(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) **EP 4 450 871 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
23.10.2024 Bulletin 2024/43

(21) Application number: **23168619.7**

(22) Date of filing: **18.04.2023**

(51) International Patent Classification (IPC):
F23G 5/08 *(2006.01)* ***F23G 5/30*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F23G 5/085; F23G 5/30

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

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(54) **A DEVICE AND A METHOD FOR HIGH-TEMPERATURE PLASMA DESTRUCTION OF WASTE**

(57) The device for high-temperature plasma destruction of solid and liquid waste according to the invention comprises a reactor with an inlet for leading waste material into the intertior of the reactor and an outlet for leading created gas and/or heat towards a device for recovery of the resulting heat into simultaneous production electricity and/or green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere. The main principle of the process of high-temperature plasma-chemical destruction of matter is the principle of superadiabatic filtration combustion. Said reactor has three zones - a gasification zone, a high-temperature fluidized bed and a boundary zone in-between the gasification zone and the fluidized bed, the latter being exposed to hydrogen, oxygen and hydroxyl radicals produced by a plasma reactor, thus leading to oxidation and consequently destruction of waste material as well as any potentially toxic compounds, vapour, gas or byproduct.

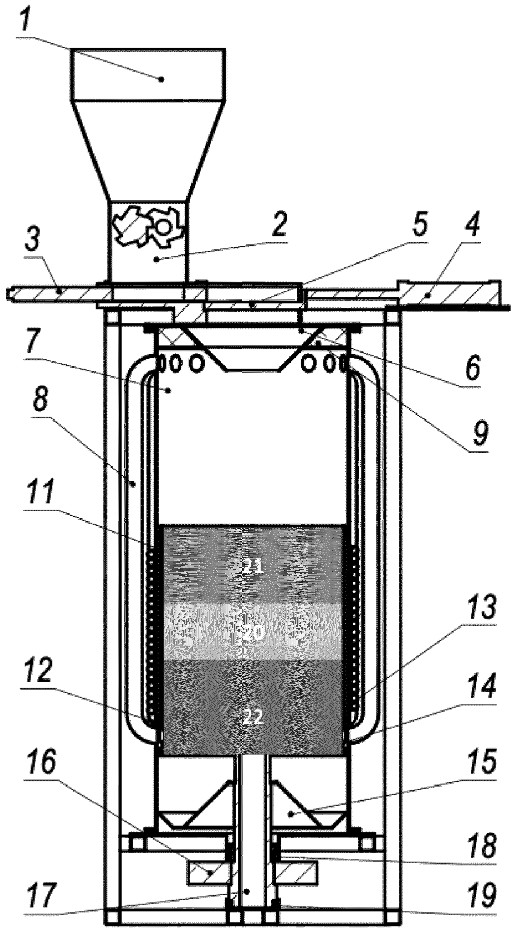

Figure 1

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Description

Field of the invention

[0001] The present invention belongs to the field of combustion devices and combustion processes for removal of waste. The invention relates to a device and a method for high-temperature plasma destruction of solid and/or liquid waste.

Background of the invention and the technical problem

[0002] Waste disposal includes the processes and actions required to manage waste from its inception to its final disposal. Waste can be solid, liquid, or gases and each type has different methods of disposal and management. Waste management may have various origins, such as industrial, biological, household, municipal, organic, biomedical, radioactive wastes. Waste can pose a threat to human health, hence safe and efficient treatment and disposal is required.

[0003] Due to the constantly deteriorating environmental situation, the problem of purifying industrial gas emissions from gaseous and dispersed impurities has long been a global problem. Currently, 25 billion tons of carbon dioxide alone enters the atmosphere annually, up to 58 million tons of nitrogen oxide, agents of chemical pollution. According to the World Health Organization, there are about 500,000 tons of such compounds, of which 40,000 tons are harmful substances and about 12,000 tons are ultra-toxic ones.

[0004] The most promising trend in the development of technology for cleaning up toxic industrial and energy gas emissions, water treatment and disposal of industrial wastewater is the use of high-energy external fields like cold and high-temperature plasma, ultrasonic wave coherence, multiphase coherence, acoustic-plasma discharge with the formation of a high-energy hydroxyl radical group. The energy of the electric field affects the physicochemical characteristics of the processed liquid and gaseous medium and its ionic composition, the structure of dissolved organic substances and the viability of the microorganisms present without any additional introduction of chemical reagents.

[0005] The technical problem addressed by the present invention is design of a reactor and a method for efficient destruction of various waste materials without the use of atmospheric air and without producing dioxins, furans and other toxic substances.

Prior art

[0006] Utility model CN217973078U discloses a composite gasification device based on a filtering combustion mode, and belongs to the technical field of synthesis gas production through solid fuel gasification. The problems of low carbon conversion efficiency, high tar content and low synthesis gas yield are solved. The device comprises a gasifying agent inlet, a preheating section, a reaction section, a reforming section, a synthesis gas outlet and a discharge section, the gasifying agent inlet is communicated with the preheating section, two ends of the reaction section are respectively communicated with the preheating section and the reforming section, the synthesis gas outlet is communicated with the reforming section, the discharge section is communicated with the reaction section, and the reforming section is communicated with the reaction section. The preheating section and the reforming section are both composed of inert porous medium fillers in various forms, the interior of a porous medium accumulation bed layer is provided with complex pore channels, mass transfer and heat transfer are facilitated, and a porous medium can be composed of inert particles such as ceramsite or glass beads and similar substances, metal wire meshes, foamed ceramics and the like; the device is mainly used for high-efficiency gasification of various solid fuels. This solution uses filtration combustion and the adiabatic effect for gasification of solid products, such as coal or other burning fuel. Furthermore, this disclosure is not discussing superheated steam to be split into oxygen, hydrogen and hydroxyl radicals.

[0007] Patent application WO2018164651A1 relates to a method for gasification of solid fuel in a gasifier comprising a casing defining a cavity and having a fuel compartment, a reverse gasification zone and a direct gasification zone disposed therein, the method comprising the steps of:

- loading of solid fuel into the fuel compartment,
- supplying solid fuel and oxidizer into the reverse gasification zone, c. supplying carbon particles obtained in the reverse gasification zone to the direct gasification zone,
- supplying oxidizer to the direct gasification zone, thereby generating a producer gas,
- removing the producer gas from the direct gasification zone, and
- mixing the producer gas with solid fuel supplied to the reverse gasification zone,

wherein an adsorption filtration zone is formed between the reverse gasification zone and the direct gasification zone, and the mixture of solid fuel and producer gas is then supplied to the reverse gasification zone and the producer gas generated in the reverse gasification zone is then removed for disposal through the adsorption filtration zone. This solution works at temperatures around 1000 °C and does not relate to destruction of waste including the potentially toxic gases formed during waste processing.

Brief description of the solution to the technical problem

[0008] The invention aims to provide a device and a method for destructing any type of waste including any possible emission gases, which address the shortcomings as well as complexity of the presently known solutions. Most importantly, the goal of the present invention is to design the device and the method so there is no need for further processing of flue gases emitted during waste processing, as the device itself ensures all potentially toxic gases are destructed too. The technical problem is solved as defined in the independent claims, wherein preferred embodiments of the invention are defined in the dependent claims.

[0009] This invention is based on the method of superadiabatic filtration combustion, in which there are several active layers of influence on the feedstock, the reaction fluidized bed, the boundary layer and the gasification layer of the fuel feedstock. Filtration combustion is understood as the propagation of exothermic transformation waves in the porous medium of an ionized fluidized bed, when all combustion products, flue gases (synthesis) and condensate are filtered through the fluidized bed until complete oxidation (destruction of matter). With this technological feature of the constructive geometry of the reactor, the technology makes it possible to destroy the products of gasification of any solid and gaseous fuel. Heating expanding gases moving up the toroid from the boundary layer from the area of heating and gasification, flue gases practically cannot leave the reactor without passing through a high-temperature ionized fluidized bed, which is plentifully purged with oxidizers and radicals of the hydroxyl group obtained from water vapor. The mechanism of propagation of the thermal reaction zone in this system includes layer-by-layer heating of the initial substances (solid fuel) ahead of the combustion front, down from the boundary layer forming a combustion zone (fluidized bed), and up from the boundary layer a gasification zone. A specific element that determines the combustion feature of this system is the filtration of all flue gases (synthesis gas) through a fluidized bed, which acts not only as a participant in a chemical reaction, but also as a coolant that forms the thermal structure of the combustion wave. The propagation of an exothermic transformation wave in a mixture of condensed fuel with an inert component during filtration through a fluidized bed in the presence of an active group of oxidizers and OH° radicals leads to the so-called "superadiabatic" heating. They arise due to the fact that the released heat is not carried away with the reaction products through the pipe into the atmosphere, as in traditional combustion methods, but is concentrated in the combustion zone, which allows a significant increase in temperature in it and ensures complete burnout of flue gases. The ease of implementation and the highest efficiency of superadiabatic heating processes in combination with filtration combustion is fundamentally different from other combustion processes (destruction of matter), and in the presence of an abundant amount of OH ° radicals, they form avalanche chain reactions with high reactivity and oxidizing ability, capable of triggering self-sustaining thermochemical reactions.

[0010] The device for high-temperature plasma destruction of solid and liquid waste according to the invention comprises a reactor (incinerator) with an inlet for leading waste material into the intertior of the reactor and an outlet for leading created gas and/or heat towards a device for recovery of the resulting heat into simultaneous production electricity and/or green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere.

[0011] Said reactor has a reactor shell, lined with a convection tubes for toroidal gas convection, heat exchanger for cooling the reactor bottom, ceramic protection layer and the high temperature shield and thermal insulation provided on the top of the shell provided with the inlet. On the opposite end from the inlet the reactor is provided with a grate and an ash drip tray. In the central part of the reactor three zones are provided, namely a gasification zone, a high-temperature fluidized bed and a boundary zone inbetween the gasification zone and the fluidized bed. The fluidized bed zone with high temperatures in the range from 1500 and higher, also higher than 2000 °C, is exposed to an outlet of a device for generation of high-temperature reactive gas flow from water vapour (i.e. plasma reactor), which provides hydrogen, oxygen and hydroxyl radicals to the highly heated waste material in the fluidized bed, thus leading to oxidation and consequently destruction of waste material as well as any potentially toxic compounds, vapour, gas or byproduct. Namely, during destruction of various materials including waste, dioxins, furans and other potentially toxic compounds are formed. These compounds are also destructed by the temperature of 1800 ° and above as well as the highly reactive gas mixture produced by the plasma reactor, thereby leading to complete destruction of waste without emission gases. This is a process of filtration combustion at ultrahigh temperatures.

[0012] During the treatment in the reactor formed emission gases are flowing in one direction, which is downwards, so they have to pass through the fluidized bed. Furthermore, the gas streams due to the grate may be recirculated inside the reactor until the complete destruction of any harmful gases. The final processed gases are then led from the reactor towards a user, which may be a steam generator, a hydrogen producing device, etc. Due to leading away the gases, there is no pressure in the combustion chamber in the reactor. Rather, there is a negative pressure, i.e. a vacuum.

[0013] The device for generation of high-temperature reactive gas flow from water vapour (plasma reactor) may be any device that ensures that the water as fuel is transformed into the resulting gas flow, which comprises hydrogen, oxygen and hydroxyl radicals, which may be further separated based on needs of users, systems and subsequent processing.

[0014] All produced heat may be used for the production of water steam, which can be further split into hydrogen and oxygen, thus producing green hydrogen as a commercial product, while the oxygen may be used for optional ozonation of incoming waste material or for operation of the reactor.

[0015] In a preferred embodiment, hot gases from the reactor enter the vortex cyclone through the pipeline. In said cyclone ash and slag fractions are separated from the exhaust gases, while the heat may be further used with subsequent recovery of the resulting heat into simultaneous production electricity and green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere and bottom ash in accordance with the EPA standard. For example, the gas flow enters a steam boiler, the hot gas recovery boiler generates steam to rotate the turbine, with subsequent recovery and condensation of the exhaust steam through the condenser-recuperator back into the water supply system to the steam boiler. Next, the superheated steam from the steam boiler enters the steam turbine, the turbine rotates the generator, which in turn generates electricity (power transformer). The system allows for the disposal of 30 tons of garbage per day to generate up to 2 MW of electricity.

[0016] The method for high-temperature plasma destruction of solid and liquid waste comprises at least the following steps:

a) Waste in any form is created, preferably hazardous industrial emission or various waste,
b) Waste is led to a hopper, where it is combined and shredded
c) Optionally waste is treated with ozone
d) Waste is led to a reactor, where it is exposed to high-temperatures and highly reactive gases comprising oxygen, hydrogen and hydroxyl radicals, where all waste and flue gases are oxidized and destroyed,
e) Optionally heat is recuperated as electricity and/or hydrogen is produced by using the generated heat to produce superheated water steam from which hydrogen can be purified using suitable filters and membranes.

[0017] The device and the method according to the invention are characterized in that:

- The movement of gas flows in the reactor is enabled by the toroidal design of the structure of gas exchange pipes, which are located behind the reactor vessel and form toroidal convective flows of gasification products;
- The exit of flue gases occurs downwards, from under the grate;
- Flue gases from the reactor are sucked off by a special heat pump turbine and pass through the entire system, followed by cooling and purification of gases in a plasma-chemical reactor;
- The lower part of the grate is active, rotates and is used to remove the lower fluidized bed;
- The reaction zone consists of three layers, the fluidized bed zone, the boundary layer, and the gasification zone.
- The fluidized bed zone is actively purged with a hydrogen-oxygen mixture, which is produced only from water by splitting water vapor into hydrogen oxygen and OH hydroxyl radicals.
- The nozzles for forcing the hydrogen-oxygen mixture are located along the entire circumference of the fluidized bed and create a vortex turbulent flow in the area of the fluidized bed.
- Due to the pumping out of gases by the flue pump, the turbine creates a negative pressure in the reactor.
- The design of the reactor does not allow flue gases and combustion products to leave the reactor without participating in the processes of thermochemical degradation reactions.
- The nozzles for introducing superheated steam into the reactor are, by their design, a plasma torch, thereby forming a plasma jet up to 5.000 °C with a sharp thermal wave gradient up to 1 m.
- The internal walls of the reactor in the high temperature zone are protected by a reflector screen made of resistant materials, such as high-temperature tungsten carbide alloys.
- The upper grate and the active lower grate are made of resistant materials, such as high-temperature alloys of tungsten carbide and titanium oxide.
- The ash collection area under the grate is protected by a protective screen with a high-temperature ceramic plate lining.
- The zone of fuel supply to the reactor consists of a sealed sluice, consisting of a hydraulic seal blocking the access of gas from the reactor to the zone of fuel supply.
- The two-chamber vortex cyclone provides separation of solid slags and bottom ash from emission gases.
- Post-combustion of gas emission takes place in a heat recovery steam boiler with an active supply of a steam hydrogen-oxygen mixture.
- A specially designed plasma-chemical reactor, operating on the principle of resonance of electromagnetic fields and high-voltage corona discharge, produces a high-energy highly reactive hydrogen-oxygen mixture from superheated steam, which creates plasma-chemical processes in the zone of thermochemical reactions and afterburning of exhaust gases.
- Due to the tightness of the reactor, atmospheric air is not allowed into the combustion process, all oxidizers and combustion reagents are forced in and produced from steam.

[0018] The main principle of the process of high-temperature plasma-chemical destruction of matter is the principle of superadiabatic filtration combustion, resulting in complete combustion of flue gases with subsequent recovery of the resulting heat into simultaneous production electricity and green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere and bottom ash in accordance with the EPA standard. The invention ensures the destruction and removal of 99.99% of all major hazardous components, and for the most hazardous organic components of toxic waste, such as PCDD, PCDF and PCBs, destruction and destruction by 99.9999%.

[0019] The present invention is suitable for disposal or destruction of solid and liquid municipal waste, sludge from industrial, petrochemical, coal, organic agricultural wastes with a high content of non-combustible components, biological sewage treatment plants, meat processing waste and other solid waste, as well as any vapor-gaseous, liquid hazardous waste, including low-calorie waste in terms of the content of combustible components. The invention ensures utilization of various above-mentioned wastes without an expressed need for grinding them, without limiting them in terms of moisture, without using additional fuel, without environmental restrictions on the use of ash residue.

Brief description of drawings

[0020] The invention will be described in further detail based on exemplary embodiments and figures, which show:

Figure 1	The device for high-temperature plasma destruction of solid and liquid waste with shown zones of treatment
Figure 2	The device for high-temperature plasma destruction of solid and liquid waste
Figure 3	Scheme of a combustion wave with super-adiabatic heating. The flow of solid material from top to bottom, the gas flow is fed from the side of the reactor into the fluidized bed. The high-temperature combustion zone is shown with a lighter background colour
Figure 4a	The device for generation of high-temperature reactive gas flow from water vapour (plasma reactor) according to a first embodiment
Figure 4b	The device for generation of high-temperature reactive gas flow from water vapour (plasma reactor) according to a second embodiment
Figure 5	Schematic diagram of a plasma chemical plant with subsequent generation of electricity and hydrogen
Figure 6	Temperature (T) and concentration profiles (Soh - gaseous oxidizer, Cf - solid propellant) of the filtration combustion wave in the case of equal heat capacity of the counter fluxes of solid and gas phases. The arrow indicates the direction of gas flow. In this case, the resulting hydrogen, oxygen and OH ° radicals act independently; under conditions of strong ionization and high temperature, the radicals exhibit special oxidizing properties. Having one or two unpaired electrons, the radicals of the hydroxyl group exhibit the highest chemical reactive oxidative activity. They enter into oxidative reactions with products of combustion and gasification, thereby splitting the molecules of matter in the course of the reaction, creating chain avalanche reactions, forming irreversible oxidative destructive processes. As a result, dioxins, furans, and other dangerous toxic gases are destroyed.
Figure 7	Cylindrical diffusion membrane filter for preparation of hydrogen

Detailed description of the invention

[0021] As shown in figures 1 and 2 the device for high-temperature plasma destruction of solid and liquid waste according to the invention comprises a reactor with an inlet for leading waste material into the intertior of the reactor and an outlet for leading created gas and/or heat towards a device for recovery of the resulting heat into simultaneous production electricity and/or green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere.

[0022] The inlet comprises a hopper 1 in its bottom provided with a grinder or a shredder 2 for grinding waste material. A shutter is provided between the hopper 1 and the reactor, wherein the shutter comprises a shutter frame 3, a hydraulic cylinder 4 and a feed hopper shutter 5. Below this a guide cone 6 for leading waste into the reactor is provided, wherein the guide cone area is thermally insulated to prevent losing heat in the reactor. The loading to the reactor may have more than one hydraulic pistons, wherein one is driven by a hydraulic drive, while the second counter hydraulic piston actuates a loading hatch, which blocks access to the lock of gas flows from the reactor, ensuring tightness. The raw material loading guide cone 6 has thermal insulation 9, thereby preventing the propagation of a thermal wave in the upper part of the reactor cover, which also serves as thermal reflectors and a swirler for the upper internal gas flows.

[0023] The shredder 2 may be combined with a pre-ozonation device, which contributes to the partial displacement of atmospheric air from the supply zone to the reactor, and pre-treatment with ozone of the feedstock fed to the reactor. For this, an additional device for ozone treatment is used, which receives ozone from atmospheric air, or from oxygen obtained by filtering (separating) superheated steam. Ozone is known for its high oxidizing properties; at the preliminary stage of ozonation, it penetrates into the depth of the crushed raw materials. Ozone is a heavier gas, displacing atmospheric air upwards, filling with it the piston feed zone into the reactor

[0024] Said reactor has a reactor shell 7, lined with a convection tubes 8 for toroidal gas convection, a heat exchanger 10 for cooling the reactor bottom, ceramic protection layer 12 and the high temperature shield 11 made from high-temperature alloy (tungsten carbide, titanium oxide) and thermal insulation 9 provided on the top of the shell where the guide cone 6 is installed. On the opposite end from the inlet the reactor is provided with a grate comprising an upper static part 14 and a rotatable lower part 13, which facilitates discharge of the lower fluidized bed 7, wherein the lower grate 13 is movable due to a shaft 17 of the grate, a motor 16, preferably a reduction ger motor for lower grate shaft rotation, and upper and lower bearings 18, 19 for supporting the shaft of the grate. The bottom of the reactor is provide an ash drip tray 15. The lower part 13 of the grate is movable, it rotates around its axis, dropping the spent as part of the fluidized bed into the ash tray 15, thereby ensuring the movement of all processed fuel (garbage) down the process, this makes it possible to systematically regulate the processes occurring in the boiling zone 22.

[0025] In the central part of the reactor three zones are provided, namely a gasification zone, a high-temperature fluidized bed 22 and a boundary zone inbetween the gasification zone and the fluidized bed. The fluidized bed zone with high temperatures in the range from 1500 and higher, also higher than 2000 °C, is exposed to an outlet of a device for generation of high-temperature reactive gas flow from water vapour (i.e. plasma reactor), which provides hydrogen, oxygen and hydroxyl radicals to the highly heated waste material in the fluidized bed, thus leading to oxidation and consequently destruction of waste material as well as any potentially toxic compounds, vapour, gas or byproduct. Namely, during destruction of various materials including waste, dioxins, furans and other potentially toxic compounds are formed. These compounds are also destructed by the temperature of 1800 ° and above as well as the highly reactive gas mixture produced by the plasma reactor, thereby leading to complete destruction of waste without emission gases. This is a process of filtration combustion at ultrahigh temperatures.

[0026] Figure 3 shows a scheme of a combustion wave with superadiabatic heating. The flow of solid material from top to bottom, the gas flow is fed from the side of the reactor into the fluidized bed. The high-temperature combustion zone is shown with a lighter background colour. Due to the fact that almost any fuel initially contains chemically inert impurities (for example, ash as a product of combustion), the porous medium before the reaction zone is generally a mixture of condensed fuel with an inert material. Behind the combustion front, a porous residue containing ballast and condensed combustion products remains. The heat released in the reaction is transferred to the unreacted layers of the reactor with a lower temperature and initiates its own heat release in them, resulting in a self-sustaining process of propagation of the reaction wave. Due to the heterogeneous interaction of a solid fuel with a gaseous oxidizer, both condensed and gaseous products can be formed in the filtration combustion wave. Depending on the ratio of the heat capacities of the phase flows (the product of the specific heat and the mass velocity of the phase), a stable combustion wave front is formed when the heat capacity of the condensed phase flow is greater than the heat capacity of the gas phase flow and the reaction zone goes ahead of the boundary layer of the convective heat transfer wave.

[0027] Figures 4a and 4b show two embodiments of the plasma reactor. The device for generation of high-temperature reactive gas flow from water vapour (plasma reactor) is divided into four stages (sections, sectors) of water vapor treatment, wherein the main reagent is water and water vapor and wherein the resulting gas flow comprises hydrogen, oxygen and hydroxyl radicals, which may be further separated based on needs of users, systems and subsequent processing. The plasma reactor comprises:

- a first sector comprising at least:
    - ◦ a vaporization device, preferably comprising a reservoir for water, a highpressure compressor and an ultrasonic nozzle for vaporization of said water,
    - ◦ a pipe, preferably a pipe twisted by a bifilar winding method of a spiral from titanium or tungsten carbide, for leading the water vapor, and
    - ◦ a heater to heat the water vapor and obtain superheated water vapor at temperature higher than 400 °C, wherein said heater is an inductor or a burner burning natural gas,
- a pipeline for leading the superheated water vapor from the first sector to a second sector,
- the second sector comprising a device for generating turbulent flow, preferably a swirler to create a swirling flow of superheated water vapor,
- a third sector comprising a plasma-chemical flow reactor comprising multilayer electrodes, i.e., cathodes and anodes, wherein preferably the cathode has a 2-3 mm thick quartz glass or ceramic insulation and the anode is a metal string or a metal plate made of stainless-steel, titanium or nichrome with jagged protrusions of a special geometry, and a power supply arranged to apply high-voltage direct impulse current of 18.000-60.000 kilovolts to the cathode and anode, that causes splitting of water vapor into hydrogen, oxygen and hydroxyl radicals,
- a fourth sector comprising:
    - ◦ a porous medium, which comprises a wire or shavings of tungsten carbide,
    - ◦ an inductor coil extending from the third sector

to the fourth sector, and

◦ a power supply, arranged to perform a continuous steam combustion, which occurs with the release of a large amount of heat, the resulting heat of the hot reaction gases moving further along the reactor tube enter the first sector towards an outlet, and

- the outlet for leading the obtained highly reactive high-temperature gas mixture to a point where it is needed.

[0028] Furthermore, in the third sector of the device can be arranged to allow the gas mixture to be filtered using suitable filters in order to obtain pure hydrogen and oxygen gases stored in separate tanks. The pipelines installed downstream of said filters may be provided with compressors to control the intensity of the gas flow. In an alternative embodiment of the device, the first and fourth sector may be combined to form a joint sector.

[0029] The method for generation of high-temperature reactive gas flow from water vapour with the plasma reactor comprises the following steps:

a) supplying water to a vaporization device to create water vapor,
b) generation of a superheated water vapor with a temperature higher than 400 °C by heating
c) leading the superheated water vapor to a device for generating turbulent flow, preferably a swirler to create a swirling flow of superheated water vapor,
d) leading the turbulent flow of superheated water vapor to a plasma-chemical flow reactor comprising several layers of cathodes and anodes,
e) applying high-voltage direct impulse current of 18.000-60.000 kilovolts to the cathodes and anodes to cause an avalanche corona discharge, said avalanche corona discharge also causing at least one inductive coil to create an electromagnetic filed,
f) creating a high-energy, high-temperature highly reactive gas mixture comprising hydrogen, oxygen and hydroxyl radicals due to splitting of the water molecules under the influence of temperature, electromagnetic field and avalanche corona discharge as the intermolecular static bonds of the water molecule are split,
g) and preferably leading the high-energy, high-temperature highly reactive gas mixture obtained in the previous step to a heated porous medium boiling zone and combusting atomic hydrogen and atomic oxygen to release heat to propel the gas mixture towards the outlet.

[0030] The method also allows a step in which the gas mixture is separated into hydrogen and oxygen by separation through membrane filters. The filtration may be performed with selective membranes made of alloys based on palladium (Pd), preferably obtained by rolling. Efficient membranes with an ultrathin layer of palladium coated with ruthenium or silver may be used to filter hydrogen due to their improved hydrogen permeability.

[0031] In a possible embodiment of the method, steps a and b may be combined to perform vaporization and heating together in one step. Additionally, a branch pipe may be provided for the removal of the gas stream split into hydrogen and oxygen, which is directed to the active membrane separator, in which separation takes place gas flow into hydrogen and oxygen with a hydrogen purity of 99.999%. For this purpose, the method in addition or instead of step g) further comprises the following steps:

h) the membrane with high hydrogen permeability is first heated by passing a pulsed electric current through it at a certain frequency,
i) heating of the gas mixture to increase the diffusion capacity of the gas is performed, wherein due to the heating of the membrane element containing the catalyst with superheated steam, upon contact with the gas mixture, hydrogen molecules H_2 are split and H atoms pass through the crystal lattice of the membrane, followed by the formation (recombination) of H_2 molecules,
j) pumping the hydrogen through a nozzle by a compressor into a suitable storage tank, wherein the remaining oxygen is also pumped through a second nozzle by a second compressor in a second storage tank.

[0032] Additionally, an ultrasonic wave may be created inside the membrane filter chamber at the resonance frequency of the water molecule, which additionally creates an excited environment and significantly contributes to the intensification of the process.

[0033] During the treatment in the reactor formed emission gases are flowing in one direction, which is downwards, so they have to pass through the fluidized bed. Furthermore, the gas streams due to the grate may be recirculated inside the reactor until the complete destruction of any harmful gases. The final processed gases are then led from the reactor towards a user, which may be a steam generator, a hydrogen producing device, etc. Due to leading away the gases, there is no pressure in the combustion chamber in the reactor. Rather, there is a negative pressure, i.e. a vacuum. The entire movement of the gas mission is allowed by the operation of a thermal pump 25, which creates a rarefied medium in the reactor and determines a given forced flow of emission gases.

[0034] The intensity of plasma-chemical combustion processes is controlled by the supply of an oxidizers originating from the superheated steam that has been processed in the plasma reactor 23, and optionally by the supply of additional oxygen obtained as a result of the separation of superheated steam through a special membrane 24. The flows of oxygen gases and the treated superheated steam are mixed in an injection mixer equipped with a special valve that prevents ignition of the vapor-gas mixture supplied inside the pipeline and is equipped with a nozzle 26 for supplying the step mixture into the reaction zone of the fluidized bed 22 along the grate at an angle of 30°. Said nozzles are directed tangentially along the body, which creates a circular vortex flow (which additionally creates electrostatic discharges around the grate. Said nozzles are made of a high-temperature alloy, they act as a purge of the combustion zone of the fluidized bed with a hydrogen-oxygen mixture. The temperature may therefore reach 3.000° C (combustion temperature of HHO gas) and more. This mode is used to dispose of the most hazardous waste. A softer mode is provided by adjusting the intensity of dissociation of water vapor into hydrogen and oxygen in the plasma-chemical reactor 23, there are several options for supplying gas to the fuel mixture. Thus, an ionized vapor-gas mixture saturated with hydrogen, oxygen, ozone, and radicals of the hydroxyl group OH ° 100 % is sold into the reaction (combustion) zone derived from water. To increase the oxidizing properties of oxygen, additional ozonation of oxygen is possible by-passing oxygen through the ozone providing device, as mentioned above. It is known that the oxidizing properties of ozone are three times higher than oxygen, and have higher reactivity.

[0035] From the reactor hot gases through the pipeline 27 enter the vortex cyclone 26 where ash and slag fractions are separated from the exhaust gases, while the heat may be further used with subsequent recovery of the resulting heat into simultaneous production electricity and green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere and bottom ash in accordance with the EPA standard. For example, the gas flow enters a steam boiler 31, the hot gas recovery boiler generates steam to rotate the turbine, with subsequent recovery and condensation of the exhaust steam through the condenser-recuperator back into the water supply system to the steam boiler. Next, the superheated steam from the steam boiler 31 enters the steam turbine 32, the turbine rotates the generator 33, which in turn generates electricity (power transformer) 34. The system allows for the disposal of 30 tons of garbage per day to generate up to 2 MW of electricity.

[0036] Figure 5 shows a schematic diagram of a plasma chemical plant with subsequent generation of electricity and hydrogen. In addition to the above described device for destruction of waste and the plasma reactor the plant further comprises a PEM proton exchange membrane oxygen and hydrogen separation membranes 24, 25 provided downstream of the plasma reactor. Vortex cyclone 26 is used for collection and granulation of ash residue, which is collected in the collector 29. A steam boiler 31 with a secondary after burning system of reactor combustion products with hydrogen-oxygen mixture is connected to the pipeline leading from the cyclone 26, wherein a nozzle 30 is provided for leading hydrogen-oxygen mixture to the steam boiler. A steam turbine 32 is connected to the steam boiler 31, followed by an alternator 33, a power transformer 34. Hydrogen may be supplied to the plant also from additional reservoirs 36 and/or hydrogen compressor 35. A vacuum pump 37 installed at the outlet is provided to provide vacuum conditions for the combustion.

[0037] Figure 6 shows temperature (T) and concentration profiles (Soh - gaseous oxidizer, Cf - solid propellant) of the filtration combustion wave in the case of equal heat capacity of the counter fluxes of solid and gas phases. The arrow indicates the direction of gas flow. In this case, the resulting hydrogen, oxygen and OH ° radicals act independently; under conditions of strong ionization and high temperature, the radicals exhibit special oxidizing properties. Having one or two unpaired electrons, the radicals of the hydroxyl group exhibit the highest chemical reactive oxidative activity. They enter into oxidative reactions with products of combustion and gasification, thereby splitting the molecules of matter in the course of the reaction, creating chain avalanche reactions, forming irreversible oxidative destructive processes. As a result, dioxins, furans, and other dangerous toxic gases are destroyed.

[0038] The preferred embodiments of the invention include separation of hydrogen and oxygen, which may be achieved with a device for separating hydrogen and oxygen from steam. The most effective method for deep filtration of hydrogen-containing gases is filtration with selective membranes made of alloys based on palladium Pd. Existing membrane elements based on palladium alloys Pd obtained by rolling. Efficient membranes with an ultrathin layer of palladium coated with ruthenium or silver have been developed and implemented in order to increase its hydrogen permeability, as well as full-sized reinforced filters for industrial use and high-performance plants based on them for hydrogen production. The main method for obtaining films with a given selective structure, phase composition, and surface morphology is magnetron sputtering. Said device is essentially an active metal membrane, i.e. a cylindrical diffusion membrane filter shown in figure 7. It comprises:

- An inlet for a gas mixture and an output for releasing hydrogen, wherein between said inlet and output the following is provided
- A filter,
- a housing with a filter membrane connected to a voltage transmission bus insulated by an insulator at the connection to the inlet,
- and A DC power supply to ensure heating of the membrane.

[0039] For best results, the membrane element is first heated by passing a pulsed electric current through it at a certain frequency. Heating of the gas mixture (to increase the diffusion capacity of the gas) is not required, because in this system we have a large amount of superheated steam and the reactor cooling system 10. Due to the heating of the membrane element containing the catalyst with superheated steam, upon contact with the gas mixture, hydrogen molecules are split, and H atoms pass through the crystal lattice of the membrane element, followed by the formation (recombination) of hydrogen molecules. To prevent sticking of oxygen molecules and atoms on the inner working surface of the membrane filter, an ultrasonic wave is created inside the membrane filter chamber at the resonance frequency of the water molecule, which additionally creates an excited environment and significantly contributes to the intensification of the process. All other components of the gas mixture are not able to overcome the membrane barrier due to the significant size of their molecules, they pass further, are pumped out of the working zone of the membrane filter and pumped into a storage cylinder. In this case, this is oxygen, which is subsequently used for oxidative processes in the reactor. Thus, the purity of the released hydrogen is 99.999% and the efficiency of the membrane filter. Then the resulting hydrogen is pumped into the storage tank and can be used for any purpose.

[0040] The method of waste destruction with the device as described above is the following. From the moment the reactor enters the operating mode, thermodynamic equilibrium is instantly established in the reaction zone. Thus, it happens that the products of gaseous emission leave the reaction zone at the maximum combustion temperature. This is extremely important from the point of view of the subsequent generation of hydrogen and electricity. To create a highly efficient superadiabatic filtration reactor, it is necessary to create a highly effective thermal insulation of the reactor walls, in which case the heat loss through the reactor walls will be insignificant relative to the thermal power generated in the plasma-chemical reaction zone, heat losses through the reactor walls can be neglected. The removal of heat from the reactor occurs due to the forced flow of hot reaction products. There is no conductive heat removal from the ends of the reactor. All generated heat is a valuable product, used to produce superheated steam for hydrogen production by membrane filtration, as well as to generate electricity by converting steam energy in a steam turbine into mechanical energy to rotate a generator. The efficiency of superadiabatic combustion is largely due to the recovery of heat flows, the heat recovery from combustion products to the initial reagents unequivocally leads to an increase in temperature and is adiabatic for a given gas mixture. In fact, due to intense interfacial heat transfer, in a closed system, the temperature of the initial components entering into the reaction significantly exceeds the temperature and approaches the temperature of the combustion front. The thickness of the thermochemical reaction zone can be considered small compared to the total thickness of the heated layer including the gasification zone, so the reaction zone is a break in the fluidized bed with infinite rates of chemical reaction and heat transfer, limited by the upper boundary layer separating the fluidized bed and the gasification zone. In the presence of a gaseous oxidizing agent (hydrogen, oxygen, OH° radicals) water vapor, it reacts with the carbon surface at a high temperature above 800 °C. The product is enriched with hydrogen and carbon monoxide, the efficiency tends to the maximum value. Adding carbon dioxide to a gaseous oxidizer works similarly. Thus, endothermic reactions most effectively create a thermal wave gradient locally, which reduces the thermal stress of the structure. The efficiency of the general thermal front in the zone of chemical reactions the efficiency of gasification approaches 100%.

[0041] In the reaction zone, the reagents are completely consumed, complete burnout of the fuel from the condensed phase and complete consumption of the oxidizer supplied in excess, supplied with the gasifying agent. The formation of CH4 during carbon gasification can be neglected, since it is important mainly during gasification at a pressure above atmospheric pressure.

[0042] It is in the superadiabatic mode that the efficiency of recuperation can be as high as possible, and it is precisely in the presence of a sufficiently large amount of inert material (creating a fluidized bed) in the solid fuel and a sufficiently high content of the inert component in the gaseous oxidizer. This is due to the fact that with such an organization of the process, the inert components of the system are a very effective heat carrier, due to which both the fuel and the oxidizer can be heated with maximum efficiency before entering the chemical reaction zone. The solid fuel is heated from the gaseous products of combustion, and the gaseous oxidizer is heated from the ash residue and the solid inert component, which is systematically removed mechanically by the lower grate 13. The most effective feature of combustion waves in this system is the non-linear dependence of the temperature of the steady-state combustion wave on the thermal effect of the reaction front. With counterflows of oxidizer and fuel, such an important characteristic as the burning rate, under the condition of high temperature, is determined not by the heat transfer rate, but only by the flow of reagents into the combustion zone (filtration rate). In addition, in front of the combustion zone the high-temperature region of the most efficient flow of the main chemical reactions responsible for the thermal regime of the process, there is usually a reducing zone of the boundary layer with a large amount of fuel and a sufficiently high temperature, which contributes to a more complete consumption of the gaseous oxidizer, below the combustion zone, on the contrary, a zone with a high content of the oxidizer, which, in the presence of high temperatures, ensures complete combustion of the material.

[0043] This makes the filtration combustion process extremely stable and very efficient in practical applications, especially when:

- it is required to o burn any type of fuel with a low fuel content, or to neutralize hazardous waste, with a small expenditure of energy.
- high combustion temperatures are needed,
- it is aimed to achieve maximum completeness (pu-

rity) of combustion of solid and gaseous fuels,

- it is required to carry out in the reactor the spatial separation of the zones of heating, pyrolysis, evaporation, oxidation, condensation, cooling, etc.

[0044] Energy costs are minimized due to efficient heat recovery in the filtration superadiabatic combustion wave.

[0045] Optimization of heat transfer by equalizing the heat capacity of the oncoming flows of the gas and solid phases makes it possible to organize effective gasification processes of low-grade low-calorie, in particular high-ash or high-moisture, fuel raw materials. Thus, the requirements for the quality of fuel raw materials are sharply reduced. With a countercurrent of solid fuel and gaseous oxidizer, intensive internal heat exchange occurs between products and reagents without the use of additional devices;

- the heat released in chemical reactions is concentrated in a relatively narrow combustion zone, which makes it easy to control and manage the reaction processes, the products leaving the reactor are non-hazardous, fully reacted, have a high temperature.
- in the reactor are self-trapped. In each zone, physical and chemical processes take place in accordance with the conditions (temperatures, properties of the medium, fuel raw materials, concentrations of reagents). This makes it easy to organize the processes of isolating valuable components, or to completely destroy the raw material without smoke (cleanly), and also to effectively carry out several technological processes simultaneously in one device (reactor).
- If it is necessary to carry out additional purification of gaseous emissions from sulfur, chlorine or fluorine compounds, dust, mercury vapor, it is easier to purify the gaseous product than flue gases due to the low temperature, significantly lower volume and lower concentration of pollutants, in addition, sulfur is present in the product in reduced forms (H_2S , COS), which are much easier to absorb or absorb than SO_2 , organochlorine compounds under high-temperature pyrolysis in a reducing hydrogen-containing atmosphere, mostly partially, are dehydrochlorinated, forming HC1, which is much better than Cl_2.
- During gasification, nitrogen-containing organic compounds are partially decomposed in an oxygen-free environment (above the boundary layer), due to which the content of nitrogen oxides in flue gases is minimal.
- the cleanest method of combustion of all known, due to the high completeness of combustion, flue gases contain extremely little CO and residual hydrocarbons, including carcinogenic polyaromatic ones.

[0046] OH ° hydroxyl radicals, the formation of dioxins, polychlorinated dibenzodioxins and dibenzofurans, is sharply reduced, since, even in the presence of chlorine in a preliminary diffuse flame, OH ° radicals suppress the appearance of soot particles and aromatic compounds in flue gases predecessors dioxins and provides a low content of dust particles of catalysts for the formation of dioxins in flue gases. The ash unloaded from the reactor has a low temperature and does not contain unburned carbon and organic substances, it is well granulated and can be used for construction purposes.

Claims

1. A device for high-temperature plasma destruction of waste, **characterized in that** the device comprises at least a reactor with an inlet for loading waste material into the interior of the reactor and an outlet, wherein

   - said reactor has a reactor shell (7), lined with a convection tubes (8) for toroidal gas convection, a heat exchanger (10) for cooling the reactor bottom, ceramic protection layer (12) and the high temperature shield (11) made from high-temperature alloy of tungsten carbide and titanium oxide, and thermal insulation (9) provided on the top of the shell where the guide cone (6) is installed,
   - on the opposite end from the inlet the reactor is provided with:

     ◦ a grate comprising an upper static part 14 and a rotatable lower part 13, which facilitates discharge of the lower fluidized bed 7, wherein the lower grate 13 is movable due to a shaft 17 of the grate, a motor 16, preferably a reduction gear motor for lower grate shaft rotation, and upper and lower bearings 18, 19 for supporting the shaft of the grate, and
     ◦ an ash drip tray,

   - in the central part of the reactor three zones are provided, namely a gasification zone, a high-temperature fluidized bed and a boundary zone inbetween the gasification zone and the fluidized bed, wherein the fluidized bed zone with high temperatures in the range from 1500 and higher, is exposed to an outlet of a device for generation of high-temperature reactive gas flow from water vapour (plasma reactor), which provides a highly reactive gas mixture comprising hydrogen, oxygen and hydroxyl radicals to the highly heated waste material in the fluidized bed, thus leading to oxidation and consequently destruction of waste material as well as any potentially toxic compounds, vapour, gas or by-product,

- wherein flue gases are led downwards with a heat pump and leave the reactor under the grate (13).

2. The device according to claim 1, wherein nozzles for supplying the higly reactive gas mixture from the plasma reactor are located along the entire circumference of the fluidized bed and create a vortex turbulent flow in the area of the fluidized bed.

3. The device according to any of the preceding claims, wherein the inlet comprises a hopper 1 in its bottom provided with a grinder or a shredder 2 for grinding waste material, and a shutter provided between the hopper 1 and the reactor, said shutter comprising a hydraulic seal blocking the access of gas from the reactor to the inlet.

4. The device according to any of the preceding claims, wherein below the inlet a guide cone 6 for leading waste into the reactor is provided, wherein the guide cone area is thermally insulated to prevent losing heat in the reactor.

5. The device according to any of the preceding claims, wherein the shredder 2 is combined with a pre-ozonation device for pre-treatment with ozone of the waste loaded into the reactor.

6. The device according to any of the preceding claims, wherein the plasma reactor is divided into four sectors of water vapor treatment, wherein the main reagent is water and water vapor and wherein the resulting gas flow comprises hydrogen, oxygen and hydroxyl radicals, wherein the plasma reactor comprises:

- a first sector comprising at least:

◦ a vaporization device, preferably comprising a reservoir for water, a highpressure compressor and an ultrasonic nozzle for vaporization of said water,
◦ a pipe, preferably a pipe twisted by a bifilar winding method of a spiral from titanium or tungsten carbide, for leading the water vapor, and
◦ a heater to heat the water vapor and obtain superheated water vapor at temperature higher than 400 °C , wherein said heater is an inductor or a burner burning natural gas,

- a pipeline for leading the superheated water vapor from the first sector to a second sector,
- the second sector comprising a device for generating turbulent flow, preferably a swirler to create a swirling flow of superheated water vapor,
- a third sector comprising a plasma-chemical flow reactor comprising multilayer electrodes, i.e., cathodes and anodes, wherein preferably the cathode has a 2-3 mm thick quartz glass or ceramic insulation and the anode is a metal string or a metal plate made of stainless-steel, titanium or nichrome with jagged protrusions of a special geometry, and a power supply arranged to apply high-voltage direct impulse current of 18.000-60.000 kilovolts to the cathode and anode, that causes splitting of water vapor into hydrogen, oxygen and hydroxyl radicals,
- a fourth sector comprising:

◦ a porous medium, which comprises a wire or shavings of tungsten carbide,
◦ an inductor coil extending from the third sector to the fourth sector, and
◦ a power supply,

- arranged to perform a continuous steam combustion, which occurs with the release of a large amount of heat, the resulting heat of the hot reaction gases moving further along the reactor tube enter the first sector towards an outlet, and
- the outlet for leading the obtained highly reactive high-temperature gas mixture to a point where it is needed.

7. The device according to the preceding claim, wherein in the third sector of the device can be arranged to allow the gas mixture to be filtered using suitable filters in order to obtain pure hydrogen and oxygen gases stored in separate tanks.

8. The device according to any of the preceding claims, wherein the gas mixture is separated into hydrogen and oxygen by separation a device for separating hydrogen and oxygen from steam comprising membrane filters.

9. The device according to the preceding claim, wherein filtration is performed with selective membranes with an ultrathin layer of palladium coated with ruthenium or silver may be used to filter hydrogen due to their improved hydrogen permeability.

10. The device according to the preceding claim, wherein the membrane filter comprises:

- An inlet for a gas mixture and an output for releasing hydrogen, wherein between said inlet and output the following is provided
- A filter,
- a housing with a filter membrane connected to a voltage transmission bus insulated by an insulator at the connection to the inlet,
- and A DC power supply to ensure heating of the membrane.

11. The device according to any of the preceding claims, wherein the device is further provided with a device for recovery of the resulting heat into simultaneous production electricity and/or green hydrogen in compliance with environmental requirements for emissions of pollutants into the atmosphere.

12. The device according to the preceding claim, wherein the gas flow enters a steam boiler, the hot gas recovery boiler generates steam to rotate the turbine, with subsequent recovery and condensation of the exhaust steam through the condenser-recuperator back into the water supply system to the steam boiler, and wherein the superheated steam from the steam boiler enters the steam turbine, the turbine rotates the generator, which in turn generates electricity.

13. The device according to any of the preceding claims, wherein waste is selected in the group comprising solid and liquid municipal waste, sludge from industrial, petrochemical, coal, organic agricultural wastes with a high content of non-combustible components, biological sewage treatment plants, meat processing waste and other solid waste, as well as any vapor-gaseous, liquid hazardous waste, including low-calorie waste in terms of the content of combustible components.

14. A method for high-temperature plasma destruction of solid and liquid waste comprising at least the following steps:

a) waste in any form is created, preferably hazardous industrial emission or various waste,
b) waste is led to a hopper, where it is combined and shredded,
c) optionally waste is treated with ozone,
d) waste is led to a reactor, where it is exposed to high-temperatures and highly reactive gases comprising oxygen, hydrogen and hydroxyl radicals, where all waste and flue gases are oxidized and destroyed,
e) optionally heat is recuperated as electricity and/or hydrogen is produced by using the generated heat to produce superheated water steam from which hydrogen can be purified using suitable filters and membranes.

15. Use of the device in disposal or destruction of solid and liquid municipal waste, sludge from industrial, petrochemical, coal, organic agricultural wastes with a high content of non-combustible components, biological sewage treatment plants, meat processing waste and other solid waste, as well as any vapor-gaseous, liquid hazardous waste, including low-calorie waste in terms of the content of combustible components.

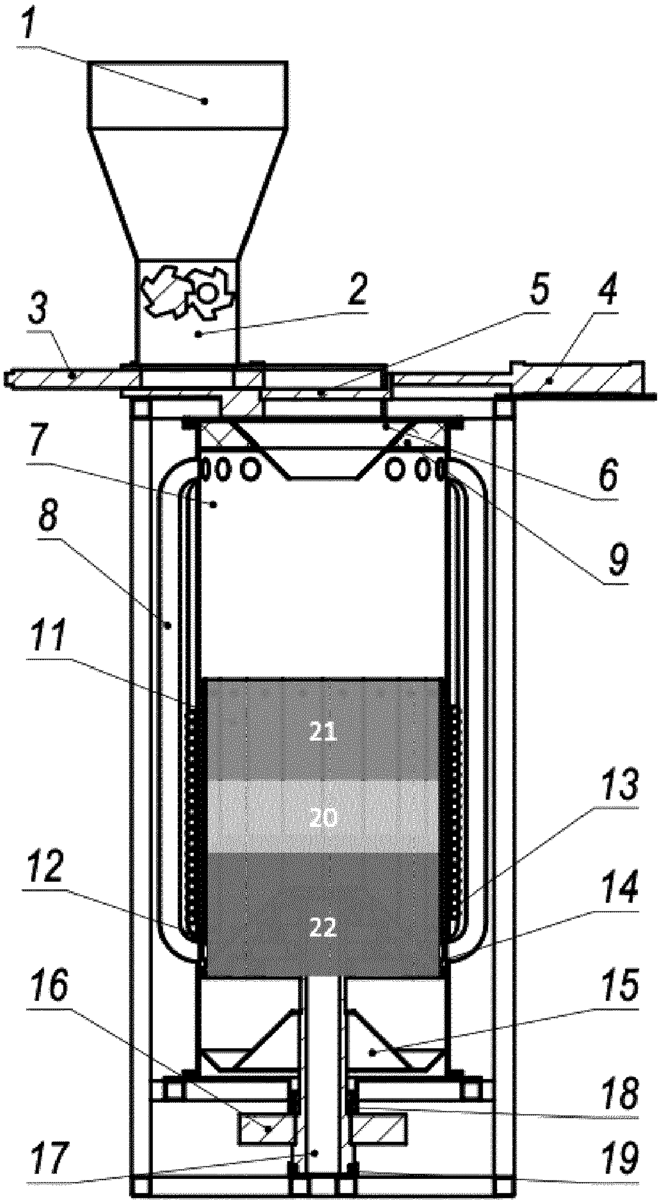

Figure 1

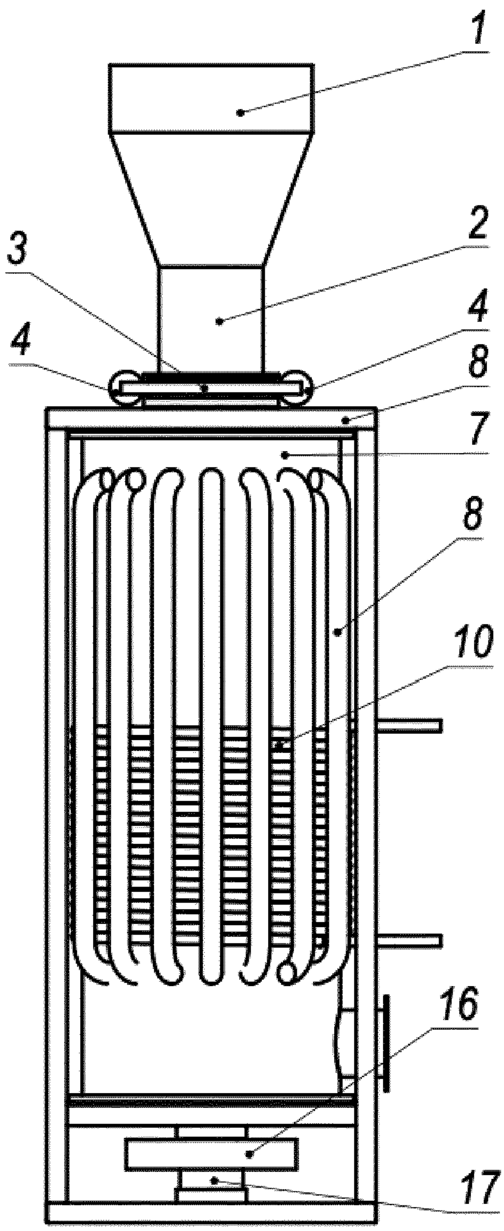

Figure 2

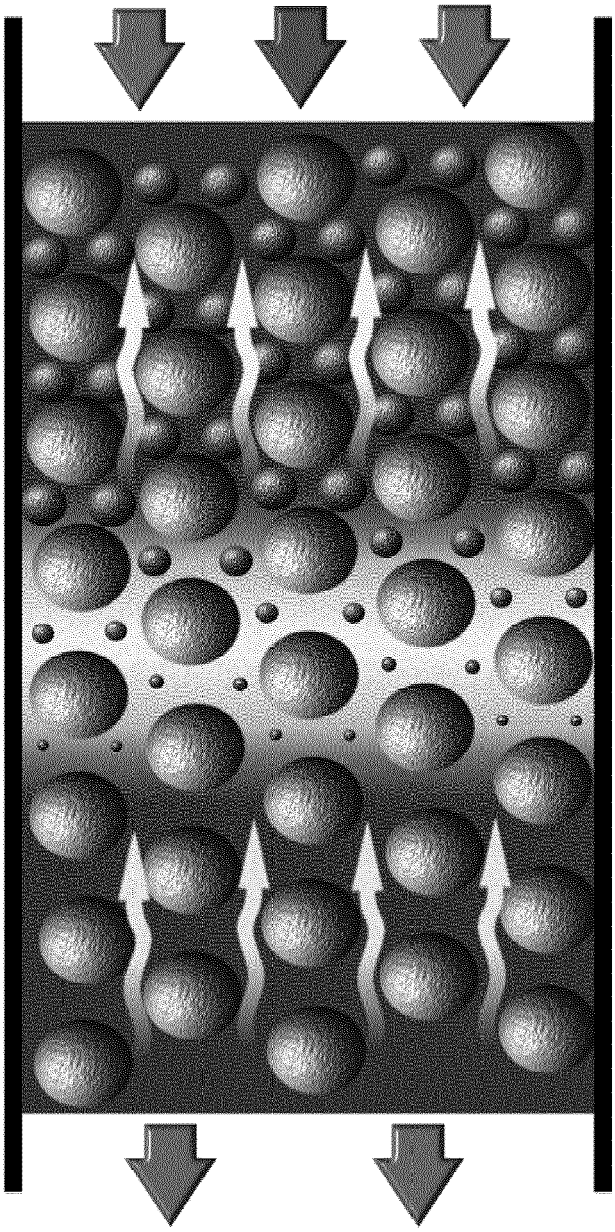

Figure 3

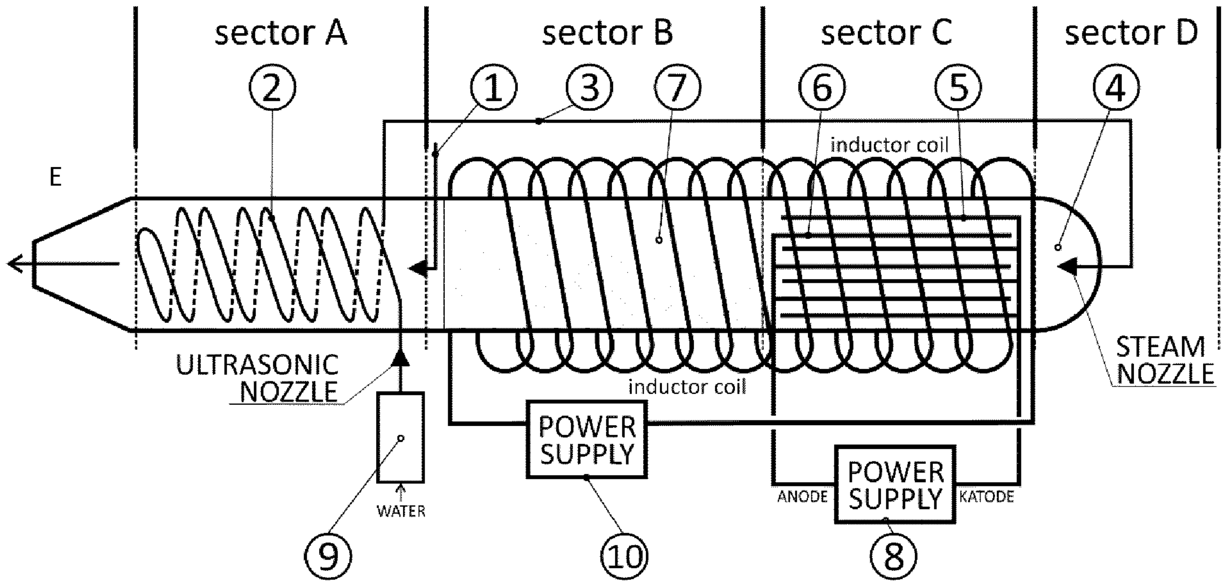

Figure 4a

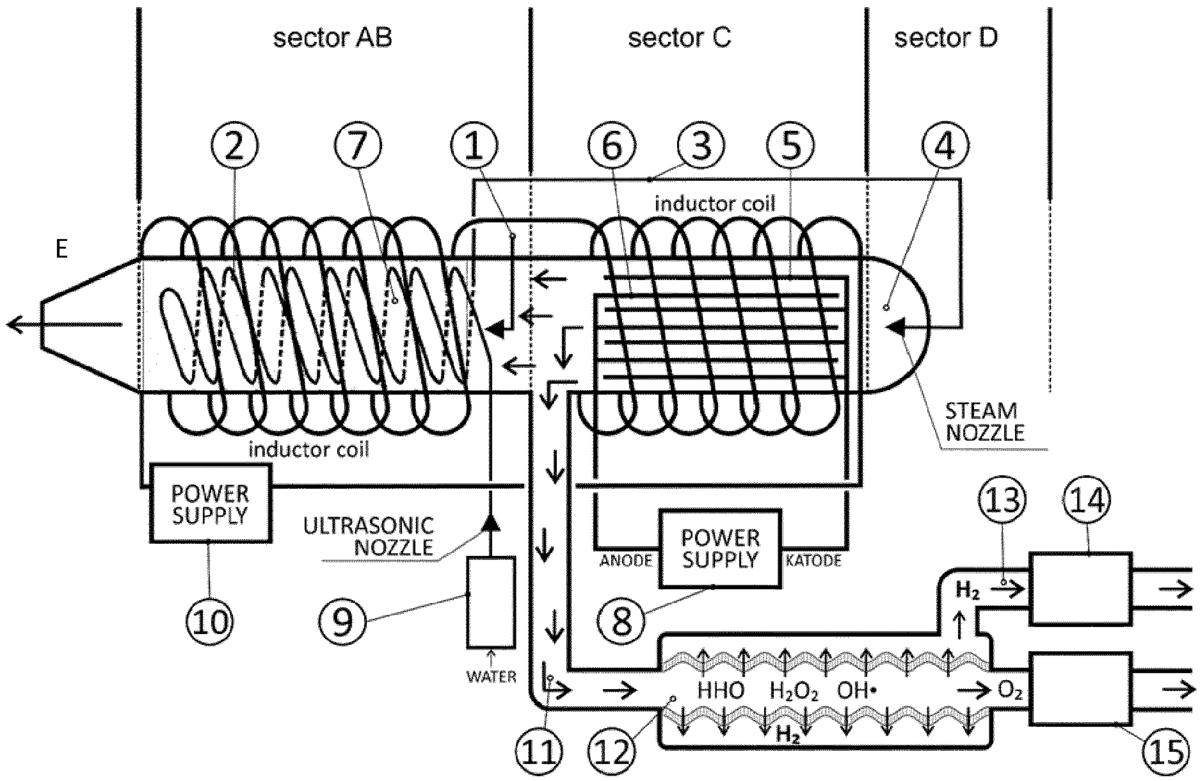

Figure 4b

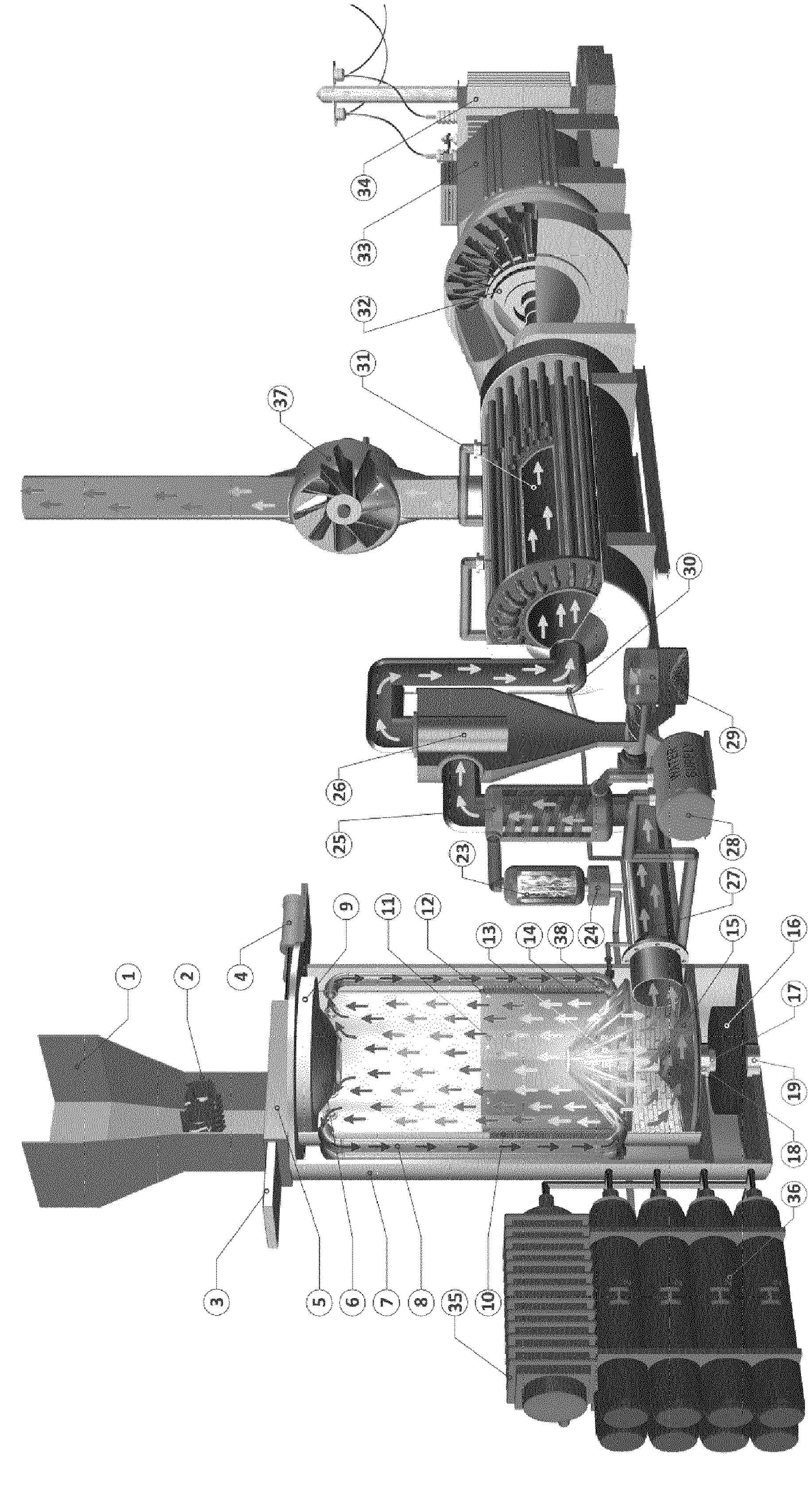
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Figure 5

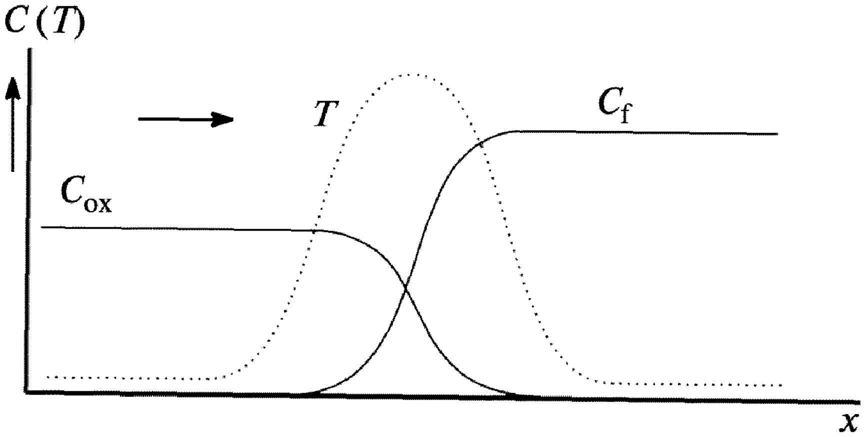

Figure 6

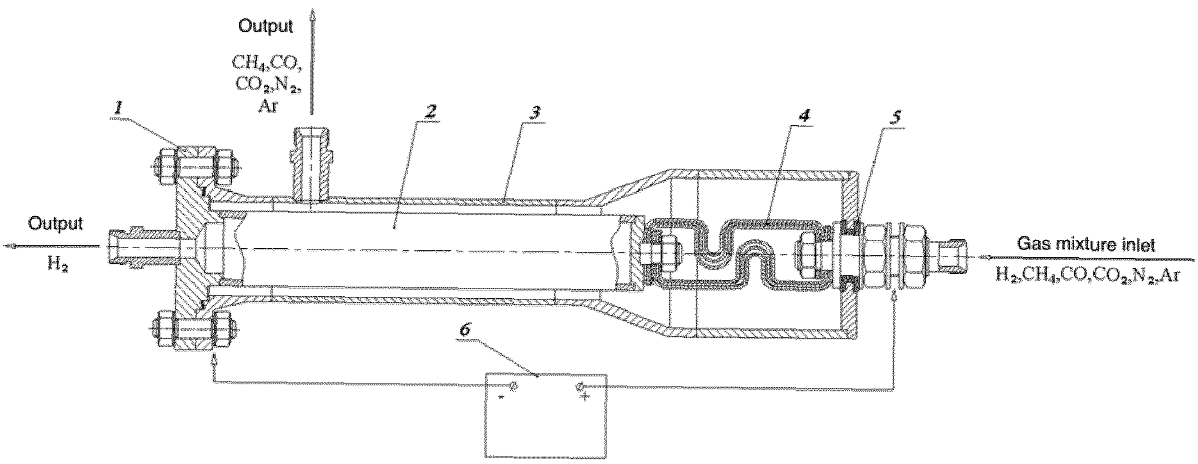

Figure 7

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EUROPEAN SEARCH REPORT

Application Number
EP 23 16 8619

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	US 2007/199485 A1 (CAPOTE JOSE A [CN] ET AL) 30 August 2007 (2007-08-30) * paragraph [0002] - paragraph [0061]; figures 2,3 *	14,15 1-13	INV. F23G5/08 F23G5/30
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F23G

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	10 October 2023	Theis, Gilbert

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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