile (liquid residue)		
		Waste, containing organic substances, elements, their oxides, salts of organic compounds of elements, which give rise elements of oxides (CuO, CU_2O, TIO_2, NiO, ZnO, Fe_2O_3 and Cr_2O_3) under oxidative treatment		Non-volatile (solid residue)		

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The classification of thermally treated waste is made around 7 main parameters:

- according to the aggregate condition waste is divided into 3 groups; liquid, solid and sludge

In accordance with the FKKO-2014 (the Federal Waste Classification Catalogue) as to the aggregative state and physical form are divided in the following way (the ninth and tenth category of the code): liquid (10); solid (20), disperse systems (30), solid bulk material (40); products out of solid materials, apart from fibres (50), products made out of fibres (60); mixtures of solid materials and products (70).

- Based on the combustibility, waste is divided into two classes – combustible and non-combustible.

The combustible waste burn independently at indoor temperature without any consumption of additional fuel.
For the thermal treatment of non-combustible waste at indoor temperature there is a need to consume additional fuel.

- As to the composition, waste is divided into 5 groups.

The first group includes waste, containing organic and non-organic matter, which under oxidising treatment form the harmless flue gasses CO_2, H_2O and N_2, which do not need any treatment at all.
The third group is made up of waste, which, apart from the substances from the first group, also contain nitrogen, which during combustion produce nitrogen oxide, NO.
The third group contains waste containing the organic compounds of S, P, Cl, and F that during processing produce the gaseous acids and oxides SO_2, P_4O_{10}, HCl and HF.
The fourth group is comprised by waste, which during the processing form NaCl, Na_2SO_4, Na_2SO_4, Na_4P2O_7, Na_2CO_3 and KCl.
The fifth group is comprised of waste, containing organic substances, elements and their oxides, salts or organic compounds, which during oxidising processing produce elements of oxides (CuO, Cu_2O, TiO_2, NiO, ZnO, Fe_2O_3 oar Cr_2O_3).

- Based on the type of neutralizing agent used in the system of gas, the waste is divided into 4 groups.

The first group is comprised of waste that during the processing of which the alkaline reagents NaOH, Na_2CO_3,

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KOH and K_2CO_3 are used. These reagents are use at high temperatures of the process and the possibility of a gaseous phase reaction of neutralization.
The second group include waste, during the treatment of which, as a neutralizing agent, the alkaline earth metals $Ca(OH)_2$, CaO, and $CaCO_3$. These reagents are used at relatively low temperatures of the treatment process under the possibility of a heterogeneous reaction of neutralisation.
The third group is comprised of waste, during the treatment of which as a neutralizing agent are used alkaline and alkaline earth reagents.
The fourth group are comprised of waste, during the processing of which not neutralizing agents are needed.

- Based on the volatility, the organic content of the waste is divided into 5 groups; When assessing the volatility of the substances a correlation is made between their boiling temperature T_{boil} and the temperature of the equilibrium temperature of evaporation T_{evap} of waster is made, in the atomized state in the contact with the flue gases or with the boiling temperature of water at atmospheric pressure. Depending on the volatility, all substances present in the waste are divided into highly volatile, volatile and low-volatile substances (as liquid or solid residue)

As highly volatile substances are considered those with a boiling temperature lower than 85°C.

As volatile substances are considered those with a boiling temperature higher than 85°C but lower than 100°C.

As low-volatile substances are considered those with a boiling temperature higher than 200°C.

As non-volatile substances are considered those that practically do not evaporate.

- Based on the melting temperature of the mineral products of the waste, three groups are formed:

a) Waste with a temperature of the beginning of the sintering process of the ash, considerably higher than the temperature of the treatment process,
b) Waste with a temperature of the beginning of the sintering process of the ash, close to the temperature of the treatment process,
c) Waste with a temperature of the beginning of the sintering process of the ash, considerably lower than the temperature of the treatment process,

Based on the sublimation properties of the products of the thermal waste treatment, the waste is divided into three types:

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a) Fully sublimating substances
b) Partly sublimating substances
c) Practically non-sublimating substances

In the practice of high-temperature treatment of waste, containing organic substance, three methods [2] have gained wide application:

a) The high-temperature oxidising method (combustion). The essence of this method is the burning of combustible waste or the thermal (pyric) processing of non-combustible waste with a high-temperature heat transfer agent (the products of the burning of fuel, a plasma jet, molten material, etc.). When using this method the toxic components are subject to thermal decomposition, oxidation and other chemical transformations with the formation of gases CO_2, H_2O, N_2 as well as solid products or molten material (metal oxides, salts and other)
b) Pyrolysis – the process of thermal decomposition of organic-matter containing waste, under conditions of absence of oxidising agent, as the result of which a solid charcoal-like residue is formed as well as a pyrolysis gas, containing highly boiling resin-like compounds. The burning heat of the gas is about 13-21MJ/m^3. At lower temperatures of pyrolysis (≈700 – 1050°C) the share of gaseous products is larger.

Oxidising pyrolysis is the process of thermal decomposition of waste under a partial combustion or in direct contact wit the products of fuel combustion. The gaseous products of the decomposition of the waste is mixed with the products of the burning f the fuel are a part of the waste, which is the reason why at the exit from the reactor they have e low burning heat, however a higher temperature. After this, the gas mixture is burned in conventional burning installations. In the process of the oxidising pyrolysis a

solid carbonic residue is formed (coke). After this, the coke may be used as a solid fuel or for other purposes.
Dry pyrolysis is the process of thermal decomposition of waste or solid or liquid fuel without access to an oxidising agent. As a result of a dry pyrolysis of the waste a pyrolysis gas is formed with a high combustion heat, liquid products and a solid carbonous residue. The quantity and quality of the products of dry pyrolysis are subdivided into three types of dry pyrolysis:

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1. Low-temperature pyrolysis or low-temperature coking (450-550°C), under which a maximum yield of liquid products and solid residue (semicoke) is attained as well as a minimal production of pyrolysis gas with a maximum of heat of combustion;
2. Intermediate-temperature pyrolysis, or intermediate-temperature coking (up to 800°C) under which the yield of gas is increased under a reduction of its combustion heat, while the yield of liquid products and the coke residue is reduced;
3. High-temperature pyrolysis or coking (900-1050°C), during which a minimal yield of liquid product as well as solid residue is attained while a maximum yield of pyrolysis gases with a minimal combustion heat.

c) Gasification is the process of thermal processing of waste, containing organic substances, a oxidation agent (air, oxygen, water vapour, carbon dioxide or a mixture of the above agents) with a consumption of the below stoichiometric, with the production of generator gas (synthesis gas) and the solid or molten mineral product. Waste processing by gasification has the following advantages as compared with the combustion method:

1. The produced fuel gases may be used as both energy and production fuel, while – under combustion – the only practically possible solution is the energy use of the heat of the waste (the production of waster vapour of hot water);
2. The resin produced may be used as liquid fuel as well as a chemical raw-material;
3. the emissions of ash and sulphur compounds to air are reduced.

The results of a systemization of the equipment used in Russia for the thermal treatment of concrete types of waste according to the information presented in the questionnaires by the companies are shown in tables 1.2, 1.3, 1.4 1.5, 1.6 and 1,7 based on the sections: incineration, pyrolysis and gasification: The presented techniques and equipment is systemized:

- according to the groups of waste being treated (the FKKO-2014 codes) [3],
- based on the productivity
- according to the used technique of thermal processing,
- according to the gas treatment systems
- according to the energy generation,
- according to the waste produced,
- according to the stage of introduction,
- according to the presence of a permit for the use as well as a conclusion of the state environmental review

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- based on the facilities where they are introduced

The considered equipment has a design technical documentation for new equipment and technique that have received a positive conclusion of the state environmental review. The basis for this information is the information presented in a Rosprirodnadzor letter of the 22.01.1015, no. VS-08-01-28/721, forming a part of the register issued on the Rosprirodnadzor site http://rpn.gov.ru/ and also available in the answers to the questions in the companies' questionnaires by the Rosprirodnadzor and its territorial authorities on the proposed technical documents on new equipment and technique for the period 2011-2014.

As to the quantity of equipment introduced in Russia within any of the fields of thermal waste treatment, it is not possible to collect the full information, since many of the companies did not answer to the request to present the questionnaires. Based on the received questionnaires it is possible to establish the fact that the largest distribution was found by incinerators of the type Forsazh, IN and KTO.

Table 1.7 reflects the geographical distribution of the thermal waste treatment equipment over the federal districts of the RF. As explained by the information in the table, the techniques for thermal treatment and the equipment for waste incineration are located practically in every federal district. The facilities for pyrolysis and gasification are significantly less distributed over the country.

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Table 1.2 – The results of the systematization of the techniques of waste treatment based on the questionnaires presented by the companies.

Incineration methods

No.	Code and name of the group of waste types according to the FKKO-2014	Equipment	Capacity, tons/hour	Technique	Gas treatment system	Energy generation	Waste formed	Extent of introduction	Is there permit for the use, a conclusion by the State Environmental Review	Application
INCINERATION METHODS										
1	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for incineration of municipal solid waste (three lines)	8,33 t/h x3 = 25 t/h	Incineration on a reverse sheering grate	Wet and dry absorption device	Energy production 1,2x3=3,6 MW	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	GUP Ecotekhprom, Spetszavod no2, Moscow
2	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for incineration of municipal solid waste (two lines)	24 t/h x2 = 48 t/h	Incineration on a reciprocating grate	Control absorption device	Energy production 11 MW	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	OOO EFN Ecotekhprom, MS3 no 3, Moscow
3	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for incineration of municipal solid waste (Three lines)	13,5 t/h x2 = 27 t/h	Incineration on an eddy fluidized bed	Wet and dry absorption device (lime slurry + activated charcoal	Energy production 6x2= 12 MW	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	GUP Ecotekhprom, Spetszavod no 4, Facility for solid domestic waste and domestic waste (solid household and biological), Moscow

4	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for incineration of municipal solid waste (Three lines)	6 t/h x3 = 18 t/h	Inciner ation on a reverse sheerin g grate	Settling chamber, multicyclone device	Heat release	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	MUPD Spetszavod no1, Vladivostok
5	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for the incineration of municipal solid waste (Two lines)	15 t/h x2 = 30 t/h	Inciner ation on a roll sheerin g grate	electrofilter	Heat release	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	OAO Zavod TBO, Murmansk
6	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for the incineration of municipal solid waste (Three lines)	15 t/h x2 = 45 t/h	Inciner ation on a roll sheerin g grate	Electrofilter	Heat release	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	OAO Pyatigorskiy Complex, Pyatigorsk
7	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Municipal solid waste	Production line for the incineration of municipal solid waste (Two lines)	1,5 t/h 1,5 x2 = 3,0 t/h	Fuel-bed firing with movabl e hearth	Afterburner, lime and coal feed, sack filter	Heat release	Slag and ash from the incineration process	Industrial model	Yes, no conclusion of the SER has been presented	Cherepovetsskiy Zavod for the integrated processing of MSW, Cherepovets
8	2.10 Waste from the extraction of fuel and energy resources	UZG-1m	6 t/h	Inciner ation in a rotating furnace	Scrubber	None	Ash from the incineration process	Industrial model	Yes, SER no 292-g08/KhME-0242/022 of the 14.07.2008, SER no22 of	1. OOO ECO Plyus city of Langepas; 2) ZAO SA-NECO, Republic of Bashkortostan,

									the 20.04.2012	Ufa
9	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 7. Waste from water supply, water discharge as well as activities for the collection and processing of waste. 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8. Waste from production and consumption of the 3 – 5 hazard classes including solid and liquid waste containing petroleum products, medical waste, biological waste and waste from chemical production	Incinerator IN 50	50-500 kg/h	Inciner ation in a hearth furnace	Gas afterburner chamber, cyclone, scrubber (dry/wet)	There is a possibility of adding a water-heating waste heat boiler (a heat exchanging unit)	Ash from the incineration process	Industrial model	Yes, SER no 202, of the 12.04.2013	A list of the companies, where the aforementioned facility is used is found in table 1.3.
10	7.20 Waste from the collecting and	Wastewater sludge	3,4 t/h	Inciner ation in	Electrofilter, 2-stage	Yes, electric	Ash from the incineration	Industrial model	Yes, no SER has been presented	GUP Vodokanal, St. Petersburg,

	processing of wastewater The processed sediment of wastewater as well as the surplus condensed sludge of the filter cake	incineration plant of the South-West Sewage Treatment Plant, imported equipment		a fluid-bed furnace	scrubber	energy is produced by the steam turbine				city of St. Petersburg
11	3.01 Waste from the production of food, beverages and tobacco products 4. 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 Petroleum-containing waste, waste containing plant and animal fats, alcohol-containing waste	Chamber furnace UUN 0,8	0,5-2 t/h	Incineration in a drum-type chamber furnace	1 A course mesh filter (cyclone) 2 A fine mesh filter (scrubber with water treatment) (10% alkaline solution NaOH)	None	Ash from the incineration Process sludge	Industrial model	Yes no SER conclusion has been presented	OOO Agentstvo Rtutnaya Bezopasnost', Krasnodarskiy Kray, Abinskij rayon, st. Kholmskaya
12	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9	KTO-1000.3 V/KTO-1000.Ch	1 t/h	Incineration in a rotating furnace	Gas afterburner, Mechanical gas treatment (bag filter, ceramic cartridge filter, wet dust separation)	Yes, heat energy is produced as hot water or steam 2,5 – 3kW	Ash from the incineration	Industrial model	Yes, SER no 677 of the 28.10.2014	1) OOO TK NefteKhimGas, Moscow 2) OAO RZhD, Moscow

	7. Waste from water supply, water discharge as well as activities for the collection and processing of waste. 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8. Solid household waste (including petroleum-containing and used wooden sleepers), medical and biological waste				Chemical gas treatment (dry, half-dry, wet scrubber)					
13	7.20 Waste from the collecting and processing of wastewater Industrial effluents (including methanol solution)	KTO-1000.BMKSZH/ KTO-1000.BM.Ts	1 t/h	Incineration in a cyclone reactor	Gas afterburner	Yes, heat energy is produced as hot water or steam 1,5 – 2kW	Ash from the incineration	Industrial model	Yes, SER no 677 of the 28.10.2014	A list of companies, at which the aforementioned facility is used is shown in table 1.4
14	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 7. Waste from water	Waste incineration facility CW 128SW-L	0,3 t/h	Incineration in a chamber furnace, equipped with an ash box system	Gas afterburner	none	Ash from the incineration	Industrial model	SER no 180 of the 18.12.2014	AO ChGGK, ChAO, Anadyr

	supply, water discharge as well as activities for the collection and processing of waste. Solid household waste, petroleum-containing waste									
15	3 – Waste from the processing industry; 7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. Solid household waste, petroleum-containing waste	Installation Forsazh-2M	180 kg/h	Incineration in a burning chamber (drum)	Gas afterburner	None	Ash from the incineration	Industrial model	Yes, SER no 273 of the 24.11.2004	OOO UNR-17, Vladimir
16	7.30 Municipal, and similar to municipal waste during production, waste formed during rendering of service. 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8. Waste from food production, waste from pulp and paper production, organic waste, waste from medical institutions and the like	Incinerator IU-80	0,18 t/h	Incineration in a furnace	Gas afterburner	None	Ash from the incineration	Industrial model	Yes, no SER conclusion has been presented	MUP MO NR Pererabotchik, Neryungri

17	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 7. Waste from water supply, water discharge as well as activities for the collection and processing of waste. Solid household waste, petroleum-containing waste 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8. Solid household waste (including petroleum-containing), medical, biological waste	KTO-50.K20P, KTO-50.K40P, KTO-50.BMP, KTO-100.K40P KTO-100.MK KTO-150.ZP KTO-150.BM.P	KTO 50: 0,05 t/h; KTO K100: 0,1 t/h, KTO 150: 0,15t/h	Inciner ation in a hearth furnace	Gas afterburner, Mechanical gas treatment (bag filter, ceramic cartridge filter, wet dust separation) Chemical gas treatment (dry, half-dry, wet scrubber)	Yes, for the KTO 150, energy in the form of heat as hot water of steam 0,3 – 0,4 kW	Ash from the incineration	Industrial model	Yes, SER no 310 of the 06.06.2013, SER no 481 of the 01.08.2013	A list of companies, at which the aforementioned facility is used is shown in table 1.5
18	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having	Mobile incinerator HUrikan-150	50-75 kg/h	Inciner ation in a chambe r furnace	Gas afterburner	None	Ash from the incineration	Industrial model	Yes, no SER conclusion has been presented	OOO Agentstvo Rtutnaya Bezopasnost', Krasnodarskiy Kray, Abinskij rayon, st.

	lost their consumption properties, not being part of the items 1-3 and 6-9 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8.									Kholmskaya
19	4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 Petroleum-containing waste, used filters, oil-drenched textile rags, saw-dust, used sorbents, other combustible materials	Installation Forsazh-1	0,05 t/h	Inciner ation in a incinera tion chambe r (drum)	Gas afterburner	None	Ash from the incineration	Industrial model	Yes, SER no 77.01.30312L0 7782.04.3 03.04.2003	A list of companies, at which the aforementioned facility is used is shown in table 1.6
PYROLYSIS METHODS										
20	2.10 Waste from the extraction of fuel and energy resources. Oils sludge, drilling waste	UTD-2	250800-1500 kg/h	Low-temper ature pyrolysi s without	Pyrolytic gas filter	Yes, an additional system of heat recovery is added as	Pyrolysis fuel, pyrolysis gas, sand	Industrial model	Yes, SER no 576 of the 18.09.2014	OOO NPP Soyuzgaztekhno logiya, Tyumen’

				access to oxygen in the reactor		well as the production of electricity				
21	3 – Waste from the processing industry; Rubber-containing and polymer-containing waste	Pyrolysis installation Fortan-2	345 kg/h	Low-temperature pyrolysis in a retort furnace	None. Extra equipment in the form of a foam gas treatment system is part of plans	None	Pyrolytic oil, technical carbon, metal cord	Industrial model	Yes, SER no 0811 of the 17.12.2014	OOO TT GRUPP, Krasnodar. The installations are operated in Moscow and Tver' Oblasts, in Murmansk, in Petropavlovsk-Kamchatskiy, Sakhalin Oblast
22	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 7. Waste from water supply, water discharge as well as activities for the collection and processing of waste. Solid household waste, petroleum-containing waste Solid Household Waste, rubber	Waste Processing Facility ECOMASH-01/The EcoMachine Complex AMR-100	250 kg/h	Low-temperature pyrolysis in a vertical shaft reactor	Three-stage gas treatment	Yes, Generator gas is produced for the gas piston generator	Synthetic (Pyrolysis) gas, Pyrolysis liquid, ash (soot)	Industrial model	Yes, no SER conclusion has been presented	Orenburg, Perm', Yaroslavl', Tver'

	technology products, plastic, waste from the pulp and paper industry, organic waste, waste from medical institutions, etc.									
23	4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 rubber-containing waste and rags	UPOR-1Sh	250 kg/h	Pyrolysis in a reactor	Centrifuge aerosol separator	None	Pyrolysis fuel, metal scrap, ash	Industrial model	Yes, SER no 292-08/KhME-0242/02 of the 14.07.2008	OOO ECO Plyus, Langepas
24	Rubber technology products, tyres	UTD-1	100 kg/h	Low-temperature pyrolysis without access to oxygen in a reactor	Filter for the pyrolytic gases	Yes, additional equipment in the form of a heat recovery system and electricity is generated	Pyrolysis fuel, pyrolytic gas, metal scrap, ash	Industrial model	Yes, SER no 576 of the 18.09.2014	1) GUP Kaliningradskoy Oblasti Yedinaya Sistema Obrashcheniya c otkhodami, Kaliningrad 2) OOO NPPP Soyuzgaztechnologiya, Tyumen’
25	3 – Waste from the processing industry; 4. Production and non-production consumption waste; materials having lost their consumption	Incinerator S.R. 50	0,05 t/h	High-temperature pyrolysis in a chamber furnace	Gas afterburner, ”dry” gas treatment based on reagents in the form of Calcium	Yes, heat energy for the heating of water	Ash from the incineration	Industrial model	Yes, SER no 82-1 of the 12.08.2011 SER no 581 of the 19.09.2013	1) OOO Biopotentsial, Krasnodar 2) GUS OBSME, Tula 3) OOO Firma Stalker, Komsomolsk-

	properties, not being part of the items 1-3 and 6-9 7. Waste from water supply, water discharge as well as activities for the collection and processing of waste. 9. Waste formed during the carrying out of other types of activities, not forming part of 1-3 or 6-8. Medical waste of all kinds, biological waste, food industry, pharmaceutical industry, persistent organic pollutants, unusable, prohibited agricultural toxic chemicals, solid production waste including plastic, containing chlorinated hydrocarbons; liquid, including highly toxic, containing petroleum products) Wastewater sludge, , Solid household				stones and activated carbon					na-Amure

	waste reject material, etc									
GASIFICATION METHODS										
26	7.40 Waste from waste processing activities solid household waste reject material	Vortex gas generator GGV-3000	1000 - 1200 m³/h	Thermal conversion under conditions of oxygen deficiency	Scrubbers with heat exchangers	Yes, Generator gas is produced for the gas piston generator	Ash from the incineration	Industrial model	Yes, no SER conclusion has been presented	OOO NIKKOM, Moscow
27	7.40 Waste from waste processing activities Polluted gaseous waste	Regenerative gas afterburner DGR-0,5, DRG-5, DRG-10, DRG-20	500m³/h	Afterburning of the gases in a burning chamber, tow generative chambers with gas permeable heat exchange filling under conditions of intensive agitation	Yes	(DRG 0,5 not present) DRG-5-20 hot water	Ash from the incineration	Industrial model	Yes, no SER conclusion has been presented	OAO ChRS Moscow Oblast, city of Chekhov
29	7. Waste from water	Thermal	10 m³/h	Sprayin	None	none	Ash from the	Industrial	Yes, SER no	OOO NPP SGT,

	supply, water discharge as well as activities for the collection and processing of waste The liquid phase of drilling waste	wastewater destruction facility UTLSV		g into steam like conditio n in the flame of the gas flame			incineration	model	576 of the 18.09.2014	Tyumen’
30	4. Production and non-production consumption waste; materials having lost their consumption properties, not being part of the items 1-3 and 6-9 7. Waste from water supply, water discharge as well as activities for the collection and processing of waste wastewater, used compressor and machine oil, tank and blow-down gases, residual oil, air from local exhaust suction units,	Production waste incineration Furnace	6,30m^3/h	Therma l destruc tion of various product ion waste in a nature gas flame	Not indicated	None	Not indicated	Industrial model	Yes, SER no 576 of the 18.09.2014	Filial Azot OAO Obyedinyonnay a khimichesikaya Kompanya URALKhIM in the city of Berezniki

Table 1.3 plants, where the incinerators IN 50 are in use

No	Name, location
1	OAO MRTS-Vostok, Yuzhno-Sakhalinsk
2	TOO Minertools
3	OOO Med-Ecologiya
4	Department of Property Relations of the Administration of the town of Novyy Urengoy, Novyy Urengoy
5	FKGU Rosgranstroy
6	OOO Stroitel'naya Investitsionnaya Gruppa, Belgorod Oblast'
7	OOO DIS, Nakhodkinskaya City Hospital, Nakhodka
8	The Air port of Ulan-Ude
9	OOO TELROS Integratsiya, city of St. Petersburg
10	Tomsk Airport
11	OOO TELROS Integratsiya, city of St. Petersburg
12	ZAO Gold Extracting Company (Zolotodobyvayushchaya Kompaniya) Polyus, Krasnoyarsk Kray
13	OOO EcoTransService, Cherepovets
14	BUZ Voronezh Oblast Centre for the Prevention and Control of AIDS and Infectious Diseases, Voronezh
15	Municipal Solid Waste Landfill, Nal'chik
16	OOO Ecologicheskiye Sistemy, Novosibirsk
17	OOO Tsentr Utilizatsii (Recycling Centre), Tomsk
18	OAO Sea Commercial Harbour in Ust'-Luga, FGUP Rosmorport, Leningrad Oblast'
19	OOO Bloom König OGUP Unified System of Waste Handling (ECOO), Kaliningrad
20	GUZ Chita Oblast Oncological Health Centre, Chita
21	OOO EcoServis, Barnaul
22	OOO Promecologiya, Yekaterinburg
23	OOO EcoTecknologii, Omsk
24	OAO TNK-VR
25	OOO TNK-Uvat, Tyumen' Oblast', Oil/gas fields of: Tyamkinskoye& Urnenskoye, Ust'-Tegusskoye, Yuzhno-Petskoye. Operator: OOO Universal-Service
26	OAO Gazprom, peninsula of Yamal, DOAO Spetsgazavtotrans, Labytnangi
27	The Production Site of the Bovanenkovo Field, Izhevsk, Udmurtiya, NK Rosneft'
28	ZAO Vankyurneft', Moscow
29	OAO Transneft'
30	OOO SMNP Koz'mino, Primorskiy Kray, Nakhodka
31	ZAO Trest Koz'mino, Primorskiy Kray, Nakhodka
32	OAO Boksit Timana, Ukhta, Rotational Village of the Sredne-Timanskiy Mine
33	The Russian Antarctic Expedition of the Antarctic Station Progress-2 at the Antarctic Station Novolazerskaya
34	The Alexandra Island Military Base Village at the Franz Josef Land
35	OOO ELECTRO-LT, Moscow

36	The Foreign Intelligence Service of Russia, troop unit 55240, Moscow
37	OOO Utilitservice, Tyumenskaya Oblast’, Surgut, Tyumen’
38	OOO Utilitservice, Novosibirsk
39	Too Olzhas, Kazakhstan, Almaty, Aktobe, Astana, Karaganda, Taraz
40	The Federal Customs Service of Russia, The Customs Terminal at the border checkpoint Adler, The Vesyoloye Station at Sochi
41	OOO RSU no 5, St. Petersburg
42	The Federal Customs Service of Russia, MAPP, Verchniy Lars, Vladikavkaz
43	OOO Direktsiya po Stroitel’stvu MAPP
44	FGUP State Health Care Products, Moscow
45	Central Bank of Russia, Tekhnologicheskiy Tsentr Nudol’, Village of Narynka, Moscow Oblast’
46	OOO Ekologicheskaya Initsiativa, Kirov
47	Municipal Solid Waste Landfill, village of Kostino
48	OOO Sakhalin Company for the Recycling of Waste Ekoservis, Yuzhno-Sakhalinsk
49	OOO Centre for the Management of Medical Waste, Kurgan
50	OOO Centre for the Management of Medical Waste, Permskiy Kray, Municipal Solid Waste Landfill in ZATO Zvyozdnyy
51	Ministry of Defence of The RF, Military hospital of the Airborne Forces, Krasnozemensk
52	Ministry of Defence of The RF, Military hospital of the Airborne Forces, Tula
53	Ministry of Defence of The RF, Military hospital of the Airborne Forces, Vyborg, Leningrad Oblast’
54	Garrison Hospital of the Rybachiy Village, ZATO Vilyuchinsk, Kamchatka Oblast’
55	FGP GUSS Dal’spetsstroy, Khabarovsk
56	The RF Ministry of Defence, The Out-Patient Consulting and Diagnostic Centre of Kambarka, Republic of Udmurtiya
57	ZAO PKO Tyumen-Universal
58	The Government of the Republic of Udmurtiya
59	GUZ Respublikanskiy Clinical Oncologic Centre
60	GU UKS of the Government of the Udmurtskaya Republic
61	FGUS TsMSCh no 38 FMBA of Russia, Sosnovyy Bor, Leningradskaya Oblast’
62	The Angara City Hospital no 1, Angarsk
63	OOO Clinic of the 21 Century, The Kh. M. Sovmen Modern Medical Centre, Republic of Adygeya, Aul Afipsip, Takhtamukanskiy rayon
64	The Mayor’s Office of the city of Olsburg, Denmark, EU (TASIS Programme)
65	The Mayor’s Office of Kaliningrad, GUZ State Multi-Discipline, Kaliningrad
66	The Government of St. Petersburg, MUZ City Tuberculosis Hospital no2, St. Petersburg
67	The Administration of the Irkutsk Oblast, OGUZ Irkutsk Oblast’ Psychiatric Hospital no 3, d Sosnovyy Bor, Irkutsk Oblast.
68	Maternity Clinic of the MUZ Krasnogvardeyskaya Tsentral’naya Hospital, Krasnogvardeyskoye, Stavropol’skiy Kray
69	Maternity Clinic of Balakovo, Saratov Oblast’
70	The Veterinary Corporation OOO Vit-Dzhorzhiya, Tbilisi, Georgia
71	OOO Gerakl’, Kotlas, Arkhangelsk Oblast
72	The Airport of Nizhnyevartovsk, OAO, Nizhnyevartovsk

73	The Airport of Khanti-Mansiysk, OAO Yugra-Avia, KhMAO
74	The Administration of the City of Ufa, MUP City Cleaning Special Vehicle Enterprise, Magadan
75	The Administration of the Arkhangelsk Oblast', SMUP Special Vehicle Enterprise, Severodvinsk
76	The Administration of the City of Magadan, MU Green Enterprise Plant, Magadan
77	GMUP Motor Transport Administration, KhMAO, Nizhnyevartovsk, Langepas
78	MGUP Promotkhody, Moscow
79	ZAO Zavod TECON, operator: OOO TsUOO, St. Petersburg
80	OOO Promstroy CU-1, Chaykovskiy, Permskiy Kray
81	OOO Penzavtosyryo, Penza
82	OOO Vidkom, St. Petersburg
83	TOO Vest Dala, Atyrau, Kazakhstan
84	TOO Bart Media, Almaty, Kazakhstan
85	TOO CpetsServis-Aktay, Aktau, Kazakhstan
86	OOO YUTA, City Solid Waste Landfill
87	Solid Waste Landfill, city of Berezniki, Permskiy Kray
88	OOO Stimul, Lipetsk
89	FGBUN Institute of Chemical and Energy Problem Technologies of the RAS, Biysk
90	GNTs RF FGUP TsNIIKhM named after D.I. Mendeleyev, Moscow
91	OAO Gazprom
92	ZAO YamalGazInvest
93	OAO Giprospetsgaz, St. Petersburg – general designer Magistral'nyy Gazoprovod (main gas pipeline) SRTO Torzhok, KS Vuktyl'skaya, KS Privodiono, Ks Novogryazovetskaya, KS Novoyubileynaya
94	OAO AK Transneft'
95	AMERCO International LTD, Great Britain
96	OOO Spetsmornefteport Primorsk, Leningradskaya Oblast'
97	NK Lukoil
98	OAO RPK Vysotsk-Lukoil-2, Oil Sea Terminal Vysotsk, Leningradskaya Oblast'
99	OAO RZhD, The October Railroad Administration, St. Petersburg
100	TOO Olzhas, Almaty, Kazakhstan
101	Rotational Village of the Oil Sea Terminal in the Village of DeKastri (Sakhalin-1)
102	PoongLim Co, South Korea, Main Contractor
103	Astrakhanskiy GPS, Astrakhan'
104	TOO Ivolga Holding, Kostanay, Kazakhstan
105	ZAO RosProdImport, Vladivostok
106	OAO NIPI Gazpererabotka, Krasnodar
107	FGUP Company for the Production of Bacteria Products of the Pasteur NIIEV , St. Petersburg
108	OAO Mozhginskoe Construction Incorporation, Mozhga, Republic of Udmurtiya

109	The Health Care Administration of the Arkhangelsk Oblast', Severodvinsk, Novodvinsk
110	UNR Ministry of Defence of the RF, District Military Hospital SKVO MO RF, 522 Reception Treatment and Dispatch of the Diseased Centre, Rostov-na-Donu, IN-50.1 (50 kg/h), cargo 200
111	District Social Gerontology Centre and Orphanage, village of Snezhnyy, Surgut
112	SGMUP Teplovik, Surgut, Tyumenskaya Oblast'
113	MU Tuberculosis Hospital no 11, Solnechnogorsk, Moscow Oblast'
114	OAO NK Rosneft', Rotation Village for Construction Workers of the Resting Base of the Development Vankor, Krasnoyarskiy Kray
115	OAO Morskoy Port, St. Petersburg
116	Children's Recreation Centre Mayak
117	FGUP Rosmorport, Moscow, Seaport Vostochnyy 2, Nakhodka, Primorskiy Kray
118	US Government, Fluor International Inc Raytheon Technical Services Company LLC
119	FGU Federal Centre for Animal Health Protection, Vladimir
120	OOO Utilitservis, Tyumen Oblast, Tyumen', Surgut
121	TOO Olzhas, Kazakhstan (for the city of Chimkent), Almaty
122	Plant Goznak, St. Petersburg
123	Foreign Intelligence Service of Russia, military unit 55240, Moscow
124	OAO Nizhfarm, Nizhniy Novgorod
125	OAO Krasnyy Gidropress, Taganrog
126	OAO Petrokholod, St. Petersburg
127	ZAO Mospromstroy, Firm Mosstroy-16, Moscow
128	St. Petersburg Government, I.P. Pavlov State Medical University, St. Petersburg
129	The Veterinary Administration of St. Petersburg, Government of St. Petersburg, GU City Veterinary Centre, St. Petersburg
130	Government of St. Petersburg, GUZ Leningrad Oblast Children's Clinical Hospital, St. Petersburg
131	NMP Clean City, Municipal Solid Waste Landfill, Novokuybyshevsk
132	Unitary Municipal Scientific and Production Enterprise for Waste Handling Ecopol, Municipal Solid Waste Landfill, Voronezh
133	Plant for the Processing of rubber technology products, Moscow
134	The Trav Car barn of St. Petersburg
135	The Wood Processing Plant of the Housing and Utilities Board of the Pargolovskiy District of St. Petersburg
136	IP Dyakonov, Aleksandr Aleksandrovich, Yuzhno-Sakhalinsk
137	GU Bureau of Medicolegal Review of the Novosibirsk Oblast, Novosibirsk.
138	GU Bureau of Medicolegal Review of the Leningradskiy Oblast, Tosno, Leningradskaya Oblast'
139	OAO MRTC-Vostok, Yuzhno-Sakhalinsk
140	State Corporation Rosatom
141	FGUP Electrokhimpribor Plant, City of Lesnoy (Sverdlovskaya Oblast')
142	ZAO Uraloborudovaniye, Yekaterinburg
143	FGUP Rosmorport, Nakhodka, Primorskiy Kray
144	OAO AK Transnefteprodukt, Commercial Seaport of Primorsk, Leningradskaya Oblast'

145	OAO RZhD OOO Tikhoretskiy Sleeper Impregnation Plant, Krasnodarskiy Kray
146	NK Lukoil, OOO Lukoil-Kaliningradmorneft', Kaliningrad
147	Federal Agency of Atomic Energy, General Designer: FGUP State Specialized Design Institute, Moscow
148	US Government, Fluor International Inc Raytheon Technical Services Company LLC
149	FGU Federal Centre for Animal Health Protection, Vladimir
150	ABB LummusGlobal, USA
151	Sakhalin-1, Rotation Village, oil/gas field of Chayvo
152	The Administration for the OSS for the Veterinary Service of the Government of St. Petersburg, GU City Veterinary Centre
153	GUP, PM Saranskiy Veterinary and Sanitary Recycling Plant, Saransk
154	Committee for City Economy, of the Administration of the Urban District, Centre for the Destruction of Stray Animals, Kaliningrad
155	OOO Kolskaya Korporativnaya Kompaniya, Village of Kola, City of Murmansk
156	OOO Chistyy Gorod (Clean City), Blagoveshchensk, Amurskaya Oblast'
157	ZAO Avgust-Bel, Minsk Oblast', Belarus
158	OAO Vurnarskiy Plant for the Production of Mixed Preparations, village of Vurnary, Republic of Chuvashiya
159	OOO Utilitservis, Tyumen', Surgut
160	ZAO RosProdImport, Vladivostok
161	ZAO Volgogradskiy Bearing Production Plant, Vologda
162	MUP Spetsavtobaza
163	OOO Green-Port, Odessa, Ukraine
164	OOO Ekoresurs, Krasnoyarsk
165	OOO Gazprom, KS Portovaya
166	ZAO RusGazInzhiniring, Vyborg
167	OAO RZhD, East-Siberian Railroads. Plant for the Recycling of Waste, Station of Tagul, Irkutskaya Oblast'
168	OOO Roshal'skiy Plasticizer Production Plant, Roshal', Moscow Oblast'
169	OOO Plastoil, Perm'
170	FGUAL Pulkovo, St. Petersburg
171	ZAO Poligon LTD, Surgut, Tyumenskaya Oblast'
172	TOO Vest Dala, Atyrau, Kazakhstan
173	Extraction sites: Masteryelskoye, Severo-Masteryelskoye, OAO Komnedra, Republic of Komi
174	SHELL, Great Britain/Holland, SalymPetroeumDevelopment N.V. Tyumen'
175	OAO St. Petersburg Seaport (III district)
176	ZAO RosProdImport, Vladivostok
177	Extraction sites: Masteryelskoye, Severo-Masteryelskoye, OAO Komnedra, Republic of Komi
178	TOO Potential Oil, Atyrau, Kazakhstan
179	UPSV Oktyabrskaya Pravoberezhnogo TsPTNG, OAO Saratovneftegaz, Saratovskaya Oblast'
180	OAO Kontsern Energoatom, UKS Rostovskaya Nuclear Power Plant under construction, Landfill for Toxic Waste of the Volgodon Chemical Plant, Volgodonsk, Rostovskaya Oblast'

181	OAO Commercial Seaport of Ust'-Luga, village of Ust'-Luga, Leningradskaya Oblast'
182	Specialized Municipal Solid Waste Landfill of the village Kostino, Kirovskaya Oblast'
183	The Federal Agency for Science and Innovation, of the Russian Federation, Moscow
184	OOO Ekologicheskaya Initsiativa, Kirov
185	Extraction Site Peshchanoe of the OAO NAK, Aki-Otyr, ChMAO (Chanti-Mansiyskiy Autonomous District)
186	Verkhne-Salatskoe Oil and Gas Field, Tomskaya Oblast', OAO Tomskneft'

Table 1.4 plants, where the facilities KTO-1000.BMKSZh/KTO-1000.BM.Ts are in use

No	Name, location
1	OOO Gazprom invest Zapad, KS Portovaya, St. Petersburg
2	OOO Gazprom Extraction Nadym, Bovonenkovskoe NGKM, YaNAO, Nadym
3	OAO Vyksunskiy Metallurgical Plant, Nizhegorodskaya Oblast', Vyksa
4	OOO Gazprom Invest Zapad, KS Kirinskaya, St. Petersburg

Table 1.5 plants, where the installations KTO-50, KTO-100 and KTO-150 are in use

No	Name, location
1	ZAO Vankorneft', Krasnoyarsk
2	OOO RN-Severnaya Neft', Usinsk
3	OOO RN Uvatneftegaz, Tyumen'
4	OOO Irkutskaya Oil Company, Irkutsk
5	OOO Firma ECOTRAC, Moscow
6	IP Karabanov, A.V. Vologodskaya Oblast', Cherepovets
7	OAO Pribornyy Zavod Signal, Kaluzhskaya Oblast', Obninsk
8	OAO Pervenets, Irkutskaya Oblast', Bodaybo
9	OOO OKSA, ChMAO-YuRGA, Surgut
10	OOO GMK, Primorskiy Kray, Vladivostok
11	OOO Zolotar', Vladivostok
12	OOO Bumerang, Primorskiy Kray, Ussuriysk
13	EcoServis, Yuzhno-Sakhalinsk, Restricted area of the Airport of Yuzhno-Sakhalinsk
14	TOO ETK KazSlanets, Kazakhstan, Ust'-Kamenogorsk
15	MBU UKS for the Development of the Nizhnevartovskiy District, ChMAO-Yurga, Nizhnevartovsk
16	OAO Limited Oil Company Bashneft', Republic of Bashkortostan, Ufa
17	OOO Paramushir-Grad, Kamchatskiy Kray, Petropavlovsk-Kamchatskiy
18	ZATO Administration of Solnechnyy, Tverskaya Oblast, Worker's Housing Centre Solnechnyy
19	Committee on Nature Exploitation and Ecology of the Administration of Surgut, ChMAO, Surgut
20	Scientific and Production Centre for Environmental Protection, a branch of the OAO RZhD, Yaroslavl

Table 1.6 plants, where the installation Forsazh-1 is in use

No	Name, location
1	OAO Port Troitsy, village of Zarubino, Khasanskiy District, Primorskiy Kray
2	OOO, Firm EkoSvet, Krasnodar
3	OOO BSK GRAND, Tomskaya Oblast'
4	OOO Intek Agro, Yaroslavl'
5	OAO Sibir'-Polimetally, Altay Kray, Rubtsovskiy District, Village of Poteryayevka
6	OAO MK Orenbyrgskaya Oblast', Orsk

Table 1.7 Geographical distribution of the equipment for thermal treatment of waste over the Federal Districts of the Russian Federation

No	Name of the equipment	Central	South	North-East	Far-East	Siberia	Ural	Volga	North Caucasus	Crimea
	INCINERATION									
1	Facility UZG-1m (for the recycling of patched substrate, sludge)	-	-	-	-	V	-	V	-	-
2	Incinerator IN 50	V	V	V	V	V	V	V	V	
3	Wastewater sludge incineration installation	V	-	-	-	-	-	-	-	-
4	Oil sludge incineration plant UUN 0,8	-	V	-	-	-	-	-	-	-
5	Systems KRO-1000.3 V, KTO-1000.Sh, KTO-1000.BM.KSZh, KTO-1000.BM.Ts	V	-	V	-	-	V	V	-	-
6	Waste incineration installation SV 128SW-L	-	-	-	-	-	V	-	-	-
7	Installation Forsazh-2M	V	-	-	-	-	-	-	-	-
8	Incinerator IU-80	-	-	-	-	-	-	V	-	-
9	Installations KRO-50.K20.P, KTO-50-K40.P, KTO-50.BM.P, KTO-100.K40.P; KTO-100.MK; KTO-150.3.P; KTO-150.BM.P	V	-	V	V	V	V	V	-	-
10	Mobile Incinerator Hurikan-150	-	V	-	-	-	-	-	-	-
11	Installation Forsazh-1	V	V	-	V	V	-	V	-	-
	PYROLYSIS									
12	Thermal destruction Facility UTD-2	-	-	-	-	-	V	-	-	-
13	Pyrolysis installation FORTAN-2	-	V	-	-	-	-	-	-	-
14	Waste processing installation ECOMASh-01/EcoMachineAMR-100	V	-	-	-	-	-	V	-	-
15	UPOR-1sh installation	-	-	-	-	V	-	-	-	-
16	Installation UTD-1	-	-	V	-	-	V	-	-	-
17	Incinerator Müller C.P.50	-	V	-	-	-	-	-	-	-

GASIFICATION										
18	Vortex gas generator GGV-3000	V	-	-	-	-	-	-	-	-
19	Gas generation afterburner DGR-0, DRG-5, DRG-10, DRG-20	-	-	-	-	-	V	-	-	-
20	Thermal wastewater destruction facility UTLSV	-	-	-	-	V	-	-	-	-
21	Production waste incineration furnace	-	-	-	-	-	-	V		

1.2. A Short Overview of the Main Environmental Problems in the Field of Thermal Waste Treatment

1.2.1 Environmental Aspects

The environmental problems in the field of thermal waste treatment are defined by the environmental aspects that have a direct influence or may have a direct influence on the environment. According to ISO 14001 [4], the environmental aspect – is the element in the activities of an organisation, its production or its services, which may have an interaction with the environment.

When dealing with thermal treatment of waste, the environmental aspects, which have a direct impact on the environment and human health are:

- emissions to air
- discharges of wastewater
- production of waste
- collection and storage (accumulation) of treated waste and reagents, including hazardous ones

The environmental aspects that have an indirect environmental impact and en influence on human health are:

- The efficiency of the system for management of environmental protection;
- The competence of the personnel in the field of environmental protection;
- The control and the monitoring of the environmental impact (the presence, adequacy and quality of the measuring and control equipment);
- The consumption of raw material and other material
- The consumption of energy resources and the like

Incineration is the controlled process of oxidation of solid or liquid combustible waste, containing organic matter. During incineration generally, carbon dioxide, water and ash are formed. Sulphur and nitrogen, forming part of the waste, during combustion form various oxides, whereas chlorine is reduced into HCl. Apart from the gaseous products, obtained during the incineration of waste, solid particles are also formed metals, glass, slag and others, which call for a continued recycling process or landfill burying. During incineration the molecules of organic compounds are destroyed, whereas the inorganic compounds are transformed into oxides and carbonates, which are produced together with the slags and ash. The fine dust particles of oxides and carbonates contained in the furnace gas, are trapped in

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”wet” scrubbers or bubble aeration [5,6]

The thermal waste treatment on a modern level of development of science and technology serves for the practically full destruction of the organic hazardous compounds contained in the waste, which is attained wit the aid of high temperatures (above 1000°C). This is the case with dioxins and furans, which are destructed by more than 90 %. At a temperature of 850°C their component parts are disintegrated. During cooling of the flue gases , there is a possibility that a very small part of the formed fragments will unite again. In order to safely separate them bag filters are used in the flue gas cleaning system with a possibility of additional feeding of pulverised activated coke, and, by doing this, one attains an efficient separation of all dioxins and furans [7,8,9]. These technological solutions are incorporated when creating a whole number of facilities for he thermal waste treatment through the incineration and are direction

realized at modern waste incineration plants. In order to treat the flue gasses at waste incineration plants for the thermal treatment of solid household waste in Russian, an equipment is used, mainly imported equipment, with a three-phase system for the treatment of the exhaust gasses, adapted to the use of chemical reagents of Russian manufacture [10,11,12). At the first stage, the treatment in the absorber tower a neutralization of the acid components of the flue gasses takes place with the aid of lime in the presence of finely dispersed water droplets. At the second stage a thorough cleaning takes place in a bag filter from the flue ash and the sorption of heavy metals and dioxins in the process of filtration of the flue gasses though a layer of lime and activated carbon on a filter textile material. At the third stage of the treatment process, a reduction of the Nitrogen oxides contained in the flue gasses into molecular nitrogen, with the use of an ammonia solution.
The inorganic harmful substances, such as heavy metals, which are not affected by the treatment process, even at high temperatures, in the multi-step installation for the treatment of flue gases or during the processing of the remainder of the incineration process, will have to be separated in a concentrated form, be extracted and be bound to some other material. After this the handing of them must be carried out in an environmentally safe way. The low-hazard slag, formed in the process of burning and that are similar to rock material, may be recycled without risk. In Germany, Holland, and other countries they are used, among other purposes as a substitute for road stone or for the sound isolation of walls [13, 14].
The pyrolysis and gasification methods of waste treatment are not widespread, as compared to incineration.

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The thermal waste treatment pyrolysis technology consists in the irreversible chemical change under the action of an elevated temperature without access or a restricted access to oxygen with the production of combustible pyrolytic gas (pyrogas) [2, 15]. The technological chain of this type of recycling consists of four consecutive steps: The preparation of the waste; the Processing of the prepared waste in the reactor in order to produce pyrolysis gas out of the pollutants (chlorine, fluorine, sulphur compounds as well as cyanides) in order to raise its environmental quality and the energy content; the burning of the cleansed pyrolysis gas in recovery furnaces in order to produce steam, hot water or electric energy. The Thermal processing without the use of oxygen or with a strong deficit of oxygen under conditions of endothermic process proceeds with the use of external energy, produced through the burning of the pyrolysis gas, which is used in order to maintain the process. The coke residue formed has a high density, which strongly reduces the volume of the formed waste.
Gasification is the process of thermal processing of waste, which contain organic compound using a oxidising agent (air, oxygen, water steam, carbon dioxide or a mixture of the abovementioned) with an expenditure lower than the stoichiometric level, under the production of generator gas (synthetic gas) and a solid or molten mineral product.
In this way, considerable environmental aspects of the thermal waste treatment mainly determined by the technological processes are:

- Emissions to air, the composition and level of which considerably depend on the group of types of processed waste;

- The level of use of energy resources, which also to a considerable level depend on the groups of types of processed waste.

When determining the correspondence of the presented techniques and equipment to the BAT criteria, a considerable importance will be attributed to the determination of the list of marker pollutants in the emissions to air, in respect to which actions will be taken of state regulation in the field environmental protection, according to the resolution of the Government of the Russian Federation of the 8 June 2015, no 1316-r:

1.2.2. The main environmental problems

The main environmental problems, connected to thermal waste treatment may be defined depending on the reasons of their occurrence in the following way:

- Organizational-legal
- Resource conservation
- Technical and technological
- Financial and economic
- Purely environmental and public health
- Control and monitoring
- Social and psychological

1.2.2.1 Organizational-legal problems

At present, in the Russian Federation there is no regulatory legal act of the Federal level, which would serve for the regulation of the use of thermal methods of waste treatment, or served for the determination of the conditions and established the requirements for the realization of these activities. It is possible, that there is a need to elaborate and adopt the needed technical regulations.
The week development of the selective collection of municipal solid waste, their sorting and the use of modern sorting systems, that would exclude the probability of secondary material resources, hazardous waste from consumption (mercury lamps and other mercury containing instruments, batteries, accumulators, etc) ending up in the flow of waste to be thermally processed, creates a serious problem for the development of a thermal treatment of waste, including as to the guaranteeing of the allowed levels of environmental impact. The Adoption of the Federal Act of the 21.07.2014 no 219-FZ (version of the 29.12.2014) on the amendments to the Federal Act On Environmental Protection, and Several Acts of Law of the Russian Federation to a considerable extent promotes the solution of the aforementioned problems under conditions of realization of its provisions to the full extent.

1.2.2.2 Problems concerning the economy of resources

It is necessary to pay special attention to not only the creation of conditions for the extraction from the effluents of the waste, the valuable secondary material resources and their subsequent efficient use, but also to the problem och maximum use of the secondary energy resources, which are formed as a result of the thermal process of waste treatment. This problem is especially

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urgent for such large plants as waste incineration plants, also in terms of raising the economic efficiency.

1.2.2.3 The technical and technological problems

It is necessary to take into account the complex and diversified character of the process of thermal waste treatment, which include, among other things the following steps:

- The collection and accumulation of waste to be treated. In order to attain a rhythmical uninterrupted function of the main equipment for the thermal waste treatment, which guarantees, among other things, also the level of the allowed environmental impact, there is a need for the necessary space and equipment of the premises (site). In order to serve for environmental, industrial and fire safety, an efficient incoming inspection of the received waste to be treated, as well as a permanent production control need to be arranged.
- a preliminary preparation of the waste before their dispatch to be treated which also calls for the corresponding technical equipment as well as a permanent production control.
- the thermal treatment, also connected to the to the operation of a complicated set of industrial production equipment, the necessity to thoroughly observe the production modes, the regular maintenance of the equipment, the necessity of keeping the processes of thermal treatment at a modern, updated level;
- The treatment of emissions and discharges arisen as a result of the thermal waste treatment, which calls for a solid technical equipment level as well as a permanent production control, including by the use of analytical methods.
- The collection and accumulation of waste, formed as a result of the thermal waste treatment, including those formed as a result of the auxiliary activity (maintenance of the equipment, the execution of repair work, the maintenance of the production site, the personnel support, etc.) which calls for the organisation of the handling of the said waste in accordance with the established requirements;
- the recycling of the secondary energy resources

When carrying on the thermal waste treatment there arises a need to observe quite severe conditions of the realization of the thermal process:

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- the necessity of burning the waste with a considerably surplus of air, because of the wide range of temperature change of the burning process and the composition of the waste
- the compulsory exposure of the gaseous products of the incineration process at a temperature of above 850°C during 2 seconds and more for the destruction of organic pollutants, primarily polychlorinated dibenzodioxins and furans;
- the restriction of the temperature of the flue gases at the exit to the convective surfaces (not above 750°C) as to minimize the formation of slag on the surface on these surfaces
- the maintenance of a temperature of the flue gases on exit from the furnace optimal for the function of the gas purification (usually 180-200°C) ;
- the obligatory use of a multi-step gas cleaning system.

The pyrolysis and the gasification and their high temperature modification – the plasma treatment [16,17] – have certain advantages, however for a full treatment of municipal solid waste (hereinafter MSW), at present, it is used fairly seldom, due to the requirement to granulate the waste before treatment, the low reliability or the raised energy consumption. Thus, there are quite strict requirements to the preparation of the MSW dispatched for pyrolysis (gasification):

- The sorting of the waste in order to extract the ballast fractions (glass, metals, stones, the fine fraction);
- Drying of the waste
- The preliminary fragmentation of the waste

The last requirement leads to the lowering of the reliability of the waste processing companies, using the pyrolysis method, since the presence of large non-fragmented fractions quite often being the case with MSW disturbs the work of the installation and brings the equipment out of operation.
For the conditions in Russia, when setting up plants and when designing the needed installation, it is necessary to take into account the following properties of Russian MSW:

- the composition of waste is extremely heterogeneous. The composition changes considerably depending on the "batch" of waste and also with time. In the autumn and winter, the waste is in a state of maximum humidity and compactness. In the spring and summer periods there is a raised content of polymeric waste, organic waste and waste from street cleaning.
- the moisture of Russian waste is 15-20% higher than in west European countries.

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- Russian waste is characterized by the structural mechanical coherence, due to the fibre and moist fractions
- Russian waste is distinguished by its caking ability during storage and transport, as well as the discharge of filtrate water
- Russian waste is distinguished by the increased abrasiveness, connected with the presence of china, glass and stones.
- A high moisture level and the content of various salts in the waste promote the corrosive impact on metal upon long-term contact.
- There is an occasional presence of heavy objects that are hard to fragmentize and that leads to the knocking out of operation of the processing equipment.

These facts may create certain problems when adapting foreign techniques of thermal waste treatment.
Companies, dealing with the burning of hazardous waste, constantly stumble upon the problem of the exceeding of the content of nitrogen, sulphur and carbon oxides. , as well as dioxins, benzapyrene, etc, in the gaseous emissions above the maximum allowed rates. The increase of the harmful emissions occur mainly when loading a new batch of waste and the sharp lowering of the oxygen concentration in the reactor or because of the insufficient stirring of the combustive masse, and, as a consequence of this, a low heat transfer. In order to fight this effect it is necessary to equip the furnace reactor with a system of pausing the waste feed until the moment when the concentration of oxygen has been restored to the optimal level or wit an additional system of injection of oxygen into the burning zone.
The presence in the exhaust gasses of dioxins and biphenyls considerably complicates their treatment, mainly because of the low concentration of these highly toxic compounds (having, by the way, extremely low levels of MAC); this calls for the creation of modern and expensive multi-step (usually three-step) treatment systems.
All the above calls for the needed technique solutions, a quite high qualification of the operating personnel as well as material and financial expenditure.

1.2.2.4 Financial and economic problems

The creation and operation of plants for the incineration of, mainly, MSW calls for quite substantial financial expenditure.
For instance, in USA, for the plants (Installations) for the mass incineration of waste with a capacity of 100 to 3000 tons/day, the capital costs range from 80 to 100 thousand dollars per unit of capacity (one ton of burned waste per 24 h)

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This price tag includes the price of the facilities for the preparation of the waste, however, it is well known, that, for instance only the fragmentation of the waste calls for high-energy expenditure. The operational costs are around 20 dollars per ton of MSW. One needs also to take into account, that the time needed for the design and construction in such a plant in the USA, on average, is 5-8 years.
Based on some estimations, in Russia, only the relative capital costs (based on the 2014 price level) in order to build a plant for the thermal treatment of waste by using various methods were estimated to be 17 000 – 30 000 roubles per 1 ton of MSW per year.

1.2.2.5 The Environmental and Public Health Problems

Waste incineration is sometimes not a fully controllable process with the discharge (including those not accounted for) of side products, many of which harm the environment and human health. In the majority of cases as a result of the burning of waste there is a production of (emissions to the environment) of a considerable group of pollutants. As pointed out above, in order to restrict the harmful emissions it is necessary to use quite complicated and expensive systems for the cleaning of the exhaust gasses.
Any incineration is a source of emission of greenhouse gasses, regulated (restricted) by international agreements.
The Production (waste-) water is also something that calls for the needed treatment systems.
Ash (trapped) and the slag formed during the burning of waste, based on their physical and chemical properties (they contain heavy metals, frequently in quite high concentrations) may not be buried at MSW landfills or be used in the production of building material, but need to be disposed at special landfills or in special depositories (with a control system and the treatment of effluent water), which creates certain organizational and environmental problems. The operators and the workers responsible for the collection and transport of the ash are to be regarded as a special risk group.
The slag from waste burning plant is usually not treated as hazardous waste. However, it also contains toxic compounds, which may be washed away from the places where they are buried and cause a considerable harm to the environment.

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A special problem (especially for the operating personnel) may be created by the unorganized emissions from facilities and equipment at the sites of waste storage, in some cases smell, industrial noise and vibrations as well as biological pollution of the ”fresh” waste.

1.2.2.6. Problems Concerned with Control and Monitoring

The functions of the companies (plants and installations) for the thermal waste treatment are dependent upon the necessity to organize systems for the environmental production control and the environmental monitoring of its activities. This, in turn, defines the necessity of the acquisition both by the companies and the controlling authorities of special (usually expensive) means of control as well as the use of special chemical and analytical instruments and certified methods (in the presence of the needed specialists).

For instance; the Directive of the European Parliament and the EU Council no 2000/76/EC of the 4 December 2000 ON Incineration of Waste regulates the following substances in the emissions of the corresponding plants (facilities): fly ash, and dust, organic compounds, hydrogen chloride, hydrogen fluoride, sulphur dioxide, nitrogen oxides, carbon oxide, ammonium, cadmium, thallium, mercury, cobalt, chrome, manganese, nickel, arsenic, copper, lead, antimony, vanadium, dioxins and furans. This list needs to be supplemented by benzapyrene.

1.2.2.7 Social and Psychological Problems

The population is to a great extent negatively disposed to the presented manner of waste treatment, especially in the cases where the specialised plants and facilities for thermal waste treatment are placed in the immediate vicinity to farming, recreational and natural importance territories.

Usually the adversaries of waste incineration appeal to the fact that it contradicts three principles of international law: the precaution, the prevention and the reduction of trans-border effects.

Another observation is that the present idea of getting electrical energy when burning household waste does not contribute enough to the solution of the energy resources problem, since no less than 80% of the produces energy is used from the own needs of the plant. According to an analysis, carried out in 2001 by London School of Economics, the energy produced from the burning of MSW represents only 5% of the energy costs, used for the production of the material that the MSW comprises.

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Apart from this, according to the Stockholm Convention on Persistent Organic Pollutants, which was joined by Russia in 2002, the waste need to be removed in such a way, as to guarantee that the persistent organic pollutants contained in it will be destructed or irreversibly transformed so as to not display their properties as persistent organic pollutants. The observation of this requirement calls for major material-technical and financial expenditure.

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Section 2. Information List on the Techniques in Use in the Field of Thermal Waste Treatment

2.1. General Provisions

In general, the technological scheme of the integrated installation for the high-temperature waste treatment of waste, containing organic substances includes [7] the following stages (sections):

- The primary section including the reagent processing of the waste;
- The thermal processing proper of the waste (high-temperature, fire);
- The heat use section (in the simplest form, the cooling section for the high-temperature gaseous products of the treatment using water or air as coolant)
- The section of production of secondary mineral products (ceramics, cement, mineral salts, acids, metals, etc.);
- The multi-step treatment section for the cleansing and deactivation of the exhaust gasses before they are released into the air.

The initial values for the development of a facility for high-temperature treatment must include the characteristics of the treated waste in accordance with the quoted (section 1) classification of waste and the aggregate capacity (load). As for the aggregate capacity, one could emphasize:

- The local stationary or mobile (moved, i.a. by motor-vehicle transport systems or on a rail transporter) facility with a low capacity rate (10-500 kg/h);
- An average capacity facility, including those that are transportable (i.e. those that may be relocated to another industrial site) with an aggregate capacity of 500-2000 kg/h;
- Centralized, regional facilities, i.e. stations wit a high aggregate capacity (2 000–10 000 kg/h)

In the frames of creating BAT it is possible to implement out various technological schemes, providing for the maximum energy economy or the production of energy and the production of mineral and organic side-products.

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All technical decisions are based on the Metopic Recommendations for the Determination of Techniques as BAT (a Minpromtorg of Russia order of the 31 March 2015, no665), taking into account the total relevant criteria.

2.2. The Main Environmental and Energy Technique Parameters [7]

The energy technique parameters define the environmental and economic efficiency and reliability of the process of waste treatment:

a) The temperature level of the process. This parameter enables the subdivision of the processes in the reactor into low-temperature (Flue gas temperature (t_{flue} of 400-600°C); average temperature (t_{flue} =600-1000°C) and high-temperature (t_{flue} =1000-2000°C)

b) The period of stay (not counting the afterburner), of the toxic components in the working zone of the thermal reactor (T_{stay}). Based on the period of stay, thermal reactors may be divided into the following groups:

   1. T_{stay} < 0,1 s (a low relation of the working volume of the reactor V_p(m^3) to the volume consumption of the gasses V_g (m^3/s); (an average relationship of V_pV_g);

2. T_{stay} = 0,1 – 0,5 s (an average relationship of V_pV_g);
3. T_{stay} = 0,5 – 2 s (an elevated relationship of V_pV_g)
4. T_{stay} > 2 s (an average relationship of V_pV_g)

c) The intensity of the stirring of the components in the working zone of the thermal reactor. Two hydrodynamic modes are defined: the laminal (lower than the critical Reynolds numbers $Re<Re_{crit}$); turbulent ($Re \geq Re_{crit}$)

d) The composition of the atmosphere in the thermal reactor. Two modes are defined:
1. Oxidizing atmosphere (the coefficient of the oxidizing agent consumption $\alpha>1$);
2. A reducing atmosphere, (the coefficient of the oxidizing agent consumption $\alpha<1$)
3. Fluctuating over the various zones of the reactor (for instance reducing-oxidizing)

e) The heat generation principle (type of external, additional energy source). In practice, the following are used:
1. Organic fuel (gaseous, liquid or solid, as well as combustive waste);
2. Electric energy (induction, electric arc or plasma source);
3. Combined source:

f) Type of oxidizing agent; the following are used:
1. Air
2. Bulk oxygen
3. Oxygen enriched air blow
4. Water steam
5. Carbon dioxide

g) The slag removal mode. The following modes are in practice:
1. Liquid slag removal
2. Solid slag removal

h) The means of neutralization of the gaseous oxides and acids formed during the thermal waste treatment: SO_2, SO_3, HCl, HF, and P_4O_{10}, the following means are used:
1. Means, including the primary, reagent processing of the waste
2. Means, including the feed of reagents directly in to the thermal reactor;
3. Means, characterized by the feed of reagents at the stage of cooling of the gaseous products of the waste treatment process
4. The means using the feed of reagents at the stage of low-temperature treatment of the gasses

The optimization of the environmental and energy technical parameters allow for the choice of the relevant type of thermal reactor for the treatment of liquid, solid and paste-like waste.

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2.3. The Main Types of Existing Reactors, Using Organic Fuel [18,19]

2.3.1. Stratified furnaces

In domestic and foreign practice the widest used furnaces are the layered furnaces, when it comes to high-temperature solid and paste-like waste, containing organic substances

During the past few years, it is noticeable the presence of a larger quantity of Russian designs and foreign deliveries of local facilities of igneous treatment of waste with the use of grate-fired furnaces. For instance, the facility of the type Smart Ash (one-chambered) and Mediburn (two-chambered), each with the capacity of 22 kg/h (USA)(fig.1.1, 2.2), as well as the two Russian plants Forsazh-2 and USO-200.

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Fig. 2.1 – Smart Ash device (USA) [19]

Fig. 2.2 – Mediburn device (USA) (19)

In none of these processing units there is a system for the treatment of exhaust gasses. Some of the devices consist of a burning chamber, a balanced forced draft flue system a device for dry gas treatment (cyclone-fly ash collector) and the main linking tubes. The feed of the waste is made manually in the majority of cases, and the burning of the waste is carried on in a fixed layer on a lined continuous bed.
The more modern and developed layered furnaces are delivered with

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capacity of 170 and 340 kg/h (Austria), from 12 to 250 kg/h of 10 nominal sizes (Germany); the capacity of 200 to 1000 kg/h (Switzerland, Great Britain; France, The Republic of Korea), the incinerator Müller S.P.50 (France) etc.
Analogous plants of the type KTO (fig. 2.3.), IN-550 (fig. 2.4.) and EChUTO" have been developed by Russian designers. The last design incorporates the primary thermal degradation of the organic components of the waste in an atmosphere void of oxygen (pyrolysis), after which the formed steam-gas mixture is dispatched to the afterburner.

Fig. 2.3 – KTO-type plant [20]

For the burning of MSW, a widespread occurrence has been found by layered hearths with furnace grates, sometimes water-cooled. The most frequent grates used during the layered burning of waste are: shearing grate, reversed shearing grate and a roll-type grate.
During layered burning of waste, the temperature on the inclined grate changes from the temperature of the environment in the upper part of the feed until 1100 – 1200°C in the igneous (lower) zone. In proportion to the movement of the material it is heated gradually, and, at the same time, undergoing drying, pyrolysis and burning.

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Fig. 2.4 – The IN-50 installation

It should be mentioned that the layered furnaces are reliable in operation, simple to maintain (especially the furnaces with fixed hearths) and have a long operation period service life. They are however eligible for only for the thermal processing of a restricted class of waste. In these furnaces, it is practically impossible to efficiently treat waste with a content of easily molten mineral compounds as well as substances that are in a plastic condition, since the layer in those cases will be luting and slagging.
One flaw of the local stratified furnaces lies in the low environmental efficiency of the thermal waste treatment – i.e. a raised mechanical underburning, i.e. there is a presence of residue toxic organic compounds in the slag, and the emissions of supertoxicants with the flue gases: hydrogen chloride, HCl, molecular chlorine C_2, phosgene gas $COCl_2$, polychlorinated dibenzodioxins (PCDD) as well as dibenzofurans (PCDF).
The low relative loads when treating the waste, the bulkiness and the metal consumption, the relatively high capital and operational costs and, not to forget, the low environmental efficiency do not allow for the recommendation of the stratified furnace for thermal waste treatment of organic waste in local installations of low capacity.
The disadvantage of the majority of high-temperature installations with layered furnaces is:

- The slipping through of toxic components, periodically aggravated by the loading of relatively large single volumes of waste to be destroyed.

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- The formation of toxic slag, containing soluble salts of heavy metals and residual organic components.

2.3.2 Rotating Drum Furnaces

The rotating drum furnaces are widely used abroad, for the burning of solid and paste-like industrial, household and medical waste, and also of de-watered wastewater sludge. Usually the rotating drum furnace consists of a steel drum, have a coating out of fireproof brick, concrete or a water-cooled, rotating with a speed of 0,05-2 rev/min. The drum furnaces are mounted with a slight tilt in the direction of the movement of the waste. The temperature in a drum furnace, depending on the type of waste burned is maintained within the range 900-1400°C. If needed, additional fuel or liquid combustible waste is fed through the burner device, increasing the temperature inside of the furnace. The fed waste is mixed during the rotation of the furnace, is slightly dried, partly gasified and moved to the fire zone. The radiation from the flame in this zone heats the lining of the furnace and promotes the burning of the organic part of the waste as well as the drying of the waste newly fed into the system. The waste and the fuel, as well as the oxidizing agent (air) is fed from the direction of the loading of waste, whereas the slag is unloaded from the opposite side of the furnace in the solid state or as a molten mass.
In connection with the low efficiency mixing of the waste the rotating drum are characterized by a low relative head and mass load of the volume burned, they are cumbersome and there is incomplete chemical combustion in the flue gases.
This being said, the rotating drum furnaces with a liquid slag removal, equipped with a chamber for the afterburning of the gaseous products of the treatment process, exhibit a high environmental efficiency.
In Germany, USA, Switzerland, Finland, as well as in other countries a great experience has been gathered as to the development of centralized stations for thermal treatment with rotating drum furnaces. At present, overseas there is a successful operation of

rotating drum furnaces for the co-combustion of solid, paste-like and liquid waste wit an aggregate load ranging from 2 to 6 t/h.
In 1996 in Brunsbüttel (Germany) the company Noell – KRC Energie und Umwelttechnik GmgH one has taken into operation one of the largest rotating drum furnaces in the world with a load of solid and paste-like waste of

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40 000 t/year. The diameter of the furnace is 4,8 m, the length – 12 m. The temperature of the exhaust gases (at the exit to the afterburner chamber) is 1200°C.
In April in Izmit (Turkey), the company Lurgi AG put into operation a centre for the thermal treatment of solid and past-like waste with a capacity of 35000t/year. The cost of the centre was 450 million German Marks. The neutralization of the hydrogen chloride formed during the treatment of the chlorine-containing organic waste is carried out in a system of wet gas treatment through the spraying of the relevant alkaline of alkaline-earth reagents.
In Russia, work is going on in order to develop and introduce rotating drum furnaces (fig. 2.5).
It is necessary to underline that from a technological viewpoint, the rotating drum furnaces are the most universal thermal reactors for the treatment of coarse waste of variable content.
It should be mentioned, that the lining of the furnaces during the rotation is in a state of frequent change of temperature, which causes the formation in the lining of cracks and a fast malfunction. The exchange every six months of the inner part of the furnace lining is a time-consuming, complicated and expensive operation – the costs is about 10% of the cost of the furnace. The use of expensive heatproof and chemically resistant linings in the drum furnaces leads to a considerable increase in the costs of the assemblies.

Fig. 2.5 – Rotating drum furnace [20]

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In order to raise the longevity of the furnace, sometimes, instead of the brick lining, a water-cooled metal lining is used on the walls of the drum (Japan), or the brick lining of the furnace is cooled (Finland).
Because of the high capital and operational cost, the specialized plants of environmentally efficient low-capacity rotating drum furnaces for the thermal treatment of organic waste are recommended only for certain regions. Such a plant, manufactured in Czechia has been introduced in Sverdlovsk Oblast for the treatment of medical waste. At the same time, there are no doubts about the technical and economic feasibility of the construction in the regions, centralized stations for co-combustion of toxic solid, paste-like and liquid waste wit a high aggregate load based on rotating drum furnaces.
In the present section, the experience from high-temperature MSW and industrial organic waste destruction, used tyres in the rotating cement industry furnaces has not been considered.

2.3.3. Shaft Furnaces

In Russia, and other countries, there is development and studies going on with experimental and demonstration installations of the processes of pyrolysis and gasification of solid and paste-like waste in shaft furnaces in a dense filtered bed.
In Russia some designs of shaft gasification of the blast furnace type with a liquid slag removal (the Purvox process) have been presented, however these designs are not realized in production. So far, no practical implementation of the shaft pyrolysis of solid household waste using the plasma heating principle has been maid. (“plasma pyrolysis and vitrification of MSW).
The NPO Radon has implemented a shaft furnace with plasma heating for thermal processing of solid radioactive waste.
In Russia a process of steam-air gasification of waste in a shaft gasificator with the subsequent afterburning of the combustible gases has been developed.
The process in the shaft gasificator is carried out in the following way: Into the shaft, a mixture of inert material (fireclay) and waste is introduced The loaded mass is blown from below by a air-steam mixture. The fireclay exerts the function of heat medium and creates the optimal conditions for the gasification process. The movement of the working mass in the reactor is progressing under the influence of

its own weight.
In the top zone of the reactor, at a temperature of 100-200°C, there is a drying process of the loaded raw material, which is blown forward by a synthesized gas. In the oxygen-free environment a thermal decomposition and the coking of the organic mass are performed. In the mid-part of the reactor, at a temperature of 1000-1200°C a process of gasification of the coke residue takes place, along with the formation of CO and H_2. In the lowermost zone of the shaft furnace the solid residue finally is cooled down to a temperature of 100-150°C (Fig.2.6.).
The combustible synthesized gas produced in the shaft furnace is subjected to treatment by the acid gasses, for instance HCl, and is, subsequently, burnt in the burner of the steam boiler under conditions of surplus of secondary air.
Since the process of the steam-air gasification is carried on in a compact layer of coarse material at low linear speed of the stream, in the produced from the reactor, synthesized gas, there is practically no fly ash. Moving top-down, the waste mixture and the fireclay

proceed successively pass through the zones of heating drying and pyrolysis and gasification. The produced as a result of this process slag practically does not contain any products of mechanical incomplete burning and, after unloading from the reactor, they are subjected to screen separation for the separation of the fireclay, which will be used repeatedly.

Synthetic gas exit loading

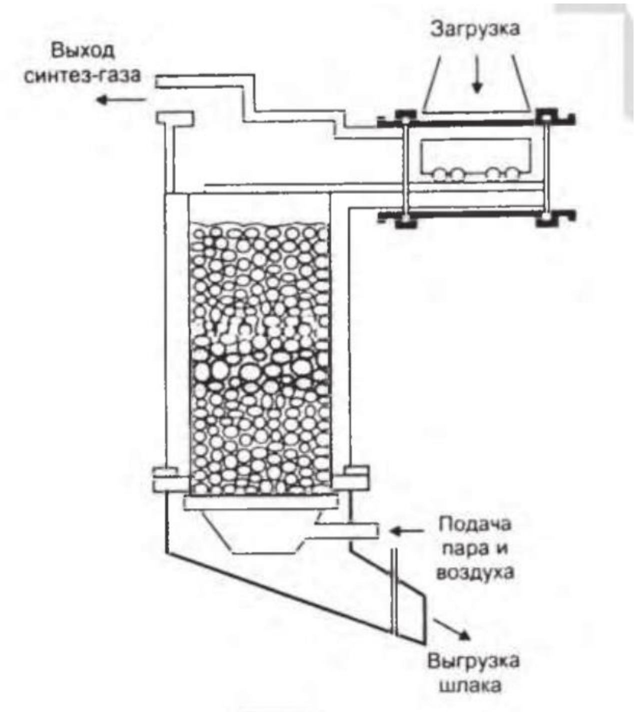

Fig. 2.6 Shaft furnace [19]
Upper arrow: Gas and air feed;
Lower arrow: removal of slag

The homogenizing of the combustible waste and their uniform feed into the process of thermal processing are the necessary for the guaranteeing of a stabilization of the thermal process, as well as its efficiency and the subsequent gas cleansing.
The advantages of this process for the treatment of waste in a shaft furnace are: the high-energy coefficient of efficiency (up to 95%), allowing for the processing of the waste

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with a low concentration of combustible material (ash content: 90%) or with a high humidity; the burning of the synthetic gas in modern gas burners – is the most common ways of burning, during which there is no underburning in the flue gases.
In Russia, at the company AO Elektrostal'mash, there is some experience of the operation of plants for the thermal treatment of paste-like waste (annealing oil).

When assessing the environmental and technological parameters of the gasification process of the organic waste in a shaft furnace, we have noticed the following environmental advantages compared to other thermal processes:

- The prevention of fly ash ending up in the gases, and, consequently the trapping in the special filter of toxic heavy metals;
- The temperature of the combustible gas when leaving the reactor is not exceeding 150°C, a temperature, at which the volatile heavy metals (CD, As, Pb, Zn) are in the condensed forma and are practically fixated in the slag.
  This said, the process of gasification in shaft furnaces is suited for the thermal treatment of a restricted number of waste, and, besides, only fragmented, bulk and gas permeable ones. Pastelike, large-size solid waste, with a low melting temperature is hard to process using the method of gasification. The demonstrated main disadvantage of the process in the filtered dense bed leading to a disturbance of the gas permeability and to the congestion of the cross-section of the reactor was observed at bench-top demonstration installations. In particular, the effort to perform the process of gasification of solid waste from the production of aminocaproic lactam on a bench-top installation at the Institute of the Problems of Chemical Physics of the RAS (at Chernogolovka) ended in a complete failure – by the sealing by melting of the cross-section of the reactor.

2.3.4. Furnaces with a Liquid Metal Bath

Among the many proposed techniques of thermal waste treatment, there is one that through is originality – namely the technology for the destruction of toxic organic waste in a hot melt of inorganic salts (USA).
The essence of the method lies in the following: Cheap inorganic compounds (for instance soda or quicklime) are melted in a ceramic reactor at temperatures of 800-1000°C. Through this liquid melt, air is blown and organic waste is fed into the reactor. The level of destruction according to the author is 99,9999%.
At present, this method is used in Australia for the destruction of PCB.

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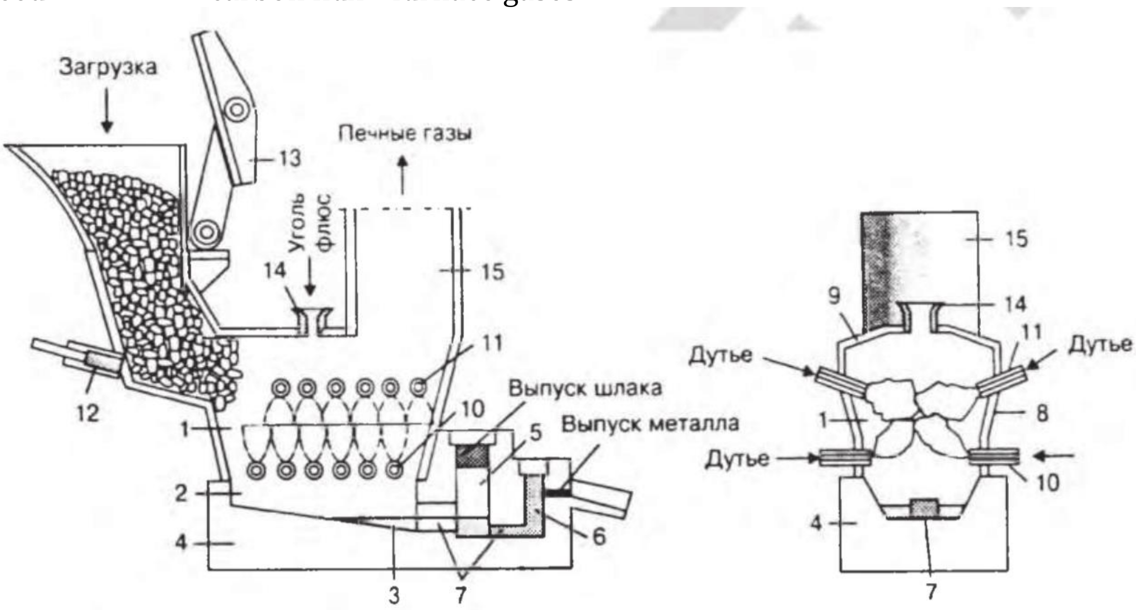
In the beginning of the 90s, for the thermal processing of solid household waste and industrial waste, a Russian technology was proposes for the burning in a bubbling melt of slag on the basis of the Vanyukov furnace (fig. 2.7). The essence of the technological process of the waste processing lies in the high-temperature degradation of the waste in a layer of bubbling slag melt at a temperature of 1250-1400°C and a stay of 2-3s. The melt is formed out of the fed into the fire reactor of various slags in particular ash slag waste from a TPP cogeneration plant.

Feed carbon flux furnace gases



Slag discharge; metal discharge: air blasting, air blasting, air blasting

Fig 2.7 Furnace with a liquid metal bath [22]
1 – bubbling layer of slag, 2 – layer of calm slag, 3 – metal layer, 4 – fire resistant hearth, 5 – siphon for slag discharge, 6 - siphon for metal discharge, 7 – cross flow, 8 – water cooled walls, 9 – water-cooled arch, 10 – bubble jets, 11 – Jets for afterburning, 12 – load mechanism, 13 – lid, 14 – load funnel, 15 – gas release nozzle

The waste to be treated is continuously loaded through the vault of the furnace onto the surface of the slag melt, which is ventilated by an oxidizing agent through the bottom tuyere. When entering the melt, the waste is turned into slag and is distributed over the volume of the melt. When this is going on , moisture and volatile components are removed from the waste. The mineral fraction of the waste is diluted in the slag, the composition of which is corrected by mineral additions. Out of the metals, contained in the waste, a metallic bath is formed, located lower then the level of the slag.

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The formed metal and slag is continuously and separately emptied out of the furnace through separate tap holes. The combustible gases, separated from the slag bath are afterburned directly over the surface of the melt by an oxygen air-blast, fed through the upper jet tuyere.
Both techniques are tested in industrial testing settings at the experimental factory ”Gintsvetmet” in Ryazan’ (MSW processing) as well as the South Korean plant of the Company Samsung Heavy Industries (the processing of certain types of industrial waste).
The main advantage of the Vanyukov Process as compared to the traditional stratified burning of waste is the substantial lowering of the quantity o flue gases through the use of an oxygen-enriched jet and the production of a harmless slag melt.
The main disadvantage of the process is the use of expensive melting metallurgic technique for the thermal waste processing.

Besides, the melting metallurgical furnace proper with its compressed air sinking water-cooled barriers, the system for the oxygen-air jet action under the surface of the melt, the zone-wise discharge of the melt makes the reactor more complicated to operate if compared to reactors with a direct combustion of the waste. The combustive head from the waste burning only to a limited extent is consumed for the melting of the slag, since in the melting furnace only a partial oxidation of the organic components of the waste takes place, whereas the afterburning process, the main source of heat is removed beyond the melt bath.

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2.3.5. Cyclone Reactors

Cyclone reactors are environmentally efficient and reliable facilities for the thermal treatment of organic waste. The high relative mass load of cyclone reactors is explained, apart from the specific aerodynamic structure of the gas flow by a dispersion of the waste by special spray nozzle or directly by a high-velocity gas flow in the reactor space [2].
In Russia, cyclone reactors with various modifications have been developed [fug. 2.8.) for the fire (high-temperature) treatment of liquid waste, containing organic and mineral compounds.

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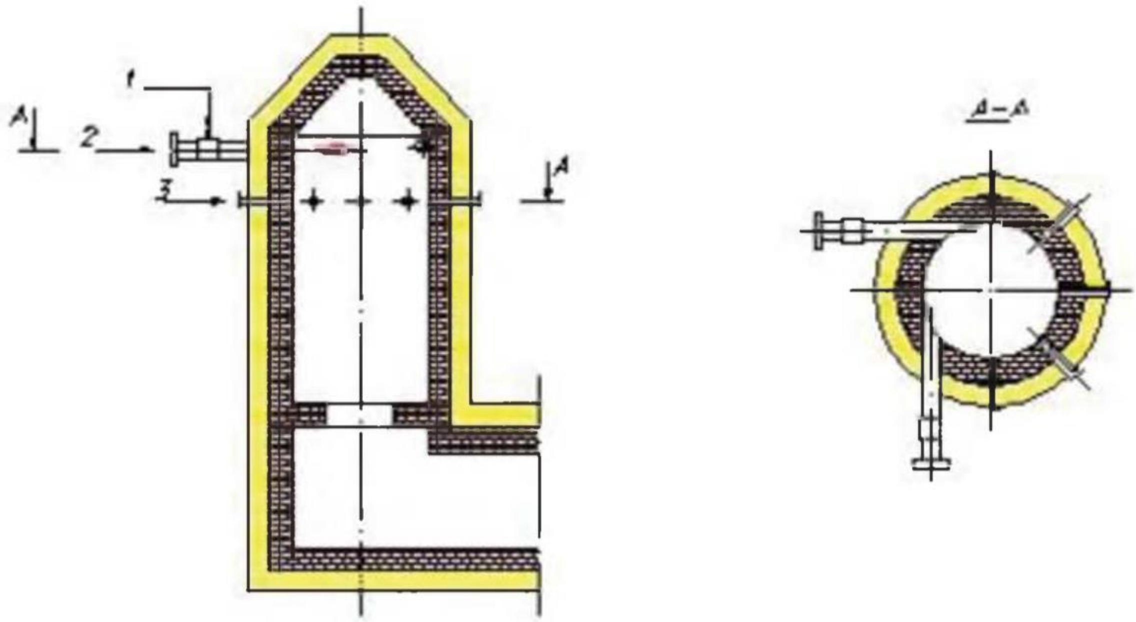

Fig. 2.8 – Scheme of a cyclone reactor with fire-resistant lining and heat isolation [2]
1- fuel, 2 – air, 3 – liquid waste

The skull melting lining of these reactor used during the treatment of mineralized waste serves for the long-term use of the system before maintenance. Over all the Soviet Union from Grodno in the west to the Siberian Kemerovo and the Uzbek city of Chirchik, more than 150 such facilities were introduced, the capacity of which ranged from 200 kg to 16t of waste per hour. Licences for the facilities were sold to a number of countries of the socialist commonwealth as well as to Japan, and – later – to South Korea.

Compared to the conventionally uses chamber and shaft kilns, the cyclone reactors are the most efficient and universal, which is explained by their aerodynamic properties. The relative mass load in the cyclone reactors are more than an order o magnitude higher than the loads of shaft and chamber kilns, which allows for the building of smaller size facilities.
The practice of operation of the facilities for thermal waste treatment wit cyclone reactors has been confirmed by their technical and economic advantages before other types of plants:

- The reduction of capital investment
- The reduction of operational costs
- The possibility of extraction of secondary mineral products

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- The high environmental efficiency, corresponding to the most stringent European requirement criteria, during the treatment of any type of organic waste containing among other things polychlorinated biphenyls (PCB), pesticides and other supertoxicants;
- The fast start-up
- The reliability and durability of operation

In this way, positive results have been received during cyclonic burning of dispersed solid waste and pastelike waste from wastewater (fig. 2.9.). The successful experience has been gathered also in the USA during thermal treatment of ash from waste incinerating plants, and polluted soil with the production of vitrified slag, as well as in Germany during the combustion of used activated charcoal (coke) from a system for the dry treatment of flue gases.

Fig. 2.9 – Horizontal cyclone reactor for the thermal treatment of sludge

Meanwhile, in the cyclone reactors during coarse dispersion of solid and pastelike waste (or the impossibility of their fragmentation and atomization) the intensity of the treatment process sharply decreases. The relative mass loads of such reactors are lowered down to 100-150 kg/m^3*h, which corresponds to the loads of stratified and drum kilns.
It is necessary to underline that when pastelike waste is finely dispersed in cyclone reactors, relative mass loads of up to 1000 kg/m^3*h are attained,

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which enables the erection of compact, small-scale facilities with small capital expenditure.
The high intensity of the stirring of the waste particles in the gas flow or the cyclone reactor makes possible the almost full combustion of toxic organic substances directly in the reactor - the residue concentration of carbon dioxide in the flue gases does not exceed 50 mg/m^3.
The effect of the centrifugal separation serves for the trapping of the major quantity of mineral content (up to 80%) with the discharge of them in the solid stage of as a melt (sterile slag).
In this way, in order to treat pastelike waste under its fine dispersion (using pneumatic or mechanic spray nozzles), it is recommended to use cyclone reactors.
If there should arise any problems concerned wit the atomization of such waste, then, it is not feasible to use cyclone reactors, since the above-mentioned advantages in that case would be evened out.

2.3.6. Reactors with a Boiling Layer

The principle of reactors with a boiling layer is the feed of gases (air) through a layer of inert material (sand with a grain size of 1-5 mm), supported by a bar grate. At a critical speed of the gas flow the inert layer is transferred to a suspended state, reminding of a boiling liquid. The waste entering the reactor is intensively mixed with the inert layer while there is also a intensified heat exchange.
The air distribution grate serves for the even passage of the airflow through the layer in order to guarantee a high quality of the pseudoliquidization. There are three types of usually used grates – the perforated grate, the grate with a header and a tube grate.
For facilities in which the heating of the layer is carried out with the aid of gas burner or fuel oil burner, the grate construction heed to be designed for the passing of hot gases. Usually in such cases, a water-cooled grate is used, or a grate made out of heatproof steel alloy.
Depending on the character of the pseudoliquidization, three modifications of the boiling layer are described:
a) Reactors for the burning of waste, sludge and precipitation from wastewater with a stationary boiling layer usually consist of cylindrical or straight angle burning chambers (fig. 2.10.), restricted by the gas distribution grate, the design of which allows for the possibility of removal of the slag. The Reactors with a stationary boiling layer are widely used for the burning of waste in USA, Germany, Japan and many other countries.

Fig. 2.10 – Kiln with a boiling layer [11]

b) some quantity of the inter material during the increase of the speed of the gas above the terminal velocity, starts to depart from the from the layer so intensively as to provoke its replenishment. The circulating boiling layer (CBL) differs from the stationary boiling layer by the presence along the path of the flue gases cyclonic ash traps (fig 2.11.). The trapped material is returned from the cyclones to the layer, where the processing of the waste is continued.
On the world market techniques for the destruction of waste using a boiling layer have been described (Germany, USA). The Technique of the burning of solid waste and the cleared sludge wit the use of an CBL was first tested in the Netherlands and Great Britain. En Germany this burning method started to be used after the introduction of the law requirements 17BimSchV in the field of environmental protection as to the content of dioxins in flue gasses (0,1 ng/m^3). In August 1995 the industrial operation of the TPP cogeneration plant Northampton (USA) was begun with the boiler Foster Wheeler with a power of the circulating boiling layer (CBL) 110 MW during burning of waste from coal beneficiation, whereas in 1997 a facility was put into operation with CBL for the burning of MSW on Robins Island in Chicago (USA) wit the capacity of 500 thousand tons/year. The load on both of those two kilns wit CBL is 25 t/y. The size of the loaded material is 100 mm, whereas the minimal heat of the burning is 2450 kcal/kg.

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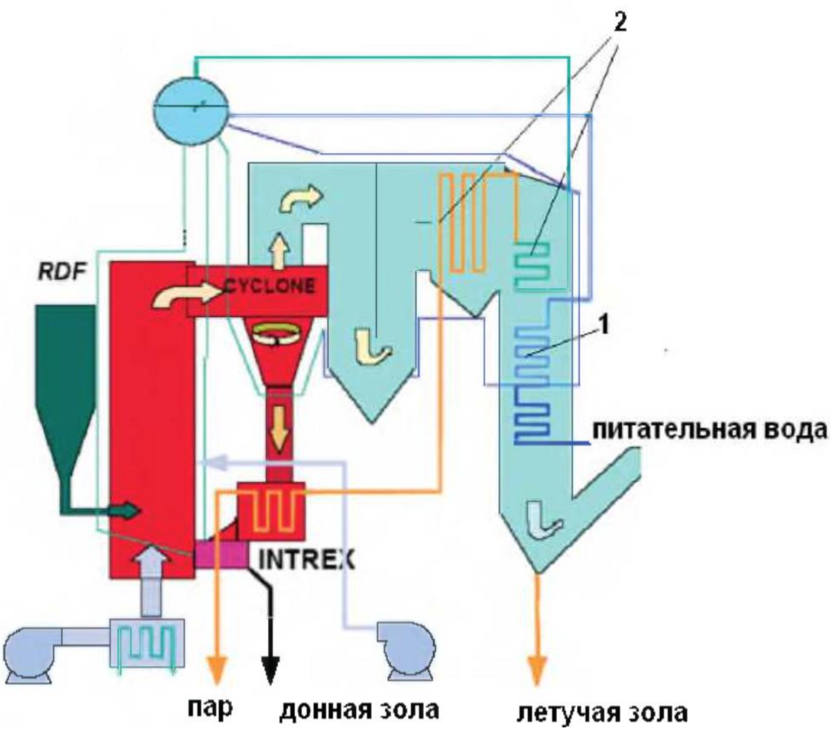

feed water

steam bottom ash fly ash

Fig. 2.11 – Kiln with CBL for the burning of household waste, mounted at the company Lomellina (Italy) [11]
1 – feed water economizer; 2 – convective steam superheated; 3 – cyclones

The Feasibility of the burning of waste using the pseudoliquidization method must be defined taking into account both the advantages and disadvantage of this method. The major advantages are:

1. The intensive stirring of the solid phase, leading to, practically speaking, the temperature, concentration and other parameter equalization over the full volume of the pseudoliquidized layer.
2. The favourable hydrodynamic conditions, defined by an elevated relative velocity of the gas
3. An insignificant hydraulic resistance of the layer;
4. The possibility to use quite large waste in the solid, liquid and pastelike condition (for especially large waste it is necessary to fragment it before it is fed into the reactor);
5. The relatively simple construction of the machinery and the possibility of their automatisation.
6. The lack of movable part and mechanisms in the hot zone of the reactor;
7. During the burning of the waste in the boiling zone acid halogen, sulphur and phosphor compounds are readily bound through the addition into the layer of neutralizing calcium compounds.

As for the disadvantages of the method of pseudoliquidization (both stationary and using a circulating layer) we find:

1. The irregular time of stay in the pseudoliquidized layer of the processed particles of the solid phase. For instance, it is as possible to have a fast passing of the particles as a stay as to have a longer of stay than the average statistic time of stay.
2. The possibility of baking and adhesion of the solid particles. In order to avoid the possibility of slagging of the layer, its temperature needs to be lower than the melting temperature of the waste from the ashes;
3. The necessity of mounting large ash trapping devices at the exit of the gas from the pseudoliquid layer, especially at varied granulometric content of the waste

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The abovementioned disadvantages may be eliminated if one uses reactors with pseudoliquid layer of the new, third generation (after the stationary and the circulating).

c) In Great Britain a technique for the burning of solid fuel in a kiln with a rotating boiling layer has been designed. This work was the first try to create a vortex or rotating boiling layer. The Kiln with the boiling zone of the company had a tilted grate, divided into 3 sections with varied air consumption in each and every one of them, whereas a part of the front membrane screen is placed parallel to the grate and executes the role of baffle. The forced circulation of the boiling layer is maintained not only by the designed solution, but also by an injection of solid fuel in the front and back walls of the kiln. IN furnaces of this kind one has been able to successfully burn such waste as coal and coke waste, fragmented automobile tyres as well as glycol alcohol. In Great Britain more than 10 smaller facilities have been tried with a single vortex-boiling layer. The plants are used for the treatment of industrial, medical and solid household waste. The facilities have been used in 1-2 shift mode.
The Japanese firm continued the development of this technique, where it was introduced at many Japanese MSW incineration plants. In Europe, this technique is known under the name Rowitec (Fig. 2.12.).

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Fig. 2.12 – the principle of the functioning of the vortex-boiling layer [19]
1 – loading of waste, 2 – the rotating boiling layer, 3 air feed for the creation of the boiling layer, 4 – exit of the flue gases, 5 – baffle (deflection plate), 6 – unloading of ash of the boiling layer (slag), 7 – the slanting nozzle array

The technique of incineration in a rotating boiling layer Rowitec has 3 peculiarities
The bottom tuyere (grate) consists of a number of chambers, through which various flows of primary air is fed in order to attain a pseudoliquid layer in combination with the rotation. The tilted grate promotes the unloading of slag from the reactor.
The baffles (deflector plates) above the kiln chamber serves for the rotation of the layer, defines the level of its expansion and reduced the loss of heat carrier, thanks to which a precise geometrical rotation of the layer is achieved.
Two elliptical vortices turning in opposite directions meet and get in contact with each other in the middle and give rise to the optimal distribution and the intensive abrasion of the waste, which makes possible the burning of the waste to a level above 99%. After the preliminary fragmentation down to pieces smaller than 300 mm with the aid of two countermotion screw feeders, the waste is moved to the burning chamber, where a temperature above 850°C is maintained.
In order to achieve a full incineration of the toxic components of the flue gases in the zone above the boiling layer, secondary air is introduced, which promotes the full afterburning of the flue gases at a temperature of 1100-1200°C.
In Russia, this technique has been introduces in industrial scale at MSZ No4 (Rudnevo Industrial Site)
The rotating boiling layer technique has shown good results when burning the following kinds of solid and pastelike organic waste:
MSW, industrial sludge containing petroleum products, plastic waste, agricultural waste, automobile tyres, etc.

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Experiments, carried out on fire experimental stands at two test industrial facilities in Pusan (Korean Republic), and at Orekhovo Zuevo (Moscow Oblast), have shown good perspectives of the use of local reactors of quite modes capacity (up to 200 kg/h) with a single-vortex rotating boiling layer for the thermal destruction of solid and pastelike organic waste. The use of a single-vortex boiling layer with a high relative load considerably simplified the design of the apparatus of the process and the maintenance of the facility.
When treating coarse chlorine-containing waste (size of separate lumps up to 70 m), the high environmental efficiency was maintained. In the first step of the reactor in the zone of the rotating layer at temperatures of 800-900°C in the presence of lime (CaO or $Ca(OH)_2$ a full burning of the main organic mass was achieved as well as the neutralization of hydrogen chloride HCl together under the formation of $CaCl_2$.
In the second step of the reactor, in the afterburning zone, a full oxidation of the admixtures was achieved (the residual concentration of $CO<50$ mg/m^3) as well as the neutralization by sodium carbonate (Na_2CO_3) remaining HCl (the concentration of HCl in flue gases was lower than 10 mg/m^3).

2.4. The Use of Plasma Sources of Energy

During the past few years in domestic and foreign literature there has been a large mass of materials to a high degree of a commercial PR character, on the use of plasma sources of energy (electric arc generators) in facilities for the high temperature processing of various kinds of waste, containing organics (solid household, industrial and medical waste).

We would like to point out, a propos, that in many publications as we see it, one uses an unclear term, for instance, "plasma gasification", even though one is looking into the process of thermal processing – the incomplete oxidation of organic substances, to which plasma does not have any direct connection. Plasma takes on the role of energy source, i.e. the generator of high temperature gases – a substitute for the products of incineration of organic fuel.
The main version of the use of plasma sources of energy in techniques using high temperature processing and destruction of solid household, industrial and medical waste is:

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- Plasma-chemical destruction of supertoxicants directly in the plasma arc
- Action on the layer of toxic waste by a percussion plasma ray
- The thermal treatment of waste in a fine-mesh filter layer with the use of plasma sources of energy
- The afterburning of the gases that leave the kiln with the aid of plasma energy sources

2.4.1. Plasma-chemical Disposal of Supertoxicants

Liquid and dispersed solid waste, containing persistent organic pollutants may be subjected to treatment directly in the plasma arc [2]. At temperatures a above 4000°C through the energy from the electrical arc in the plasmotron, molecules of oxygen and waste are split into atoms, radicals, electrons and positive ions. Under cooling in the plasma the reactions are proceeding with the creation of simple compounds, CO_2, H_2O, HCl, HF, P_4O_{10}, and others. The level of decomposition of the polychlorinated dibenzodioxins and furans (PCDD and PCDF), the polychlorobiphenyls (PCB), the Chlorine, Fluorine, sulphur- and phosphor- containing pesticides reached a level of 99,9999%. Test including the destruction of CCl_4 with methyl ethyl ketone and waster and the destruction of transformer oil containing 13-18% PCB and the same amount of trichlorbenzene, showed that the efficiency of chlorine containing components exceeded 99,9995% [2].
When treating chlorine containing waste , as a result of the breaking of the chemical bonds between the atoms of the original compounds, in the plasma there is formed a great number of chlorine atoms, which, during the slow cooling of the exhaust gases (the absence of an efficient tempering of them), interact wit the ions of carbon, oxygen and hydrogen, again forming secondary supertoxicants, including PCDD and PCDF.
In Russia, in 2007 a method was developed based on the recycling of PCB-containing liquid waste through its preliminary evaporation and feed directly into the plasma forming gas jet [23]. The input of the waste is carried out together with a neutralizing agent – quicklime, fragmented down to a coarseness lower than 75 microns. The binding of chlorine into $CaCl_2$ prevents the synthesis of secondary organic supertoxicants.
Russian specialists have also designed a technique and a reactor for the plasma processing of pesticides [fig. 2.13.]. The distinctive feature of this

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technique is the neutralization of the acid gases in the system of wet treatment beyond the tempering step of the exhaust gases.

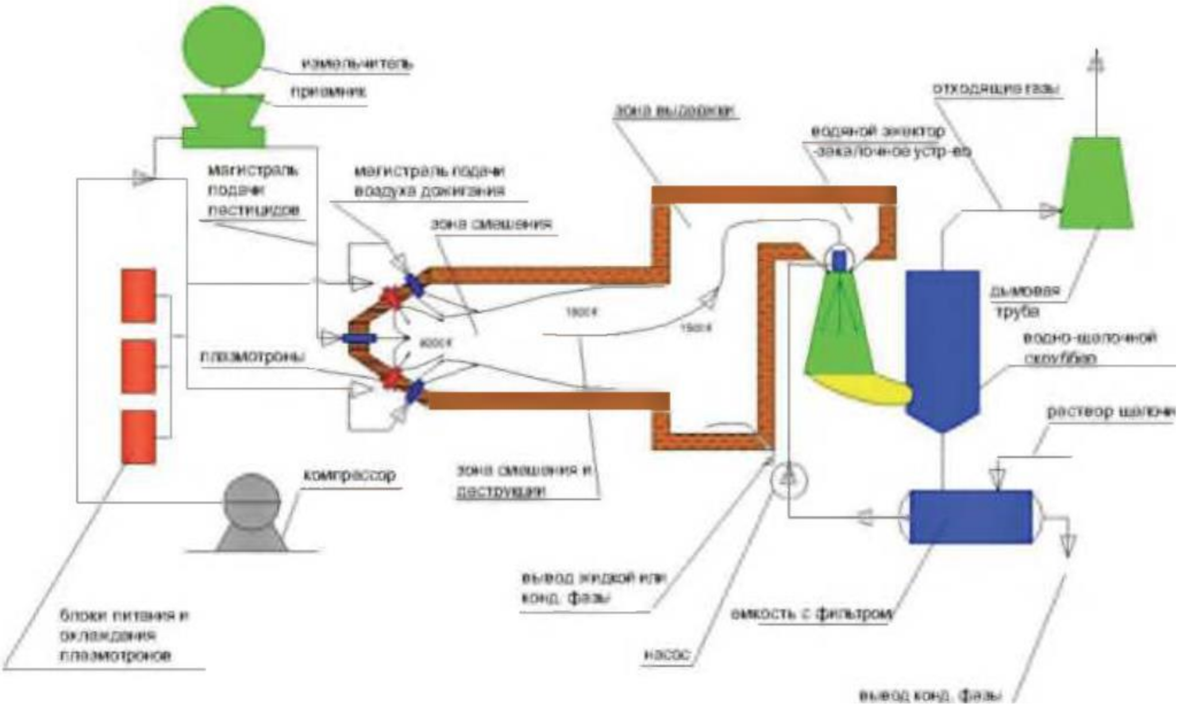

Fig. 2.13 – the process scheme of the set-up for the plasma processing of pesticides [23]

The high costs of energy and the complicated apparatus of the reactor design restrict the possibilities of a broad application of this means of oxidation processing of waste directly in the plasma jet.
A more promising method is the application of the injection of liquid waste in the plasma jet in order to process waste in a reductive environment in order to produce valuable products.
In the Soviet Union, for instance, a method was developed and carried on to the experimental industrial stage of pyrolysis of liquid chloro-organic waste in a low-temperature reducing plasma, allowing for the production of acetylene, ethylene, hydrogen chloride and products based on the aforementioned [24].
The principal scheme of the plasma-chemical set-ups for the processing of chloro-organic waste is shown on figure 2.14.

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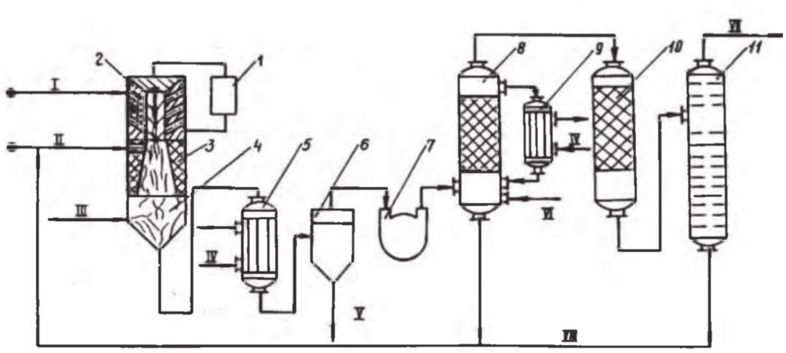

Fig. 2.14 – The Principal scheme of a plasma-chemical facility for the processing of chlorine-containing waste [24]
1. source of electricity; 2 – plasmatron; 3 – reactor, 4 – tempering system, 5, 9 – heat exchanger; 6 filter; 7 – compressor; 8 – reactor for selective cleaning; 10 – synthesis reactor; 11 dispersion column.

I – plasma forming gas; II – waste; III – tempering agent; IV – coolant, V – technical carbon; VI – chlorine; VII organic products; VIII – residual oil

The technological process consists of the following stages:

- Pyrolysis of the waste
- Cleaning of the pyrolysis gases (pyrogas) from the technical carbon
- The treatment of the pyrolysis gases to remove acetylene homologues and hydrocarbons C_3, C_4;
- Synthesis of chloro-organic products

Pyrolysis of the waste is taking place in the plasma aggregate, consisting of a plasmatron 2, the plasma-chemical reactor 3, and the tempering system 4. The power supply to the plasmatron is arranged from the electric power supply system 1.
The plasma system work in the following way: The plasma forming gas is heated in the plasmatron up to the average mass temperature of 3500-5000 K, and after this, in the form of low-temperature plasma, it is fed into the plasma-chemical reactor, into which the chloroorganic waste is injected through atomizers. During the stirring of the waste when it is mixed with the plasma, they are evaporated, they go through pyrolysis with the production of olefin hydrocarbons, HCl, and soot (technical carbon). The produced gas is subjected to a rapid tempering in the tempering apparatus, after which it is cooled, cleaned from soot, and it is selectively cleaned from acetylene homologues and hydrocarbons C_3 and C_4. The cleansed gas is dispatched to the synthesis of chloroorganic products.
The capacity of the facility waste-wise is 750 kg/h, the energy expenditure for the waste treatment is not above 2 kW/kg
The process is close-circuit, does not produce waste, is profitable and is used in the chemical and petrochemical industries.

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2.4.2. Impact on the Layer of Toxic Waste of the Percussive Plasma Jet

In the 1990s, in Switzerland, in the city of Muttenz, a facility wit a capacity of 1 t/h for the high-temperature treatment of hazardous waste was developed and introduced. (fig. 2.15.).

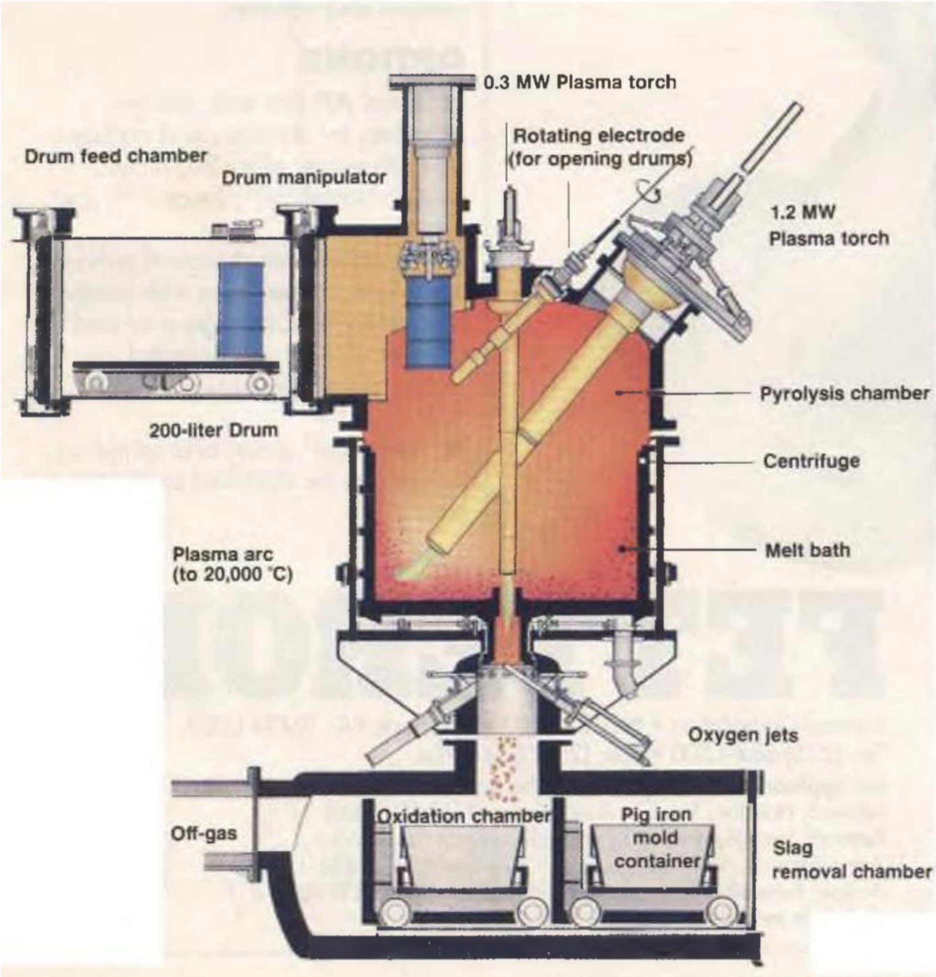

Fig 2.15 – set-up for the high-temperature treatment of hazardous waste [25]

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This technique was named Plasmox [25]. The central element of the facility is the centrifuge with the plasma torch mounted onto it. The waste in drums is fed by the feeder into the slowly rotating water-cooled centrifuge, where it is distributed on the hearth of the furnace. The plasma torch with a direct current, of the power 1,2 MW heats the material and destructs the toxic organic substances. On the hearth a melt of mineral components is formed with a temperature of ≈ 1600°C. The thermal destruction of the organic components is accomplished by the main plasma torch. The gases formed pass through a constriction in which additionally yet another hot zone is introduced, heated with the aid of a torch with the power of 0,3 MW, and (the gases) subsequently pass into the oxidation chamber, in which they stay during 2 seconds at the temperature of 1200°C.
The technology and the system for the plasma chemical destruction of PCB-containing concentrates have been proposed by an American firm. The Plasma Arc Centrifugal Treatment System, PACT-8 (the number 8 corresponds to the diameter of the centrifuges expressed in feet, 1 foot is 0,3048 m), was developed by the firm starting in 1985 [26].
PCB-containing condensers are milled in a special machine and are feed through a screw feeder to the primary treatment chamber. In the reaction zone of the primary chamber,

oxygen is added (air) as well as the waste that is under the influence from the plasma flow from the electric arc plasmotron. At a high temperature in the treatment chamber (the temperature in the reaction zone goes up to 1300°C) a destruction of the PCB (through pyrolysis and incineration)as well as the melting of the inorganic components of the waste. AS a result of this a gaseous waste is formed, which is dispatched to further processing, and slag.
During the rotation of the centrifuge a uniform heating is carried on as well as the mixing of the waste and the slag melt, thanks to which a high level of PCB destruction is achieved, as well as the destruction of toxic components of the waste. IN the facility PACT-8, an original system of the forming of the plasma flame is used, which uses waster cooled electrodes.
The gaseous waste pass to the secondary treatment chamber. All gases exiting from the primary chamber will have to stay in this chamber a temperature exceeding 980°C for no less than 2 s, under a oxygen concentration no less than 6 %.
The technical features of the PACT-8 plant: Power 1 MW, temperature in the zone of the plasma arc: 10000- 20000°C; temperature in the reactive zone: 1000-1300°C; capacity for condensers 300-500 kg/h, level of

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destruction: 99,9999%, quantity of solid waste per ton of treated condensers – 0,4 t.
A simplified version Plasmox and PACT-8, without any mounted centrifuge is the smelt-furnace EUROPLASMA (Bordeaux, France), for the treatment of toxic ash from waste incineration plants (fig. 2.16.). The capacity of these systems (France, japan and other countries) starts from 6 and ends with 41 tons/day. The non-volatile mineral components, including heavy metals salts are extracted out of the furnace as a melt ((a secondary product), whereas the sublimate of the volatile substances (cadmium, mercury and lead) after the sorption system and the trapping are collected for the subsequent concentration, recycling or disposal (burial).

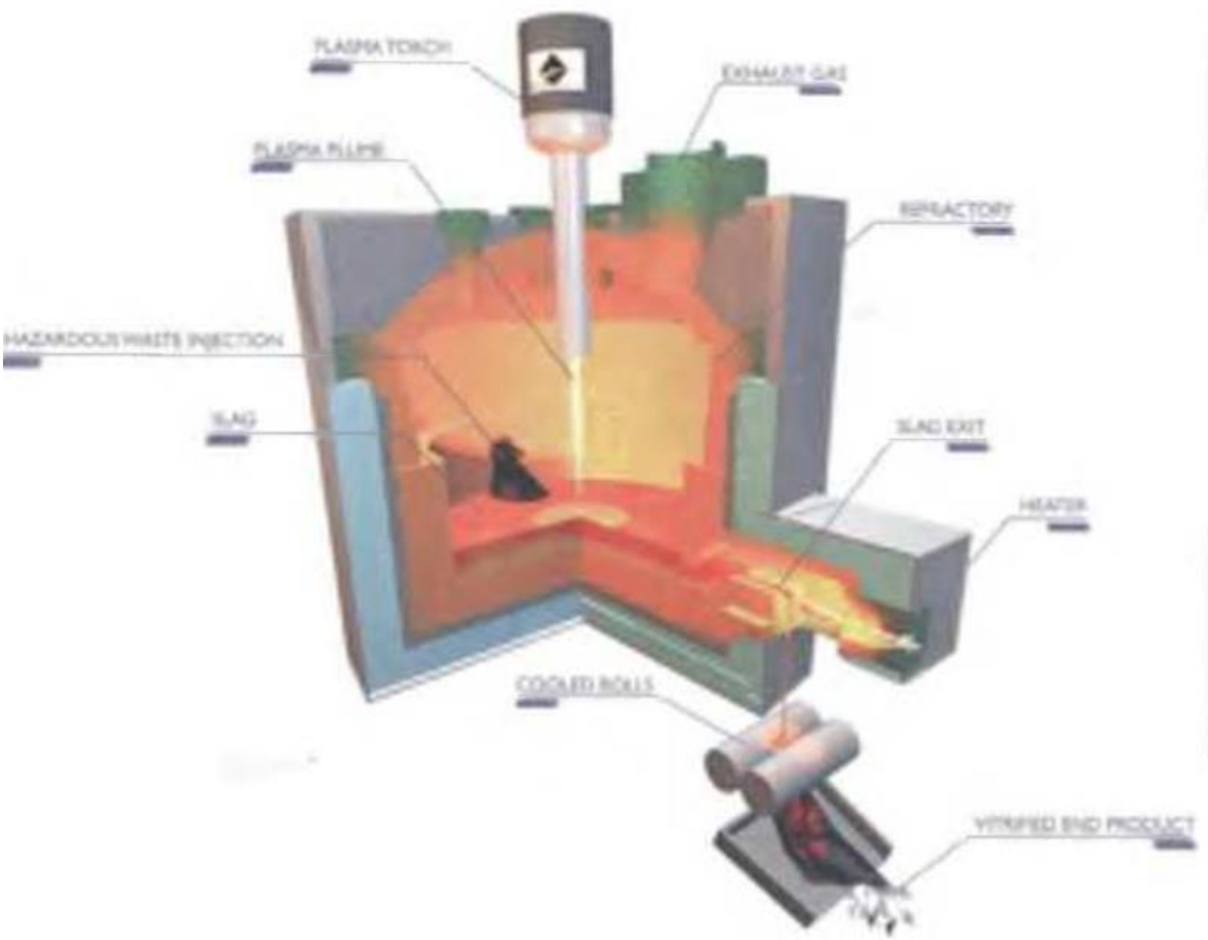

Fig. 2.16 Plasma furnace EUROPLASMA for the treatment of toxic ash from waste incineration plants [19]
The words are (blurry on the picture), Plasma torch, Exhaust gas, Refractory, Hazardous waste injection, slag, plasma plume, slag exit, heater, cooled rolls, vitrified end product.

Specialists in Belarus have developed, manufactured and tested a plasma chamber furnace with periodic action, and with a power of 50 kW and a capacity of 20-30 kg/h, as shown on fig. 2.17 [27]. This Furnace is intended for the treatment of relatively small volumes medicine and biological waste. After the loading of waste with about 10-15 kg and after the plasmotron has been switched on, the treatment cycle (incineration) takes about 10 minutes, depending on

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waste composition. After the conclusion of the work cycle, the plasma torch is turned off, and the kiln is switched over to the cooling mode and slag is discharged. The total time of the realization of all the stagers is about 30 minutes, after which the furnace is prepared for the next load and to be switched on.

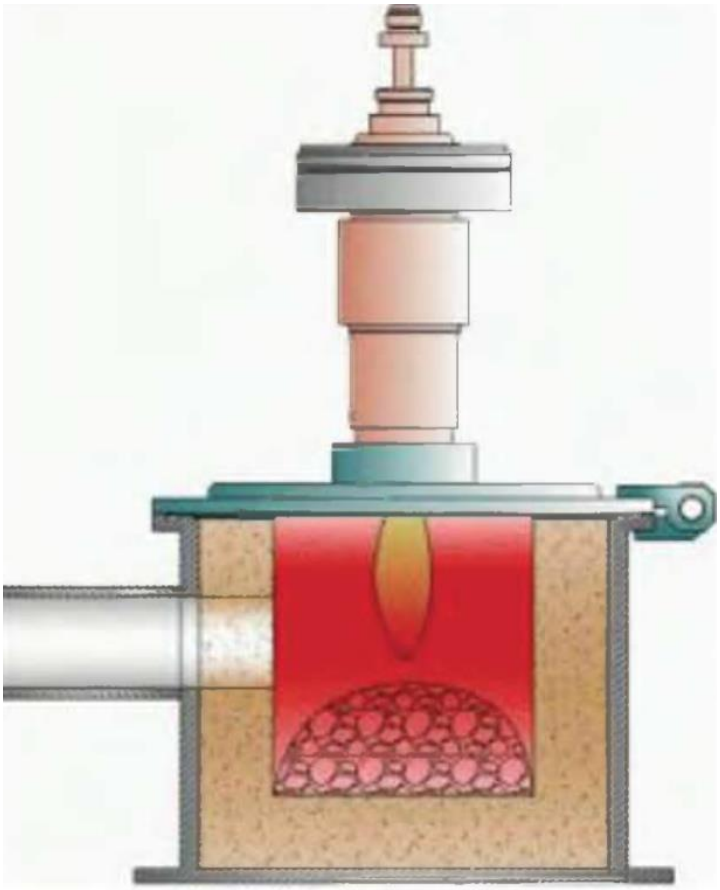

Fig. 2.17. Plasma furnace for the treatment of medical and biological waste [27]

The plasma system for the treatment of infected medical waste was built at the Moscow city infection clinical hospital no1 [28, 29]. The principle technological scheme of the facility is shown in fig. 2.18.

The basis for the system is a two- chambered metallurgic furnace wit a slag and metal melt bath and the plasma torch on the side walls, maintaining a temperature level from 2000 to 5000°C. The maximum design output is 60 kg waste per hour (500 tons per year).

For a number of technical and economic reasons, this set-up has not been taken into permanent operation.

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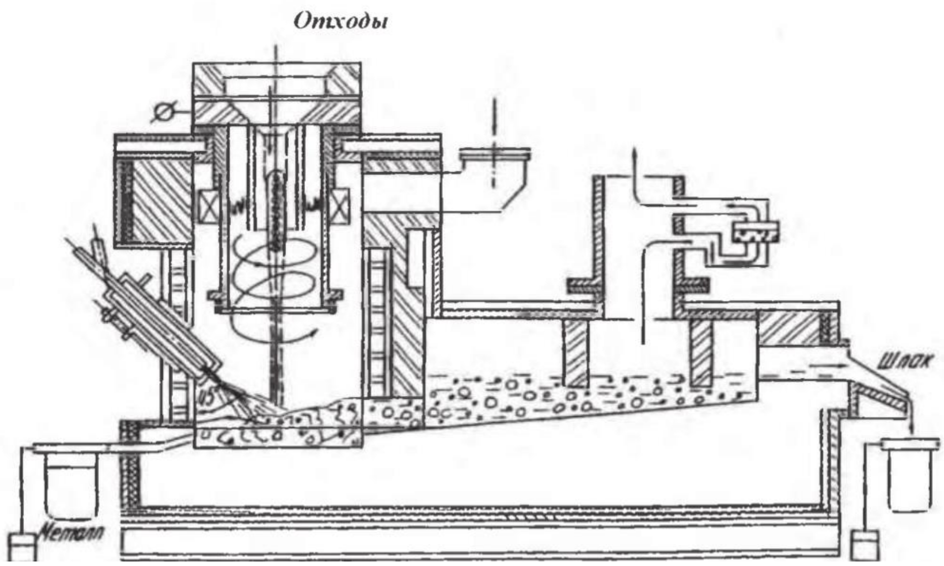

Fig. 2.18 – Technological scheme of the plasma system for medical waste treatment [28]

In general, the considered technology for the treatment of an immobile layer of toxic waste by a percussive plasma jet is characterized by a low efficiency of heat and mass exchange. The substantial complication on account of the integrated centrifuge for the mixing of the melt on the hearth does not raise the environmental and technological parameters of the process.

2.4.3. Thermal Waste Treatment on a Dense Filtration Bed

The most widespread use in the practice of pyrolysis and gasification of solid household, industrial and medical waste has been conquered by the vertical shaft furnaces.
One classical example of the counter current shaft furnace for the pyrolysis of solid waste is the reactor [30] represented on fig. 2.19.
Through the waste packages load mechanism the waste proceeds to the upper layers of the shaft and, while it descend by force of gravity it is heated from the heat in the gas, travelling upwards towards them from below.
The energy source is the plasma arc torches, mounted in the hearth part of the furnace above the bath. The function of the plasma forming gas is fulfilled by air. The use of air plasma torches of a relatively high power allows for the possibility of refraining from the use of additional fuel. In the upper part of the kiln, the waste goes through the stages of frying and pyrolysis, this being accompanied by an intensive gas release.
In the high temperature zone of the shaft kiln and in the lower layers of waste, there is a volatilization of the volatile compounds. At the same time, in the mid- and upper levels

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of the furnace shaft, in the zone where the temperature is relatively low, these compounds are concentrated and collected in the waste layer.
The coke residue is burned to a large extent, however, the mineral components are melted and dispatched to the zone of melt accumulation.

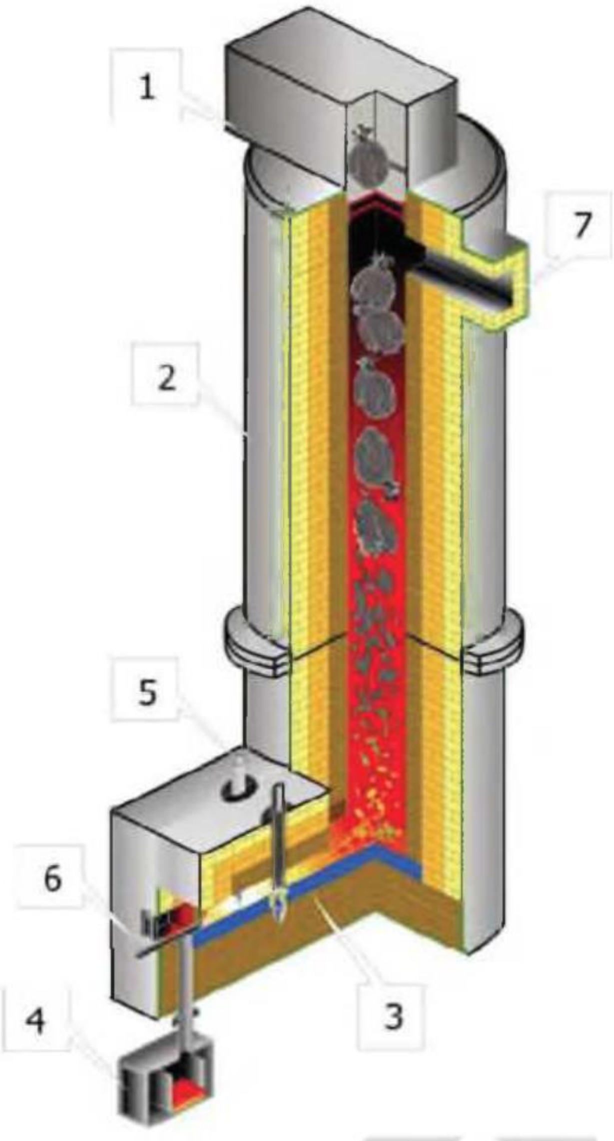

Fig. 2.19 – Plasma shaft furnace for the treatment of solid radioactive waste [30]
1 – loading mechanism, 2 – shaft, 3 – hearth, - 4 – container for slag collection, 5 – plasmatron, 6 – locking mechanism, 7 – pyrogas output

The technological scheme of the experimental industrial facility Pluton is developed for the treatment of radioactive waste, with an aggregate load of 200-250 kg/h [31] is shown on fig. 2.20. This facility allows for the treatment of mixed solid waste, containing not only fuel components (wood, paper, rags, plastic), but also non-combustive (metal, glass, soil, isolation material, etc.)
The temperature of the flue gases at the exit from the shaft kiln, did not exceed 150-300°C, the pyrogas, apart from combustive gases, contained resinous matter and aerosols of soot and ash, which were subjected to treatment in the multi-step system of dust and gas treatment.

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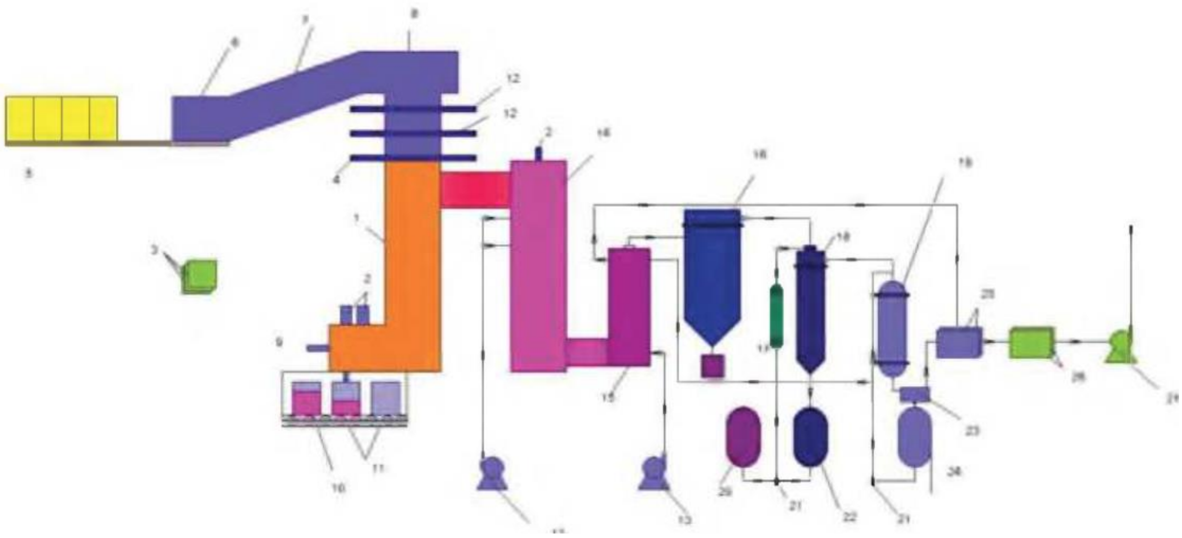

Fig. 2.20 – The technological scheme of the Pluton facility [31]

1 – shaft kiln; 2 – plasmatron; 3 – power supply of the plasmatrons; 4 heat deflector; 5 – radioactive waste storage; 6 – receiving bin; 7 – hermetic conveyer; 8 – load bin; 9 – blocking device; 10 – container for the receipt of slag melt; 11 – metal container; 12 – chimney valve; 13 – forced draft-fan; 14 – afterburner chamber; 15 – evaporator heat exchanger; 16 –bag filter; 17 – heat exchanger; 18 – scrubber; 19 – cooler; 20 – container and batcher for alkali liquor; 21 – pump; 22 – recirculation container; 23 – gas separator; 24 – condensate collector; - 25 – gas mixer; 26 fine treatment filter; 27 – exhaust blowers.

The temperature of the slag melt in the bath of the kiln is 1600-1800°C and after the cooling, at product was received that met the requirements for save storage.
Based on the facility Pluton, a system for solid household waste treatment has been designed in Israel with a design load of 500 kg/h (fig. 2. 21), and taken into operation in 2007 under a contract wit the Israeli company EER.

Fig. 2.21 – general view of the technological complex for the treatment of solid household waste in Israel [17]

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The shaft kiln for the thermal treatment of solid household, industrial and medical waste wit the aggregate load of 200 kg/h has been developed in Belarus [32, 33]. As plasma burner electric arc DC and AC current plasmatrons are used.
The shaft treatment process opened the possibility to implement the mode of counter current under heating and thermal treatment of the waste, as well as the cooling and the filtration of the flue gasses directly in the layer. In order to do this, organic filtrating material (fine sawdust) was added to the mix of compounds in the shaft.
The authors developed a DC plasmatron, PDS-50/3-03, the parameters of which are shown in table 2.1.

Current, A	Voltage V	Gas consumption (air) g/s	Coefficient of efficiency, %	Enthalpy of the plasma jet, MJ/kg	Temperature of the plasma jet
120	320	3,6	58	6,5	3700
130	340	4,5	59	6,1	3550
110	340	4,0	60	5,9	3500

Table 2.1 – The working parameters of the plasmatron PDS50/3 [32]

The deep regenerative use of the heat from the exhaust gases, typical of the abovementioned counter current shaft organic waste pyrolysis and gasification kilns guarantees minimal expenditure of additional energy to entertain the process. However, when using the counter current kilns (reactors), quite substantial disadvantages are also manifested. The pyrolysis resinous products, formed in substantial quantities in the upper zone (in the zone of relatively low temperatures), are transported out of the kiln by the raising (counter current) gas flow, polluting the produced synthetic gas. This leads to the necessity of a thorough multi-stage treatment of the synthetic gas, quite substantially complicating the process and increasing the cost of the equipment, as well as the operational costs.
IN direct current reactors with a low flow of the pyrolytic products, formed in the upper low-temperature zone of the reactor, pass through the lower high-temperature zone of the reactor, where they are subjected to thermal decomposition. While this is happening, the output of fuel gas and its combustion heat is increased, ad, most important, the necessity to clean the synthetic gas from resinous products is eliminated.
Let's look into o the direct current gas generator, developed in Russia [34]. The reactor/gas generator (fig 2.22.) is comprised of a vertical shaft, lined by fireproof bricks. The waste, loaded through the upper lid,

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fully fills up the internal volume of the reactor and sits on the furnace grate, which is situated in the lower part of the shaft.
The plasmatron is mounted on one of the side flanges and the flow of hot plasma is distributed along the edges of the shaft through a number of side openings, equally spaced. The synthesized gas produced is collected from the lower par of the reactor.
The execution of the gasification process at a temperature above 1200°C makes possible the exclusion of the appearance in the synthetic gas of liquid fractions (resins). The high temperature of the process guarantees the destruction of toxic organic components of the waste, and, if there are chlorine-containing impurities in the waste, it excludes the synthesis of supertoxicants (PCDD or PCDF) [35]

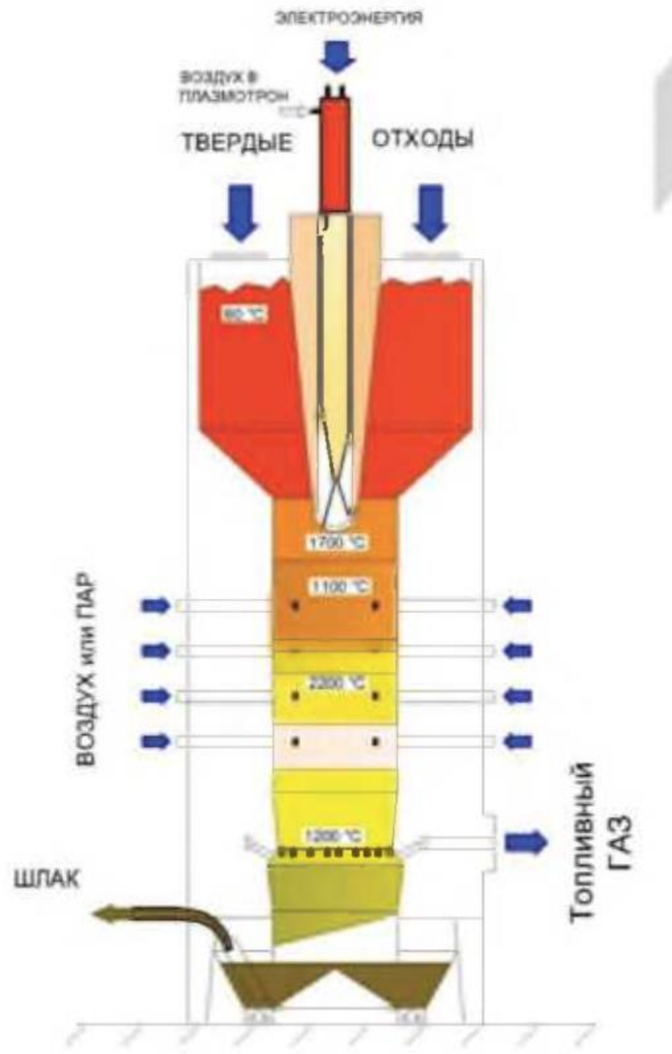

Fig 2.22 A gasification reactor [34]
1 – loading mechanism; 2 – storage bin; 3 Plasma generator ; 4 – reactor shaft; 5 – openings for additional air blasting; 6 temperature gauges; 7 – output of the produced gas; 8 rotating grate; 9 – water lock

In general, one should note, that the high-temperature direct current waste gasification technology has a higher potential of an efficient functioning than the pyrolysis process, which is explained by the high temperature of the process, the almost total conversion of carbon-containing substances in the synthetic fuel gas, as well as the production of a harmless inorganic slag.

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When the temperature is raised in the reactor up to approximately 1100-1200°C through the use of plasma arc sources of energy the possibility and feasibility has emerged of use water steam as a heat medium and oxidising reagent.

AT present there is no technical means, apart from plasmatrons, that could allow for the heating of a large amount of H_2O up to the plasma state. The level of development of the plasmatron technology allows us to state, that powerful electric arc generators of water plasma, stably and reliably functioning over a long period will conquer a place in industry [36].

These two factors will raise the energy and environmental attractiveness of the high temperature steam gasification of solid household, industrial and medical waste.

2.4.4. Afterburning of the Effluent Gases from the Furnaces with the Aid of Plasma Energy Sources

During the past few years a two-stage thermal organic waste treatment is practiced; the first stage being realized in a chamber drum shaft kilns or a pseudoliquid layer reactor, wherewith an incomplete incineration, pyrolysis of gasification takes place, and – in the second stage - the afterburning of the products of the incomplete burning takes place (of carbon, H_2, CO, C_nH_m as well as resins), after they were collected with the gaseous flow from the first stage [7].
Some designers (France) propose the use of a plasma source of energy in the afterburner chambers (Fig. 2.23). A similar solution was used by a number of Russian companies and organisations, which mounted plasmatrons in the pyrolysis afterburner chamber for the burning of the gas that is exhausted from the shaft kiln [37].
However, the calculated and experimental studies show, that the plasma generators are not able to serve for the efficient mixing of the relatively large volume of flue gases with the maintenance of their temperature

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at a level of ≈ 1200-1250°C when the time of stay under this temperature is no less than 2,0 seconds.

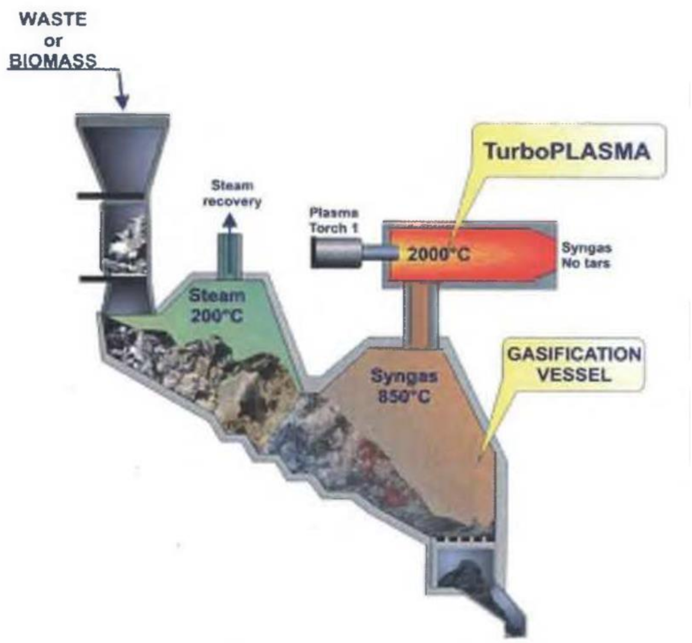

Fig. 2.23 – the technological scheme of the facility for thermal waste treatment, using a plasma afterburner

Experience shows that only the use of a lined cylindrical afterburner chamber with a tangential mixing of the gaseous products and the practically speaking full oxidation of the residual organic compounds in the flue gases.

2.5. High-Temperature Combustion Supertoxicants Treatment (PCB, Pesticides)

The technology of thermo oxidation (fire) treatment of liquid PCB in a cyclone reactor became the winner of the International tender for the best technology of PCB destruction, organised by the Nordic Environmental Finance Corporation (NEFCO) [38].

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The basis for the organization of the process of igneous treatment of liquid waste, containing PCB are the following principles [39, 40]:

a) The waste treatment is carried on in a cyclone reactor with a fireproof air cooled lining;
b) A neutralization of the formed acid gasses (HCl) is carried on directly in the volume of the cyclone reactor through an injection of a solution of an alkaline reagent under the production of non-toxic mineral salts;
c) The securing of the conditions for the efficient destruction of supertoxicants, i.e. dioxins and furans:
    1) The temperature of the process is 1200-1250°C
    2) The time of stay of the products of the treatment process in the high temperature zone ≈2 seconds
    3) The concentration of oxygen in the dry flue gasses is more than 3% (a coefficient of consumption of the oxidant higher than 1,2),
    4) An efficient turbulent mixing of the gases in the reactor volume;
d) Tempering of the high temperature flue gases taken place in the vaporising scrubber.

The principal technological scheme of the facility for the high temperature liquid PCB treatment is shown in figure 2.24.

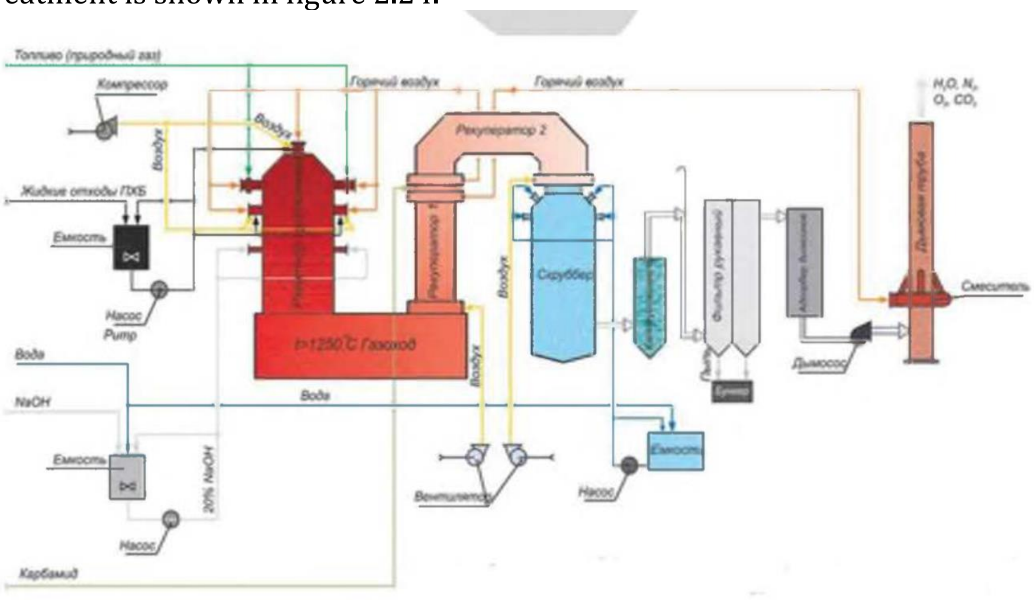

Fig. 2.24 – The principal technological scheme of a facility for the high temperature treatment of liquid PCB [39, 40]

In the facility for the high temperature treatment of liquid PCB, the following technological solutions are envisaged:

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- The use of the heat of the exhaust flue gases for the heating of the injection air in the regenerative heat exchanger;
- The dry treatment of the flu gases to remove the mineral dust escape in a bag filter;
- The heating of the exhaust flue gases after the flue-gas fan.

The facility for the high-temperature treatment of liquid PCB consists of a lined cyclone reactor, a lined gas tract, a recuperator of the first step, the recuperator of the second step, an evaporative scrubber, a drop trap, a bag filter, an apparatus for the adsorptive final cleaning, a mixer, a smokestack and accessory equipment; tanks, pumps, fans, a flue-gas fan, and a compressor.

The wet waste is received in a tank and by the action of a pump is fed into the pneumatic nozzles of the cyclone reactor. The Atomization of the liquid waste is carried out by the use of compressed air from a compressor. The heating of the cyclone reactor is carried out by the use of natural gas (liquid duel). The air needed for the burning of the fuel and the liquid waste is fed from the recuperator of the second step. The solution of lime is prepared in a tank, equipped with a mixing facility. The prepared solution with the concentration exceeding 20% is fed by a pump to the mechanical nozzles of the cyclone reactor.

In the cyclone reactor, incineration of the natural gas is carried out (the liquid fuel) as sell as the liquid chlorine- containing waste. The thermal decomposition and oxidation of the organic components of PCB takes place according to the following chemical reactions in the flow of the high-temperature products of the combustion:

$C_6H_3Cl_3 + 6O_2 \Rightarrow 6CO_2 + 3HCl$

$C_{12}H_7Cl_3 + 13O_2 \Rightarrow 12CO_2 + 2H_2O + 3HCl$

$C_{12}H_6Cl_4 + 12{,}5O_2 \Rightarrow 12CO_2 + H_2O + 4HCl$

$C_{12}H_5Cl_5 + 12O_2 \Rightarrow 12CO_2 + 5HCl$

The gaseous hydrogen chloride , formed during the thermal decomposition of organic compounds is neutralized by the alkaline reagent directly in the tank of the cyclone reactor at high temperatures.

$HCl + NaOH \Rightarrow NaCl + H_2O + Q_1$

The surplus NaOH is subjected to carbonization:

$2NaOH + CO_2 \Rightarrow Na_2CO_3 + H_2O + Q_2$

The mineral salts together with the flue gases from the cyclone reactor are dispatched to the lined gas duct. The inner volume of the gas duct according to the conditions for an efficient

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destruction of supertoxicants is manufactured taking into account the guaranteeing of the necessary time of stay of the flue gasses in the high temperature zone - no less than 2 seconds.

From the gas duct, the flue gases enter the recuperator of the 1st step, in which air is heated, and subsequently directed to a mixer in order to heat the flue gases and to reduce their humidity.

The air going into the recuperator of the second stage is fed by a fan.

In order to reduce the nitrogen oxides, formed during the burning of the fuel, a steam-carbamide mixture is fed into the gas duct after the 1 step recuperator. The feed of steam carbamide mixture is carried out through nozzles, mounted in the lower part of the second stage recuperator.

The reduction of the nitrogen oxides takes place according to the chemical reaction:

$2NO + CO(NO_2)_2 + 0{,}5O_2 \Rightarrow CO_2 + 2H_2O + 2N_{2+Q}3$

The partly cooled down to ≈930-960°C flue gases from the second step recuperator are sent to the scrubber, where they are cooled through the evaporation of waster, fed to the scrubber injector from the tank by action of a pump. The cooling of the flue gases is carried out down to temperatures , defined by the requirements of the filtering material of the filter.

In order to exclude the event that drop moisture from the filter ends up in the filter, a drop trap is installed in the gas duct between the scrubber and the filter. IN the filter the trapping of non-toxic mineral salt dust is carried out.

The treated flue gases exiting the bag filter are sent to the adsorption after treatment device and further by a flue-gas fan to the smokestack, in which a mixer is installed. In the mixer the flue gases are mixed wit the hot air, fed from the 1st stage recuperator, and is then emitted to air.

2.6. High-Temperature Treatment of Medical and Biological Waste

In order to treat medical waste the following experimental and industrial techniques are uses: thermal treatment (incineration, pyrolysis, plasma processing) sterilization in autoclaves, chemical disinfection, laser processing, microwave disinfection and a host of other methods [19, 41].

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One of the most efficient methods of treatment of medical waste, guaranteeing a high toxic and epidemiologic safety, is the high temperature (igneous) method.

The main restriction criterion – the high environmental efficiency of waste treatment, especially for the removal of supertoxicants and epidemiologically hazardous elements – is defined by the necessity of a preliminary realization of the main task – the full destruction of the abovementioned hazardous properties, leaving to the side issues of economic efficiency.

The possibility of transformation at high temperatures of any organic compounds, including the epidemiologically and chemically harmful into harmless products in possible only under special technological, design and mode parameters of the process – the temperature level in the kiln/reactor, the relative waste loads, the relevant time of stay of the gases and particles in the high-temperature zone, the aerodynamic structure and the level of turbulence of the gas flow in the reactor, etc..

The first kilns with assemblies for the thermal treatment of medical waste were made in the 1960s. At present, local assemblies of small capacity have been widely spread on the USA, Germany, Japan, France, and other countries, which is explained by the relatively small capital costs, the fast construction as well as the danger connected with the transport of highly toxic, even infectious medical waste over large distances to a regional installation with higher capacity.

It should be noted, that in the majority of cases, in order to destroy medical waste in local facilities with a load starting at 20, ending at 200 kg/h, primitive kilns are used, mainly the layer type.

Many furnaces are characterized by low environmental values (emissions to air of harmful substances, the formation of “dirty” slag, containing residues of organic impurities), a low mission life, and a low intensity of the treatment process.

In the period of 1990s and 2000s, it was prohibited to operate a number of thousands of layer incinerators for medical waste in Europe and USA because of the discovery of pathogen microflora in the spore state in the slag and the fly ash. However, the companies in the industrial countries continue the wide delivery of primitive facilities of the countries of Asia, South America and Africa. Often such facilities are also bought in Russia.

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At present, some satisfactorily functioning facilities for the thermal destruction of medical (including biological) waste are known, for instance the facility with a chamber kiln (Germany), a furnace delivered to the sanitary-veterinary plant “Ekolog” in Lyubertsy of the Moscow Oblast- (fig2.24). This plant consists of a primary combustion chamber and an afterburner chamber, a heat-recovery boiler a system of chemical sorption of the gas treatment system to remove secondary dioxins (a reactor with Sorbalit® injection and a bag filter). At present, unfortunately, the operation of the plant is discontinued.

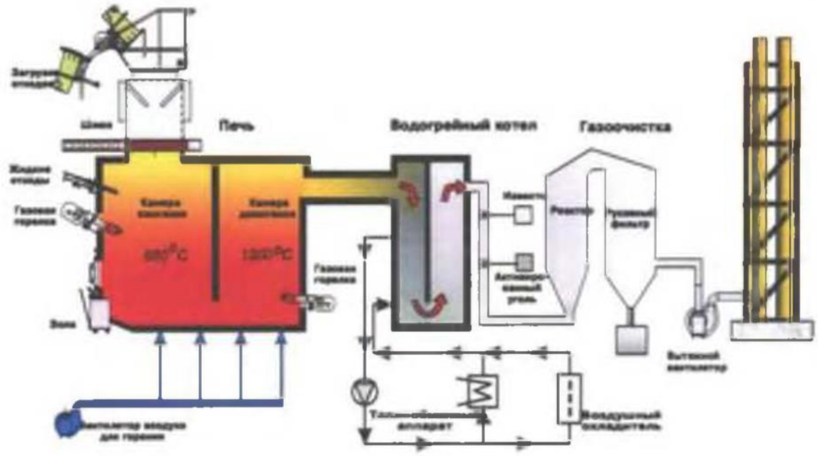

Fig. 2.25 The Sanitary-Veterinarian plant ”Ekolog” [19]

The economic parameters of local facilities for the high-temperature treatment of the classes ”B” and ”C”, are to a considerable degree defined by the conditions for the guaranteeing of toxic and epidemiological safety. The cost of the simplest set-ups for heat-recovery of the high-temperature flue gases with a single-step treatment and with the production of a hard ”dirty” residue of mineral compounds is 7-150 thousand Euro. The capital costs for the construction of modern facilities with an aggregate load for medical waste of 100-150 kg/h and with the use of the heat from the flue gases as well as their treatment in a multi-step system to avoid the passage of organic or mineral compounds and the production of a sterile, molten slag, amounts to a number of hundred thousand Euro.
The cost of a highly efficient treatment of class B and C waste amounts to 300-500 Euro/t (abroad, this cost is 500-1500 Euro/t).

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Section 3: Parameters of assessment of techniques and the present levels of emission to the environment

3.1 Industrial Impact on the Environment

The production process for the thermal treatment of waste is based on the handling of waste of various hazard classes (see section 1) through the use of special technical systems within the corresponding production lines.
When waste arrives at a plant it is expedient to sort it into the following groups:
Waste, not permitted to be treated with a thermal method (including mercury-containing waste);
Waste, containing POPs
Solid or pastelike petroleum-containing waste (PCW)
Liquid PCW
The first type of waste includes vessels under pressure, containers, containing radioactive and explosives as well as Arsenic-containing waste
The second type of waste contains mercury-containing waste (Hazard Class (HC) I); products, equipment devices that have lost their consumption qualities, containing mercury (HC I) (incandescent, luminescent and others), glass with applied fluorescent dye, isolated wires, cables and other isolated electrical conductors (HC I-II).
As belonging to **the third category** are treated the waste, prepared to be granulated, not containing thick-walled (above 2 mm) metal objects, stones, glass objects, etc.
The fourth type of waste to be directly entered into the furnace is constituted by waste, weighing less than 20 kg.
The fifth type of waste includes pesticides, herbicides and other toxic chemicals and need to undergo preparation processes before their treatment.
The sixth type of waste include petroleum-containing liquids, collected from places where emergency spills of oil and petroleum products have taken place during their storage, transportation, as well as bottom sediments after the cleaning of production equipment and storage facilities and also waste, produced after the treatment of petroleum-containing liquids from emergency technique oil waste pits.
The seventh type of waste is petroleum-containing liquids that can be used as an alternative type of fuel.

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The environmental efficiency of the thermal waste treatment of waste containing toxic components is achieved by the maintenance of the following parameters:

- the temperature level of the process
- the feeding speed of the waste going into the furnace
- the time, during which the gases are subject to a certain temperature, exceeding 2 seconds
- an optimal oxygen saturation
- a sharp cooling process down to 250-300°C, which excludes the secondary formation of dioxins.
- cleaning of the exit gases in a scrubber and a adsorber (including having the possibility to trap heavy metal oxides and the trace quantity of aerosols, including those, arisen from the possibly present secondary dioxin-like compounds on the carbon sorbents in the sleeve filters);
- Recycling of sludge

The receipt of waste of the various classes need to be preceded by a **preliminary entry control** of waste that is accompanied by a hazardous waste certificate and/or protocols from a chemical analysis, as follows:

- radiation control of entering waste
- laboratory control and the determination of the chemical composition of the waste

The main air protection activities are directed towards guaranteeing the observation of environmental quality standards in the working zone as well as the reduction of the hazardous emissions to air from all sources of pollution from all stages of operation down to the environmental regulatory level.

Pollution reduction activities concerning emissions to air at a plant for thermal waste processing have to be prepared in accordance with the standards 96-AZ [42], as well as the regulatory framework currently in force, which entails planning and realization of activities aimed at the trapping, treatment, reduction or elimination of emissions to air of pollutants.

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The smokestack exhaust gasses emission reduction needs to be considered through the:

- uninterrupted production process
- efficient thermal treatment
- an increased heat use efficiency
- the maintenance of the predicted heat output

In order to minimize the negative environmental impact, the following main technical and organizational solutions are proposed:

- the use of an multi-stage thermal waste treatment
- the installation of gas-treatment equipment (scrubber, sleeve-filter-adsorber)
- monitoring of the flue gasses
- temporary storage of slag waste in a container with a lid and placed in an open space with a concrete cover
- the use of only fault-free equipment, cleared as to the toxicity of the processed gasses
- the regulation of the fuel components of the equipment in order to lower the fuel consumption
- during unfavourable meteorological conditions it is recommended to carry out activities with a minimal use of technical means at the production site
- the development and use of an environmental monitoring programme

The types and concentrations of pollutants depend upon the type of fuel, used during the process of thermal waste treatment.

For transport purposes and the diesel-fuel generator, and also as a heat transfer agent it is imperative to use the types of fuel that correspond to the requirements of the GOST (Russian state standards) requirements, not forgetting the guarantee that there is technical maintenance and control of the lifting facility.

The lowering of emissions of nitrogen oxides from the engines of vehicles and equipment when in operation at low mode may be attained by the regulation of the fuel devices, allowing for the reduction of the fuel injection advance angle.

The prevention of impact on water bodies shall be attained through the:

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- selective collection and feeding systems in the specialized containers and vessels to the corresponding waste processing lines.

- chemicals and other hazardous compounds, the liquid and solid waste must be collected, stored before the processing, in specially prepared places and containers, which shall exclude their entering into the storm runoffs,
- the temporary storage of waste to be fed into the processing system is to be performed in closed containers on a concrete-covered site under shelter with an edge protection solution of in closed premises, directly in front of the thermal processing plants at a volume covering 24h use.
- the set-up of the collection of the production waste (not processed at the production site) shall be solved by containers, placed in contained waterproof sections and by the subsequent removal.
- The diesel fuel consumption tanks as well as the reception containers for liquid petroleum-containing waste shall have double walls, and the space between them shall be filled up with a control liquid (tosol cooling agent) in order to exclude the risk of petroleum product spills in the premises, etc.

As conditionally polluted shall be regarded water that has passed the heat exchange devices, since, in them, no change in composition is made, but only changes in temperature. Other production effluents will be regarded as polluted.
The elimination of pollution of surface and ground waters must be guaranteed by carrying out the following measures:

- delivery of waste in waterproof packing
- performance of all the waste receipt operations at especially equipped sites/sections (closed premises, open sites with hydro-isolated cover, asphalt or concrete covered sides with a sloping or edge protection)
- vehicle and mechanism wash in especially equipped areas
- arrangement of the parking spaces for vehicles excluding the pollution of ground and surface water.
- the use of hydro isolating materials with no negative environmental impact.
- car/vehicle wash as well as repair and maintenance works only at especially prepared for the purpose sites, situated out of water protection zones and coast protection zones of water bodies.

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- the set-up of observation wells for preventive measures of ground and surface water protection

The size of the geologic environment impact depends to a great extent on the observation of the use of the prescribed techniques. As an addition to the above listed measures, the following main measures shall be taken in order so protect the geological environment and the soil:

- fulfilment of the requirements concerning the removal and storage of the fertile soil layer.
- Placing of the equipment at prepared areas (with a hard surface cover)
- The obligatory observation of the borders of the areas, set apart for the temporary or permanent use during the period of construction, operation and phase-out of the thermal waste treatment operations.
- The use, during operations, of well-functioning equipment without any oil or fuel leakage, and also well cleaned and free from any lubricant cables, straps as well as any other used installations or mechanisms
- The observation of the requirements of technical maintenance
- The observation of the requirements of the territorial authorities of the Rosprirodnadzor and Rospotrebnadzor.

The equipment used needs to be placed at sites in specially designed buildings (premises) with a hard surface cover and with a protective bordering, hydro isolation and drainage.

The minimization of the physical impact is attained by the exclusion of sources of electromagnetic impact or ionizing radiation at the site.

The following are measures for the protection from physical factors:

- use of certified equipment and vehicles that satisfy the established standard requirements
- the placing of the equipment in closed premises and on special fundaments
- speed limits for the vehicle transport within the production site (not exceeding 10 km/h).

One determining factor of physical impact is the noise impact.
It is necessary to carry out the acoustic calculations taking into account the level of attainment by the plant of the design capacity with the operation of the plant in the nominal mode of operation of its installations and equipment units.

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The main sources of acoustic noise at the production site is the operation of vehicle transport as well as the production tools.
In order to avoid the impact in the plant an animal world, the siting of the production plants will have to be directed towards places, where it is already an integral part of an already developed industrial zone outside of the region of any animal or plant habitats.
It is necessary to take into account the following measures in order to mitigate the harmful impact on plant communities:

- The control of the operations in order to clear the plant cover in order to respect the borders of the agreed land allotment plots.
- The carrying out of operations for the vegetation cover restoration as well as the prevention of erosion processes
- Taking measures in order to conserve the nature landscapes

The conservation of the animal world is served for through the:

- Ban on the carrying out of construction work in the period of mass reproduction and migration of land vertebrates
- Ban on the use of construction machinery with defective cooling, power supply or lubrication systems
- Ban on the erection of compact, continuous artificial barriers and buildings without special passages on the migration paths of animals.
- The storage of fuel (petroleum products) in hermetically sealed containers

The layout of the various sites and the manner of temporary storage (build-up) of waste shall be consistent with the hygienic requirements for the handling of production and consumption waste.
In the operation process the installation of the thermal treatment of waste, the temporary storage of the formed slag, ash, etc., trapped in the scrubber, are transferred to the ash-trap with a lid and placed on a concrete-covered site.

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The usual component of the ash waste are silicates, compounds containing alkaline earth metals, chlorides, sulphates, heavy metals (for instance As, Cd, Cu and Pb). The main components are the mineral fraction, the uncombusted fraction and metal scrap.

After the filling-up of the containers for the accumulated ash waste it is necessary to carry out the collection of samples for the carrying out of an integrated chemical analysis, after which one determines the subsequent handling of the waste.
The civil servants, dealing with waste, being received for treatment and also with the formed waste after the processing shall have the corresponding professional background.
A programme needs to be worked out for the industrial environmental control (monitoring) of the handling of the received and formed waste.
Among the measures for the control of the sites of temporary storage (accumulation) of waste as sell as the industrial sites for the treatment of waste it is necessary to include:

- the satisfaction of environmental, sanitary and other requirements in the field of waste handling
- the observance of the rules of fire safety in the field of waste handling
- The observance of the criteria on environmental impact, when handling waste and also the fulfilment of the conditions or the permit documentation concerning waste disposal, etc.

At the stage of experimental industrial testing within the field of modernisation of the production lines it is imperative to take into account the full list of parameters under control (taking into account the possibility of checking the concentration of harmful compounds of a certain section of the smokestack as well as the concentration of harmful compounds in the residue ash and the residue from the gas treatment system, including the evaluation of the immediate toxicity through bio testing of every type of waste or waste mixture) It is also necessary to determine and justify the list of waste that could be treated with the aid of the corresponding modernised production lines, as to the maximum level of safety.

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3.2 Levels of Impact and Consumption in the Field of Thermal Waste Treatment

According to 7-FZ [43] environmental protection means the activities of the national state authorities of the Russian Federation, the authorities of the national state authorities of the constituent territories of the Russian Federation, the authorities at the local level of autonomous power, NGOs and other non-commercial organisations, legal entities or natural persons, aimed at the conservation and reclamation of the natural environment, the rational use and regeneration of natural resources as well as the prevention or negative impact from economic or other activities on the environment and the mitigation of their consequences.
Negative impact on the environment entails the payment of fees. The form of feed for the negative environmental impact are determined by federal acts of law.
Article 21 [43] deals with the environmental quality standards, that are established in order to enable the state of the environment in order to be able to conserve the natural environmental systems, the genetic pool of plants, animals and other organisms. When establishing the environmental quality standards, one takes into account the natural characteristics of the land territories and territorial waters, the purpose of use of the natural sites as well as natural/manmade sites, especially protected territories, including especially protected natural territories, as well as natural landscapes that have a special nature conservation value.

The maximum allowed environmental impact standards are established both for legal entities and for natural persons in order to prevent negative environmental impact by economic or other kinds of activities and must guarantee the observation of the environmental quality standards taking into account the natural characteristics of territories and territorial waters.
The maximum allowed removal of components from the natural environment (article 26 [43] and the order o their establishment is determined by the acts of law concerning

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mineral resources, as well as water and forestry legislation, the acts of law on the animal kingdom as sell as other acts of law in the field of environmental protection, environmental management and in accordance with the requirements within the field of environmental protection and the conservation and reproduction of special types of natural resources, established by federal law, other federal acts of law and other laws and regulations of the Russian Federation in the field of environmental protection.
The standards of allowed anthropogenic load on the environment (article 27 [43]) is established in respect to every type of impact from economic or other types of activities on the environment and the total impact from all sources, situated within these territories and (or) territorial waters.
Air protection in the Russian Federation is carried on in accordance wit the provisions of the 96-FZ [42].
The present federal law establishes the fundamental legal principles of air protection and is aimed at the enjoyment of the constitutional rights of the citizens to a favourable environment and reliable information on the condition of the environment.
In [42] you will find a description of the requirements of air protection during the stages of design, siting, construction, reconstruction, as well as economic or other activities and also the regulation of issues concerning harmful substances during the production and the operation of transport or other means of transportations, as well as during storage, disposal, treatment and incineration of production and consumption waste.
According to Article 14 [42]: emission of harmful (polluting) substances to air by a stationary source is allowed on the basis of a permit, issued by a territorial authority of the federal executive authority of an executive in the field of environmental protection, by the executive authorities of the territorial entities of the Russian Federation, carrying on the state management in the field of environmental protection, in the order that is established by the Government of the Russian Federation.
In accordance with the Article 67 [43] [item 5 is introduced by [44]) during the realization of the industrial environmental control it is imperative to carry out measurements of the emissions and discharges of pollutants, in respect to the pollutants that are typical for the used techniques as well as the characteristics of the

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production process at the plant that have a negative environmental impact (marker substances).
The industrial control programmes control programmes must take into account the minimal level of marker substances including the technique acquired of a certain level of capacity and the waste treated by it.
The high environmental efficiency of the thermal treatment of waste depends on the possibility of degradation and the transformation of practically any organic and

oxidisable inorganic impurities at high temperatures into harmless products of complete combustion. This possibility is realized when guaranteeing certain parameters of the process conditions – the level of temperature in the reactor, the relative load of the working capacity of the reactor, the dispersity of the carburation (concerning liquid waste), the aerodynamic properties of the structure as well as the turbulence of the gas flow in the reactor and the types and quantity of added reagents, etc.
In order to evaluate the environmental efficiency of the process of thermal waste treatment, containing organic matter, there are two methods that may be used:
The EPA method (The Environmental Protection Agency of the USA), which is based on an appreciation of the configuration of thermal treatment of waste as Efficiency of Destruction DE or the efficiency of Destruction and Removal Efficiency, DRE.. The DE (%) shows the relation between the eliminated compounds and the components entering the system with the waste within the thermal reactor, whereas the DRE [%] shows the relation between the indicated toxic components for the set-up of the overall thermal waste treatment

$$\mathrm{DRE} = \frac{m_i^{\text{исх}} - m_i^{\text{выброс}}}{m_i^{\text{исх}}} \cdot 100\ \%,$$

where the $м_i^{\text{исх}}$ - $м_i^{\text{выброс}}$ respectively signify the concentration of the toxic organic components in the waste and in the smokestack.
In accordance with the standard 40CFR 264.343, adopted by the EPA, an installation for thermal treatment of waste containing organic substances, needs to serve for he destruction and removal at a level of DRE=99,99%. We note that in respect to polychlorinated biphenyls, this index need to equal DRE=99,9999%.

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The methods used in Western Europe takes into account the control of the remaining concentrations of the toxic components in the effluent flue gases when working at the standards established by law.
For a full environmental evaluation of a set-up for thermal waste treatment, it is necessary to use two methods at the same time.
The maximum allowed reading of the concentration of harmful substances, emitted into the atmosphere are established by the Directive [45]. These requirements, at present, are the most severe environmental standards when it comes to gaseous emissions. The average 24-hour concentration of harmful substances (at 11% oxygen, dry gas) must not exceed the figures shown in table 3.1.

Table 3.1 – Maximum Allowed Values of Concentration of Harmful Substances

Component	Residual concentration mg/m^3
Dust	10
Organic carbon content	10
HCl	10
HF	1
SO_2	50
CO	50
NO_x	200
PCDD; PCDF	0,1 ng/m^3
Hg	0,05
Cd + Tl	0,05
∑ other heavy metals	0,5

It is also necessary to carry on a registration of the toxic components in the emissions with the effluent gases that are formed at various stages of the production process itself (for instance, the forming of and emissions of phosgene $COCl_2$ when burning chlorine-containing organic waste).
The setting-up and carrying out of the observations of the pollution of the air in cities& at the regional and background levels, the methods of chemical analysis of concentrations of harmful substances in the air, the collection methods, the processing and the statistic analysis of the results of the observations are determined by the [46]

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In order to provide for the conformity of measurement in the environmental pollution-monitoring network, a federal list of methods for the carrying out of measurements has been introduced. The methods on the said list are allowed for the use while carrying out of activities in the field of natural environment pollution measurement. [47].
In accordance with the 52-FZ [48] and [49], hygienic standards have been worked out (item 1.1 [50] of the maximum allowed concentrations (MAC) for pollutants in air within populated sites.
According to the item 1.4 [50], the abovementioned standards are used when designing production processes.
Furthermore, it is necessary, during a goal-oriented (limited) analysis to determine the content of marker substances within the scope of the confidence interval of the set-up standards for the maximum allowed emissions and discharges of pollutants to the environment.
The method instructions (51) establish the order of the choice of the sites and programmes of observations, and also defines the manner of setting apart marker substances when organising research projects within the star system of social-hygienic monitoring at the local level.
In accordance with item 3.2 [51], one of he conditions of an efficient air monitoring is the presence of a system of the sufficient minimal exponents, allowing for the control of the sanitary-epidemiologic and environmental-hygienic situation the lowest possible time, finance and work expenditure.

As diagnostic indices (markers) are regarded those parameters, the change of the values of which tells us about the possible changes in a whole set of other parameters and makes possible the prognosis of the level of impact on the human population.
The specification of marker pollutants in the emissions to air in the course of the thermal treatment of certain groups of waste gives the possibility of reduce the list of substances to be measured with the aid of instruments, based on the interrelationship between the substances in the bulk of the emission.
When doing this, the ability of the substances to act as markers (as a diagnostic parameter) is dealt with as the main criterion for the choice of basic parameters to become a part of the monitoring programme (see item 6.1 [51] if observations are make regularly and with a certain periodicity of observations.
Through a RF government decree [52] in accordance with Article 4.1 [42], a list has been approved of pollutants, in respect to which environmental state regulations measures are taken.

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In accordance with the law, pollutants in respect to which there are measurement methods were introduced to the list.
The recommended periodicity of the control of marker pollutants in the emissions to aid during the thermal treatment of waste are shown in table 3.2.

Table 3.2 – The periodicity of the control of marker pollutants in emissions to air.

Name of the marker pollutant	Periodicity of the control programme based on the total capacity of the facility, t/24 hours					
	Up to 10			Above 10		
	Every 24 hours	Monthly	Yearly	Every 24 hours	Monthly	Yearly
Nitrogen dioxide	+	-	+	+	-	+
Nitrogen oxide	+	-	+	+	-	+
Sulphur dioxide	+	-	+	+	-	+
Carbon oxide	+	-	+	+	+	+
Total saturated hydrocarbons	+	-	+	+	-	+
Carbon (soot)	+	+	+	+	+	+
Industrial dust (dust forming a part of the industrial emissions)	+	+	+	+	+	+
Benzapyrene	-	+	+	-	+	+
Hydrogen chloride	+	-	+	+	+	+
Hydrogen fluoride	+	-	+	+	+	+
Dioxins (polychlorinated dibenzo-p-dioxins and dibenzofurans) in terms of 2,3,7,8-tetrachlordibezno-1,4-dioxine, ng/nm^3	-	-	+	-	-	+
Polychlorinated bi-phenyls (PCB)	-	-	+	-	-	+
Heavy metals (Hg+Cd+ Zn + P + Cr + As)	+	+	+	+	+	+

The set-up includes a set of interrelated technical and industrial solutions to serve for the keeping of pollutants in the effluent smokestack gases within the range of the maximum parameters, established in the operation documentation. In connection with this, it is not

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considered possible to make correct estimation of the emissions of pollutants to the extent attained by calculation or in an experimental set-up.

In order to forecast the environmental impact and the consumption within the thermal waste treatment sphere, it is possible to use the methods of system analysis and mathematic modelling:

- the method of analogous evaluations and the comparison with universal standards
- the expert evaluation method in order to appraise the impact that does not lend itself to direct measurements
- The ”list method” and the ”matrix method”, in order to define the significant types of impact
- The cause and effect model of the relationships in order to analyse indirect types of impact.
- The calculation method in order to determine the forecasted emissions, discharges and the waste formation rate

The emissions in regard to any concrete installation is determined by individual project, taking into account the nomenclature of the treated waste as well as the sanitary-technological requirement criteria of the maximum allowed emissions.

Taking into account the existing system for the handling of waste in the zone of set-up of the facility, for the operation period, it is necessary to determine the range and volume of the waste being treated based on lumped parameters, which will call for a narrower specification during the process of commissioning and start-up.

An example of marker pollutants in the emissions to air during the treatment of the man groups of waste (regarding the substance composition) is presented in table 3.3.

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Name of the pollutant	**Criterion used**	**Value of the criterion, mg/m³**	**Hazard class**	**Type of thermally treated waste ***
Nitrogen dioxide	MAC o.t.r. (one-time reading)	0,200000	III	1-5
Nitrogen oxide	MAC o.t.r.	0,400000	III	1-5
Sulphur dioxide	MAC o.t.r.	0,500000	III	1-3,5
Carbon oxide	MAC o.t.r.	5,000000	IV	1-5
Total saturated hydrocarbons	MAC o.t.r.	1,000000	IV	1,2,5
Carbon (soot)	MAC o.t.r.	0,150000	III	1-5
Suspended matter	MAC o.t.r.	0,500000	III	1-5
Benzapyrene	MAC o.t.r.	0,000001	I	1-5
Hydrogen chloride	MAC o.t.r.	0,020000	II	3,4
Hydrogen fluoride	MAC o.t.r.	0,020000	II	1-3,5
Dioxins (polychlorinated dibenzo-p-dioxins and dibenzofurans) in terms of 2,3,7,8-tetrachlordibezno-1,4-dioxine, ng/nm³	MAC o.t.r.	0,000500	I	1-5
Mercury chloride (in equivalents of mercury)	MAC o.t.r.	0,000300	I	1-3, 5
Cadmium chloride (in equivalents of cadmium)	MAC o.t.r.	0,000300	I	1-3, 5
Thallium carbonate (in equivalents of thallium)	MAC o.t.r.	0,000400	I	1-3, 5

*) The types of thermally treated waste: 1 – waste, containing organic and inorganic substances; 2 – waste, which apart from the substances from group no. one also contain nitrogen; 3 – waste, containing organic compounds with the elements S, P, Cl, F; 4- waste forming NaCl, Na_2SO_4, SO_4, Na_4PsO_7, Na_2CO_3, KCl; 5: waste containing organic substances, elements as well as their oxides, salts or the organic compounds of these elements

It is necessary to bear in mind the fact that the morphologic content, the physical and chemical properties and the volume and weight characteristics of waste differs. The classification of waste to be thermally treated includes seven main parameters, which are presented in the sub-section 1.1 of the reference document.
The practical possibilities to attain the maximum completeness of combustion of waste is to a large extent complicated by the fat then the calorific value of waste as to compare to conventional fuels, in general, is low and may change in a wide interval of values depending of the content.
Based on the information in the questionnaires and their technical addenda, received from the companies that carry on thermal waste processing, a number of conclusions and recommendations may be made.
The ash, slag and dust from the burning facilities and from the thermal waste processes belong to hazard classes IV-V with incomplete combustion comprise, generally, not more than 3%.
The ash residue, formed as a result of the operation of thermal waste treatment, needs to be unloaded to the ash collector, where it needs to be irrigated with water. The manual unloading of the ash residue calls for additional organisational and technological solutions.
The used suspension, from the scrubber need to be forwarded to be treated, whereas it is recommended to use the purified water cyclically.
Below, in the tables 3.4 and 3.5 are shown the current levels of impact on the environment in accordance with the information in the questionnaires, received from the companies.

Table 3.4 – the current levels of emissions to air:

Name of the pollutant	Level of emissions mg/nm^3
Nitrogen dioxide	30-100
Nitrogen oxide	
Sulphur dioxide	1-40
Carbon oxide	5-30
Total saturated hydrocarbons	1-10
Carbon (soot)	<10
Suspended particles	1-5
Benzapyrene	0,001
Hydrogen chloride	
Hydrogen fluoride	
Dioxins (polychlorinated dibenzo-p-dioxins and dibenzofurans) in terms of 2,3,7,8-tetrachlordibezno-1,4-dioxine, ng/nm^3	0,01-0,05
Mercury with associated compounds	0,001-0,02
Cadmium with associated compounds	0,001-0,03
Thallium	
Heavy metals (∑ remainder)	0,005-0,05

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The value of the levels of emissions are comparable to similar maximum allowed values of concentration of harmful compounds in accordance with the EU directive [45].

The conditions of the heat and mass transfer in the afterburner chamber. In order to raise the temperature of the flue gases, it is necessary to use additional fuel.
It is recommended to use pre-prepared liquid combustible waste with a sufficient calorific value and a lowered ash content of the residue.
Based on the information, presented by the companies, carrying out activities of thermal waste treatment, the total relative consumption of diesel fuel (kg/kg treated waste) needs to be held at a number lower than 0,15.
The operation of facilities for the thermal processing of waste also presupposes a minimal relative consumption of heat and electrical energy (kW/kg of processed waste). The use of electrical energy as such by the facility for thermal waste treatment needs to be held at a level of lower than 5% of the total supplied heat power.

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table 3.5 – the current levels of discharge of effluent water from the wet gas cleaning system.

Name of the pollutant	**Levels mg/l**
Total amount of suspended matter	10-45
COD	50-250
pH	6,5-11
Mercury and its compounds (Hg)	0,001-0,3
Cadmium and its compounds (Cd)	0,01-0,05
Thallium and its compounds (Ti)	0,01-0,05
Arsenic and its compounds (As)	0,01-0,15
Lead and its compounds (Pb)	0,01-0,1
Chromium and its compounds (Cr)	0,01-0,5
Cupper and its compounds (Cu)	0,05-0,5
Nickel and its compounds (Ni)	0,01-0,5
Zink and its compounds (Zn)	0,01-0,1
Antimony and its compounds (Sb)	0,005-0,85
Cobalt and its compounds (Co)	0,005-0,05
Manganese and its compounds (Mn)	0,02-0,2
Vanadium land its compounds (V)	0,03-0,5
Tin and its compounds (Sn)	0,02-0,5
Polychlorinated dibenzodioxins (PCDD), ng/l	0,01-0,1
Dibenzofurans (PCDF), ng/l	

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Section 4. Methods of Determination of Best Available Techniques

4.1 General Methods of Determination of Thermal Waste Treatment Techniques as BAT

The criteria in the Russian Federation for the determination whether or not a certain technique is BAT are set out in Article 23.1 of the Federal act On Environmental Protection [43]. According to the said Article, the use of best available technology is directed towards the integrated prevention and (or) reduction of negative environmental impact. The combination of criteria for the attainment of the environmental goals for the determination of BAT are:

- the lowest possible negative environmental impact with expressed as a value per time unit or per volume of produces goods (products), the amount of operations carried out, the amount of services rendered or any other characteristics found in international agreements, signed by the Russian Federation (criterion 1);
- the economic efficiency of its introduction and operation (criterion 2);
- the use of resource and energy saving methods (criterion 3);
- the period of introduction of the technique (criterion 4);
- the industrial introduction of this technique at one or two plants with a negative environmental impact (criterion 5).

Article 28.1 of the FZ On Environmental Protection also stipulates the following:

- the order of determination of a certain technique as BAT is established by the Government of the Russian Federation;
- the method recommendation for the determination of a certain technique as BAT is developed by a Federal executive authority, authorised by the Government of the Russian Federation.

At present The rules for the Determination of a Certain Technique as BAT as well as the Design, Updating and Publishing of Digital Reference Documents for Best Available Technologies [53,54] (Hereinafter – the Rules) have been approved through the Russian Federation Government Decree no. 1458 of the 23 December 2014 On the Order of Determination of a Certain Technique as Best Available Technology and the Development of BAT Reference Documents. The abovementioned Rules define the order of determination of

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a technique as BAT, including the determination of the production processes, the equipment, the technical means and methods for a concrete field of application.
In the Rules, there is a more precise wording of the abovementioned criteria, which form the foundation of the determination as BAT certain processes, equipment, technical means and methods:

- the lowest possible level of negative impact on the environment expressed per time unit or per produced unit of goods (products),
- the lowest possible negative environmental impact with expressed as a value per time unit or per volume of produces goods (products), the amount of operations carried out, the amount of services rendered or any other characteristics found in international agreements, signed by the Russian Federation (criterion 1);
- the economic efficiency of its introduction and operation (criterion 2);
- the use of resource and energy saving methods (criterion 3);
- the period of introduction of the technique (criterion 4);
- the industrial introduction of this technique at one or two plants with a negative environmental impact (criterion 5)

Furthermore, the Rules establish, that the determination of the production processes, the equipment, the technical means and methods (hereinafter – the techniques) as BAT is to be carried out in accordance with the methods recommendation for the determination of a certain technique as BAT, which, as pointed out in article 28.1 of the Federal Act on Environmental Protection are elaborated by an executive body,

authorized by the Russian Federation Government. At present The Method Recommendations for the Determination of a Certain Technique as BAT [55] (hereinafter – The Recommendations) have been approved (and elaborated in accordance with the abovementioned regulative legal act) through The Instruction no. 665 of the Ministry of Industry and Trade of the Russian Federation (Minpromtorg) of the 31 March 2015. The main purpose of the Recommendations is the create a scientific method basis for the technical working groups (TWG) and for the definition of techniques as BAT, based on information, received from the industry and other sources. The Recommendation, the sum of the criteria for the determination of a technique as BAT are established, the general method approaches to the definition of BAT are examined, the order of determination of a certain technique as BAT and the principles of cooperation of the members of the TWG are laid down.
Some method aspects of the determination as BAT, including those, having to do with thermal waste treatment

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(waste incineration) are found in a number of other documents [56-61], in which there is a mentioning of the fact that when determining a certain technique as BAT it is expedient to take into account its fulfilling of the requirements of the newest developments in the respective field of application; the economic and practical applicability of the technique in question for the specific plant; the justifiability of the application of the technique from the viewpoint of lowest possible industrial environmental impact.
In a general set-up when determining whether or not a certain technique of thermal waste treatment (hereinafter TWT) is the BAT, the following order of actions is to be followed:

a) it is expedient, as a first step, to set apart the techniques that are aimed at a solution of the earlier defined environmental problems (taking into account marker pollutants, the waste emerging during the treatment process, emissions, discharges and other kinds of negative impact as well as the resource and material consumption).
b) For the chosen technologies an evaluation of their impact on various components of the environment as well as the levels of consumption of various resources and materials is made.
c) An evaluation of the existence of the necessary information, expenditure for the introduction of the technology and the maintenance of the equipment, possible benefits and the advantages after the introduction of the technique as well as the length of the period of introduction.
d) Based on the results of the evaluation, the TWT technologies are chosen:
    a. that guarantee the prevention or the reduction of impact on various components of the environment (as for emissions – for every main pollutant; for the waste from treatment processes – for the main types of waste, defined earlier).
    b. the introduction of which does not lead to any substantial increase in the volumes of emissions of other pollutants, discharges of wastewater, the build-up of waste from the treatment process, the resource use or other kinds of negative environmental impact;

   c. the introduction of which does not lead to excessive material or financial expenditure (taking into account possible benefits and advantages after the introduction)
   d. that have reasonable time periods of introduction

e) The establishment of techniques that have received a positive opinion of the state environmental review as to the draft technical documentation of the new equipment and technique , the use of which may have an impact on the environment.

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4.2 Methods, Allowing for the Step-wise Consideration of a Number of Techniques and the Choice of BAT

In practice, according to the Recommendations [55], the appraisal of the techniques as to their fulfilments of the established regulatory legal acts of the criteria as BAT is carried out in the following order, consisting of 5 successive steps. The final (6th) step is the decision made by the TWG as to weather a certain technique should be regarded as BAT or not, which is made in accordance with the order, established by the Recommendations [55] (tabel4.1).

Table 4.1 – the order of examination of criteria, taken into account when deciding whether or not a TWT should be considered BAT or not.

The order (step) of the examination (the evaluation algorithm) of the technique	The main actions
1	The evaluation of criterion 5. The industrial introduction of the industrial processes, equipment, technical means and methods at 2 or more plants in the RF, which have a negative environmental impact.
2	The evaluation of criterion 1. The lowest possible negative impact on the environment expressed per unit of time or per volume of produced goods (products), operations performed or service rendered, or the corresponding other parameters of environmental impact, laid down in international agreements, signed by the RF.
3	The evaluation of criterion 2. The Economic efficiency of introduction and operation
4	The evaluation of criterion 4. The period of introduction.
5	The evaluation of criterion 3. The application of resource and energy conserving methods.
6	The decision made by the members of the TWG on whether or not the specific technique is BAT or not.

4.2.1 Step 1. Consideration of Criterion 5: Industrial introduction of Industrial Processes, Equipment, Technical Means and Methods at two or More Industrial Sites in the Russian Federation, with a Negative Environmental Impact

The consideration of this criterion is made in two steps:

- Stage one. The gathering of general information on the applied in practice technology of TWT.
- Stage two. Choice of TWT technique, introduced at tow or more RF plants.

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- the technical characterization and the production parameters of the used equipment (main and environmental protection equipment) with the indication of the manufacturer (company and country);
- information on the physical balance
- information on the relative emissions of pollutants (discharges, emissions, waste), including information on the observance of the air quality standards after the dispersal of the emissions.
- Information on the hazardous and harmful factors of the production;
- Information on the fire hazard of the production environment (in accordance with [62];
- Information on the conformity of the production to the fire hazards requirements;
- Information on the performed technological, technical and organizational measures
- Information on the developer of the technique and equipment;
- Copies of the technical and permitting documents (equipment certificates, the opinions of the environmental review, etc.)

The questionnaire is filled in by companies and organisations, having introduced the production processes, the equipment, the technical means and methods of thermal waste treatment. For the purposes of the determination of promising BAT the questionnaire is also filled in by companies (organisations), carrying out scientific and R&D introduction work or the experimental industrial introduction of the technique in the abovementioned sphere. One needs to take into account that in respect to BAT, apart from the technological processes, of the thermal treatment per se, there are also other stages of the production process that may be considered, as for instance the organisation of the receipt, preparative processing and storage (build-up) of the waste to be treated, the treatment of the effluent gasses, the treatment of wastewater, the methods of handling waste, as well as the recycling of the received secondary energy resources. When describing the characteristics of the discharges formed when performing the thermal waste treatment, it is necessary to take into account the environmental setting at the industrial site, affecting the environment.
As additional sources of information one should use the international digital BAT reference documents, the statistic reference documents, results presented in scientific works and dissertations, other sources of information as well as information received during consultations with experts in the respective field.

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The final result of this stage is the receipt of the following information:

- a list and short characterization of the waste that at present is treated thermally

- the distribution of companies, using TST;
- The distribution of companies as to their production capacity
- The territorial distribution of companies with respect to their climate conditions
- The main stages of production
- The main environmental problems for the specific field of BAT application (which are considered in the sub-section 1.2);
- The characteristic general and relative volumes of emissions/discharges of pollutants (one needs to specify the key, or marker pollutants), the general and relative parameters of formation of waste and intermediate products (one shall especially define the waste, dispatched for storage, and intermediates, dispatched for continued use) as well as the resources consumption (of water, energy, reagents, etc.).

At the 2nd stage there is a choice of TWT technique to be made, that will have to be introduced at two or more companies in Russia, and this will be made by using the algorithm, recommended in [55] [fig. 4.1).

Gathering of information on TWT

The processing of general information on the techniques:	Processing of information on techniques, including the stages and data on:	The processing of information on the current environmental impact:
- number of companies, using the specific technique, the territorial distribution, etc.; - Economic parameters - Main environmental problems, etc.	- treated waste (raw material); - auxiliary material - energy used - preparation of raw material - processing of raw material and material - the use of by-products, etc.	- the characteristic of the total emissions (emissions, discharge, waste) - the relative emissions (emissions, discharges, waste); - determination of marker pollutants - resource consumption

Choice of technique		Definition of parameters
Choice of technique: based on the environmental problems defined earlier (see section 1.2) out of the techniques one shall choose those that: - guarantee the reduction or the prevention of emissions of one or a number of	→	The definition of parameters of the chosen techniques, the use of which permits the attainment of a high environmental efficiency: - a side effect, acting on various components of the environment - the technical characteristics

marker pollutants (contained in the emissions, discharges or waste), or - guarantee the reduction or prevention of other characteristic types of environmental impact (noise, odour), or - guarantee the reduction in resources consumption (of energy, raw material, water, etc.)		

Out of the chosen techniques one would set apart those, which may be regarded as BAT (if the industrial introduction of the technique is not defined or if it is used only at one RF plant, then the technique is excluded from the list of promising technologies)

Figure 3.1 – the algorithm of the choice of TWT technique as BAT.

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The data processing for the choice of TWT, introduced at 2 or more plants in the RF includes:

- the grouping (classification) of the used promising techniques for TWT based on the types of waste (for instance, unprocessed municipal solid waste (MSW), MSW after preliminary processing, waste belonging to 1-4 hazard classes of a wider spectrum, wastewater sludge, medical waste, mercury containing waste, etc.);
- the grouping of the industrial processes, the equipment, the technical means and methods, based on the stages at which they are applied;
- the recording of restrictions as to the applicability of a certain technique, connected to the territorial (regional) conditions, including climate conditions; if there are considerable differences in the applied techniques depending on the territorial (regional), including climate conditions it is necessary to group then depending on the conditions under which they may be applied; in such a case, BAT is determined both in relation to the field of application of BAT in general and for each group of techniques separately.
- The appraisal of the environmental impact, and the consumption of resources at all stages of production, including the determination the stage of production, characterised by the largest possible environmental impact (depending on the type of impact, the types of pollutants as well as the hazard class of the waste) and the resource consumption (divided along the types of resources – water, energy, reagents, etc.).

4.2.2 Step 2. Consideration of Criterion 1: Lowest Possible Level of Negative Environmental Impact, Calculated per Time Unit or per Volume of Produced Products (Commodities), Performed Operations or Rendered Services or Corresponding to other Parameters of Environmental Impact, as Expressed in International Agreements, Signed by the Russian Federation.

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This criterion is considered out of two main aspects:

- the hazard connected with the substances used or formed during the industrial processes to air, soil, water systems, man as well as other living organisms and ecosystems in general;
- the character of the negative impact as well as the relative (per unit of treated waste) amount of harmful substances (as part of the emissions).

In the first case, all types of emissions are determined (as part of the content of the emissions/discharges/waste) as well as their amount (mass). When evaluating the hazard level of the used and (or) formed during the production processes harmful substances one establishes the so called marker pollutants, which are emitted to air, discharged to water bodies or entered into the intermediate products or solid waste. Depending on the level of impact on the body, the harmful substances are subdivided into four hazard classes; 1 – extremely hazardous substances; 2 – highly hazardous substances; 3 – moderately hazardous substances; 4 – negligibly hazardous substances. One should especially pay attention to the information on the observance of air quality standards after the dispersal of the emissions, especially concerning the 1st and 2nd hazards classes, as well as to the composition of the waste from the treatment (residue substances after the processing of waste), formed during the technologic processes, and also on the composition of the emissions to air.

When handling waste from the treatment process it is necessary to take into account the following:

- The technological processes are accompanied by the formation of solid and liquid waste of the treatment process, which may be further processed and contained either at the site where they were formed, or transported away from the plant for processing, use or disposal at another site;
- When comparing alternative techniques, which give rise to treatment waste, it is recommended to analyse its quantity, composition and possible environmental impact. When performing an inventory of treatment waste (residue products), formed as a result of each considered existing technique, it is necessary to divide them into environment hazard classes: I class (extremely hazardous); II –(highly hazardous); III (moderately hazardous); IV (negligibly hazardous), V class (practically unhazardous) [64].

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- for each of the categories shown it is necessary to specify the amount of formed waste from the treatment (residue products) in kilogrammes per produced unit (per unit of treated raw material – amount of treated waste).

When evaluating the emissions to air it is necessary to take into account the following parameters:

- the distance of the plants (enterprises) from population centres;

- the nature of the consequences of the impact – a long-term irreversible impact is recommended to treat as one that harms to environment to a larger extent, than short-term reversible consequences;
- pollutants, which are highly persistent, bio-accumulating, toxic and carcinogenic are recommended to be dealt with as priority pollutants in connection with the possibility of their transfer over long distances (including trans-border transfer).

The properties of a negative impact as well as the relative values of the emissions (included in the emissions/discharge/waste) are evaluated based on the following parameters:

1. for the emission of pollutants to air:
   1.1. emission of pollutants to air;
   1.2. a list of pollutants contained in the emissions to air;
   1.3. the volume and/or mass of emitted pollutants before treatment indicated per ton of treated raw material (treated waste);
   1.4. the presence of a treatment plant
   1.5. the treatment method, recycling
   1.6. the volume and/or mass of the pollutants, indicated per ton of treated raw material;
   1.7. The possibility of observing the air quality standards after the dispersal of emissions;
2. For discharge of pollutants:
   2.1. The sources of discharge of pollutants
   2.2. the direction of the discharges (to a water body, to a sewage system etc.);
   2.3. a list of the pollutants, contained in the effluents;
   2.4. the volume and/or mass of the pollutants, indicated per ton of treated raw material **123**
   2.5. the presence of a treatment plant
   2.6. the treatment method, recycling
   2.7. the volume and/or mass of the pollutants, indicated per ton of treated raw material
3. for the waste of the treatment process (residue products) and consumption waste:
   3.1. sources of formation
   3.2. a list of the formed waste according to the hazard class
   3.3. volume of formed waste (absolute and relative) and their sources of formation
   3.4. a list of disposed waste according to hazard class;
   3.5. the volumes of disposed waste (absolute and relative)
   3.6. a list of treated, processed and recycled waste (absolute and relative);
4. for other impact factors (noise, odour, electromagnetic and heat impact)
   4.1. a list of the factors
   4.2. sources of impact
   4.3. level of environmental pollution before the reduction indicated per ton of produced goods (or a permanent level);
   4.4. the method of reduction of the impact;
   4.5. the level o environmental pollution after the reduction indicated as ton per produced goods (processed raw material).

It is recommended to treat as an additional criterion for the classification of a certain technique as BAT the possible (likely) change (reduction) of the risks of negative impact of the emissions (as part of the emissions/discharges/waste) after the introduction of the indicated technique.

It is recommended to exclude from the analyses al types of impact, which do not have a substantial impact on the end result when determining whether or not a certain technique is BAT. In order to guarantee transparency when presenting the end results, the types of impact that were excluded as not significant, need to be specified and their exclusion need to be justified.
Based the results of the consideration of criterion 1 " The lowest possible level of negative impact on the environment indicated per time unit or volume of produced goods (products), performed operations, rendered services or

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in accordance with other parameters of environmental impact, foreseen in international agreements, signed by the RF, the corresponding section of the BAT reference document is composed, including the following provisions:

- A description of the surroundings, which shall include an analysis of the main physical parameters of the studies field as well as a description of the population that potentially might be subject to the impact
- The identification of the routes of impact, the sources of pollution, the potential routs of dissemination and the possible sites of impact on the population;
- A quantified description of the exposure – the determination and evaluation of the magnitude, frequency and duration of the impact on each of the analysed routes of emission movement.

4.2.3. Step 3. Consideration of Criterion 2: Economic Efficiency of Introduction and Operation

The analysis of the economic efficiency consists in the evaluation of expenditure for the introduction and operation of the technique as well as the advantages of its introduction bye using the method of analysis of cost and benefit [55]. If the introduction of different techniques give positive results, then the technique with the highest result would be regarded the one with the best relationship price/quality. The lacking of such an analysis lies in the necessity to process a great quality of data, and while doing this understand that some of the benefits are hard to present in a monetary form. The alternative method of cost/benefit-analysis , as shown in the Recommendations [55], could be the analysis of efficiency of the expenditure, used in order to determine what measures are the most preferred in order to attain a certain environmental goal at lowest possible cost.
It is recommended to define the economic efficiency of a certain technique in the following way:

$$\text{Economic efficiency} = \frac{\text{Yearly expenditure (rub)}}{\text{Reduction of emissions, (tons-/year)}}$$

In the context of defining the BAT it is insufficient to only use the approach of economic efficiency. Still, the ranking of the alternative BAT along a scale of increasing economic efficiency is useful

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for instance, in order to exclude the alternatives, which are unjustifiably expensive when compared to the received environmental benefit.
The methodology of calculation of the expenditures is established by an algorithm, rendering possible the gathering and analysis of data on the capital and operation expenditures for the buildings, the installation, the know-how or the process based on criterion 2 (the economic efficiency of introduction and operation".
The use of a successive (stepwise) approach, enables the comparison alternative versions even in a case, where the information has been received from various companies, various branches of industry, various regions or countries.
The main principles (stages) of the evaluation are shown below in figure 4.2.

Main principle #1 **Determination of the field of application and the evaluation of BAT**

Main principle #2 **Gathering of main data on the cost of the introduction of the technique**

Main principle #3 **Determination of the cost structure for the introduction of the technique;** **The running production costs;** **The technical maintenance costs;** **The revenue and savings on costs**

Main principle #4 **The processing and presentation of the information on costs as a result of:** **the change in the stock exchange price** **Inflation;** **The prices, determined during the reference year;** **The discounting and the yearly interest rate;** **The calculation of the yearly costs**

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Main principle #5 **The evaluation of environmental protection costs**

Figure 4.2 – the main principles of evaluation of the economic feasibility of the introduction of BAT/cost evaluation method

Main principle 1 – The definition of the field of application and the identification of alternative techniques. This principle is analogous the main principle 1 in the methodology of evaluation of the integrated environmental impact of the technique.
Main principle 2 – The collection and control of the correctness (validation) of the information on the cost for the introduction of the technique. This principle helps the user to go through all the stages, necessary for the collection, analysis and rationale, taking into account any uncertainty of the information at hand.
Main principle 3 – the determination of the cost structure. This principle establishes the structure of the costs, which need to be included into the estimation of or excluded out of the evaluation. When appraising the results, this principle is useful for decision makers, because it helps to understand the structure of the costs as well as the cost item to which a certain cost is referred; capital or operational: The principle demands that the costs be presented as transparent as possible.
The distribution of costs to certain components (for instance, investment, operational costs, etc.) is something essential for the guaranteeing of the transparency of the process, however it often happens that in practice it is hard to make a clear demarcation between the costs for the realization of the process and en environmental costs (the costs of environmental protection).
Main principle 4 – the processing and presentation of the information on the costs. This principle gives an account of the procedures for the processing and presentation of the cost information. Here it is necessary to take into account the rate of discounting and the yearly rate of interest, the usable life of capital stock and the price of the scrap, formed at the end of the life cycle of the equipment. Where possible the costs have to be presented as yearly costs.

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Main principle 5 is the definition of the costs that has to do with the environment. This principle establishes the difference between the costs of environmental protection and other costs, for instance the costs of modernisation of the process of the cost of a efficiency increase of the process.
During the calculation of the evaluated economic feasibility of the introduction of BAT it is n3ecessary to take into account the following information:

- the experience of earlier successful use in industrial scale of comparable technology;
- information on well-known accidents, connected with the introduction and operation of the specific technique during industrial use;
- the geographical factors of the climate of the introduction of the technique (the position in relation to the energy sources, its availability, logistical chains), as well as the technological restrictions, connected to the regional physical and geographical conditions as well as the presence of especially protected natural territories, cultural sites and recreation spots.

When collecting and underpinning of information having to do with costs of introduction of the technology, it is recommended to pay special attention to the following conditions:

- the source and the date of the information must be clearly pointed out;
- the information on the cost must be as fully covered as possible;
- information on costs needs to be collected from several (independent) sources
- the sources for the collection and the origin of all facts must be pointed out as precisely as possible;
- it is recommended to use modern available information still in force
- in order to underpin the facts it is necessary to present the range of quantity parameters; if this is regarded as impossible it is recommended to use a quality characteristic

When determining the cost structure for the introduction of the technique it is recommended to pay attention to the following conditions: when the needed information is at hand one should divide the costs into capital cots (the costs of the installation of the equipment and installations as well as the costs of the environmental protection equipment; miscellaneous costs); the operational cots and the costs of technical maintenance/repair (the costs of the energy resources, costs of material and service, cost of remuneration for labour, fixed operational cots and the costs of services as well as the costs during upcoming periods.

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As a result of the information collection on the costs it is recommended to process this information for the guarantee of a further objective comparison of the considered alternative versions. When doing this there might be a call for a consideration of such issues, as various operation service life of the technique (equipment), the yearly credit interest rates, as well as the cost for paying debts, the influence of the inflation and the rate of exchange.

The introduction of a technique is a complicated and labour-consuming process. This is explained by the necessity to introduce automatic methods of management, as well as by the presence at an operating plants of technical systems serving various purposes.

When determining the economic efficiency of the carrying out of environmental measures and the calculation of the economic damage afflicted to the economy by the pollution of the environment, it is recommended to be guided by the conditions, approaches and the methodical practice, justified in the Temporary standard Method of Determination of the Economic Efficiency of the carrying out of Environment Protection Actions and the Evaluation of the Economic Damage, caused to the national economy by the Pollution of the Environment [14].

4.2.4. Step 4. Consideration of Criterion 4. Period of Introduction

In order to estimate the time needed for the introduction of a certain technique it is necessary to use the pay-off period of a certain technique as compared with the costs connected with the provision of environmental protection. It is essential to carry out an estimation of the pace of introduction of BAT, since it is exactly the period of introduction that may be critical for the industry. In addition it is recommended to consider separately the pace of BAT introduction within the following time scopes [55]: short term (beginning at a few weeks to a few months); the medium term (starting from a few weeks up to a year); long term (usually a few years).

By way of integration the technical and technological BAT solutions must open for the possibility to create production-technical complexes. These complexes shall be open to modernization and development, consistent with the provisions of the present reference document.

The choice of time for the modernization must coincide with the planned exchange of the present equipment, whereas the investment cycles may be an efficient means of a profitable introduction of a technique. When estimation the pace (period) of BAT introduction, it is recommended to made an additional analysis of the maximum expenditures on modernization. For BAT, which call for substantial investment

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capital expenditures or considerable modification of the production processes and infrastructure, it seems to be unavoidable to take into account longer introduction periods.

4.2.5. Step 5Consideration of Criterion 3: The Use of Resource and Energy Conserving Methods

This criterion is an additional positive factor when making decisions concerning the determination of a certain TWT as BAT. When considering this, it is recommended to carry out a general analysis of the consumption of main resources, taking into account the:

a. energy consumption
    1. the level of energy consumption during the various industrial processes of BAT application
    2. the type of fuel (natural gas, petrol, fuel oil, etc.)
b. water consumption:
    1. The production processes, where water is used
    2. The volume of waster consumption
    3. The type of use of water
c. amount of used raw material

One must also consider the possibility of regeneration and recycling of substances and recovering of the waster used in the production process, taking into account, that:

a. In order to lower the energy consumption it is possible to use one of the following methods and means:
    1. The introduction of energy management systems at the plant;
    2. Energy efficient design when constructing the plant;
    3. Flameless combustion (flameless oxidation);
    4. The use of compressed air as a means of energy conservation, etc.
b. In order to lower the water consumption:
    1. The modification of the production process (air cooling instead of water cooling, a closes water rotation system
    2. A preliminary processing of the water as well as the recycling of water
c. In order to lower the raw material consumption:
    1. Return of reagent that have not been mixed with other substances
    2. The return of scrap into the production process
    3. The use of waste from other industrial branches as raw material, etc.

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4.2.6. Step 6: The Decision by the Members of the TWG on the Determination of a Certain Technique as BAT

The TWT technique may be defined as BAT as an agreement between all members of the TWG within the specific issue [55]. If there would arise divergent opinions within the TWG within one issue or another the federal executive body, responsible for the development of the digital BAT reference document a compromise may be proposed. Should there arise considerable divergent opinions as to what technologies should be defined as BAT, a deepened integrated appraisal of the technique may be carried out. Should there arise serious divergent opinions as to the economic efficiency of the introduction of BAT an additional evaluation will be carried out in order to estimation the economic efficiency of the introduction of the technique.
A final decision as to the choice of technique is made, not only its environmental friendliness but also based on its availability from a financial point of view. In this case, it is recommended to use the following logical approach for orientation (Figure 4.3).

Technically possible	**no**	**not BAT**
Yes		
Are there any advantages for the Environment	**no**	**not BAT**
Yes		
Are the advantages for the environment more important than the costs?	**No**	**not BAT**
Yes		
Are the costs feasible for the branch	**No**	**not BAT**
Yes		
BAT		

Figure 4.3 – a possible logical approach for decision-making on BAT

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If there is a differing view as to the determination of a TWT as BAT, not supported by all members of the TWG, such a technology may be determined to be BAT and including in the BREF, which will be accompanied by a special indication of the special opinion and is permitted under the following conditions:

- The special opinion is underpinned by information, accessible to the TWG and a federal executive body, responsible for the elaboration of BREFs at the time of the preparation of the conclusions concerning BAT.
- The interested members of the TWG have presented their well-founded arguments for the inclusion of the technique in the BAT list. The arguments are well-founded, if they are confirmed by technical and economical information, information on the impact on various components of the environment and also by the conformity of the considered technique to the notion of Best Available Technology as well as by the criteria for the definition of BAT in accordance with the Federal Ac of the 10 January 2002, no. 7-FZ On Environmental Protection.

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Section 5. Best Available Techniques, Belonging to the Priority Fields of BAT Application

The use of the listed below BAT offers the opportunity to solve the most urgent environmental problems of the companies of the priority fields of BAT application and to be able to meet the conditions concerning wastewater formed at normal operating conditions at the enterprises considered. In a number of cases, as BAT are regarded also approaches applied to discharges of water that are released in an emergency mode.

Section 5 is composed based on the thought that the present BREF has a methodical character, contains generalized information on the general approaches to cross-sectorial techniques and (or) technical and managerial decisions on wastewater treatment and should not contain any concrete technological parameters or lists of marker substances for various industrial branches. IN the present section, BAT is systematized in accordance with the classification of environmental problems.

At the stage of discussion of the structure of the BAT reference document (BREF), the work group came to the conclusion on the necessity of a classification of the techniques along the priority fields of BAT application in order for the proposed for the priority branches BAT would be considered also for related industries. However, during the working groups considering of the corresponding section it turned out, that the choice of BAT for each separate company of the branch, not belonging to the priority fields of BAT application becomes too complex. Based on this fact, a decision was taken to group the BAT of the priority branches of its application, but based on the existence of concrete pollutants in the wastewater.

In this manner, the general algorithm for the choice of BAT for the handling of wastewater at a concrete plant loos the following way:

- the choice of Bat based on the fourth Section taking into account the demonstrated restrictions of BAT application;
- the analysis of the flows of wastewater at the plant;
- the choice of Bat based on Section 5 taking into account the fields of application of the demonstrated restriction of BAT application.

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In the present document preliminary recommendations are presented on the stage of the life cycle of the plant, at which it is possible to introduce any of the presented BAT. Doing this, with “new plants” we understand plants that are in the design phase and at which in some especially non-stipulated cases, in the stage of construction and commissioning and start-up, and a “companies under modernization”, en active plants, operating plants, at which a programme of considerable modernisation and change of equipment as the up-grading of the technological processes is taking place or at which the carrying out of such a programme is taking place. A analogous content can be fount under “new treatment plant”, “active treatment plants” as well as “treatment plants under modernization”.
It is understood, that all the techniques that may be used at active plats, also may be used on those under modernization and new, and all techniques that may be used at plants under modernisation also may be used at new ones.

This being said, in special specified situations, it is understood, that at new plants, all presented BAT may be introduced, and, because of this, the event of introducing them at new plants has not been dealt with separately. Since, at the moment of the creation of the present BREF, there was practically no reliable information at hand on the introduction on the BAT listed below (less than 4% of the studied questionnaires, received from the companies), any conclusions on the possibility of introduction of BAT at active plants and (or) plants under modernization, were made based on expert evaluations of specialists of various branches. The shown conclusions should not be regarded as final – they shall be subject to review at the stage of public discussion of the present BAT reference document.

BAT V-1. The Reduction of the Entry of Especially Hazardous and Biologically Non-Degradable Pollutants into Wastewater.

BAT means the reduction of the entering into wastewater especially hazardous biologically non-degradable pollutants with the aid of any of the methods listed below or a combination of those taking into account the application conditions:

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a. refraining from the use of chlorine in production, in order to avoid the formation of organochlorine substances;
b. refraining from the use of especially hazardous substances (for instance polychlorinated biphenyls (PCB), pentachlorophenol, trichlorbenzene, arsenic alkyl phenol ethoxylate, mercury and their compounds as well as cadmium) and the transfer to technologies that don't use those substances;
c. the substitution in production of biologically non-degradable substances by biologically degradable ones, that are harmless to the environment, for instance biodegradable chelate reagents and polish agents;
d. separate collection and removal of residues of disinfectants after their use and also used preservation agents

Approaches a and b are subject to application at plants undergoing modernization, whereas approaches c and d – at already active plants.

BAT V-2. The Removal of Pollutants from Wastewater in Correspondence with their Phase-Dispersed Composition

BAT is the

BAT is the consecutive removal of pollutants in accordance with their phase-dispersed composition, starting with the colloidal pollutants and ending with ion forms, through the use of one or more of the approaches listed below, taking into account the conditions of application:

a) removal of colloidal pollutants from the wastewater before the main treatment processing stage
b) separation of the solid phase of the wastewater through filtration through a sieve and a textile filter
c) the separation of fast-settling particles in sand-traps and hydrocyclones;
d) the separation or the bulk of the solid matter through sedimentation or floatation
e) intensified sedimentation and floatation aided by coagulants and flocculants;

f) fine treatment for the removal of suspended matter by filtration;
g) intensified treatment for the removal of suspended matter through the use of membranes

Approaches a – g are to be used at modernised plants.

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BAT V-3 Treatment of Wastewater to Remove Petroleum Products, Mineral Oils and Fats

BAT is the application of one or several of the approaches listed below, taking into account the conditions of application:

a) the separation of the main amount of non-emulsifying petroleum products (fats) in petroleum (fat) traps;
b) the separation of the main amount of emulsifying petroleum products and fats using floatation and/or aerobic biological treatment;
c) the use of a de-emulsifying chemical argents before the subsequent mechanic and physical and chemical treatment;
d) the fine removal of petroleum products with the aid of coalescent filters, sorbents and biosorbents

BAT V-4 Treatment of Wastewater to Remove Biologically Degradable Pollutants

BAT is the application of any of the approaches listed below, taking into account the conditions of application:

a) the anaerobic biological treatment in bioreactors with biomass retention. The method is used for BOD_5 concentrations in the wastewater of no less than 1 500 mg/l and a BOD_5/COD above 0,3. When using the methods a local treatment plants, it is used as a distinct independent purification stage (with the removal of hydrogen sulphide, if necessary), whereas if used in connection with discharge into a waster body – as the first stage of the biological treatment;
b) the removal of the main amount of non-emulsifying petroleum products by separation;
c) The anaerobic biological treatment in bioreactor mixers. The method is used when the concentration of BOD_5 in the wastewater (liquid waste), generally is no less than 20 g/l. This has to be accompanied by a subsequent aerobic biological treatment of the liquid phase, with the exception cases where treated sewage is recycled as soil.
d) The aerobic treatment in aerotanks, bio-filters and in combined plants. The method is used for BOD_5 concentrations in the wastewater of no less than 2 000 mg/l and a BOD_5/COD above 0,3
e) The aerobic post-treatment in bio-filters and bio ponds after the aerobic biological treatment;
f) The management of air feed to the aerobic biological treatment facilities, with the use of regulated air boosters and aerators.

The approaches a – f are to be used at modernized plants.

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BAT V-5 Treatment of Wastewater to Remove Nitrogen

BAT is the use of the approached listed below taking into account of the conditions of application:

a) The distillation removal of ammonium nitrogen with the addition of lye; this method is used at concentrations of ammonium nitrogen above 1 g/l;
b) Biological nitrification – the de-nitrification in aerotanks or emerged or disc bio filters. The method is used when the concentration of ammonium nitrogen is lower than 1g/l.
c) The post-treatment for the removal nitrogen in bio ponds.

The approaches a – c are to be used at modernised plants.

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BAT V-6 Treatment of Wastewater to Remove Phosphorus

BAT is the use of the approaches listed below, taking into account the conditions of application:

a) Biological treatment (with the removal of nitrogen) with an enhanced biological removal of phosphorous.
b) The sedimentation of phosphates with the aid of reagent at the stages of clarification, biological treatment or the post-treatment by filtration;
c) The removal in the form of insoluble compounds through crystallization, with the subsequent utilization;
d) Biological treatment (with the removal of nitrogen) wit an enhanced biological removal of phosphorous and the additional sedimentation with the aid of reagents.
e) Post-treatment with the removal of phosphorous (and nitrogen) in bio ponds.

The approaches a – e are to be used at modernized plants.

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BAT V-7 Treatment of Wastewater Containing Biologically Non-Degradable and (or) Toxic Organic Compounds

BAT is the application of one or several of the approaches listed below, including those that are applied before the feed lf the wastewater to the biological treatment plants, taking into account the conditions of application:

a) Chemical oxidation at a BOD/COD above 0,3. There might be restrictions in the use of this approach because of the risk of formation of organic halides when using chlorine, hypochlorite and chlorite (or any corresponding halogen compounds) as oxidizer
b) Bioflocculation and sedimentation)flotation) in the presence of high concentration of resin or polynuclear aromatic hydrocarbons (PAHs);
c) The extraction be organic solvents with the subsequent distillation separation at BOD/COD above 0,2. This is used in respect to the pollutants, which are more soluble in organic solvents than in water;

d) Adsorption on active carbon at a BOD/COD above 0,2. This method may also be used as a post-treatment after the biological treatment;
e) Chemical hydrolysis at a BOD/COD above 0,2;
f) Ultrafiltration with the extraction of complex organic and organo-mineral components of the sewage water, also in cases of return to the main or auxiliary production processes;
g) Vacuum evaporation for the multi-component concentrated sewage waster with a high content of biological non-degradable oar toxic substances.

The approaches a – g are to be used at modernized plants.

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BAT V-8 Treatment of Wastewater Containing Heavy Metals

BAT is the application of one or several of the approaches listed below, taking into account the conditions of application:

a) Reagent sedimentation with the simultaneous neutralization (usually with lime);
b) The separation as non-soluble compounds, through crystallization with the subsequent utilization. This method is used for intermediate and high concentration sewage water and treated solutions;
c) Biological recovery of metals from anions (Chromatic reduction, sulphate reduction, etc.). This method is used for wastewater containing heavy metals in the form of anions in the stage of maximum level of oxidation;
d) Post-treatment to remove heavy metal ions by adsorption on organic and mineral adsorbents;
e) Evaporation to insoluble compounds and ions of heavy metals out of sewage water, polluted biologically degradable organic substances in the biological treatment process;
f) Advanced removal of insoluble compounds of heavy metals after the reagent processing with the aid of nano filtration;
g) Advanced removal of insoluble compounds and ions of heavy metals with the aid of reversed osmosis.

The approaches a – g are to be applied at plants under modernisation.

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BAT V-9 Treatment of Wastewater Containing Sulphides

BAT is the application of one or several of the approaches listed below, taking into account the conditions of application:

a) Catalytic oxidation;
b) Biochemical oxidation in biofilters

The approaches a – g are to be applied at plants under modernisation.

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BAT V-10 Treatment of Wastewater Containing Inorganic Salts (General Mineralization)

BAT is considered the application of one or several of the approaches listed below, taking into account the conditions of application:

a) Sedimentation using sulphate, calcium and magnesium reagents;
b) Biological sulphate reduction
c) The separation of inorganic salts with the aid of reversed osmosis

The approaches a – g are to be applied at plants under modernisation.

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BAT V-11 Reduction of the Mass of Deposits, Formed at Sewage Treatment Plants

BAT is considered the dewatering of sludge, formed at sewage treatment plants, through the application of one or several of the approaches listed below, taking into account the conditions of application:

a) The mechanical dewatering in centrifuges, in belt and chamber press filters, screw extruders or dehydrators;
b) Dehydration in geocontainers (geotubes).

The approaches a – b are to be applied at plants under modernisation.

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BAT V-12 Stabilization of the Organic Content of Deposits

BAT is considered the application of one or several of the approaches listed below, taking into account the conditions of application:

a) Anaerobic stabilization of wet sludge, including the processing and recycling of biogas. This method is to be used when more than 20 t organic matter is produced every 24 hours (primary sedimentation sludge and biological treatment);
b) Thermal drying of the sludge. This method is used for the subsequent incineration of the sludge;
c) The incineration of the sludge. This method is used if there are toxic compounds in the sludge;
d) Aerobic stabilization of the dewatered sludge (composting). This method is used for the subsequent recycling of the compost as soil.

The approaches a – c are to be applied at plants under modernisation.
The approach d is to be applied at active plants.

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BAT V-13 Processing of Sludge and Waste from Water Treatment Plants for Industrial Water Supply

BAT is considered the application of one or several of the approaches listed below, taking into account the conditions of application:

a) Concentration and dehydration of the sludge formed at drinking water treatment plants;
b) The concentration of ionite desalination filter flush water or of reverse osmosis water softening filter

The approaches a – b are to be applied at plants under modernisation.

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Section 6. Economic Aspects of the Introduction of Best Available Techniques

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When introducing BAT at a production plant, it is necessary to take into account the expenditure for all the productions stages and the need for the necessary production equipment, also taking into account the expenditures of the enterprises, the expected economic feasibility of the introduction of Bat as sell as the environmental impact.
Establishments at all the stages of the introduction of BAT are obliged to:

- Serve for the registration of the formation, treatment, recycling and disposal of waste in accordance with the criteria of their assignation to a certain environmental hazard class;
- Carry out the hazard classification of the waste, which entails the satisfaction of certain requirements when handling waste, depending on the level of harmful impact on the environment;
- Guarantee the production control of all processes of handling waste, through the establishment of monitoring.
- Carry out the monitoring of the environment at waste disposal sites and in the zone of their influence taking into account the regulation and actual levels of emissions to the environment.

The introduction of BAT may lead to changes in the number of technological measures, which, in their turn, may lead to a reduction in costs, for instance the increase in the efficiency of the modernized system for thermal treatment (incineration, pyrolysis, gasification or their integration).
As restrictions to the realization of BAT in the field of thermal methods of waste treatment, one should regard the relatively high cost of the production equipment and the need for considerable initial capital investment taking into account the guaranteed service life of the equipment.
A short survey of the main economic problems in the field of thermal waste treatment is presented in the sub-section 1.2 of this reference document.
The main principles (1-4) of the method of BAT definition based on the evaluation of the aspects of its integrated impact on the environment are presented in section 4.
The application of these main principles need to allow both the user and the decision maker to compare transparent and equally

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described versions, including those, where the thermal treatment is the only feasible method. It is also important that the social, financial and organizational tasks of the sorting of consumption waste are solved.
In practice, information on the costs is evaluated quite often, however seldom at component level or at a level, where the yearly changes in costs may be shown with the desired accuracy. This is restrained by the possibilities of the carrying out of objective comparative analysis of the techno-economic and environmental characteristics.

The costs should be structured with a relative high precision, which should show which costs are related to the investment costs and which are related to the operational costs as to the result of the analysis of the significant stages of the life cycle of the facility.
As costs for the acquisition of the special equipment are regarded:

- cost for the acquisition of the production equipment;
- cost for the control, trapping and extraction of the primary pollutants, formed in the production process;
- costs for the equipment for the treatment of emissions and discharge of pollutants, the formation (storage) waste that has been treated or formed in the process of the treatment
- auxiliary (reserve) equipment
- instruments
- payment for the transport of the equipment
- modification of other equipment

As the prevented costs are the following regarded:

- economy of raw material
- economy of auxiliary materials (chemical reagents, water) and services;
- economy of energy carriers
- economy of labour costs
- economy of costs for the monitoring of emissions/discharges

The information on the costs may be collected from various sources, however, irrespective of the source of collection of data, it is necessary that the user evaluate the reliability of the collected data, the lacunae and the ambiguity of the preliminary evaluation of the potential impact of the technique on the environment.

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In order to increase the level of justification of the cost numbers, the operator must collect them, if possible from several independent sources. The sources of all the collected data must be documented. This will enable the tracing the route of collection and justification of the data, if at a later time there should be a need to do so. If the source of the information is a published piece of information (a report or a lecture), then it suffices to set up a standard bibliography. However, if the source of the data in an oral of other undocumented statement, then the source of information needs to be recorded as well as the date of collection.
Possible sources of information as to the costs may be:

- information from the various branches of the economy (for instance, construction plans, project documentation on the planned industrial plants as well as documentation);
- the supplier of the techniques, equipment, etc. (for instance catalogues, proposals, tenders)
- executive bodies
- experts and consultants;
- specialized companies (for instance, if pilot projects are being carried out)
- official information (for instance lectures, reports, specialized journals, materials from fairs and congresses);
- studies on expenditures in identical projects in related sectors

The ranking of the versions of Bat along with the increasing economic efficiency includes the consideration of the environmental advantage. For instance, the realization of the

practical possibilities to treat the waste directly at the formation site and simultaneously use part of the solid municipal waste through composting.
After the ranking of the possible alternatives from the viewpoint of environmental efficiency, the alternative with the lowest possible environmental impact may be declared the "best", however only in the case, if such an alternative is available from an economical viewpoint.
The expenditures and the process in the waste handling sector is usually established based on the initial investment, taking into account the wide scope of changes in character and calorific value of the treated waste, not to forget the operation costs, taking into account the possibility of heat recycling.

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Sometimes the unforeseen expenses are included into the evaluation of the capital expenditures, in order to cover costs that may not be evaluated exactly. This includes also the costs are known to occur, however the detailed determination of them is not possible, and they may thus not be included into the budget estimate. As the project realisation proceeds, the cost items become more detailed, and the unforeseen costs are getting fewer and smaller. The size of the reserve for unforeseen costs is an issue of discussion and experience, which will depend on, first and foremost, the level of technical reliability (certainty) invested in the project. Unforeseen costs are usually shown as a per cent number of the capital expenditure. Any circumstances which may lead to unforeseen costs must be shown separately and guarantee transparency. If different unforeseen costs are show for the considered alternatives, for instance, the need and practical possibilities of biological treatment of the waste after its separate collection, then they need to be substantiated and confirmed.
The most evident way of comparing the cost for the carrying out of measures and the derived advantages is the representation in the monetary form and the comparison of them by cost-benefit analysis. If this comparison shows that the advantages outweigh the cost, then this means that the investment and the measure are justified. For instance, it is expedient to realize project for the modernization and new construction of facilities for the thermal treatment of waste, integrated with heat and electricity supply plants.
If different alternative measures give positive results, then the alternative that gives the highest price-quality relationship will be regarded as the one with the highest result.
When choosing the thermal waste treatment technique it is necessary to take into account its hazard class, the natural and climatic conditions and the economical possibilities of the company, introducing BAT.
The economic feasibility as such is an inherent part of the BAT concept. A deeper appraisal of the economic feasibility shall be carried out only in cases, where there is clear disagreement as to which BAT should be introduced in the industrial branch in an economically efficient way.
As to the methodology of the determination of Bat, the economic feasibility is not sufficient on its own.

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This being said, a detailed analysis is necessary only in a case, where there are realistic reasons to believe, the technique (or the combination of techniques) is undue expensive in order to be regarded as BAT.
BAT also supply a substantial economy of production costs, including resource saving. Consequently, these parameters, together with the characters of the pollutants must be included in the widest possible scope of environmental-economic parameters.
The economy of investment and operational costs may be connected with:

- the mandatory control of the waste received for treatment, guaranteeing the reduction of the risk of the equipment slipping out of the normal operational mode as well as the likelihood of the exceeding of the allowed level of environmental impact and the infliction of harm to human health;
- the choice of alternative versions of BAT, including a flue gas cleaning system, guaranteeing the attainment of the design values of emission of pollutants.

After the evaluation of the integrated environmental impact of the equipment there might be a need to compare the costs of the introduction of the considered techniques. For an objective evaluation of the alternatives it is important, that the cost information that may be received from may sources will be collected and processed in an identical way.
The use of a successive (stepwise) approach lies in the choice of the best (optimal) or an acceptable, satisfactory alternative through certain actions in relation to the multitude of alternative with the result that a smaller multitude is left of acceptable (possible) alternatives, satisfying the imposed restrictions.
A comparative analysis, for instance, of the composition of the equipment set-up of a rotary-type furnace wit a boiling layer must be carried out at equal technological conditions (for instance, capacity) and equal physical and Chemical parameters of the treated waste in order to make it easier, cheaper and more reliable.
The costs and the way of use of the resources for the carrying out of an alternative are regarded as restrictions. This enables the comparison of alternative versions, even in cases where the data was received from different companies, different

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industrial branches taking into account the geographical climate factors as well as the seasonal and regional fluctuation of the volume and composition of the treated waste.
If the considered alternatives also give additional "non-environmental" advantages and revenues, or if they may lead to the economy of some items, then these advantages must be shown separately from the operational and maintenance costs.
The following costs are considered maintenance costs:

- insurance premiums
- license fees;
- reserve to be used for unforeseen situations and emergency work;
- other general overhead costs (for instance administration costs)

All costs are to be evaluated in relation to the alternative technique. The current situation, or baseline, is usually used as the alternative technique, i.e. an alternative without the installation of the nature protection equipment. The baseline alternative is established according to the methodology of BAT evaluation, whereas the costs of the alternatives as expressed in relation to the baseline alternative.
The experience of BAT introduction has shown, that considerable costs may be connected to a modification of the construction of the furnace of the heat recovery boiler

as well as the possible reductions of emissions. For instance the realization of technical solutions for the reduction of the occlusion of the heat recovery boiler also reduces the period of stay of dust in the temperature zones that could create the risk of formation of dioxins. However the reduction of the hotness of the flues gasses after the heat recovery boiler is used in order to restrict the negative impact on the flue gas treatment system.
It is necessary to take into account the additional costs, required for the solving of the task of the coupling of the neat recovery boiler with the gas treatment system.
At the design stage, it is necessary to take into account the possibility of increasing the coefficient of efficiency of the heat recovery boiler up to 75%.
A detailed evaluation of the energy situation needs to include the minimization of the costs for the acquisition of consumables, including the possibility of using the high-energy and low-ash fuels.
The optimization of costs, attained during the operation through the decrease of maintenance and the possibility of use of energy, may lead to very

short period of pay-off period, and may later on justify the use of such a concept in the new and modernized installations.
The net profit may be composed of the planned revenues form the offering of services of thermal waste treatment, from the production of hot water, electrical energy as well as the deduction of operational costs and taxes.
In order to simplify the process of comparison of the data, the components of the costs need to be a clearly established, taking into account the possibilities of using secondary material resources.
For instance, the costs for the additional modules of the industrial process and the production resources may be compensated by the reduction of costs of the disposal of ash slag and the residue of the gas treatment, as well as their use, for instance in the cement industry.
The total yearly cost for BAT correspond to the unified early costs, which require that the corresponding operational costs, the maintenance costs as well as the capital costs be covered.
The capital costs when reconstructing and modernizing already existing facilities for the thermal waste treatment are considerable, and in some situations they may exceed the size of the budgeted advantages.
It is assumed that one would realize a standard design solution (hereinafter: SDS) in order to optimize the time and finance costs, connected with the design, construction and reconstruction of the corresponding waste treatment plants taking into account the requirements of the protection and recovery of the environment.
The application of SDS presupposes the realization of measures for the use in the production of a number of unified production lines of thermal treatment of hazardous waste in the order established by law.
The use of tested SDS allows for the exclusion of the necessity for the independent development of industrial solutions as well as the design development of critical modules and separate blocks, design and construction decisions and a reconstruction programme.
The parameters of the achieved reduction of the current level of impact and consumption during the continuous operation include:

- a waste treatment feed rate comparable to the capacity of the production equipment;
- a period of waste storage to be of the minimal allowed size for the guaranteeing of continuous operation
- the organization of a treatment waste delivery chain, providing for the even feed of the waste in accordance with the equipment's capacity;
- the use of waste as an additional fuel

The prevention of any interruption of the production line may lower the costs for thermal waste treatment in the following ways:
- as a result of the guaranteeing of the use of the facilities in accordance with the design, i.e. in the optimal mode;
- as a result of the lowering of the heat load

The procedure of the control of the received waste may lower the risk of operational failures and the exceeding of the levels of allowable environmental impact.
The results of the realization of the environmental monitoring programme must be uses as the basis for the development of a number of organizational, technological and technical measures.
An efficient control of the production process of the thermal waste treatment has the following characteristic advantages:
- the guarantee of an optimal slag composition;
- the reduction of the formation of the fly ash and the quantity of unburnt matter as a result of more stable conditions of the furnace process
- the reduction of the formation of CO and volatile organic compounds as a result of more sable conditions of the thermal process, i.e. the absence of "cold" spots;
- the reduction of the formation of NOx as a result of a more stable thermal process
- the guaranteeing of a more complete use of the heat capacity;
- the increase of the energy efficiency as a result of the decrease of the consumption of middle quality air for burning purposes;
- the optimization of the functioning of the heat recovery boiler (as a result of a more stable temperature there are fewer temperature "peaks" and, hence, the risk of corrosion is lower, as is the risk of clogging as a result of the formation of flue ash;
- the guaranteeing of a full thermal destruction in combination of a more efficient incineration of waste as a result of the functioning of the automatic regulation of the equipment, which allows for the maintenance of the needed temperature mode in combination with the feeding and unloading of the ash residue.

Thermal waste treatment facilities must be equipped with high-efficiency gas treatment systems, the cost of which may reach 50 % of the total capital investment of the erection of the installations.
The profitability of the incinerators of low capacity with a minimized gas treatment system may be defined by the existing tariff system for municipal solid waste.
The technique for wet gas treatment has been developed in detail and is efficient under conditions of a minimization of the use of bulky production equipment and the corresponding costs.
In order to reduce the emissions to air in accordance with section 5 it is recommended to use a scrubber, sprinkled by an absorbent solution. As absorption solution a water solution of the reagent is used with a working pH scope necessary for the neutralization

of acid gases of 8,5 – 9,0, which is sustained automatically. The absorption solution is treated to remove the trapped mechanical pollution, is filled up with reagent until the required pH is reached, and is recycled.
If a wet scrubber is used, there are effluents, the treatment of which will entail the formation of a resin residue, which subsequently will need additional treatment.
The use of a wet scrubber will presuppose:

- a low level of reagent consumption;
- a minimal formation of solid residue
- an increased consumption of water
- the formation of effluents, which will need treatment;
- the accumulation of deposits on the constructions of the scrubber;
- the possibility of the destruction of the material uses in the construction of the wet scrubber, if the exit temperature is too high

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It is also necessary to take into account the increased capital and investment costs, which are connected wit the introduction of the additional elements of the production process.
When performing any measures for the recycling of waste it is necessary to take into account the economic feasibility and analyse the profitability of the process.
The introduction of resource saving techniques presupposes the creation of optimal condition for the transformation of fuel into energy. This is why the techniques, under which there is a full total incineration, and, consequently, in the ash, there will remain a minimal quantity of organic carbon, to a certain extent may further the increase in energy efficiency. The intensive mixing of the waste during incineration promotes the transfer into the gaseous phase and burning of the unburnt carbon in the slag.
In installations for the burning of waste it is possible to receive additional electrical energy, steam and hot waster. In a situation, where the function of the installation is optimized, the energy value of the waste is used in an optimal way.
The issues of energy efficiency of the techniques for thermal waste treatment are presented in section 5.

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Section 7: Promising Techniques in the Field of Thermal Waste Treatment

In accordance with the PNST (Preliminary National Standard) 21-2015 as ”promising” are considered techniques that are on a R&D level of development and that allow for an increase in efficiency of production and an emission reduction to the environment. It is necessary to mention the period of time, within which these promising techniques may be commercially available. Moreover, in accordance with the requirements of the Federal Act No219-FZ (version of the 29 December 2014) On the introduction of Amendments to the Federal Act ”On Environmental Protection” (version of 29 December

2014) and Other Acts of Law of the Russian Federation, the criterion of the availability of the best technique is the "industrial implementation of this technique at two or more enterprises having a negative environmental impact". Thus, for the purpose of the BAT reference documents, in order to avoid the exclusion during the evaluation, of high-quality techniques, already in use within the industrial fields in a restricted scope, it is necessary to include also the techniques, the evaluation of which is impossible in the section of best available techniques because of its restricted scope of use.
However, since the choice of techniques during the elaboration of the reference document is based on the analysis of the questionnaires, representing only part of the information on a very small, unrepresentative selection of enterprises that are part of the field of use of the reference document, and in order to avoid ambiguity leading to the treatment as promising, techniques already in use in the industry, in this section only techniques (according to the data held by the authors of the reference document) that are in the R&D stages or in the industrial introduction testing stage are considered.
At present, the following techniques of thermal waste treatment are in the stages of research engineering and R&D.

7.1 Plasma Techniques for the Treatment of Hazardous Waste

One promising field is the use of plasma sources of energy (arc jet generators) in installations for high-temperature treatment of various kinds of waste, containing organic compounds (solid municipal, industrial and medical waste).

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Using plasma technique, it is possible to process complex waste, containing both organic and inorganic components, and, in the process, as an end-result produce stable, fully unhazardous en products. In the process, a substantial reduction of the volume of the waste is achieved (up to 95%), and the solid residue received in the process contains the hazardous components in a bound and safe form. The stability of these vitrified products is guaranteed for hundreds of years.
Apart from this, since the fundament of the plasma technology is the use of the heat of an electric arc, natural fuel is not used in the process. As a result of this, the volume of gaseous emissions are usually considerably loser (up to 90%) than in fire systems operating with the use of organic fuel. The reduction of the volume of the gaseous emissions, leads to, in turn, to a considerable reduction of the needed efficiency of the gas-cleaning systems, as well as of the instruments and means of environmental control of air pollution and – as a result – the corresponding reduction of their cost.
Assemblies of this kind are in the stage of industrial use in Japan, and – in a narrower scope (including industrial testing operation) – in USA, Canada and in a number of EU member states. Included in the number of foreign developers of plasma systems for the treatment of waste, actively working on the market of progressive environmental techniques we find the companies, Statech Environmental Corporation, Geoplasa, Recovered Energy, PyroGenesis, EnviroArc, Plaxo Energy, MSE Technology Applications (USA), Westinghouse Plasma Corporation, Plasma Environmental Technologies, Resorption Canada Limited (Canada) as well as ScanArc/EnviroArc (Sweden, Norway).
At the moment, in the Russian Federation a few plasma techniques are developed for waste treatment, the majority of which for the time being are at the stage of experimental industrial operation.

- The plasma chemical PCB destruction technique of the Russian Scientific Centre Prikladnaya Chimiya [71]

- The mobile experimental industrial plasma assembly TekhEkoPlazma [68]
- The Plasma Mine Assembly Pluton of the of the MosNPO Radon for the MNTsTE (Novosibirsk) [75];
- The Chamber Incineration Furnace of the OAO Novosibirsk NIIkhimmash and the Institute of theoretical and applied mechanics of the Siberian Section of the

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- Russian Academy of Sciences (SO RAN) [69]

The majority of such technological approaches are universal, i.e. they allow for the efficient treatment of a wide variety of waste. However, one should pay attention to the general disadvantage of the plasma technologies (Russian, as well as foreign) – i.e. the restricted service life of the plasmatrons, working both on the basis of inert and oxygen containing gases. At present, in the majority of the plasma technologies the lifetime of the plasmatrons amounts to 100-1000 hours, depending on the concrete technological process, the type of plasmatron used and the type of plasma forming gas [79]. The lifetime under continuous work of the company Plasma Energy Corporation device does not exceed 200 hours, whereas the lifetime of the plasmatrons of the company Westinghouse Plasma Corp. is around 800 h. The water vapour intensifies the process of electrode erosion, and thus restricts the lifetime even further. For instance, the plasmatrons of the Canadian Corporation High Temperature Technologies Corp. with copper electrodes, when working in air have a lifetime of 300 hours, however when working in water vapour – only around 50 h. [80].
A cardinal solution of the task of raising the operational lifetime of the arc-jet plasma generators and the raising of their capacity was found by the specialists of the International Scientific Centre of Heat Physics and Energetics (Novosibirsk) [78]. Graph 7.1 illustrates the scheme of the developed plasmatron with liquid-metal electrodes. The electrical arc is "bound to the surface) of the molten metal, constituting the electrode. Such electrodes are not subject to erosion and, thus, do not restrict the lifetime, the capacity of the arc nor the type of plasma-forming gas. The elimination of the said restrictions opens wide possibilities for the industrial use of plasmatrons with liquid-metal electrodes (graph 7.2).

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Partition

Channel

Electrical arc

Molten metal

Graph 7.1 Scheme over a plasmatron with liquid metal electrodes [78]

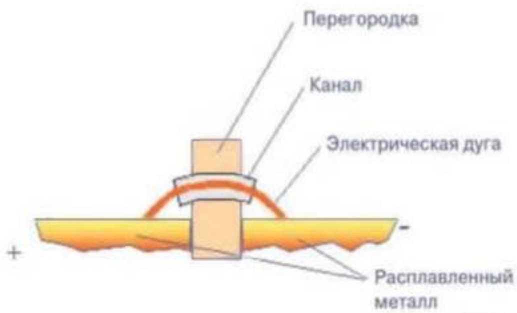

Рисунок 7.1 - Схема плазмотрона с жидкометаллическими электродами [78]

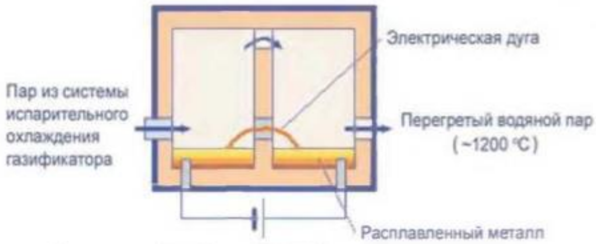

Рисунок 7.2 - Схема пароперегревателя на основе плазмотрона с жидкометаллическими электродами [78]

Vapour from the system of evaporative cooling of the gasification unit (arrow to the right of the graph)

Electric arc (middle of the graph)

Overheated water vapour (≈1200 °C)

Graph 7.2 – Scheme showing the vapour heater based on a plasmatron with liquid metal electrodes [78]

Since there are, in the working space, zones with extreme high temperatures (from a thousand to tens of thousand of degrees), there are special requirements in respect to the choice of construction of the reactor and to the material of its walls (if needed, heat resisting, and chemically inert materials in respect to the waste treated).

7.2 High Temperature Vapour Gasification of Waste using Plasma Sources of Energy

This production method, representing a two-stage pyrolysis, presupposes the carrying out of hazardous waste treatment in two stages: a low-temperature stage at temperatures up to 1000 °C (300-700°C) during which the toxic components to a maximum are separated from the inert bulk material, whereas at the high-temperature (plasma) stage at a temperature above 1400°C a full destruction of the compounds occur (in the gaseous phase) [17].
The plasma sources are used during the process of high-temperature gasification. The technology of high-temperature gasification possesses a substantially higher

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potential for efficient work than the systems of pyrolysis and incineration, which is conditioned by the high temperature of the process, an almost full conversion of carbon-containing substances of the synthetic fuel gas, as well as the production of a harmless inorganic slag, and, consequently, the securing of favourable environmental parameters.
During vaporous gasification of organic compounds in a high-temperature reactor, practically the same processes occur, as during vaporous conversion of hydrocarbons, which, at present, is the main process for the industrial production of hydrogen.
Active work within the field of conversion of waste is being conducted abroad at the Institute of electric welding named after EGO. Paton (Ukraine), the Institute of the problems of combustion (Kazakhstan), companies in the USA, Japan, the People's Republic of China, and others. Research is also being conducted in Greece, Bulgaria, Poland and other countries.
At present, in Russia, at the stages of R&D is the optimization of the instrumentation of the process of high-temperature steam gasification of waste using a plasma source of energy. Among other things, the following field are under development:

- the rational configuration of a vertical shaft reactor-gasification devise
- A plasmatron with liquid metal electrodes with a long operational lifetime (The International Scientific Centre for Thermal Physics and Energetics at Novosibirsk);
- A compact steam generator wit a temperature of the exit water steam of no less than 1200°C.

Furthermore, at present a set of R&D processes are carried out concerning the elaboration of the main components (The steam plasma generator, the shaft-type gasification device for organic waste, etc.) as well as the thermal modes of a stable carrying out of the process.
For the carrying out of the said means of waste treatment, it is proposed [73] to use the set-up (graph 7.3).

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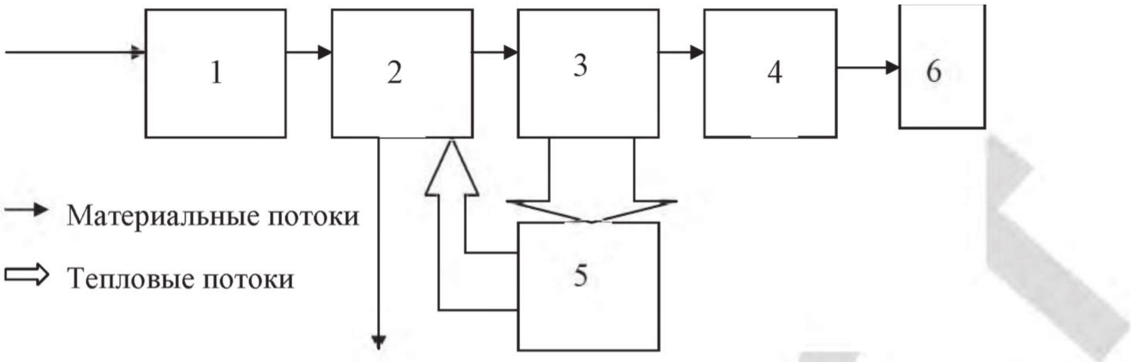

small arrow: material flows
larger arrow: heat flows

Figure 7.3 – A scheme over the plasma-pyrolysis set-up
1. – the feeding system, the movements and preparation of the preparative forms of pesticides for the primary pyrolysis; 2 – the primary pyrolysis furnace; 3 – the plasmatron; 4 – the hardening and separation system for the products of the plasma pyrolysis; 5 – the system allowing for the use of the produced heat for the entertainment of the temperature mode in the working zone of the primary pyrolysis furnace; 6 – the gas vent system.
At the State Educational Institute of Higher Professional Education, the Kuban State University an experimental set-up has ben elaborated for the treatment of unconditioned pesticides with a capacity of 1 kg/hour. This installation may be used efficiently also for the treatment of hazardous waste. The principal scheme of the installation is shown in figure 7.4.

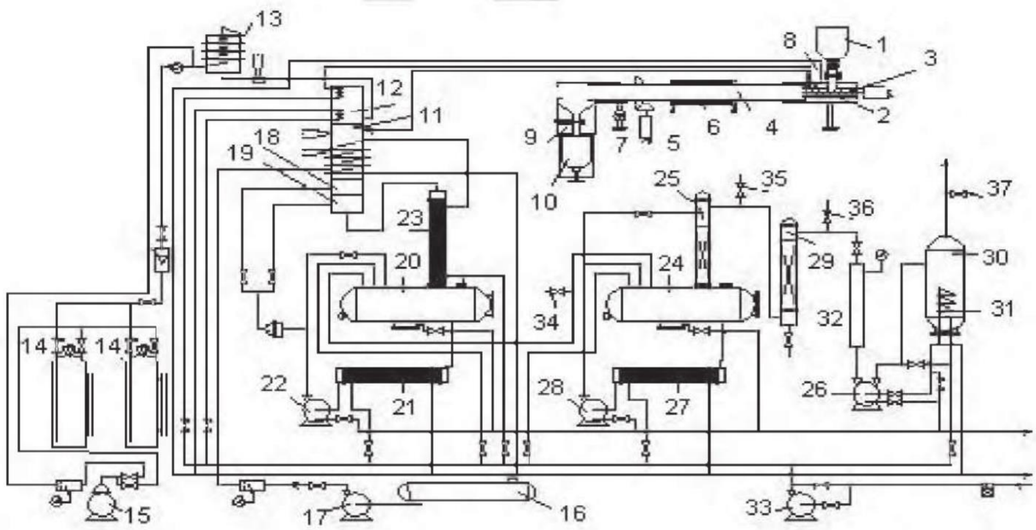

Fig. 7.4 The Scheme of an installation for the treatment of unconditioned pesticides [0]
1 – feeder; 2 – batcher; 3 – conveyer screw; 4 – rotating drum furnace; 5 – electrical engine, drum furnace; 6 – electrical heater; 7 – electromechanical elevator; 8 – screw batcher water cooler system; 9 – discharge block; 10 – receiving pocket; 11 – Reactor; 12 – plasmatron; 13 – steam generator; 14, 16 – tanks; 15 – compressor; 17, 22, 26, 28, 33 – pumps; 18, 19 – hardening blocks; 20, 24 – clarification tank; 21,23, 27 – heat exchangers

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25; – filled absorption column; 29 – adsorber; 30 – tank; 31 – cooling coil; 32 – expansion vessel; 34, 37 – samplers

This set-up has been used to work out the modes of treatment that are in use in the Krasnodarskiy Kray to be used for various kinds of unconditioned pesticides. Apart from this, one has also used it to determine the efficiency and economic feasibility. During the treatment of this kind of hazardous waste, the temperature of the working zone of the primary pyrolysis furnace has been varied within the range of 400 to 1000°C. The feeding speed of hazardous waste into the furnace of primary pyrolysis varied within the range 0,5-1,2 g/s. As working gas of the plasmatron water steam was used.
The experiments thus carried out showed, that the temperature interval 200 – 700 °C gave the desorption and transfer into the gaseous phase of any organic compounds with minimal energy expenditure, which raises the economic feasibility of the process. At the same time the thermal decomposition of the gas phase only in the plasma jet increases significantly and the process of treatment is simplified and rendered cheaper.

7.3 The use of shaft furnaces for the high temperature steam gasification of waste with the use of plasma sources of energy

Vertical shaft furnaces have gained the most widespread practice of pyrolysis and gasification of solid municipal, industrial and medical waste. The classical example of a counter-current shaft furnace for the plasma pyrolysis of solid waste is the reactor, developed by the GUP VosNPO Radon [78].
The packages containing the waste enter through the loading unit in the upper layer of the shaft, and, sinking under the influence of gravity and are heated by the heat of the gases that are moving against them from the other direction. The heat sources are the arc plasmatrons situated in the lower part of the furnace above the bath as plasma producing gas air is used. The use of air plasmatrons of a relatively high capacity has made it possible to refrain from the use of additional fuel. In the upper part of the furnace, the waste goes through the stages of drying and pyrolysis, which are accompanied by an intensive gas production. In the high-temperature zone of the shaft furnace in the lower parts of the waste layers a distillation of the volatile compounds takes place. At the same time, in the middle and upper levels furnace shaft, in the zone of relatively low temperatures, these compounds are concentrated and accumulated in the waste layer. The remaining coke is to a considerable extent burned out, whereas the mineral components are melted and enter the zone

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of accumulated liquid melt. The temperature of the effluent gases from the shaft furnace did not exceed 250-300°C, the pyro gas (apart from fuel gases) contained resinous compounds and aerosols of soot and ash, which were subject to processing in the multistep system for dust and gas treatment. The temperature of the slag melt in the furnish bath attained 1600-1800°C. After cooling a solid rest is formed, which can be safely stored.
This installation allows for the processing of mixed solid waste, containing not only fuel components (wool, paper, rags, plastics), but also non-fuels (metal, glass, soil as well as isolation materials).
One of the most efficient designs of the specialists of the GUP MOsNPO Radon, is the technology of plasma burning of solid radioactive waste of low and middle-level activity. At the company a plant, Pluton, has been set-up and operated, guaranteeing the plasma processing of waste of complicated morphology with the production of a conditioned

product using only one stage and a high coefficient of volume reduction of the radioactive waste. On the basis of a long-time cycle of scientific work, carried out using the Pluton installation, a demonstration facility was for the treatment of solid municipal waste with the design capacity of 500 kg/h was put into experimental operation in 2007 under a contract between the Russian Scientific Centre Kurchatov Institute and the Israeli company EER (Environmental Energy Resources). The design work was carried out by the OOO VAMI (St. Petersburg), with the support of OAO VNIIAM and the OAO NPO Techenergokhimprom.

7.4 The combined method of waste treatment with the use of a plasma-chemical reactor.

During a number of years already, in Russia, scientific work has been carried out in the field of the use of plasma chemical reactors for the treatment of hazardous waste. Hence, it is worthwhile to mention the installation for the plasma chemical processing of liquid organic and chlorine-organic industrial waste, develop at the V.M. Keldysha Research Centre [76]. It was produced based on the set-up of the AO NPO Tekhnolog (Sterlitamak, Bashkortostan). This installation is designed for the processing of more than 30 types of waste, including trichloroethylene, methyl chloride, polychlorinated biphenyls, contaminated petrol, kerosene, acetone, Toluol, benzene, used emulsions, mixed petroleum products, varnish, paint and the like. As heat medium air, heated to the temperature of 5000 – 7000 K in an AC current electrical arc plasmatron is used

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In the plasma-chemical reactor the waste is mixed with the fuel air and is decomposed while forming non-toxic compounds (carbon dioxide, water steam, hydrogen chloride and nitrogen). After the capture of the residue gas out of the gas mixture out of hydrogen it is emitted to the air. The capacity of the installation is up to 500 kg of waste/h; the yearly load – up to 1000 tons/year; the total electric power – 600 kW; the power of the plasmatron – 500 kW, the circuit voltage – 3-10 kV, air consumption – not exceeding 2400 m/h; maximum air pressure – 0,6 MPa; water consumption for the hardening process – not exceeding 4 m^3/h, maximum water pressure – 0,4 MPa, life-time of uninterrupted work of the electrodes of the plasmatron – no less than 240 h.

7.5 Treatment of hazardous waste using the method of supercritical water oxidation (SCWO)

This technical approach is based on the treatment of water mixtures that contain hazardous and toxic compound using supercritical water with a surplus of oxygen, at temperature of 400-600°C and a pressure of 200-300 atm. Under such circumstances, the supercritical water is a very strong oxidizing component and a practically universal solvent, which allows for the conversion of no less than 99, 99% of the hazardous compound of the original mixture into H^2O and CO^2. Figure 7.5 represents the principal scheme of the set-up for the treatment of hazardous waste, using the method of supercritical water oxidation (SCWO).

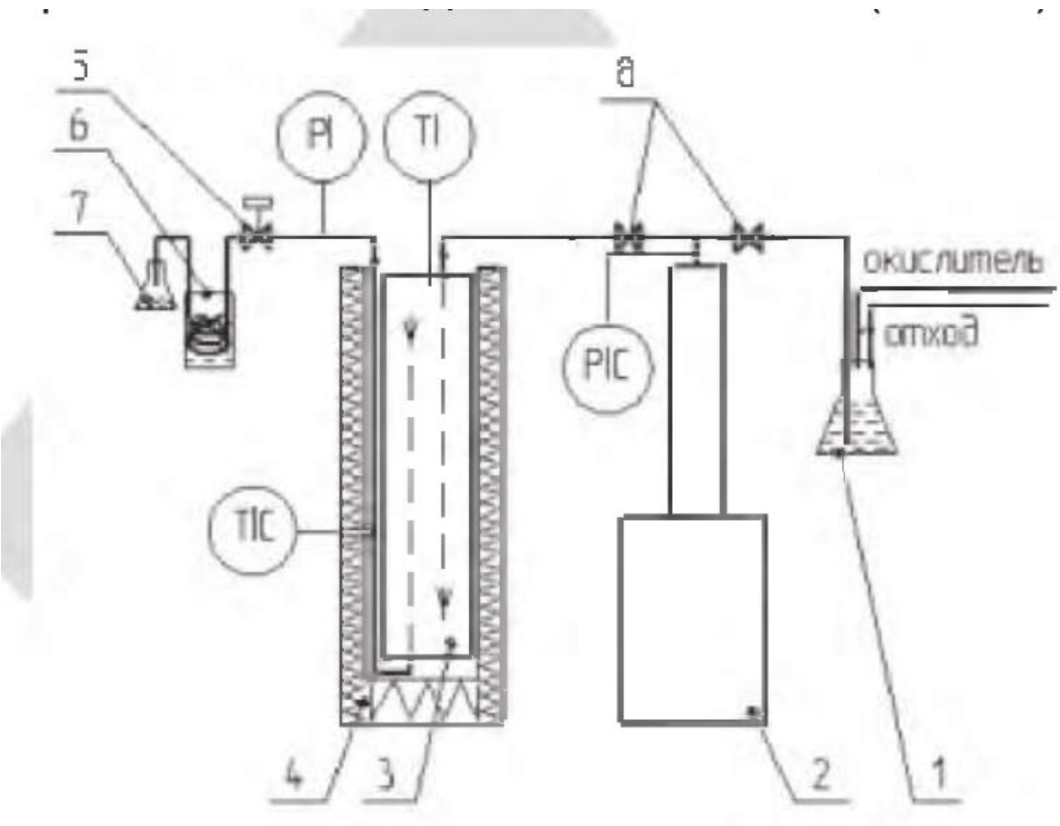

Fig. 7.5 – Scheme, showing the installation SCWO [69)
1 – vessel for the preparation of the mixture
2 – syringe pump
3 – SCWO cell
4 – furnace
5 – throttling unit
6 – refrigerator
7 – condenser tank

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8 – shut-off valve
PI – manometer
TI – temperature gauge
PIC – pressure gauge for the control and regulation of the pump pressure
TIC – temperature gauge for the control and regulation of furnace temperature

In the SCWO installation, ammonium-containing compounds and nitrogen-containing organic compounds are decomposed under the production of gaseous nitrogen. Fluorine, chlorine, sulphur and phosphor (out of the inorganic compounds) form acid residues and (if a solution of the corresponding cat-ions is added) are easily produced in the form of inorganic acids or salts. The great majority of inorganic compounds that are stable under these conditions are not easily dissolved in the supercritical water, which is shy they precipitate or are transformed into gas during cooling or lowering of the pressure. The oxidation process proceeds at a very high speed.
The study of the SCWO principle as used when processing waste was begun at Karlsruhe University (Germany) at the end of the 1980-s. In the mid-90-s a number of companies in the USA presented experimental set-ups for the processing of hazardous waste based on SCWO. One of the first such companies was MODAR, Inc (later on, in 1996, acquired by General Atomics (GA)). Based on the technological solution of the MODAT, Inc, in 1998 in Japan, the company Organo Co, erected a plant for the processing of hazardous waste with a full cycle, which is still functional. General Atomics, at present, uses SCWO only for the processing of chemical ammunition. Based on licencing of the MODAR technique, Komatsu, Ltd, Kurita Water Industries (Japan) and NORAM engineering Constructors Ltd (Canada) and others used this technique.
Model Development Corporation (USA) has developed the technique MODEC, with the use of which a higher corrosion resistance of the equipment could be attained. Based of a licence, the MODEC technology was used by the Hitachi Plant Engineering and Construction Co, the NGK Insulator Ltd. (Japan), NORAM Engineering and Constructors LTD (Canada) and others. Both the MODEC technique and the MODAR technique have been actively used in the USA for the needs of the military-industrial complex – to destroy chemical weapons and the destruction of waste in autonomous ship systems, etc.
Table 7.1 presents a list of foreign companies working in the field of waste processing based on SCWO.

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table 7.1 – Companies, working in the field of waste treatment based on SCWO.

Grantor of licence	Licence holder	Full cycle companies	Type of processed waste
MODAR	Organo	Nittetsu Semiconductor (Japan) (the company was built by Organo)	Waste from the production of semiconductors
MODEC	Organo, Hitachi, NGK	None	Pharmaceutical waste, pulp- and paper plant waste, sewage sludge
General Atomics	Komatsu, Kurita Waste Industries	U.S. Army Newport Chemical Depot (Newport, Indiana, USA)	Nerve gas, ship waste, explosives, etc.
Foster-Wheeler		U.S. Army Pine Bluff Arsenal (Pine Plaff, Arkansas, USA), operated by Sandia National Laboratory	Dies, chemical weapons, ship waste, explosives, etc.
Eco Waste Technologies (EWT)	Chematur	Huntsman Chemical (Austin, Texas, USA)	Alcohols, glycol, alcohol, amines
Chematur	Shinko Pantec	Johnson Matthey (Brimsdown, Great Britain)	Used catalysers (extraction of platinoids and the destruction of organic compounds)
Chematur	Shinko Pantec	Japan	Sewage sludge
SRI International	Mitsubishi Heavy Industries	Japan	Polychlorinated phenyls, polychlorinated biphenyls, chlorine-containing waste
Hydro processing		Harlingen Wastewater Treatment Plant no.2 (Harlingen, Texas, USA)	Municipal and industrial sewage water
Hanwha Chemical		Namhae Chemical Corp (South Korea)	Waste water from fine chemical technology

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In Russia, the technology has yet to emerge from the R&D stage. There is research going on based on the Siberian Section of the Russian Academy of Science, and, also at individual companies, however the work group does not have at its disposal information of any industrial experimental set-ups, that would be ready to be introduced into industrial operation.

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7.6 The use of installations with acoustic generators of a pulsation current for the treatment of solid waste.

An installation for the thermal treatment of various types of solid waste works along the principle of pulsating combustion with the use of acoustic oscillation gas dynamic generation, emitting resonance oscillation of high intensity in a wide frequency field through the turbulent pulsation and the magnification of these in a coincident wave lf the acoustic resonator.
The use of a pulsating mode of burning is one of the promising areas, since it solves several tasks – the production of energy through the burning of waste and its recycling through its full destruction. The intensification of the process of incineration through the oscillations, offers the possibility of burning substances that would not burn or would not reach a high level of combustion in ordinary furnaces.
The development [74] is on the stage of research engineering and the optimal parameters have been defined, that would be needed for the creation of stable resonance oscillations with a maximal amplitude of the acoustic signal. The produced power of the sound signal offers the possibility to create a pulsation flow in the combustion zone, which would be needed in order to reach an intensified process of mixing of the fuel.

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Final conditions and recommendations

For the elaboration of the reference document a Technical Work Group has been set up (TWG 9): Chemical waste treatment (waste incineration), with 53 representatives of various organisations. The composition of TWG 9 was approved by Rosstandart Instruction no. 836 of the 17 July 2015.

In order to collect information on the technical processes, equipment used at the industrial companies, as well as on the sources of environmental pollution, on the production, technical and organisational activities, aimed at the reduction of environmental pollution of the environment and an increase of energy efficiency and resource conservation, a questionnaire was produced for companies, containing a list of questions for collection of the data, necessary for the elaboration of a draft branch BAT reference document. As a basis for the development of the questionnaire the PNST 23-2014, Best Available Techniques, format for Technique Description.

The questionnaire was sent to major Russian companies that are carrying out thermal waste treatment. Information, received as a results of the survey of the companies was used when composing the BAT reference document.
The Results of the analysis of the questionnaires received from the companies showed a clear lack of information on promising techniques in the field of waste treatment. This, in particular, was the reason for the use, when creating the reference book, the results of scientific and theses material, as well as other sources of information, received during consultations with experts of the corresponding domains. While doing this, and based on an appreciation, the composers of the reference document recommend that one as promising technique also should count the progressive foreign techniques, which to date have not been implemented in the Russian Federation.
Based on the results of the preparation of the present reference book, one could make the conclusion, that the leading domestic companies are actively carrying on the introduction of modern technology processes and equipment, and are developing programmes for the increase of energy efficiency and environmental production results. However, the goals, tasks and expected results of the transfer to a system of production-based regulation based on best available techniques are understood and evaluated by the management in different ways

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The process of developing the reference document needs to reflect the principle of step-wise improvement – the main principle of modern management systems. The composers of the digital BAT reference document Thermal Waste Treatment (waste incineration), hope, that the colleagues are prepared to share this position and support the development of the document and the advance of best available techniques in the field of waste treatment.

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Attachment A. Terms and Definitions

Production and consumption waste (hereinafter – waste) is substances or objects that were formed in the process of production, the performance of operations, the rendering of services or in the process of consumption, which are removed, intended for removal or are subject to removal in accordance with the present federal act [64], Art. 19.
Waste handling is the acts of collecting accumulation, transportation, processing, recycling treatment and disposal of waste [64], Art 1).
Waste treatment is the reduction of the mass of the waste, the change of its composition, physical and chemical properties (including, incineration and (or) the disinfection in specialised facilities) in order to lower the negative impact of the waste on human health and the environment [64], Art 1).

Thermal waste treatment is the treatment of waste that contains organic substances, using the methods of incineration, pyrolysis and gasification.
Recycling of waste is the use of waste for the production of commodities (products), the performance of operations and the rendering of services, including the repeated use of waste for its direct application (recycling), its return to the production cycle after the needed preparation(regeneration) as well as the extraction of useful components for their repeated use (recuperation) [64], Art 1.
The type of waste is the aggregate of waste, which have common traits in accordance wit the system of waste classification [64], Art 1).
Municipal solid waste is waste, formed in housing premises in the process of consumption by persons, but also commodities, that have lost their consumption properties in the process of their use by natural persons in housing premises for the purpose of satisfaction of personal and household needs.

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As municipal solid waste are regarded also waste, formed in the process of activities of legal persons, individual sole traders and the like, and which as to its composition resemble waste, formed in housing premises in the process of consumption by natural persons. ([64], Art 1).
Groups of homogenous waste is waste, classified according to one or several features (origin, conditions of formation, chemical and (or) component composition, the aggregate state and physical form 8[64, Art 1).
By-product is the additional product, formed during the production of the main product, which is not the goal of the production in question, but useful as raw material in an other production or to be used as finished product ([81], item 3.16).
Ash are the unburnt residues, formed as a result of the burning of organic matter ([84) item 3.45).
Waste vitrification is the treatment of waste, as a result of which its transformation into glass material is performed. ([81], item 5.48).

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