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(54) Benævnelse: **FREMGANGSMÅDE TIL KEMISK-BIOLOGISK RENSNING AF RØGGASSER SAMT BIOREAKTOR OG ANLÆG TIL GENNEMFØRELSEN HERAF**

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Description

The present invention relates to a method for the chemical-biological cleaning of exhaust gases, wherein compounds contained in the exhaust gases and accruing as emissions are determined with regard to the chemical composition thereof and the amount thereof in the exhaust gas and are broken down in at least one reactor chamber of a bioreactor, in which a biofilm comprising at least one type of microorganism suitable for breaking down the organic compounds has settled on an inert carrier material, wherein the inert carrier material and the biofilm are humidified, by means of at least one humidification device, with an aqueous treatment liquid which is mixed with the microorganisms and with nutrients for the latter in a fermenter.

In addition, the invention relates to a bioreactor for the chemical-biological cleaning of exhaust gases, in particular for carrying out a method of the type mentioned above,

- comprising at least one reactor chamber, in which compounds contained in the exhaust gas and accruing as emissions are broken down,
- comprising an inert carrier material, which is located in the reactor chamber and on which a biofilm comprising at least one type of microorganism suitable for breaking down the organic compounds has settled,
- comprising at least one humidification device, by means of which the carrier material and the biofilm are humidified with an aqueous treatment liquid which contains the microorganisms and nutrients for the latter.

Finally, the invention relates to a plant for the chemical-biological cleaning of exhaust gases, in particular for carrying out a method of the type mentioned above, and/or including a bioreactor of the type mentioned above,

- comprising a detection device, in which compounds contained in the exhaust gases and accruing as emissions are determined with regard to the chemical composition thereof and the amount thereof in the exhaust gas,
- comprising a bioreactor, which comprises at least:

a reactor chamber, in which the compounds contained in the exhaust gas and accruing as emissions are broken down,

an inert carrier material, which is located in the reactor chamber and on which a biofilm comprising at least one type of microorganism suitable for breaking down the organic compounds has settled, at least one humidification device, by means of which the carrier material and the biofilm are humidified with an aqueous treatment liquid which contains the microorganisms and nutrients for the latter,

- and comprising a fermenter, in which the aqueous treatment liquid is mixed with the microorganisms and with the nutrients.

According to the prior art, exhaust gases contaminated by organic substances having components in gas and/or vapour form are preferably cleaned by thermal or conventional biological methods. Plants using combustion technology are challenging or problematic due to the high ongoing operating costs associated with the use of natural gas. Biological exhaust gas cleaning plants are characterized in particular by the extremely large volume of the plant and problematic waste disposal. This method is based on a settling of bacteria on usually organic carrier substances. The pollutants to be destroyed are destroyed in their vapour phase to the extent that they come into contact with the assimilated bacteria. The disposal of the biomass residues - mostly wood chips - resulting from the biological breakdown takes place at intervals of on average three to five years and requires analysis and testing in accordance with the Ordinance on Biological Agents ("Biostoffverordnung").

A method, a bioreactor and a plant of the type mentioned in the introduction are known from EP 0 933 121 A1. The introductory part of said document also contains an extensive description of the use of known biological systems in the cleaning of exhaust air, with a distinction being made in particular between three types of biosystems: biofilters, bioscrubbers, and trickling filter bioreactors.

Especially for biofilters, a description of the process fundamentals, the design and various known embodiments can be found in VDI Guideline VDI 3477, edition 11/2004, "Biological exhaust gas cleaning, biofilters". Since, in biofilters, the cultures of the microorganisms whose metabolic processes, referred to as metabolization, bring about the exhaust gas cleaning have developed on the carrier materials, which are made of organic material, the involvement of the exhaust gas components in the metabolization is often unsatisfactory because it is generally merely a case of random chemical reactions of the pollutants with the microorganisms on the carrier, the microorganisms taking their nutrients also - and in some cases disadvantageously primarily - from the organic carrier material. In addition, particularly when such biofilters are installed outside, disadvantageously no clearly determinable temperature control in the reactor is possible. Among other things, it is clear from the aforementioned guideline that plants comprising biofilters are characterized in particular by comparatively large volumes and by a waste disposal that is sometimes problematic, said waste disposal taking place at intervals of three to five years and requiring special analysis and testing in accordance with the Ordinance on Biological Agents ("BioStoffV, Verordnung über Sicherheit und Gesundheitsschutz bei Tätigkeiten mit biologischen Arbeitsstoffen" of 27.01.1999, additions/amendments of 25.11.2003, 23.12.2004, 31.10.2006, 06.03.2007, 18.12.2008).

EP 0 933 121 A1 deals with the problem of ensuring a biological breakdown of volatile organic compounds in a satisfactory and economical manner even in the case of gas emissions from multiple and/or multifunctional chemical production units. To this end, the gas emissions at each production unit are captured individually and, depending on the chemical and toxicological nature thereof, are specifically treated in different, separate technological units, such as in an adsorber, in a scrubber, and in a first and in a second biological trickle-bed reactor. In each of these two biological trickle-bed reactors, the carrier material and the biofilm are continuously sprinkled with percolation water in a downward flow, the percolation water flowing off is collected as a pump sump and is recycled via a line which contains a recirculating pump and which leads to the upper end of the biological trickle-bed reactor, a metered amount of nutrients and often microorganisms being added to the percolation water depending on requirements. By way of example, phosphates, ammonium salts, sodium salts and potassium salts and also trace elements such as calcium, iron, manganese, zinc, boron, cobalt, copper, nickel and molybdenum are therefore preferably added to the percolation water circuit in metered amounts, depending on periodic analysis results. To this end, according to EP 0 933 121 A1, a suitable nutrient solution that has a fixedly preset composition is metered into the pump sump or into the line leading to the head end.

Biological trickle-bed reactors, also referred to as biological trickling filters or as percolation biofilters, as provided in EP 0 933 121 A1, use immobilized microorganisms on particulate or structured - in contrast to biofilters - mineral or synthetic carriers. A mixture of air and the gas to be treated flows through the carriers, which are in each case arranged as a fixed bed, in counter-current or in co-current relative to the trickling water. The flow of the trickling water results from a continuous recirculation of the percolation liquid. Trickling filter bioreactors are also described in detail in VDI Guideline VDI 3478, sheet 2, draft April 2008, "Biological exhaust gas cleaning, biological trickle-bed reactors" and are suitable for cleaning both solventladen and odour-laden exhaust air having emission concentrations of up to approximately 1 g/m^3.

The reactor known from EP 0 933 121 A1 is designed in such a way that the gas emissions can be passed through the biological trickle-bed reactor in an upward flow or in a downward flow, i.e. in co-current or counter-current relative to the flow direction of the percolation water. The exhaust air inlet and outlet systems, arranged respectively in the head end and in the lower region of the bioreactor, are preferably designed in such a way that the flow direction is reversed at intervals, i.e. the exhaust air can be passed through the bioreactor alternately in a downward flow or in an upward flow. The aim of this is to enable a lower susceptibility to clogging, as well as higher densities and a more uniform distribution of the biomass fixed on the carriers. Although the technical solution known from EP 0 933 121 A1 has a number of advantageous features, it must nevertheless be regarded as complicated in terms of apparatus due to the different technological treatment units and plant sections required, and is also in need of improvement with regard to its process efficiency.

A bioreactor of the type mentioned in the introduction is also known in various embodiments from US 6 479 276 B1. This describes a reactor having two separate chambers, through which the exhaust gas flows. In one embodiment, it is provided that the reactor chamber is formed by two interconnected chambers, through which exhaust gas can successively flow. The first chamber is designed as a trickle-bed reactor ("trickling filter unit") and contains only biologically inert fillers, while the second chamber is designed as a "real" biofilter ("biological filter unit") in the sense of the above definition according to the VDI guideline since it contains compost as a biologically active medium. The two chambers are located in their own housings, the second housing additionally being vertically subdivided internally.

Finally, DE 10 2011 100 093 A1 describes a method, a bioreactor and a plant of the type mentioned in the introduction. It is provided in this case that the treatment liquid is passed through the fermenter in recirculation, each of the nutrients being metered separately into the fermenter depending on the chemical composition and the amount of the compounds contained in the exhaust gas. In the known plant, therefore, it is provided that the return line for recirculating the treatment liquid is first conducted with a first portion into the fermenter and from there is conducted with a second portion to the humidification device, which is located in the reactor chamber above the inert carrier material.

DE 199 28 087 A1 discloses a filter plant for biological cleaning of exhaust air and exhaust gas, in which the exhaust gas to be treated is conducted into an air humidification and nutrient solution container. The exhaust gas to be treated is in this case first conducted via a first supply air line into an air humidification chamber of the air humidification and nutrient solution container and is humidified there by means of an air-humidifying spray device. An air stream having a moisture content of 80-98% is conducted via a second supply air line into a humidification chamber of a biofilter above a filter filling and, after flowing through the latter, is conducted via a connecting line back into the air humidification and nutrient solution container.

In the aforementioned prior art, the following situations in particular appear to be in need of improvement.

According to DE 10 2011 100 093 A1, the surface area required to set up a biological exhaust gas cleaning device or plant is defined by a system that provides for using cuboid overseas shipping containers. Also in the context of implementing the aforementioned VDI guideline - as described in the introduction - excavated pits of large surface area are used as reaction chambers, these being lined with concrete. This results in a disadvantageously large surface area being required. In said document, the humidification of solid substrates takes place by spraying and/or sprinkling. In particular, the nutrient solutions are pumped or metered separately onto the surface of the substrate during operation. Separate metering of the nutrients is one advantageous way of selectively controlling the pollutant breakdown process, but is complicated in terms of control technology.

The problem addressed by the present invention is that of providing a method of the type described in the introduction and also a bioreactor and a plant for carrying out such a method, the aim being to ensure a high degree of efficiency and functionality of the method, reactor and plant while requiring less space or surface area and with little complexity in terms of technology and apparatus. In particular, the aim is for this to be achieved even in the case of compositions of the exhaust gases to be cleaned that change with regard to the pollutant content. In order to achieve the highest possible efficiency, the aim is in particular also to provide for controlling and adjusting the reaction kinetics of the chemical-biological metabolization processes of the microorganisms, in particular of bacteria used as such, in a way that is less complicated in terms of process and measurement technology.

According to the invention, this is achieved in respect of the method in that the exhaust gas is humidified with the treatment liquid before entering the bioreactor such that already humidified exhaust gas enters the reactor chamber.

In this case, the humidification of the exhaust gas is carried out in the fermenter by bringing a controlled amount of the exhaust gas into contact with the treatment liquid in the fermenter container. The exhaust gas thus serves as a carrier for the treatment liquid, which consists of water, phosphorus salts, nitrogen compounds and optionally chemical auxiliaries, such as solubilizers, since the treatment liquid passes from the fermenter into the reactor chamber together with the exhaust gas flow that acts as a liquid carrier.

The chemical nutrient solution (treatment liquid) necessary for the microorganisms may be introduced into the reactor chamber steadily and continuously or quasi-continuously or else in portions, wherein to this end preferably a specially designed control flap is used in the fermenter container. This control flap may in particular be at least partially perforated and may be controllable in such a way that the exhaust gas is at least partially conducted through the treatment liquid by the control flap.

Accordingly, the problem addressed by the invention is solved according to the invention in respect of the bioreactor in that the fermenter is a container which is arranged upstream of the reactor chamber in the flow direction of the exhaust gas such that the exhaust gas enters the reactor chamber through the fermenter, the exhaust gas being humidified with the aqueous treatment liquid in the fermenter.

The introduction of the treatment liquid into the reactor chamber by the exhaust gas may take place on the one hand by way of a vapour content contained therein - depending on the moisture uptake capacity of the exhaust gas at a particular temperature – and also by way of droplets which are entrained when passing through the fermenter. To increase the uptake of moisture, the exhaust gas may in particular be conducted at least partially through the treatment liquid. The treatment liquid may in this case be set in turbulence or swirled by the gas, resulting in a large “gas/liquid” contact surface area. From this point of view, it is advantageous if the exhaust gas has a flow rate of at least 7 m/s as it enters the fermenter.

Any excess treatment liquid present in the bioreactor will drip from the bioreactor back into the fermenter. If necessary, the treatment liquid may also be fed back into the fermenter from the bioreactor via an overflow line that is optionally present, while the exhaust gas flows through the bioreactor vertically from the bottom upward.

Before it enters the reactor chamber, the stream of the exhaust gas coming from the fermenter container may advantageously be divided into a plurality of partial streams by means of an air distributor which protrudes into the reactor chamber, said air distributor also being referred to as a diffuser in the context of the present application. As a result, the exhaust gas is uniformly distributed in the reactor chamber and no preferential flow channels are formed in the inert carrier material, while the biofilm barely comes into contact with the exhaust gas in other regions of the reactor chamber.

Advantageously, therefore, according to the invention, both the necessary humidification and the supplying of nutrient salts for the reaction process are carried out simultaneously, by the air stream, in particular by directly combining, in a manner preferred in the context of the invention, the reactor chamber with the fermenter, which at the same time also serves as an air humidifier and air scrubber. In this case, constant conditions can advantageously also be set with regard to the humidification and the supply of reaction components for the metabolization.

The temperature of the humidified exhaust gas can in this way advantageously be controlled or adjusted by controlling the temperature of the treatment liquid, wherein in particular a temperature in the range from 30°C to 70°C is set in the reactor chamber via the humidified and temperature-controlled exhaust gas, and wherein preferably the temperature of the treatment liquid can be controlled by a heater arranged in or on the fermenter, such as for example by heating pipes and/or by a heating jacket.

In one particularly preferred embodiment, it may be provided that the chemical composition and the amount of the compounds contained as emissions in the exhaust gas before and after the cleaning of the exhaust gas are compared with one another and/or with a specified reference value, and control signals for humidifying and controlling the temperature of the exhaust gas are formed therefrom.

In this way, it is possible to provide for controlling and adjusting the reaction kinetics of the chemical-biological metabolization processes of the microorganisms in a way that is less complicated in terms of process and measurement technology, by which the highest possible efficiency of the method according to the invention can be ensured even when the composition of the exhaust gases to be cleaned changes with regard to the pollutant content. In this case, in contrast to DE 10 2011 100 093 A1, it may advantageously be provided that the nutrients are metered into the treatment liquid in a mixture at a fixedly preset ratio with respect to one another, i.e. not separately from one another. This reduces the control complexity.

Both the moisture content of the air and the temperature thereof, as well as the latent heat present in the exhaust gas stream, depending on the degree of humidification, and the flow rate of the gas stream, which influences the contact time with the microorganisms, have a regulatory effect on the metabolization. The volume flow of the exhaust gas may preferably lie in a range from 7000 m^3/h to 30000 m^3/h.

In other words, in one particularly preferred embodiment, the method according to the invention for chemical-biological cleaning of exhaust gases is therefore a method in which compounds contained in the exhaust gases and accruing as emissions are broken down in at least one reactor chamber of a bioreactor, in which a biofilm comprising at least one type of microorganism suitable for breaking down the organic compounds has settled on an inert carrier material, wherein the inert carrier material and the biofilm are humidified, by means of at least one humidification device, with an aqueous treatment liquid which is present in a fermenter/humidifier/scrubber together with the microorganisms and with nutrients for the latter and which, after passing through the diffuser, is conducted by the air stream into the reactor chamber and from there can be fed back into the fermenter/humidifier/scrubber, after passing back through the diffuser, by the excess liquid dripping back down, wherein, after the process of humidification in the container (fermenter/humidifier/scrubber), the treatment liquid enters the reactor chamber, after passing through the diffuser, by means of the exhaust gas air to be cleaned which serves as a carrier, with excess treatment liquid dripping back into the container.

By analogy with this embodiment of the bioreactor according to the invention, the problem addressed by the invention is solved in respect of the plant in that the detection device, in which the compounds contained in the exhaust gases and accruing as emissions are determined with regard to the chemical composition thereof and the amount thereof in the exhaust gas, is part of a device for controlling and/or adjusting a degree of humidification of the exhaust gas in the fermenter. By virtue of this adjustment, as already mentioned above, it is advantageously possible according to the invention to avoid an adjustment based on separately metering the nutrients to the treatment liquid. From a reservoir, nutrients can be metered into the fermenter in a mixture at a fixedly preset ratio with respect to one another. The known plants of the type described in the introduction are also improved by an advantageously possible vertical construction of the single-chamber bioreactor according to the invention. The surface area required for the biological exhaust gas cleaning plant according to the invention is thus considerably reduced.

Further advantages consist in that, while exhibiting ease of handling and user-friendliness, particularly when using premixed treatment liquid, maximum breakdown rates of the pollutants in the exhaust gas as well as low pure gas concentrations can be ensured, and, if use is made of inert fillings consisting of in particular inorganic substrates, such as lava rock or expanded clay, or also of porous plastic granules as a permanent filling, the use of organic substrates, such as bark humus and bark mulch, wood chips, heather or straw, as the carrier material can be avoided, as well as associated random reactions. As a result, a comparatively more highly defined reaction kinetics of the pollutant breakdown processes can be set, which can be continuously controlled via the humidification.

The last feature in particular distinguishes the invention from the biofilters that use immobilized microorganisms on natural organic carriers such as compost, peat, bark and the like, in any event - as described in US 6 479 276 B1 cited in the introduction - together with synthetic particles, such as polystyrene or polyvinyl chloride, or also together with inert materials, such as clay, activated carbon or pozzolana. Generally, a mixture of artificially humidified air and of the gas to be treated flows upward through these carriers, which are arranged as a bed in the container. Biofilters are only suitable for cleaning low concentrations of volatile organic compounds that fluctuate only a little in composition and concentration. These disadvantages do not occur according to the invention, even though according to the invention it is nevertheless possible to use bioreactors, the basic structure of which is known from biofilters. A rough distinction is made between compact biofilters, container biofilters and surface filters, depending on the design. All the aforementioned types can be found in open and closed designs. However, the open design is not preferred according to the invention since it does not enable any such temperature control of the kind that the invention provides as a preferred feature.

The invention differs from bioscrubbers, such as those described in detail in VDI Guideline VDI 3478, sheet 1, draft April 2008, “Biological exhaust gas cleaning, bioscrubbers” in that the treatment does not have to take place in multiple reaction units. Like the invention, bioscrubbers are largely used to treat water-soluble compounds by means of microorganisms, but these may be in the form of an activated sludge or in some cases also in an immobilized state. The method comprises the absorption of the soluble gaseous pollutants in the water, followed by the oxidation thereof in the liquid phase. In activated sludge-based bioscrubbers, in a manner similar to the invention, the absorption takes place in a scrubbing column containing carriers, or the gas is passed in counter-current through the mixture of water and activated sludge. However, the biological breakdown of the absorbed gas then typically takes place in a separate decanter with the aid of the microorganisms contained in the activated sludge. The fermenter provided according to the invention does not serve this purpose. In bioscrubbers with a fixed biomass, the gaseous pollutants are first absorbed in the water. The water thus loaded is then dispersed on the surface of a trickling filter bioreactor, where the dissolved pollutants are oxidized with the aid of the microorganisms fixed on the carrier bodies of the bioreactor. In terms of the method, therefore, a physico-chemical exhaust gas cleaning stage is linked with a biological exhaust gas cleaning stage. In contrast, the invention is very much less complicated in terms of both technology and apparatus.

The invention fully complies with the biological laws governing the metabolism of the microorganisms used; in the context of the application, metabolism or metabolization will be understood to mean the uptake, transport and chemical conversion of substances in the microorganisms used, as well as the release of metabolic end products into the environment. These biochemical processes serve on the one hand to build up and maintain the cell substances (constructive metabolism), and on the other hand to generate energy (energy metabolism) and thus to maintain the cell functions of the microorganisms. The biochemical reactions taking place during the metabolism are catalyzed and/or inhibited, i.e. accelerated or decelerated, by enzymes.

A reaction equation (1)

$$\text{pollutants, in particular } C_{\text{organically bound}} + O_2 \xrightarrow[\text{temperature}]{\text{bacteria}} CO_2 + H_2O + \text{cell substance} + \text{energy}$$

can be regarded as characteristic of the overall metabolization in the method according to the invention.

The heat effect of this equation is exothermic and runs in a temperature range between 5°C and 70°C. It is known that the rate of cell division of microorganisms used with preference is approximately 12 minutes at 20°C and is accelerated by increases in temperature. In addition to carbon and oxygen and the biomass of the cell substance, nitrogen and phosphorus are also involved as components in the metabolization process. A high rate of cell division and thus a high biomass yield of the reaction and pollutant conversion can thus be set.

Anabolism or anabolization will be understood to mean the metabolization processes that serve to construct endogenous components of the microorganisms. For instance, according to the invention, a biomass is built up from some of the pollutants through growth and multiplication of the microorganisms. In addition to the pollutants, this biomass also requires nutrients in order to build it up, such as for example nitrogen, phosphorus, sulphur and trace elements, as well as the water from the treatment liquid as the basis of life. Since the aforementioned chemical compounds can only be used by the microorganisms when they are dissolved in water, said microorganisms grow on the carrier material in a moist biological film or lawn, with a certain proportion of the microorganisms also remaining suspended in the aqueous solution. Since, according to the invention, the degree of humidification can be set to a desired value, in particular when passing through the fermenter, the metabolization can advantageously be controlled in a very subtle and differentiated manner.

The breakdown of more complex molecules to form simpler molecules is referred to as catabolism or catabolization. Catabolism is linked to anabolism by a coupling of energy. The energy obtained during catabolism is used during anabolism to build up more complex molecules, where catabolism and anabolism are to be understood as parts of metabolism. In the method according to the invention, during the chemical-biological cleaning of the exhaust gases, the pollutants, which may contain proportions of carbon and/or sometimes nitrogen or sulphur, are separated from the exhaust air and are oxidized by the microorganisms in the catabolic sub-processes, in the presence of oxygen, to form in particular carbon dioxide and water, wherein the energy released during the oxidation is used by the microorganisms as an energy source during the anabolic processes of the metabolism to build up the cell substance. At the same time, the energy supply can be controlled via the temperature of the treatment liquid in the fermenter.

In a stable biological system that is formed in the operating state of the bioreactor according to the invention after an initial adaptation time, there is then an equilibrium between dying and newly formed microorganisms, so that the amount of biomass in the reactor remains approximately constant. The immobilization of the microorganisms takes place through the capillary forces of the carrier, which for example is in the form of a granular material. As microorganisms in a colony die, new colonies settle on the space on the surface of the granular material capillaries. By means of a riser pipe, which is equipped with a pump and leads from the fermenter to the head of the bioreactor, dead microorganisms can also be flushed into the fermenter in an optional recirculation of the treatment liquid that takes place periodically, in particular for maintenance purposes, and can be discharged from the process via a sump drain in close proximity to the bottom.

When building up the cell substance, the nutrition of the microorganisms must be taken into account, wherein a distinction is made between phototrophy and chemotrophy with regard to the type of energy source (light or oxidation of chemical substances), a distinction is made between organotrophy and lithotrophy with regard to an organic or inorganic hydrogen donor that continues to be necessary, and between autotrophy and heterotrophy with regard to the carbon donor in the equation given above (carbon dioxide or organic substances). The specific conditions of the method according to the invention characterize it as chemotrophic, lithotrophic and organotrophic as well as heterotrophic.

In the method according to the invention, energy and hydrogen ions can be made available in a chemolithotrophic reaction, for example according to the following equation (2), for example from ammonium ions contained in the nutrients:

$$4\,NH_4^+ + 3\,O_2 \xrightarrow[\text{energy}]{\text{bacteria}} 2\,N_2 + 4\,H^+ + 6\,H_2O$$

Bacteria in particular, which are preferably used as microorganisms according to the invention, use chemotaxis via their flagella to act as a gatekeeper for hydrogen and carbon, which originate from the oxidations of the pollutant molecules acting as donors. This is the first step in a so-called primary metabolization that is to be used. Further stages of the metabolism then take place chemoorganotrophically.

During the processes of cell division of the microorganisms, adenosine triphosphate (ATP), which is more energy-rich, is formed by endogenous attachment of inorganic phosphate residues to adenosine diphosphate (ADP). Adenosine diphosphate (ADP) is a nucleotide consisting of the diphosphate of the nucleoside adenosine. When it reacts to form ATP, the bond between the second and third phosphate of the phosphate chain is dissolved, thereby consuming energy, and the substrate is phosphorylated.

ATP serves as an energy store, which stores approximately 40% of the energy released during catabolism, while the remaining approximately 60% of the energy released is still available for secondary and tertiary metabolizations and/or may also bring about an increase in temperature in the bioreactor. In the context of the invention, this can advantageously be counteracted, if necessary, by lowering the temperature in the fermenter through a reduced heating output. The temperature in the bioreactor can therefore advantageously be controlled or adjusted by controlling the temperature of the treatment liquid, taking into account the heat effect of the metabolization.

In particular, the heater used to heat the treatment liquid in the fermenter can be used to control the temperature. For instance, particularly when using so-called psychrophilic, psychrotrophic and/or mesophilic bacteria as microorganisms, a temperature in a preferred range from 30°C to 65°C can be set in the reactor chamber, which can be selected to be higher than the favourable temperatures for biofilters, which lie in the range from 15°C to 40°C (in exceptional cases from 8°C to 50°C) and thus increases the breakdown of pollutants.

The carbon bound organically in the pollutants, which is reacted with a proportion of oxygen from the exhaust gas during the metabolization of the bacteria under the present aerobic reaction processes according to the method, is thus the primary energy supplier for cell division, while nitrogen and phosphorus are involved in the conversion within the cell and thus considerably influence the reaction kinetics and the rate of reaction and thus the efficiency of pollutant breakdown.

A molar ratio of the three elements carbon, nitrogen and phosphorus to one another (C:N:P ratio, cnp value) is to be regarded as decisive with regard to the effectiveness of the breakdown performance that can be achieved during the biological-chemical exhaust gas cleaning. This ratio is influenced by nitrification/denitrification reactions that take place during the metabolization, and also by the phosphorylation of ADP and/or a dephosphorylation of ATP, during which energy is released. According to equation (3) below, an optimal molar ratio

C:N:P = 100:(5-8):1

is to be assumed as a reference value, but these optimal ratios are temperature-dependent and not constant and therefore can also be modified in a range (4) of

C:N:P = 100:2.5 to 7.5:0.2 to 3.0

in the premixed treatment liquid.

The pH value in the fermenter can also be adjusted, in particular by separate manual metering of suitable acidic or alkaline nutrients. The result of an analysis of the cleaned exhaust gases emerging from the bioreactor can also be used as an indicator as to whether such an optimal ratio is actually present in the bioreactor.

By means of metering processes and metering devices which are customary in the art, the nutrient agents required for the reactions that take place during the exhaust gas cleaning, in particular solutions of nitrate salts and phosphate salts, can be supplied as a mixture in an automated manner to the fermenter and then, according to the invention, from the latter to the process in the reactor chamber by means of the humidified exhaust gas as carrier, wherein oxygen and organically bound carbon are the energy suppliers for cell division, and nitrogen and phosphorus are involved in the conversion within the cell. The energy released in one cycle is required for the next cycle of cell divisions.

In detail, the method according to the invention may proceed for example as follows: Once the in particular cylindrical reaction chamber of the reactor space has been filled with substrates, the humidification and fermentation container is filled with supplied aqueous chemical solutions. This solution contains bacterial strains which, as stock, already undergo a pre-reaction in the fermenter with the chemicals in the solution. The bacterial cultures used are mixed with the necessary reaction components for the purpose of metabolization and, following the process of humidifying the exhaust gas in the fermenter/scrubber, are passed into the reactor. In this stage, the bacterial strains are immobilized by the capillary forces of the fillers/substrates. This is therefore not to be regarded as sessile assimilation - as is the case with organic fillers. After a colony dies, new bacterial colonies settle in the space on the surface of the granulate material capillaries. By means of the treatment liquid that is circulated for this purpose, the dead cell substance can also be collected using filter technology. Suitable cleaning possibilities are provided for this, such as the aforementioned sump drain and a discharge nozzle arranged thereabove that serves to pump out the treatment liquid. As they pass through the granular material and the capillaries thereof, the pollutants dissolved in the exhaust gas, especially organic solvents, accumulate on the watery, slimy surface of the bacterium. Hydrogen bridge bond forces, electrostatic forces or also Van der Waals interactions between the interfaces "bacterium - slimy transition layers - water - air – pollutants" act here. Some pollutants may exhibit very good solubility in water, others may exhibit only moderate solubility in water, and yet others may exhibit no solubility at all in water.

In order to be able to break down the substances mentioned in VDI 3479 that are not readily soluble in water, for example xylenes, toluene, acetic acid ethyl acetate or aliphatic hydrocarbons, these substances are mixed with additions of substances that are readily soluble in water. These may be added via a preferably closable feed opening of the fermenter for manual introducing the additives. By virtue of such additions, such as for example acetone, isopropanol or other alcohols or ketones, the biological breakdown rates are considerably improved and the effectiveness of the method according to the invention is further increased. This can be implemented in practice through the configuration of the apparatus of the bioreactor and of the system as a whole, which according to the invention are characterized in particular by ease of handling and a high degree of operating convenience.

The starting conditions for the reaction processes for gas cleaning can be suitably set directly in the region where the raw gas flows into the bioreactor. By heating the fermenter, a temperature of 50°C for example then prevails therein when the metabolism begins. This energy input starts and accelerates the metabolization.

Further advantageous embodiments of the invention are contained in the dependent claims and in the detailed description below.

The invention will be explained in greater detail on the basis of the exemplary embodiments, which are illustrated by the accompanying drawing, in which:

Fig. 1 shows a diagram of an embodiment of a plant according to the invention for chemical-biological cleaning of exhaust gases in accordance with the method according to the invention and using a bioreactor designed according to the invention, which is shown in section,

Fig. 2 shows, in an illustration corresponding to Fig. 1, a side view of the bioreactor designed according to the invention,

Fig. 3 shows a perspective illustration of a preferred embodiment of a fermenter of a bioreactor according to the invention,

Fig. 4 shows, in an illustration corresponding to Fig. 3, a side view of the fermenter,

Fig. 5 shows an enlarged detail from Fig. 4,

Fig. 6 shows a longitudinal section through a preferred embodiment of an air distributor of a bioreactor according to the invention,

Fig. 7 shows, in an illustration corresponding to Fig. 6, a perspective view of the air distributor,

Fig. 8 shows an enlarged detail of the bioreactor according to the invention from Fig. 1,

Fig. 9 shows a further enlarged detail from Fig. 8,

Fig. 10 shows a plan view of the bioreactor according to the invention as shown in Fig. 8,

Fig. 11 shows a further enlarged detail from Fig. 10,

Fig. 12 shows a perspective illustration of the detail shown in Fig. 11, enlarged even further.

In the various figures of the drawing, the same parts are always provided with the same reference signs and will therefore also usually be described only once. With regard to the following description, it is expressly emphasized that the invention is not limited to the exemplary embodiments and also not to all or several features of described combinations of features; rather, each individual sub-feature of the exemplary embodiment may also, per se, have inventive significance in isolation from all the other sub-features described in connection therewith.

As illustrated first of all in Figs. 1 and 2, a method according to the invention can be implemented in a plant 1 according to the invention for the chemical-biological cleaning of exhaust gases 2, in particular by means of a bioreactor 3 according to the invention.

The bioreactor 3 according to the invention, to which Figs. to 7 also relate, is a reactor 3 having a reactor chamber 4 formed of an in particular cylindrical chamber, through which exhaust gas 2 can flow, the exhaust gas 2 flowing through the bioreactor 3 vertically from a foot F at the bottom to a head K at the top. The invention makes it possible to minimize the installation space and also the complexity of manufacture, while providing the apparatus necessary for highly effective cleaning.

The method according to the invention may take place with a constant pollutant load and constant substance loads in the exhaust gas 2 or also under self-monitoring and control, with fluctuating compositions and concentrations of the pollutants occurring in the exhaust gas 2.

A central supply air blower M1 may be provided for overall gas circulation in the system 1, which blower, from a technological point of view, is arranged upstream of the bioreactor 3 and blows the exhaust gas 2 through the bioreactor 3.

The method according to the invention can advantageously be used to clean the exhaust gases 2 from municipal and industrial wastewater treatment plants, waste recycling plants, food processing plants, sludge drying plants or other disposal sites, biogas production plants, feed production plants, rendering plants, in slaughterhouses and also for odour-laden exhaust air from production facilities, especially exhaust gases 2 from coating plants or chemical plants, as well as to clean soil that is contaminated with volatile organic substances, for example following an accident. It can advantageously also be used to remove oil spills on bodies of water.

In the method according to the invention, compounds contained in the exhaust gases 2 and accruing as emissions are determined with regard to the chemical composition thereof and the amount thereof in the exhaust gas 2 and are broken down in at least one reactor chamber 4 of the bioreactor 3. In the bioreactor 3, a biofilm comprising at least one type of microorganisms suitable for breaking down the organic compounds has settled on an inert carrier material T.

Suitable carrier materials T are particulate or structured, mineral or synthetic carriers T having a high porosity and specific surface area. Use is made of materials which are inert, i.e. which have chemically indifferent properties and which are not suitable as an energy source for the metabolization process. Such carriers T are known per se, are commercially available, and are described for example in the VDI Guideline VDI 3478 mentioned above. The use of biological carrier materials, such as bark mulch or wood chips, can advantageously be avoided. As carriers T, particular consideration is given to lava granules or lava gravel or moulded plastic elements.

The chemical composition and the amount of the pollutants in the exhaust gas 2 can be determined by measurements or by computational determinations of the foreign substances in the exhaust gas. Measurements on the pollutants in the exhaust gases 2 serve to ascertain the pollutants according to their type and according to their concentrations. In the case of gases and vapours of organic impurities, for example, gas samples can be taken and these can be evaluated by gas chromatography. In the case of organic dusts, the proportions can be determined by gravimetric counting. In the case of plants to be planned with an unknown type of pollutant and unknown quantity, a calculation based on VDI 3479 (“Reducing emissions - refined mineral oil depots”) can be carried out for organic vapours. With regard to the quality, information can be given in mg/Nm^3 for each of the individual pollutants and, with regard to the quantity, in particular the mass flow of the organically bound carbon components can be given in kg C/h.

The carrier material T and the biofilm are humidified with an aqueous treatment liquid 6 by means of at least one humidification device 5, 7. According to the invention, it is provided that the exhaust gas 2 is humidified with the treatment liquid 6 before entering the bioreactor 3 such that already humidified exhaust gas 2 enters the reactor chamber 4. As shown, the humidification of the exhaust gas 2 is carried out in the fermenter 7 by bringing preferably a controlled amount of the exhaust gas 2 into contact with the treatment liquid 6 in the fermenter 7. The humidified exhaust gas 2 is thus conducted in the bioreactor 3 in co-current with the treatment liquid 6 which serves to humidify the inert carrier material T and the biofilm. Any excess treatment liquid 6 present in the bioreactor 3 may, however, also drip from the bioreactor 3 back into the fermenter 7 in the sense of a counter-current.

Besides the fermenter 7, which according to the invention serves as a humidification device 7 and also as a gas scrubber 7, the drawing shows a further humidification device 5, which is advantageously optionally present and which is located at the head K of the reactor chamber 4. This second humidification device 5 is used in particular for maintenance that takes place periodically, and is generally not used during the exhaust gas cleaning process that is continuously taking place, even though this would be possible in the sense of an additional humidification of the carrier material T. The second humidification device 5 is formed by a top end of a riser pipe 8 for the treatment liquid 6, which leads from the fermenter 7 to the head K of the reactor chamber 4 and is equipped with a pump M2. A baffle and distribution plate 9 for the treatment liquid 6, which is preferably made of steel, is arranged below the top end of the riser pipe 8, which serves as the humidification device 5, and above the inert carrier material T and the biofilm in the reactor chamber 4. Said plate may preferably cover 40% to 75% of the free cross-section of the reactor chamber 4 and advantageously evens out the flow of the treatment liquid 6, without having to use a nozzle system for this purpose.

A reservoir 10 for metering the treatment liquid 6 is connected to the fermenter 7. Said treatment liquid is preferably a premixed liquid consisting of microorganisms and nutrients, such as nitrogen donors, phosphorus donors, trace element suppliers and/or carbon suppliers, in particular starch, which can be introduced into the fermenter 7 through a line 11 by means of a pump M3.

In addition, a separate manual metering of auxiliary substances H may also be provided. For instance, Fig. 4 and Fig. 5 in particular show, on an enlarged scale, a preferably closable feed opening 12 for such auxiliary substances H, which is located in particular on the side of the fermenter 7 and makes it possible to introduce into the fermenter 7 solubility enhancers and/or additives for adjusting the pH, for example, depending on the chemical composition and the amount of the compounds contained in the exhaust gas 2. As a result, the biological breakdown rates can be further improved and the effectiveness can be increased.

The exhaust gas lines of the plant 1 according to the invention are assigned a detection device (reference sign “PID/FID”), in which the compounds contained in the exhaust gases 2 and accruing as emissions are determined with regard to the chemical composition thereof and the amount thereof in the exhaust gas 2. This is shown schematically in the plant 1 according to the invention shown in Fig. 1 and, for continuous or at least cyclic operation, is connected in-line as part of a controlling and adjusting device 13. The detection device FID/PID may in particular comprise a flame ionization detector FID or a photoionization detector PID. Depending on the signals from the detection device PID/FID and as a function of the chemical composition and the amount of the pollutants in the exhaust gas 2, a degree of humidification of the exhaust gas 2 in the fermenter 7 can be set by means of the controlling and/or adjusting device 13. A corresponding control and/or adjustment of the temperature in the fermenter 7 is thus advantageously also possible. The metabolization reactions in the reactor chamber 4 or even pre-metabolization reactions in the fermenter 7, such as the above-described primary metabolization in accordance with the above equation (2), can thereby be controlled. Advantageously, a programmable logic controller PLC may also be used to control and adjust the humidification of the exhaust gas 2 and/or the temperature in the fermenter 7 and/or in the reactor chamber 4 of the bioreactor 3. For instance, the chemical composition and the amount of the compounds contained as emissions in the exhaust gas 2 before and after the cleaning of the exhaust gas 2 can be compared with one another and/or with a specified reference value, and control signals for humidifying and controlling the temperature of the exhaust gas 2 can be formed therefrom according to a rule laid down in the PLC.

One specific feature of the embodiment shown is that a determination of the fluctuating concentrations and types of pollutants takes place by way of parallel measurements in the clean gas 2a (measuring point MP1) and in the raw gas 2 (measuring point MP2). It is therefore provided that, even in the cleaned exhaust gas 2a, after the latter has exited from the bioreactor 3, a further determination of the chemical composition and of the amount of any residual proportion of the compounds originally contained therein takes place. In the same way as in the raw gas 2, this may preferably take place using gas chromatography and/or by means of a flame ionization detector (FID) or a photoionization detector (PID) as write-type measuring devices. The measurements may be taken continuously in an online process or at least once per hour, with the respective measuring device delivering a reference signal relating to the proportion of organically bound carbon in the pollutants contained in the exhaust gas 2.

A flame ionization detector (abbreviation and reference sign in Fig. 1: FID) is a detector for organic compounds, which is used predominantly in connection with gas chromatographs (GC). The operating principle thereof consists in measuring the conductivity of an oxyhydrogen flame between two electrodes. Substances to be analysed are transported by a stream of carrier gas into the flame, where they are thermally ionized. The electrons released during the ionization are captured by means of a mesh applied around the flame and are recorded as peaks by a connected recorder or a data system. The FID is a detector that combines robustness with high sensitivity. The signal thereof is linearly proportional, over a wide concentration range, to the amount of carbon contained in an analyte. The concentration of a hydrocarbon can thus be estimated from the signal without calibration, and the detector can readily be used to quantify organic pollutants.

A photoionization detector (abbreviation and reference sign in Fig. 1: PID) is a device for detecting and analysing chemical compounds in the air. By way of example, a PID can be used to detect aromatic hydrocarbons, some common solvents, and many different inorganic, but especially organic, substances. A PID draws in the ambient air by means of a pump and exposes it to the UV light of a gas discharge lamp. If ionizable substances are present in the air, this is indicated as a concentration on the display. The pollutant load of the exhaust gas 2 can thus be determined.

As mentioned, the measurement signals obtained can then be further processed, preferably using a programmable logic controller (abbreviation and reference sign in Fig. 1: PLC). The PLC can monitor and control the plant 1 according to the invention and can chart the technological procedure while checking the tolerances to be observed. With regard to the PLC memory, a distinction can be made between active and current data memories for carrying out the measurement tasks and calculations and the data memories for storing data from the metrological monitoring operations and the metering. In a knowledge-based database of the PLC, mathematical models of the reaction kinetics and of the heat effect of metabolization processes that are possible under various boundary conditions in the reactor chamber 4 can also be stored and used for control and adjustment purposes. The PLC program thus links and coordinates the processes taking place and ensures a high efficiency of the plant 1 according to the invention.

By means of a preferred temperature control, in particular in the range from 30°C to 65°C or even up to 70°C, the rate of the reaction in the reactor chamber 4 can be set to an optimally high level. The temperature of the treatment liquid 6 can preferably be controlled by a heater 14, as shown, in which for example heating pipes are provided, by means of which the treatment liquid 6 in the fermenter 7 is heated. It is also possible, by means of a heater (not shown) in the reactor chamber 4, to set either a very homogeneous temperature distribution in the reactor chamber 4 or else a temperature gradient, depending on requirements. The PLC can also be used for this. A log of the entire technological procedure can also be stored in a database of the PLC.

From a design point of view, the fermenter 7 is located below the reactor chamber 4 of the bioreactor 3 according to the invention. It may be flanged directly onto the underside of the foot F, or advantageously, particularly with regard to the ease of replacement of the container forming the fermenter 7, it may be provided that the fermenter 7 is connected in a container-tight manner via a compensator part 15, as shown in Fig. 1. The compensator part 15 may in particular be made of an elastomeric material and/or may be designed as a bellows, the compensator part being detachably connected in a gas-tight manner to an inlet opening 16 for the exhaust gas 2 which is located at a foot F of the reactor chamber 4.

With regard to the ease of replacement of the container forming the fermenter 7, it may advantageously also be provided, as shown in Figs. 1, 2 and 4, that the fermenter 7 is movable, in particular by way of wheels 17 mounted on the underside thereof.

In order to be able to control or adjust the degree of humidification of the exhaust gas 2 in the fermenter 7, a control flap 18 is provided, which is immersed in the treatment liquid 6 and in particular is perforated at least in part. This is shown in Figs. 1 to 4, but can best be seen figuratively from the perspective illustration in Fig. 3. The flap 18 is panel-shaped and is pivotably (arrows P1, P2 in Fig. 2 and Fig. 5) suspended in the fermenter 7 via hinges 19 in a manner oriented vertically in a rest position “A”. Said flap may preferably extend over the entire width B7 and all the way to the bottom 20 of the fermenter 7. The degree of humidification is in this case controlled by the flap position, with a greater or lesser amount of exhaust gas 2 being conducted through the treatment liquid 6 depending on the position (for example positions “A”, “B” and “C” in Fig. 2). In particular, a lateral gas inlet nozzle 21 arriving at an angle from above is provided on the fermenter 7 for the exhaust gas 2. The flap 18 can be fixed step-wise or continuously in its different pivot positions, so that it is oriented not by the exhaust gas 2 but instead in a manner dependent on a control signal from the controlling and adjusting device 13.

In a deflected position (“B”), the flap 18 is oriented parallel to the flow direction of the exhaust gas 2, so that a maximum amount of exhaust gas 2 is conducted through the treatment liquid 6. The degree of humidification thus likewise reaches a maximum. In a position (“C”) deflected towards the other side, the flap 18 is oriented transversely to the gas flow, so that only a minimal amount of exhaust gas 2 is conducted through the treatment liquid 6. In this position, the flap 18 exposes a cross-section of maximum size for the exhaust gas 2 to pass through the treatment liquid 6 in the direction of the inlet opening 16 for the exhaust gas 2, which is arranged at the foot F of the reactor chamber 4. The degree of humidification thus likewise reaches only a minimum. A middle value of the degree of humidification can be set by bringing the flap 18 into the vertical position “A” situated between the two positions “B” and “C”. In this case, the longitudinal extension of the flap is in particular oriented coaxial with the central axis X-X of the reactor chamber 4, so that half of the inlet opening 6 for the exhaust gas 2 is thus exposed. Due to the perforation 22 provided in the flap 18 in the upper part thereof that is preferably not immersed in the treatment liquid, some of the exhaust gas 2 is also blown through the flap 18 by the blower M1. This also happens in the above-described position “B” of the flap 18.

A maximum flow resistance of the control flap 18, tailored to the gas flow, can be set by the size of the perforated region 22 and the size of the holes.

In one preferred embodiment, the reactor chamber 4 is enclosed by a vertically oriented casing 23, which is hollow-cylindrical in its basic shape and in a lower region tapers conically towards the inlet opening 16 thereof for the exhaust gas 2, and is closed in the region of the head K by a cover 24, with a chimney 25 for the cleaned exhaust gas 2a being located therein.

In addition, two closable manholes 26 are formed in the casing 23 of the reactor chamber 4, in particular in the lower, conical region thereof, which manholes advantageously provide direct access to the reactor chamber 4 and, if necessary, a possibility for removing the carrier material T. In addition, due to the presence of at least one closable manhole 26, the carrier material T can advantageously be rearranged if necessary in order to destroy preferential flow channels that may have undesirably formed during operation.

It may be provided (not shown) that the reactor chamber 4 has on the underside a perforated bottom which closes the inlet opening 16 thereof for the exhaust gas 2.

However, it is provided in a preferred embodiment, and also shown in the drawing, that an air distributor 27 is arranged in a lower region of the reactor chamber 4, by which a stream of the exhaust gas 2 coming from the fermenter 7 is divided into a plurality of partial streams before entering the region of the reactor chamber 4 that is filled with the inert carrier material T. The presence and the design of such an air distributor 27, which is shown in the installed position in Fig. 1 and as an individual part in different views in Figs. 5 and 6, is assigned its own inventive significance, which is independent of the inventive way in which the exhaust air 2 is humidified.

The air distributor 27 is formed of a perforated lower gas inlet section 27a for the exhaust gas 2, which in particular is hollow-cylindrical in its basic shape and is oriented vertically in the installed position, and of an in particular solid support section 27b for the inert carrier material T, which is oriented vertically and tapers conically upward to a tip. As seen in the axial direction, the solid support section 27b may have a length that is one quarter to one half of that of the cylindrical gas inlet section 27a.

In the installed position, the longitudinal axis Y-Y of the air distributor 27 is preferably arranged concentric with the central axis X-X of the reactor chamber 4, the air distributor 27 protruding into the interior of the reactor chamber 4. In the vertical direction, it may in particular extend over 10% to 40% of the height H_T of the space filled by the inert carrier material T. In this case, in a way that is optimal with regard to flow, an annular space that steadily widens upward in the axial direction X-X may be formed between the conical region of the casing 23 of the reactor chamber 4 and the air distributor 27, as illustrated in Fig. 1.

The division of the stream of exhaust gas 2 entering the air distributor 27 in the axial direction Y-Y into a plurality of partial streams is achieved by way of the perforation 27e of the hollow-cylindrical section 27a, across the entire axial length of which the exhaust gas 2 enters in the radial direction the region of the reactor chamber 4 filled with the inert carrier material T, in particular the annular space. By means of the air distributor 27, an optimally uniform flow pattern of the exhaust gas stream in the reactor chamber 4 can be set, which encourages a maximum breakdown of pollutants by the bioreactor 3 according to the invention.

For attachment to the casing 23 of the reactor chamber 4, the air distributor 27 may have an attachment flange 27c around the circumference, as can be seen in particular from Figs. 6 and 7. In particular, the air distributor 27 can be connected to the compensator part 15 via a non-perforated, hollow-cylindrical, terminal mounting section 27d, which in the installed position is located below the flange, as shown in Fig. 1.

The invention is not limited to the exemplary embodiment shown and described, but instead also encompasses all embodiments that have the same effect within the context of the invention. In addition, the person skilled in the art can also provide further expedient technical measures without departing from the scope of the invention. One such measure can be seen for example in Fig. 1 and Fig. 8 to Fig. 12, according to which it is provided that the reactor chamber 4 is connected to the fermenter 7 via an overflow line 28 for the treatment liquid 6 which leads from the head K of the reactor chamber 4 to the fermenter 7. This overflow line 28 leading from the head K of the reactor chamber 4 to the fermenter 7 may be closed by a safety valve 29, which opens automatically if the level of the treatment liquid 6 in the reactor chamber 4 is too high. In order to ensure this, it may be provided, as shown in the enlarged illustration in Fig. 9, that the safety valve 29 is formed by a hollow ball 29b, in particular made of steel, which is held in a housing 29a and is located at an upwardly open, top end 28a of the overflow line 28. If the liquid level is too high, the hollow ball 29b moves upward due to its buoyancy and opens up the overflow line 28, so that the liquid 6 can run back into the fermenter 7.

In connection with the presence of the overflow line 28 and also the above-described riser line 8 for the treatment liquid 6, the plant 1 according to the invention and the method according to the invention have yet another specific feature that has its own inventive significance. Specifically, it may advantageously preferably be provided that the temperature of the treatment liquid 6 is controlled by a measurement stream of the exhaust gas 2 that is conducted in a measuring line 30 designed in particular as a measuring tube, by conducting this measuring line 30 in a common cladding tube 31 together with at least one line for the treatment liquid 6, i.e. for example the overflow line 28 and/or the riser pipe 8.

This embodiment, to which in particular Fig. 10 to Fig. 12 relate, is not shown in Fig. 1, but the corresponding measuring lines for the uncleaned and cleaned exhaust gas 2, 2a are each denoted by the reference sign 30 therein.

By jointly conducting gas 2 and liquid 6, energy is saved due to the fact that on the one hand both a measurement gas stream of the exhaust gas 2 and also the treatment liquid 6 are conducted downward from a region close to the head K or are conducted from the bottom upward, and on the other hand the exhaust gas 2 in its measuring lines 30 must have a higher temperature than the treatment liquid 6, in particular a temperature of 180°C. Since one or preferably both lines 8, 28 for the treatment liquid 6 are jointly conducted in a common cladding tube 31, heat given off by the measuring line 30 can advantageously be used to heat the liquid lines 8, 28. This is to be regarded as particularly economical from an energy point of view, in particular in view of the fact that the liquid lines 8, 28, over almost the entire height of the bioreactor 3, extend in the open air where in some cases very low temperatures, possibly even below freezing point, may prevail. Excessive cooling of the treatment liquid 6 can thus efficiently be prevented. Instead of a cladding tube 31, some other suitable sheath may also be provided. The cladding tube 31 may be suitably fastened to the outside of the bioreactor 3 according to the invention, for example via a pipe clamp 32. In this regard, Figs. 10 and 11 show a clamp fastening in a retaining channel 33 of the riser pipe 34 assigned to the bioreactor 3 according to the invention.

List of reference signs

1	plant
2	exhaust gas, uncleaned
2a	exhaust gas, cleaned
3	bioreactor
4	reactor chamber of 3
5	second humidification device (for maintenance purposes)
6	treatment liquid
7	fermenter, first humidification device, gas scrubber
8	riser pipe for 6
9	baffle and distribution plate
10	reservoir
11	line for 6 from 10 to 7
12	feed opening for H in 7
13	controlling and adjusting device
14	heater in 7
15	compensator part
16	inlet opening for 2 in 4
17	wheel on 7
18	control flap for 2 in 7
19	hinge for 18
20	bottom of 7
21	gas inlet nozzle of 7
22	perforation of 18
23	casing around 4
24	cover on 23
25	chimney in 24
26	manhole in 23
27	air distributor for 2
27a	gas inlet section of 27 for 2
27b	support section of 27 for T
27c	attachment flange of 27 for attachment to 23
27d	mounting section of 27 for mounting on 15

27e	perforation in 27a
28	overflow line for 6 from K to 7
28a	(open) top pipe end of 28
29	safety valve for 28
29a	housing of 29
29b	hollow ball of 29
30	measuring line of 2/2a
31	cladding tube for 8, 28, 30
32	pipe clamp around 31
33	retaining channel for 32 on 34
34	riser pipe

A	rest position of 18
B	deflected position of 18, parallel to 2
B7	width of 7
C	deflected position of 18 transverse to 2
F	foot of 3
FID	detection device, flame ionization detector
H	auxiliary substance
H_T	height in 4 filled with T
K	head of 3
M1	central exhaust air blower
M2	pump for 6 from 7
M3	pump for 6 from 10
MP1	measuring point for 2a
MP2	measuring point for 2
PID	detection device, photoionization detector
PLC	programmable logic controller
T	carrier material in 4
X-X	vertical axis of 3/4
Y-Y	axis of 27

Patentkrav

1. Fremgangsmåde til kemisk-biologisk rensning af røggasser (2), hvor forbindelser opstået som emissioner og indeholdt i røggasserne (2) hvad angår deres kemiske sammensætning og mængde i røggassen (2) bestemmes og nedbrydes i mindst et reaktorkammer (4) i en bioreaktor (3), i hvilket en biofilm med mindst en type mikroorganismer, som egner sig til at nedbryde de organiske forbindelser, er etableret på et inert bæremateriale (T), hvor det inerte bæremateriale (T) og biofilmen befugtes med en vandig behandlingsvæske (6) ved hjælp af mindst en befugtningsanordning (5, 7), som i en fermenter (7) tilsættes mikroorganismer samt næringsstoffer til disse, hvor røggassen (2) befugtes med behandlingsvæsken (6) før indstrømning i bioreaktoren (3), sådan at røggas (2), som allerede er befugtet, kommer ind i reaktorkammeret (4), hvor befugtningen af røggassen (2) sker i fermenteren (7), idet en reguleret mængde af røggassen (2) bringes i kontakt med behandlingsvæsken (6) i fermenteren (7),

kendetegnet ved, at en beholder, som udgør fermenteren (7), samtidig anvendes som befugter og gasvasker til røggassen (2), hvor en befugtningsgrad af røggassen (2) i fermenteren (7) styres af et, særligt i det mindste delvist perforeret, reguleringsspjæld, som befinder sig nede i behandlingsvæsken (6), ved hjælp af hvilken røggassen (2) i det mindste delvist føres gennem behandlingsvæsken (6).

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** den kemiske sammensætning og mængden af de forbindelser, der er indeholdt i røggassen (2) bestemmes før befugtning af røggassen (2), hvor der foretrukket i overensstemmelse med den kemiske sammensætning og mængden af forbindelserne indeholdt i røggassen (2) som emissioner dannes styresignaler for en grad af befugtningen og/eller for en temperering af røggassen (2), der strømmer ind i reaktorkammeret (4).

3. Fremgangsmåde ifølge krav 1 eller 2, **kendetegnet ved, at** temperaturen af den befugtede røggas (2) styres eller reguleres af en temperering af behandlingsvæsken (6), hvor der særligt i reaktorkammeret (4) via den befugtede og tempererede røggas (2) indstilles en temperatur i området fra 30 °C til 70 "C, og hvor foretrukket tempereringen af behandlingsvæsken (6) sker via et varmelegeme (14) anbragt i fermenteren (7).

4. Fremgangsmåde ifølge et af kravene 1 til 3, **kendetegnet ved, at** næringsstofferne doseres til behandlingsvæsken (6) i en blanding med et fast forhold til hinanden, særligt idet der i behandlingsvæsken (6) indstilles et molforhold for kulstof til nitrogen til fosfor i området 100 : 2,5 til 7,5 : 0,2 til 3,0, foretrukket 100 : 5 : 1, ved hjælp af forhåndsindstillingen af næringsstoffernes forhold til hinanden.

5. Fremgangsmåde ifølge et af kravene 2 til 4,
kendetegnet ved, at der i den rensede røggas (2a), efter at denne er strømmet ud af bioreaktoren (3), sker en yderligere bestemmelse af den kemiske sammensætning og mængden af en eventuelt tilstedeværende resterende andel af de oprindeligt indeholdte forbindelser, hvor særligt den kemiske sammensætning og mængden af forbindelserne indeholdt i røggassen (2) som emissioner sammenlignes med hinanden og/eller med en defineret referenceværdi før og efter rensning af røggassen (2), og der heraf dannes styresignaler til befugtning og temperering af røggassen (2).

6. Fremgangsmåde ifølge et af kravene 1 til 5,
kendetegnet ved, at pH-værdien af behandlingsvæsken (6) i fermenteren (7) reguleres ved dosering af egnede sure eller alkaliske tilsætningsstoffer, hvor der særligt i overensstemmelse med den kemiske sammensætning og mængden af forbindelserne indeholdt i røggassen (2), doseres en opløselighedsforstærker mellem forbindelserne opstået som emissioner og indeholdt i røggassen (2) og behandlingsvæsken (6), såsom et keton eller en alkohol, til behandlingsvæsken (6), foretrukket ved en separat dosering til fermenteren (7).

7. Fremgangsmåde ifølge et af kravene 1 til 6,
kendetegnet ved, at forbindelserne indeholdt i røggassen (2) nedbrydes i en bioreaktor (3), hvis reaktorkammer (4) udgøres af et særligt cylindrisk kammer, som kan gennemstrømmes af røggassen (2), hvor røggassen (2) strømmer gennem bioreaktoren (3) vertikalt fra en fod (F) forneden op mod et hoved (K) foroven, hvor foretrukket den befugtede røggas (2) føres i medstrøm i bioreaktoren (3) med behandlingsvæsken (6) til befugtning af det inerte bæremateriale (T) og biofilmen, og hvor særligt overskydende behandlingsvæske (6), der eventuelt findes i bioreaktoren (3), drypper ud af bioreaktoren (3) ind i fermenteren (7) og/eller føres ud af reaktorkammeret (4) tilbage til fermenteren (7) via en overløbsledning, som fører

fra et øvre område (K) af reaktorkammeret (4) til fermenteren (7).

8. Fremgangsmåde ifølge et af kravene 1 til 7, **kendetegnet ved, at** en strøm af røggassen (2), der kommer ud af fermenteren (7) før indstrømning i reaktorkammeret (4), som er fyldt med det inerte bærema-teriale (T), opdeles i en flerhed af delstrømme ved hjælp af en luftfordeler (27), der stikker ind i reaktorkammeret (4), hvor foretrukket en strømningshastighed af røg-gassen (2) i reaktorkammeret (4), særligt af delstrømmene af røggassen (2), ind-stilles via en vægtfylde af det inerte bæremateriale (T), og særligt foretrukket æn-dres via en vægtfylde af det inerte bæremateriale (T), der ændrer sig over en højde (H) af reaktorkammeret (4), mens røggassen (2) strømmer gennem reaktorkam-meret (4).

9. Fremgangsmåde ifølge et af kravene 1 til 8, **kendetegnet ved, at** røggassens (2) volumenstrøm ligger i et område fra 7000 m3/h til 30000 m3/h, hvor røggassen (2) ved indstrømning i fermenteren (7) sær-ligt har en strømningshastighed på mindst 7 m/s.

10. Fremgangsmåde ifølge et af kravene 1 til 9, **kendetegnet ved, at** en måle-strøm af røggassen (2), som føres i en måleledning (30) særligt udformet som måleslange ved fælles føring med mindst en ledning (8, 28) af behandlingsvæsken (6), som forbinder et hoved (K) af bioreaktoren (3) med fermenteren (7), tempe-rerer behandlingsvæsken (6) i et indkapslingsrør (31).

11. Bioreaktor (3) til kemisk-biologisk rensning af røggasser (2), særligt til gen-nemførelse af en fremgangsmåde ifølge et af kravene 1 til 10,

- med mindst et reaktorkammer (4), i hvilket forbindelser indeholdt i røggas-sen (2) opstået som emissioner nedbrydes,
- med et inert bæremateriale (T), der befinder sig i reaktorkammeret (4), på hvilket der er etableret en biofilm med mindst en type mikroorganismer egnet til at nedbryde de organiske forbindelser,

- med mindst en befugtningsanordning (5, 7), ved hjælp af hvilken bærematerialet (T) og biofilmen befugtes med en vandig behandlingsvæske (6), som indeholder mikroorganismer og næringsstoffer til disse, hvor fermenteren (7) er en beholder, som er placeret før reaktorkammeret (4) i røggassens (2) strømningsretning på en sådan måde, at røggassen (2) kommer gennem fermenteren (7) ind i reaktorkammeret (4), hvor det i fermenteren (7) befugtes med den vandige behandlingsvæske (6),
kendetegnet ved, at fermenteren (7) via en kompensatordel (15), som især består af et elastomert materiale og/eller er udformet som foldebælg, er aftageligt gastæt forbundet med en indstrømningsåbning (16) til røggassen (2) på en fod (F) af reaktorkammeret (4), hvor der i fermenteren (7) er fastgjort et reguleringsspjæld (18) nede i behandlingsvæsken (6), som i det mindste delvist er forsynet med en perforering (22).

12. Bioreaktor (3) ifølge krav 11,
kendetegnet ved, at fermenteren (7) kan bevæges ved hjælp af hjul (17) monteret på undersiden.

13. Bioreaktor (3) ifølge et af kravene 11 til 12,
kendetegnet ved, at reaktorkammeret (4) er omgivet af en kappe (23), som i sin grundudformning er hult cylindrisk, er vertikalt orienteret og i et nedre område er konisk tilspidset mod sin indstrømningsåbning (16) til røggassen (2), hvor der foretrukket i reaktorkammerets (4) kappe (23), særligt i dets nedre, konisk udformede område, er udformet mindst et aflukkeligt mandehul (26), og/eller hvor reaktorkammeret (4) på undersiden har en perforeret bund, der lukker indstrømningsåbningen (16) til røggassen (2).

14. Bioreaktor (3) ifølge
et af kravene 11 til 13,
kendetegnet ved, at der i et nedre område af reaktorkammeret (4) er anbragt en luftfordeler (27), via hvilken en strøm af røggassen (2), som kommer ud af fermenteren (7), før sin indstrømning i reaktorkammeret (4), som er fyldt med det inerte bæremateriale (T), opdeles i en flerhed af delstrømme, hvor luftfordeleren (27) foretrukket er dannet af et vertikalt orienteret, perforeret nedre gasindstrømningsafsnit (27a), som i sin grundudformning

særligt er cylindrisk udformet, og et vertikalt orienteret særligt massivt støtteafsnit (27b), som tilspidses konisk opad, til det inerte bæremateriale (T) og er anbragt koncentrisk med reaktorkammerets (4) midterakse (X-X).

15. Bioreaktor (3) ifølge et af kravene 11 til 14,
kendetegnet ved, at reaktorkammeret (4) er forbundet med fermenteren (7) via en overløbsledning (28) til behandlingsvæsken (6), som går fra reaktorkammerets (4) hoved (K) til fermenteren (7), hvor overløbsledningen (28) særligt er lukket med en sikkerhedsventil (29), som foretrukket er dannet af en hul kugle (29b), som særligt består af stål, og som holdes i et hus (29a) og ligger i en oversideende af overløbsledningen (28), som er åben opad, og/eller at reaktorkammeret (4) er forbundet via en stigeledning (8), som er udstyret med en pumpe (M2) og går fra fermenteren (7) til reaktorkammerets (4) hoved (K), hvis oversideende er udformet som befugtningsanordning (5) til det inerte bæremateriale (T) og biofilmen, hvor der særligt under stigeledningens (8) oversideende, der anvendes som befugtningsanordning (5), over det inerte bæremateriale (T) og biofilmen i reaktorkammeret (4) er anbragt en skærm og fordelerplade (9) til behandlingsvæsken (6).

16. Anlæg (1) til kemisk biologisk rensning af røggasser (2) til gennemførelse af en fremgangsmåde ifølge et af kravene 1 til 10 og med en bioreaktor (3) ifølge et af kravene 11 til 15,

- med en registreringsanordning (PID/FID), i hvilken forbindelser, opstået som emissioner og indeholdt i røggasserne (2), bestemmes hvad angår deres kemiske sammensætning og mængde i røggassen (2),
- med en bioreaktor (3), som mindst omfatter:
  et reaktorkammer (4), i hvilket forbindelserne indeholdt i røggassen (2) og opstået som emissioner nedbrydes,
  et inert bæremateriale (T), der befinder sig i reaktorkammeret (4), på hvilket der er etableret en biofilm med mindst en type mikroorganismer egnet til at nedbryde de organiske forbindelser,
  mindst en befugtningsanordning (5, 7), ved hjælp af hvilken bærematerialet (T) og biofilmen befugtes med en vandig behandlingsvæske (6), som indeholder mikroorganismerne og næringsstofferne til disse,
- samt med en fermenter (7), i hvilken den vandige behandlingsvæske (6) tilsættes mikroorganismerne samt næringsstofferne, hvor registreringsanordningen (PID/FID), i hvilken forbindelserne, opstået som emissioner og

indeholdt i røggasserne (2), bestemmes hvad angår deres kemiske sammensætning og mængde i røggassen (2), er del af en anordning (13) til styring og/eller regulering af befugtningsgraden af røggassen (2) i fermenteren (7).

17. Anlæg (1) ifølge krav 16, **kendetegnet ved, at** registreringsanordningen (PID/FID), i hvilken forbindelserne opstået som emissioner, som røggasserne (2) indeholder, bestemmes hvad angår deres kemiske sammensætning og mængde i røggassen (2), er del af en anordning (13) til styring og/eller regulering af temperaturen i fermenteren (7), hvor registreringsanordningen (FID/PID) foretrukket omfatter en flammeionisationsdetektor (FID) eller en photoionisationsdetektor (PID) og særligt via en måleledning (30), særligt udformet som måleslange, der fører en målestrøm fra røggassen (2), er forbundet med et sted (MP2) på røggassens (2) strøm før dennes indstrømning i bioreaktoren (3).

18. Anlæg (1) ifølge et af kravene 16 eller 17, **kendetegnet ved** en programmerbar styring (PLC) til styring og regulering af befugtningsprocessen for røggassen (2) og/eller temperaturen i fermenteren (7) og/eller i bioreaktorens (3) reaktorkammer (4).

19. Anlæg (1) ifølge den indledende del af krav 16, særligt ifølge krav 17 eller 18 **kendetegnet ved, at** mindst en måleledning (30), som fører røggassens (2) målestrøm, føres i et fælles indkapslingsrør (31) eller en kappe med en ledning (8, 28) til behandlingsvæsken (6), som forbinder et hoved/hovedet (K) af bioreaktoren (3) med fermenteren (7).

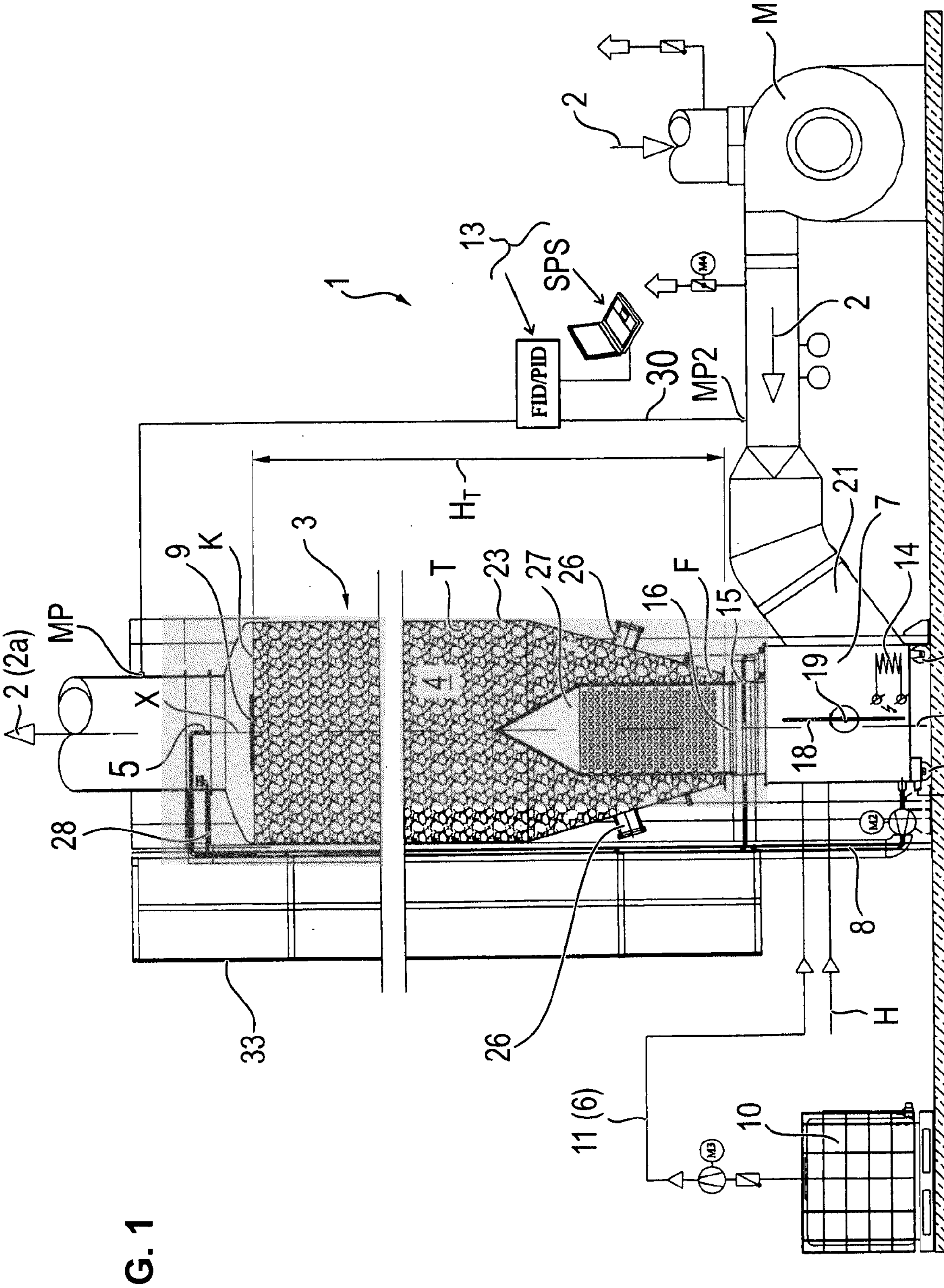

2 (2a)
MP
X
5
28
33
9
K
3
H_T
T
23
27
26
4
F
16
15
14
7
21
19
18
17
17
X
8
H
26
10
11 (6)
M3
M2
M4
FID/PID
30
MP2
13
SPS
1
2
2
M'

FIG. 1

FIG. 2

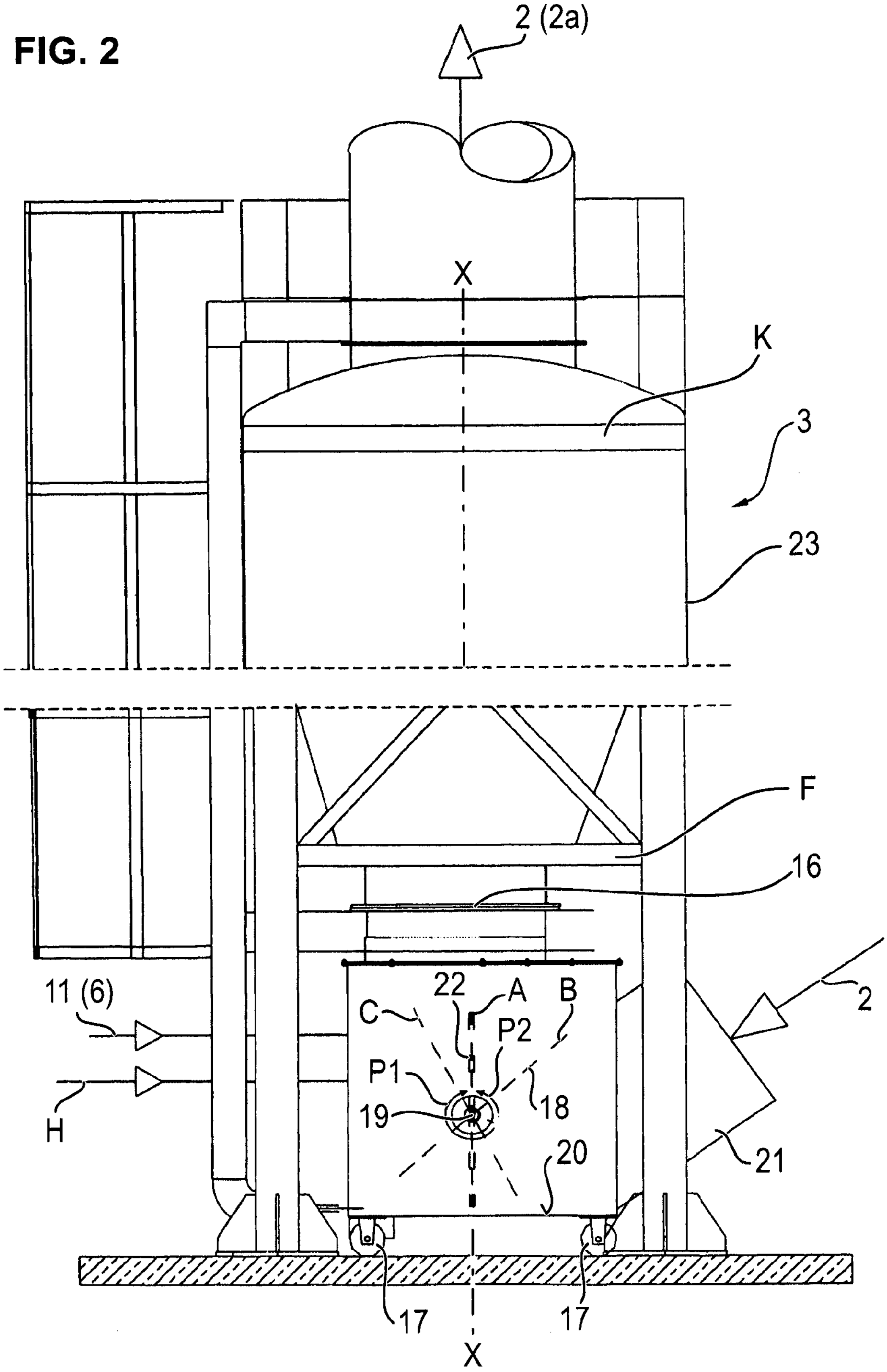


FIG. 3

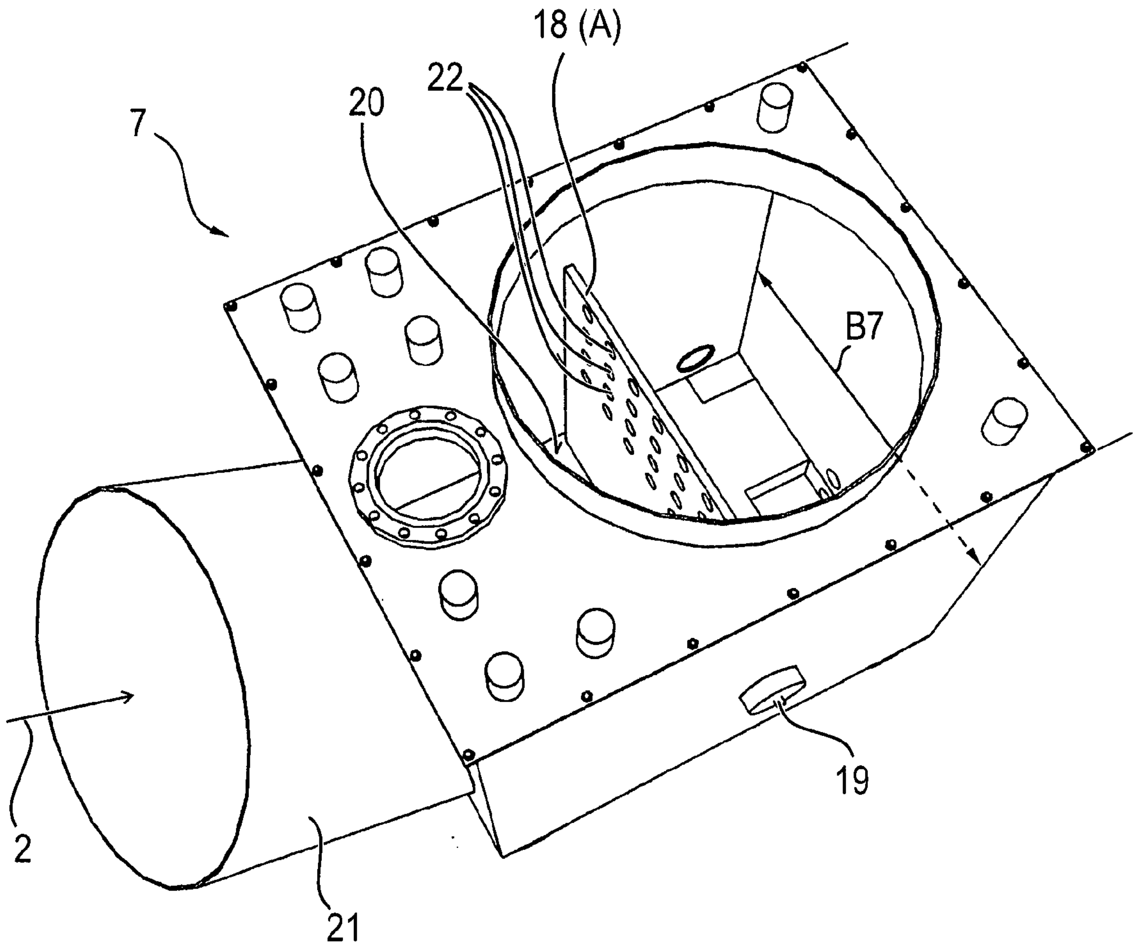


FIG. 5

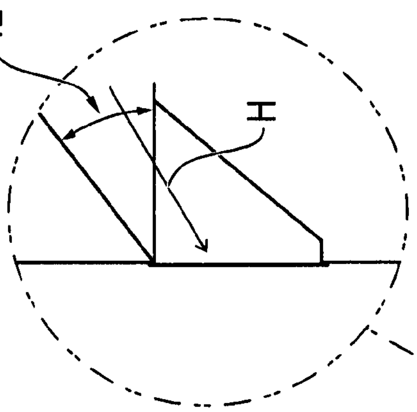


FIG. 4

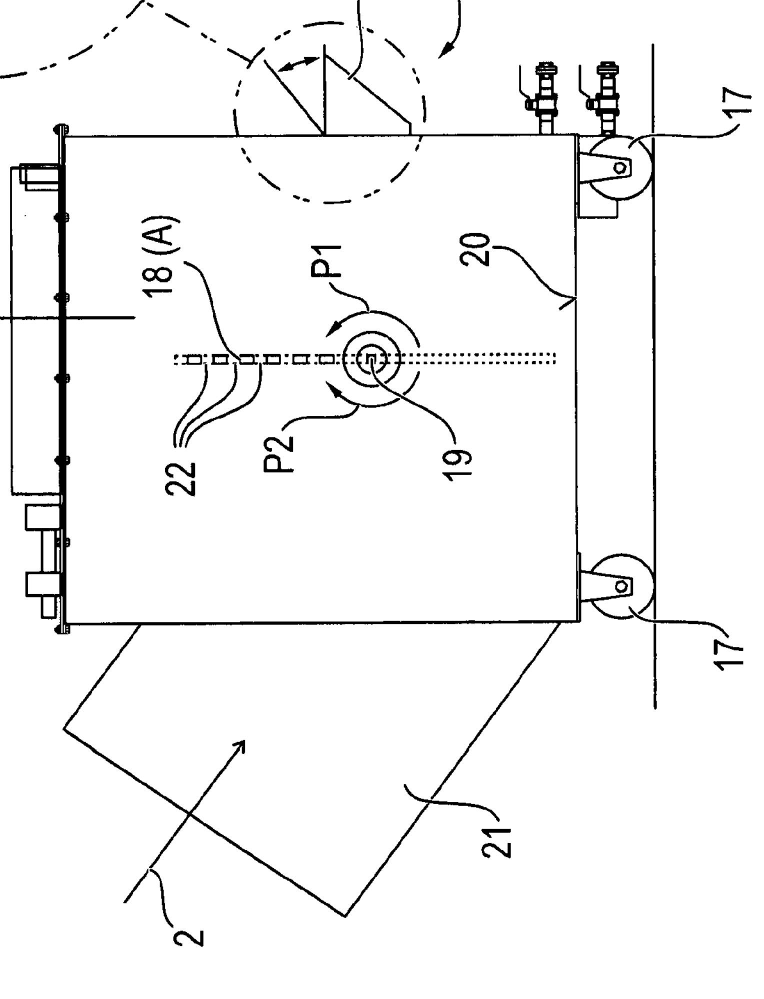


FIG. 7

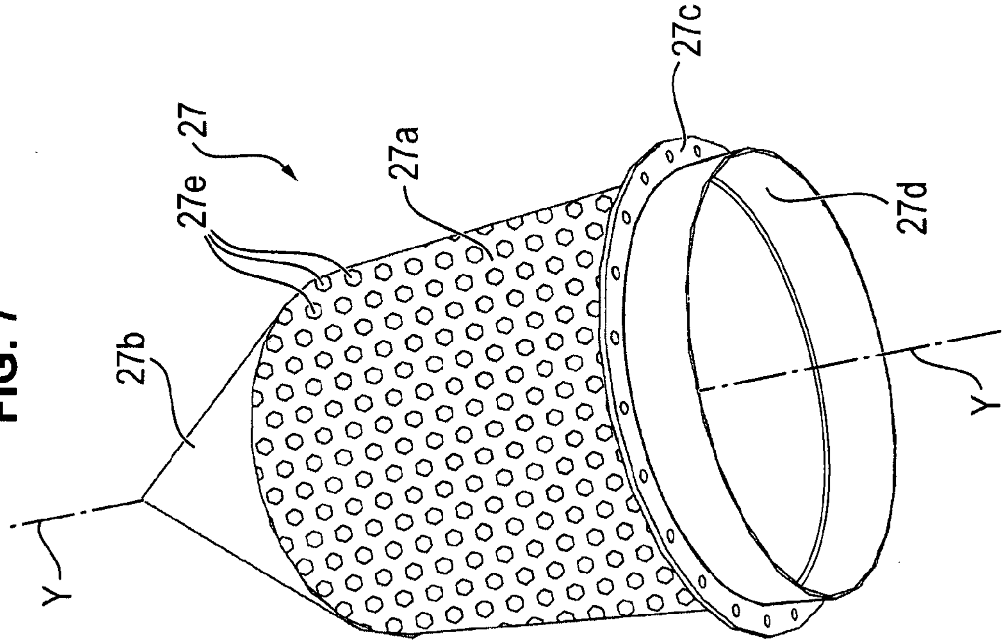


FIG. 6

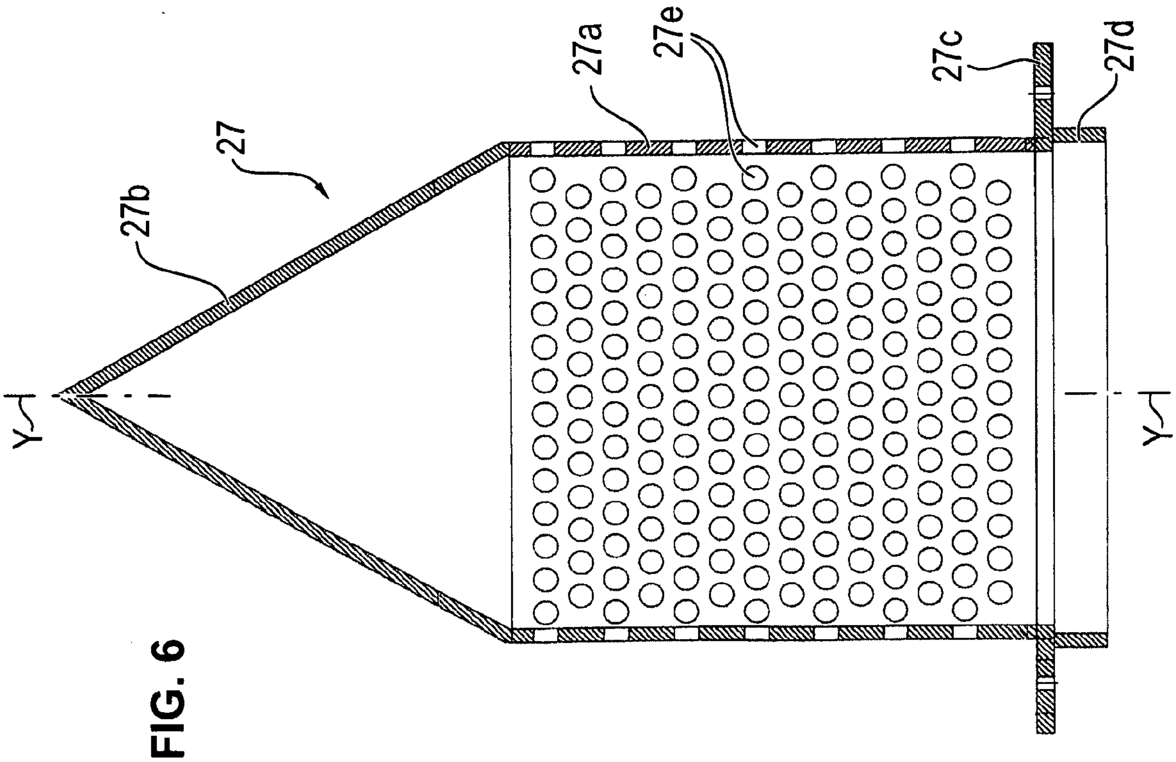


FIG. 8

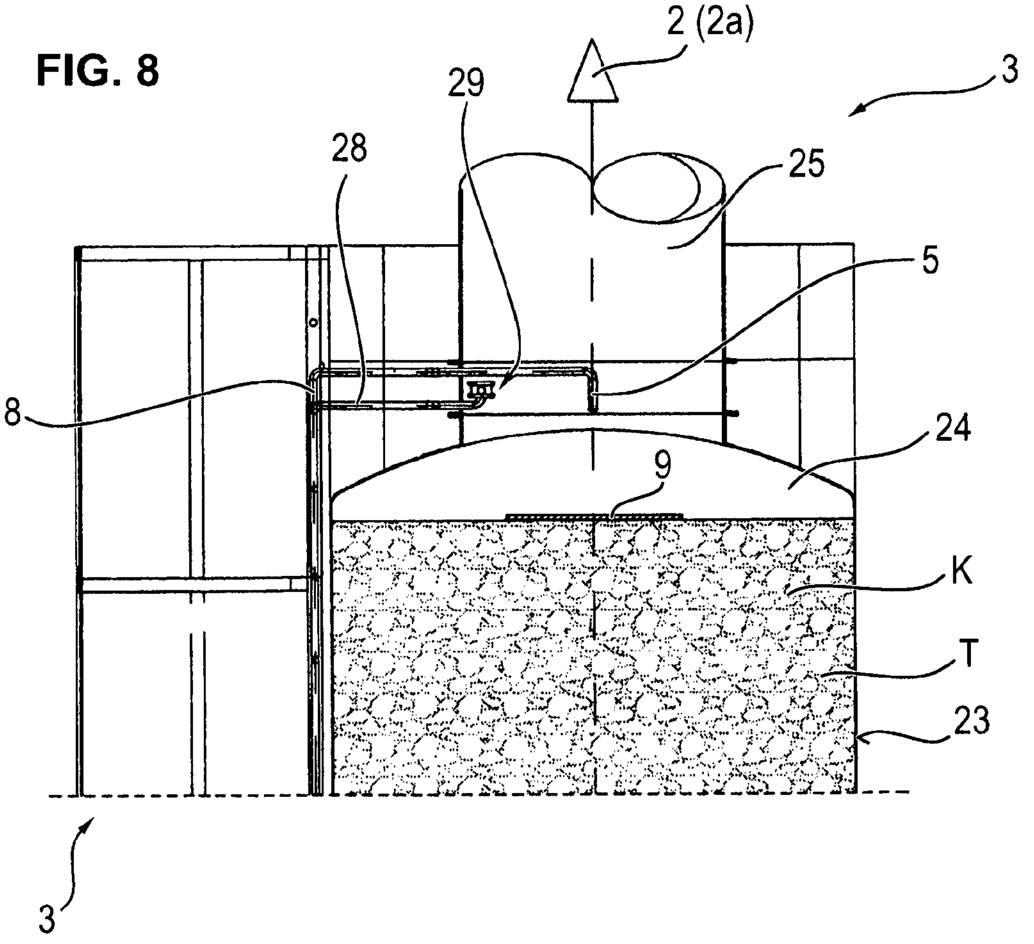


FIG. 9

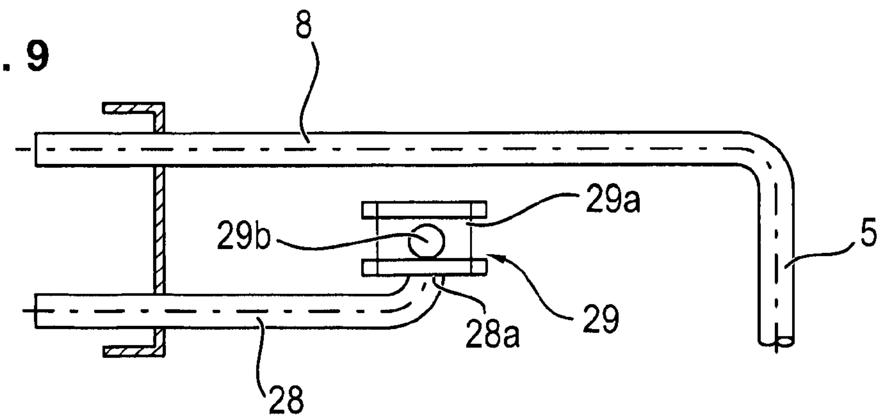
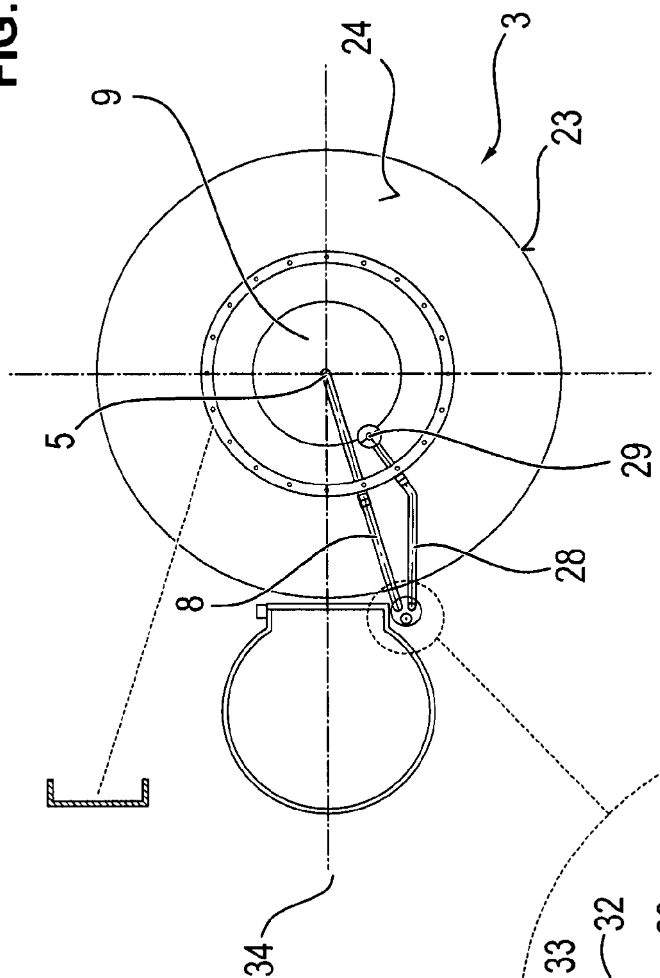


FIG. 10



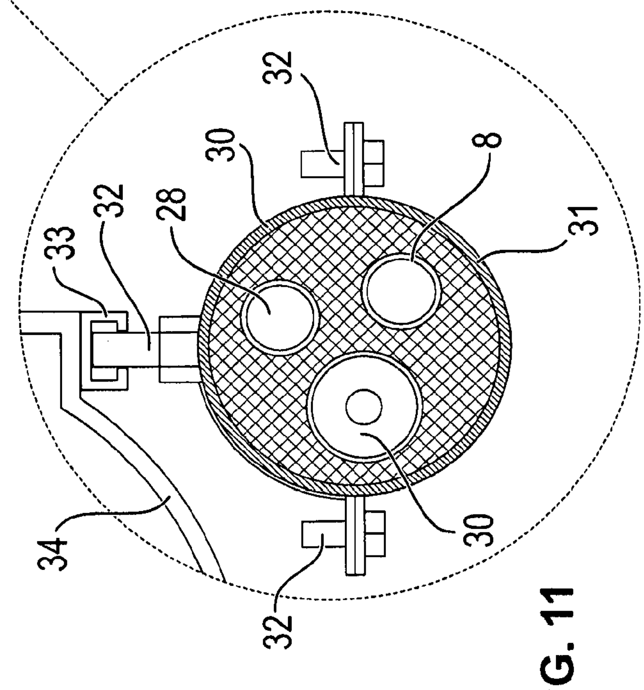


FIG. 11

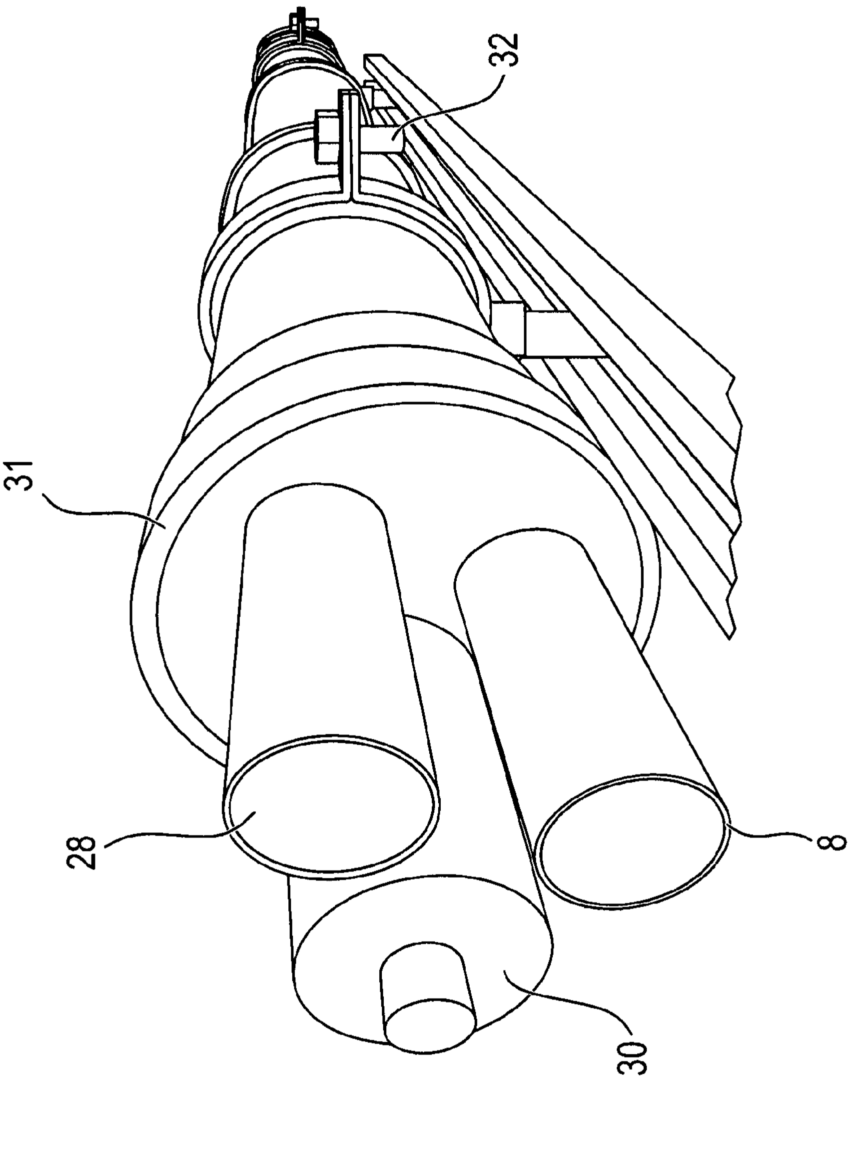


FIG. 12