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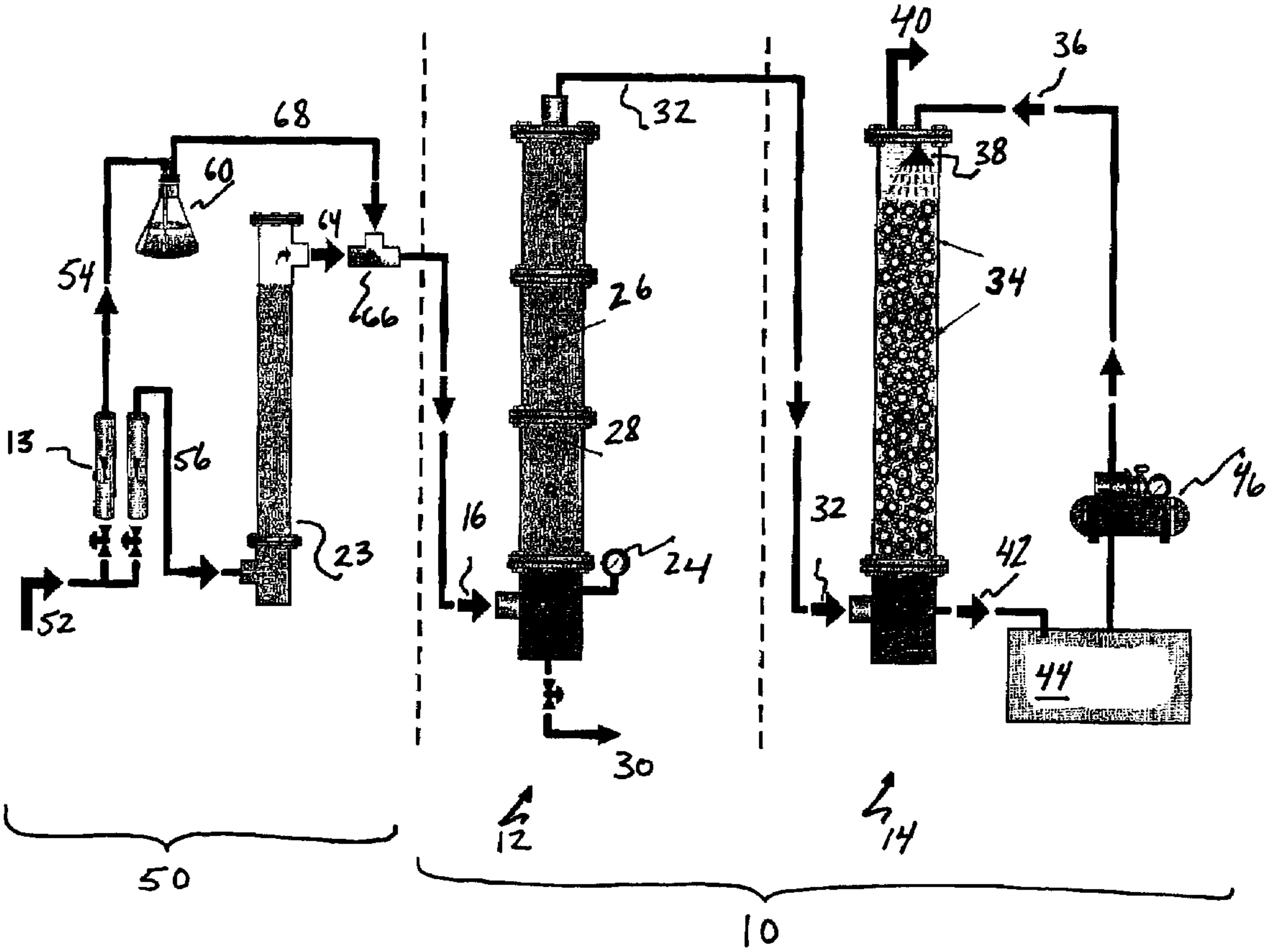
(54) Titre : APPAREIL POUR PURIFIER DU GAZ ET PROCEDE BASE SUR LA BIOFILTRATION ET DES REACTIONS ENZYMATIQUES
(54) Title: GAS PURIFICATION APPARATUS AND PROCESS USING BIOFILTRATION AND ENZYMATIC REACTIONS



(57) Abrégé/Abstract:
The invention provides a gas purification apparatus for purifying effluent gas by treating VOCs and the CO_2 gas, comprising a biofiltration chamber containing micro-organisms for degrading the VOCs and producing a partially cleansed gas containing CO_2

(57) Abrégé(suite)/Abstract(continued):
gas by-product; and an enzymatic chamber comprising an enzyme capable of catalyzing the hydration of the CO_2 gas by-product into bicarbonate ions and hydrogen ions, to produce an ion rich solution and a purified gas. Additionally, a gas purification process is provided.

ABSTRACT

The invention provides a gas purification apparatus for purifying effluent gas by treating VOCs and the CO_2 gas, comprising a biofiltration chamber containing micro-organisms for degrading the VOCs and producing a partially cleansed gas containing CO_2 gas by-product; and an enzymatic chamber comprising an enzyme capable of catalyzing the hydration of the CO_2 gas by-product into bicarbonate ions and hydrogen ions, to produce an ion rich solution and a purified gas. Additionally, a gas purification process is provided.

GAS PURIFICATION APPARATUS AND PROCESS USING BIOFILTRATION AND ENZYMATIC REACTIONS

FIELD OF THE INVENTION

The present invention generally relates to industries involving effluent treatment, such as the forestry industry, and more particularly to a technology for purifying gas effluents with a mind to the conventions on climate change that have been developed with the Kyoto protocol. More specifically, the invention concerns a apparatus and process employing biofiltration and enzymatic reaction for achieving a more complete purification of gas effluents.

BACKGROUND OF THE INVENTION

In the domain of processes for purifying gas effluents and in view of the conventions on climate change which have been developed with the Kyoto protocol, the treatment of industrial gas emissions cannot be overlooked or underestimated. Industrial gas effluents contain a variety of compounds, which vary in their toxicity, noxiousness, solubility and removability from gases. As the industrial standards in effluent gas purity increase in severity and subtlety, the known devices for purifying gas effluents are becoming antiquated and inadequate.

Certain effluent treatment processes and devices are known in the art to remove certain compounds from the effluent gas. The treatment of gas effluents by biofiltration, for instance, takes advantage of the natural degradation phenomenon of pollutants by micro-organisms for transforming different volatile organic compounds (VOCs) into degraded products that are much less harmful to the environment. Biofilters are present on the market and are used in many sectors of industry. In general, biofiltration processes include the degradation of polluting gases by micro-organisms that are typically fixed to a porous support (media). At the surface of this solid support, the micro-organisms grow in a thin layer called the biofilm. Polluted air flows within the biofilter, and the contaminants contained in the gaseous flow are absorbed by the biofilm where they are degraded by the micro-organisms. The concentration gradients of the pollutants between the gaseous phase and the biofilm cause a continuous transfer of the pollutants towards the biofilm. Biofilters are generally simple devices that use a combination of processes such as absorption, adsorption/desorption, and degradation of gaseous contaminants. United States Patent Publication no. 2004/0152185 A1 (EGAN et al.), for example, describes a process and device for the biofiltration of VOCs.

The biostimulation of micro-organisms that have an affinity for specific volatile compounds is, however, not main stream. In addition, biofiltration processes give rise to various inefficiencies in the purification of effluent gases, which in turn may lead to such processes' failure in enabling a comprehensive treatment of the original effluent gases and in adhering to certain standards of gas purity. For example, biofiltration treatments fail to reduce the quantity of certain greenhouse gases targeted by the Kyoto protocol, in particular carbon dioxide (CO_2).

Another purification process known in the art uses enzymatic bioreaction technology, and has appeared under various forms. United States patent no. 6,524,843 (BLAIS et al.), for instance, describes certain embodiments of enzymatic bioreactors. The enzyme carbonic anhydrase has become a very useful tool in the management of greenhouse gases. Carbonic anhydrase (CA.EC 4.2.1.1.) is a metal enzyme containing zinc. This enzyme is capable of catalyzing a reversible hydration reaction of CO_2. The reaction is as follows:

$$CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$$

Its catalytic activity greatly accelerates the natural reaction that transforms CO_2 gas into bicarbonate ions and hydrogen ions. However, this enzymatic bioreaction technology suffers from certain disadvantages with regard to comprehensive purification of certain industrial effluent gases.

Of particular interest is the reduction of VOCs and CO_2 gas in industrial effluent gases.

With industrial processes producing effluent gases that contain diverse chemical compounds, and with the standards for comprehensive purification of gas effluents reaching new levels of rigorousness, there is a palpable and present need for a technology that enables a comprehensive treatment to manage diverse pollutants present in effluent gases.

SUMMARY OF THE INVENTION

The present invention responds to the above-mentioned need by providing an apparatus and a process for purifying effluent gas.

In one aspect, the present invention provides a gas purification apparatus for purifying effluent gas containing volatile organic compounds (VOCs) by managing emissions of VOCs and carbon dioxide (CO_2). The apparatus includes a biofiltration chamber containing support media having disposed thereon micro-organisms suitable for performing degradation reactions of the VOCs and producing CO_2 gas by-product. The biofiltration chamber also has an inlet for receiving the effluent gas and an outlet for releasing a partially cleansed gas containing the CO_2 gas by-product. The apparatus also includes an enzymatic chamber having a gas inlet in fluid connection with the outlet of the biofiltration chamber for receiving therefrom the partially cleansed gas. The enzymatic chamber contains enzymes capable of catalysing the hydration reaction of CO_2 into bicarbonate ions and hydrogen ions. The enzymatic chamber also has a liquid inlet for receiving a solvent to dissolve said CO_2 gas by-product, a gas outlet for releasing a purified gas and a liquid outlet for releasing an ion rich solution. The gas purification apparatus is thus able to reduce the amounts of VOCs and CO_2 by-product to produce the purified gas.

In one optional aspect, the inlet of the biofiltration chamber is provided at a bottom part thereof and the outlet of the biofiltration chamber is provided at a top part thereof.

In another optional aspect, the biofiltration chamber has a liquid outlet for releasing condensation and liquid run-off.

In another optional aspect, the gas inlet of the enzymatic chamber is provided at a bottom part thereof and the liquid inlet is provided at a top part thereof, thereby enabling the partially cleansed gas and the solvent to flow counter-currently with respect to each other.

In another optional aspect, the gas purification apparatus further comprises a collection reservoir in fluid connection with the liquid outlet of the enzymatic chamber for collecting the ion rich solution.

In another optional aspect, the gas purification apparatus further comprises a regeneration unit having an inlet for receiving the ion rich solution, the regeneration unit regenerating the ion rich solution to produce a regenerated solvent, the regeneration unit also having an outlet in fluid connection with the liquid inlet of the enzymatic chamber for recycling the solvent thereto.

In another optional aspect, the gas purification apparatus further comprises a conversion unit receiving the ion rich solution from the liquid outlet of the enzymatic chamber and converting the same into a buffer solution, said conversion unit having an outlet in fluid connection with the biofiltration chamber for feeding the buffer solution therein.

In another optional aspect, the support media of the micro-organisms are chosen from the group consisting of bark, peels, wood chips, synthetic packing, rocks and combinations thereof.

In another optional aspect, a plurality of different mirco-organisms are provided on the support media for degrading a variety of VOCs.

In another optional aspect, the plurality of different micro-organisms comprise bacteria and/or fungi.

In another optional aspect, the enzymatic chamber is provided with a packing on which the enzymes are immobilized.

In another optional aspect, the enzymes include carbonic anhydrase.

In another optional aspect, the partially cleansed gas contains the CO_2 gas by-product and residual non degraded VOCs.

In another optional aspect, the gas purification apparatus is for purifying effluent gas containing volatile organic compounds (VOCs) produced by wood or timber industry.

In another optional aspect, the VOCs are selected from the group consisting of formaldehyde, phenol, alpha-pinene, hexanal, methanol and acetic acid.

In another optional aspect, the concentrations of the VOCs in the effluent gas are at most 60 ppm for formaldehyde, at most 150 ppm for phenol, at most 50 ppm for alpha-pinene, at most 125 ppm for hexanal and at most 250 ppm for acetic acid.

In another optional aspect, the gas purification apparatus further comprises a humidificiation column upstream of the biofiltration chamber for humidifying the effluent gas prior to entry into the biofiltration chamber.

In another optional aspect, the biofiltration unit further comprises a collector provided upstream of the outlet of the biofiltration unit.

In another optional aspect, the collector is a collection plate having perforations.

In another optional aspect, the biofiltration chamber and the enzymatic chamber are provided in a single reactor structure, the biofiltration chamber being arranged below the enzymatic chamber.

In another optional aspect, the biofiltration chamber comprises a collection plate having perforations provided upstream of the outlet of the biofiltration chamber.

In another optional aspect, the enzymatic chamber comprises a distributor plate at a bottom part thereof for distributing the partially cleansed gas within the enzymatic chamber; and the collection reservoir is provided within the single reactor structure below the distributor plate and above the biofiltration chamber.

In another aspect, the present invention provides a gas purification process for purifying effluent gas containing volatile organic compounds (VOCs) by managing emissions of VOCs and carbon dioxide (CO_2). The process includes the consecutive steps of:

- degrading the VOCs contained in the effluent gas by biofiltration, thereby producing a partially cleansed gas containing CO_2 gas by-product;
- dissolving the CO_2 gas by-product and catalyzing the hydration reaction of the CO_2 gas by-product into bicarbonate ions and hydrogen ions using enzymes, whereby the CO_2 gas by-product is removed from the partially cleansed gas; and
- separating the bicarbonate and hydrogen ions from the partially cleansed gas to produce an ion rich solution and a purified gas.

The gas purification process may further comprise the additional steps of:

- regenerating the ion rich solution by at least partially removing the hydrogen and bicarbonate ions therefrom to produce a regenerated solvent; and
- recycling the regenerated solvent to dissolve the CO_2 gas by-product.

In one optional aspect, the step of regenerating the ion rich solution includes at least one of the following steps:

- performing an ionic exchange; and
- precipitating the bicarbonate and hydrogen ions.

In another optional aspect, the gas purification process comprises the additional steps of:

- converting at least part of the ion rich solution into a buffer solution; and
- providing the buffer solution in the step of degrading the VOCs by biofiltration to thereby buffer said biofiltration.

In another optional aspect, the partially cleansed gas contains the CO_2 gas by-product and residual non degraded VOCs.

In another optional aspect, the gas purification process is for purifying effluent gas containing volatile organic compounds (VOCs) produced by wood or timber industry.

In another optional aspect, the VOCs are selected from the group consisting of formaldehyde, phenol, alpha-pinene, hexanal, methanol and acetic acid.

In another optional aspect, the concentrations of the VOCs in the effluent gas are at most 60 ppm for formaldehyde, at most 150 ppm for phenol, at most 50 ppm for alpha-pinene, at most 125 ppm for hexanal and at most 250 ppm for acetic acid.

In another optional aspect, the gas purification process comprises collecting the partially cleansed gas using a collection plate having perforations prior to the step of dissolving the CO_2 gas by-product and catalyzing the hydration reaction of the CO_2 gas by-product into the bicarbonate ions and the hydrogen ions using the enzymes.

BRIEF DESCRIPTION OF THE DRAWINGS

The apparatus and process of gas purification by biofiltration and enzymatic reaction, according to certain embodiments of the present invention, are further described and illustrated in the drawings, in which:

Fig 1 is a flow diagram showing the global apparatus used for experimentation of this new technology according to an embodiment of the present invention.

Fig 2 is a flow diagram showing the internal functioning of a biofiltration chamber according to another embodiment of the invention.

Fig 3 is a graph showing the concentration of CO_2 obtained at the entrance and at the exit of the enzymatic chamber following the treatment of the VOCs by the biofilter.

Fig 4 is a flow diagram of the apparatus according to yet another embodiment of the present invention.

While the invention will be described in conjunction with example embodiments, it will be understood that it is not intended to limit the scope of the invention to such embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalents of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The gas purification process and apparatus according to the present invention may be used in various industrial contexts. For instance, the purification apparatus may be used in the forestry/timber industry, where processes such as drying lignocellulosic fibres, high temperature pressing of composite wood panels and cooling of such panels after pressing, produce the effluent gas to be treated. Alternatively, the inventive apparatus or process may be used in other industries that produce complex effluent gases, for example, the pulp and paper industry, various chemical industries and the petroleum industry.

More specifically, the purification process and apparatus targets industrial effluent gases that contain varying amounts of volatile organic compounds (VOCs), which may include any number of chemicals – alcohols such as methanol, aldehydes such as formaldehyde, ketones, hydrocarbons such as methane and ethane, aromatic compounds such as benzene and toluene, and a myriad of other organic chemical species. By “VOC” it should be understood to include a broad range of chemical compounds that contain carbon atoms and may also contain oxygen, nitrogen, sulphur, halogens, hydrogen and other elements. VOCs are also “volatile” under certain pressure, temperature and concentration conditions such that the compounds may be degraded by micro-organisms. The volatility of these compounds, therefore, is more a matter of whether they may be absorbed into a biofilm, than whether they have enough vapour pressure to enter the atmosphere under STP conditions. Thus, many different compounds may be considered to be VOCs. For instance, the definition of VOCs found in the United States Environmental Protection Agency’s Code of Federal Regulations, contains a plurality of concrete examples of VOCs, but may not contain an exhaustive list of VOCs as they pertain to the invention described herein. The effluent gas may also include greenhouse gases such as CO_2 and CO, among others, in undesirable quantities.

The Effluent Gas Purification Apparatus

Preferred embodiments of the apparatus according to the present invention will be described hereafter in relation to Figs 1, 2 and 4, and examples will be presented in relation to Fig 3.

Referring to Fig 1, the effluent gas purification apparatus **10** includes at least two chambers for processing the effluent gas. The effluent gases containing VOCs are fed into the gas purification apparatus **10**. In this preferred embodiment, the gas effluent is fed into a biofiltration chamber **12** and is subsequently fed into an enzymatic chamber **14**. The biofiltration chamber **12** enables the degradation of the VOCs biologically, which generates CO_2 gas as a by-product. The enzymatic chamber **14** then reduces the amount of CO_2 in the effluent gas to produce a purified gas at its outlet. It will thus be appreciated that it is particularly advantageous to treat an effluent gas containing VOCs using the present invention, as the biofiltration and enzymatic chambers **12**, **14** cooperate to purify the effluent gas with respect to VOCs as well as CO_2 gas. The close management of such noteworthy pollutants may, therefore, be performed and coordinated.

Referring still to Fig 1, the gas purification apparatus **10** includes separate biofiltration and enzymatic chambers **12**, **14**. An effluent gas inlet stream **16** is provided for feeding the VOC-containing effluent into the apparatus **10**. In this embodiment, the effluent gas is fed directly into the biofiltration unit **12**. The biofiltration unit **12** is preferably in the form of a column, and the incoming effluent gas **16** is preferably fed to the bottom of the biofiltration column **12**. Alternatively, and as illustrated in Fig 2, the effluent gas may be fed to the top of the biofiltration column **12**. The biofiltration chamber **12** may also take the form of a fluidized bed reaction chamber (not illustrated), a rotary reaction chamber (not illustrated) or another form suitable for enabling the biological degradation of VOCs.

Still referring to Fig 2, the biofiltration column **12** contains support media **18**.

Preferably, the support media **18** are made of bark, but they may also include a number of appropriate supports or packings known in the art. Preferably, the support media **18** are porous, solid supports and may also be materials such as compost, peels, wood chips, synthetic materials, rocks, volcanic rocks or combinations of such materials. On the support media **18**, a biofilm **20** is provided and includes one or a variety of micro-organisms **22**. The micro-organisms **22** may be grown on the support media **18** using techniques known in the art. The effluent gas **16** flows into the biofiltration column **12** and is at least partially absorbed into the biofilm **20**. The VOCs contained in the effluent gas **16**, in particular, are absorbed into the biofilm **20** and are degraded by the micro-organisms **22**. The VOCs are first oxidized by the micro-organisms **22** and then broken down to various reaction products. The operating conditions of the biofiltration column **12** are controlled to maintain biofilm **20**, which implies monitoring the pressure, temperature and effluent gas flowrate, while providing the micro-organisms **22** with sufficient nourishment and ensuring that the adequate amount of VOCs are being removed from the effluent gas **16**. The concentration gradients of the pollutants between the gaseous phase and the biofilm **20** preferably cause a continuous transfer of the pollutant towards the biofilm **20**.

The support media **18** in the biofiltration column **12** are capable of supporting microbial growth, whether bacterial or fungal. The micro-organisms **22** may be fixed to or grown on the support media **18**. In a preferred embodiment, the support media **18** are enriched with a variety of micro-organisms **22**, characterised in that they have a vast and substantial catalytic potential. In the presence of a given compound in the effluent gas, such as one or more VOCs that may also be called a “substrate”, the micro-organisms **22** produce inductible enzymes capable of degrading the given compound. Following this induction phase, the micro-organisms **22** grow while catalyzing the transformation of the compound in question. The degradation of VOCs by micro-organisms is nevertheless complex and may involve a variety of mechanisms that are intracellular and intercellular, depending on the specific organism, operating conditions and VOCs involved. Degradation gases such as CO_2 gas, among others, are produced during this process. The degradation products – their production rate and composition – also depend on the specific VOC or combination of VOCs that are degraded by the micro-organisms **22**.

The apparatus **10** preferably includes a single biofiltration chamber **12**, which may have a variety of micro-organisms provided therein. Alternatively, there may be a plurality of biofiltration chambers (not illustrated), in series or in parallel, each provided with different micro-organism(s), to optimize the degradation. This latter arrangement is preferred when the conditions of chemical degradation require microbes with significantly different characteristics.

Referring to Fig 1, it should be noted that the effluent gas **16** may be pre-treated before entering the gas purification apparatus **10**, notably by a step of humidification in a humidifier column **23**. Such a column **23** is preferable when the incoming effluent is dry enough to potentially hinder the growth of the micro-organisms **22** in the biofiltration chamber **12**. Alternatively, the biofiltration chamber **12** may be humidified in another way, such as by adding water through a separate inlet stream (not illustrated) or according to techniques known in the art.

Referring still to Fig 1, the biofiltration column **12** is advantageously provided with a pressure gauge **24** and various ports **26**, **28** for taking measurements within the biofiltration column **12**. A biomass sample port **26** is used to remove samples of biomass from the column to be tested and monitored. Gas sample ports **28** are used to remove samples of effluent gas along the column **12**, to monitor the cleaning capacity, quality and progress in the biofilter column **12**. Other ports for measuring conditions relating to the gas flow, temperature distribution and reaction progress are preferably present.

The biofiltration column **12** is also provided with an evacuation stream **30**, through which condensation as well as liquid run-off are expelled from the biofilter **12**. The biofiltration chamber **12** further includes a partially cleansed gas outlet stream **32**, which preferably exits the top of the biofiltration column **12**. The partially cleansed gas stream **32** has been subjected to biofiltration and therefore contains a reduced amount of VOCs. This partially cleansed gas stream **32** also contains greenhouse and other gases that were not able to be processed by the micro-organisms **22**. Of particular interest is the elevated quantity of CO_2 gas in this clean gas stream **32**, due to the CO_2 gas by-product generated in the biofiltration chamber **12** in addition to that contained in the original effluent gas **16**. This elevated quantity of CO_2 gas has become a significant drawback of biofiltration, as its presence in expelled process gases is highly undesirable and, in many cases, unacceptable for greenhouse gas level standards. The partially cleansed gas stream **32** is thus adequately purified with respect to VOCs yet remains CO_2 rich, at least partly due to the latter's production in the biofiltration chamber **12**.

Given the versatility of micro-organisms **22** with which the biofiltration chamber **12** may be stocked, the biofiltration chamber **12** is suited for metabolizing a large spectrum of substrates. Following the microbial induction of metabolic enzymes required for a specific substrate, the catalytic potential of the biofiltration chamber **12** attains a maximum in terms of degradation. A sharp rise in CO_2 gas, a commonly generated sub-product, is liberated and treated with the enzymatic chamber **14**, as will be described in greater detail below.

Referring still to Fig 1, once filtered and treated in the biofiltration chamber **12**, the partially cleansed gas **32** is conducted with the degradation products to the enzymatic chamber **14**. The partially cleansed gases **32** preferably enter the enzymatic chamber **14** at the bottom thereof. As illustrated, the enzymatic chamber **14** preferably takes the form of a packed tower chamber, containing enzymatic packing **34**, partially or completely. The stream **32** passes through the enzymatic packing **34** present in the enzymatic column **14**. The packing **34** contains at its surface an enzyme capable of transforming the dissolved CO_2

gas into bicarbonate and hydrogen ions in a hydration reaction.

In the case that the enzymatic chamber is a packed tower chamber, the packing **34** is preferably a solid packing, such as Rachig rings, "Tellerettes" or saddles. The packing **34** may be porous or non porous. The packing **34** is arranged to optimize the surface area to maximize the mass transfer. The enzyme is preferably covalently bound and immobilized to the surface of the packing **34**. Alternatively, the enzymatic chamber may take the form of a fluidized bed reactor (not illustrated) in which the enzyme is in suspension, and into which the clean gas stream **32** from the biofiltration chamber **12** is fed using a bubbling unit (not illustrated) or another common means. The enzymatic chamber **14** may also take the form of another suitable reaction chamber known to a person skilled in the art and that may cooperate with the biofiltration chamber **12**.

The enzyme is preferably covalently bound and immobilized on the packing **34**, but may also be incorporated into the packing according to other techniques.

The enzyme used in the enzymatic chamber **14** is preferably carbonic anhydrase, which catalyses the hydration reaction of CO_2 gas. Alternatively, and particularly in the case where other undesirable gases were not degraded by the biofilter **12** or generated in the latter, other enzymes may be employed for purifying the gas stream **32**. For instance, if the gas stream **32** contains high levels of carbon monoxide (CO) gas, then an enzyme geared to the dissolution or conversion of this gas may be preferably employed in the enzymatic chamber **14**. The enzymatic chamber **14** is preferably provided with an enzyme with a catalytic potential for converting or degrading other by-product gases generated in the biofiltration chamber **12**. The enzymatic chamber **14** may include a consortium of enzymes for simultaneously catalyzing different gases, or there may alternatively be a plurality of enzymatic chambers **14** in series provided with different enzymes for targeting different gases. For example, when carbon monoxide (CO) is present in the partially cleansed gas, an enzyme capable of catalyzing its degradation is preferably provided.

At the upper part of the lined enzymatic column **14**, a solvent **36** is fed into the column **14** and preferably sprayed in micro droplets via a shower apparatus **38**, thereby coating the enzymatic packing **34**. Thus, in this preferred embodiment, the descendant liquid meets the entering gas counter-currently. There is therefore a mass transfer of CO_2 from the gas to the solvent **36**. At least part of the CO_2 gas is dissolved in the solvent. This dissolving is a function of the temperature, pressure as well as the surface of interaction between the liquid phase and the gas phase. A purified gas stream **40** preferably exits the top of the enzymatic column **14** and may be released into the atmosphere.

It should also be noted that the enzymatic chamber **14** reduces the amount of CO_2 gas by-product generated in the biofiltration chamber **12**, and, in the case where the raw effluent **16** contains CO_2 gas as well as VOCs, the enzymatic chamber **12** may also reduce the overall amount of CO_2 gas to produce the purified gas **40**.

An ion-rich solvent **42**, which is produced by the dissolving CO_2 gas into bicarbonate and hydrogen ions, preferably exits the bottom of the enzymatic reaction column **14** and is brought to a collection reservoir **44**. From this collection reservoir **44**, the ion-rich solvent **42** is preferably brought to a capture system (not illustrated), which can be an ionic exchanger type system or a precipitation system. The ions may be implicated in reactions with cations such as calcium and/or magnesium, etc, to improve the status of the industrial waste. The result is that the products of the transformation of CO_2 are captured, and thus eliminated. The solvent may thus be regenerated and may be recycled into the top of the enzymatic reaction column **14**. The ion-rich solvent **42** may be brought to the capture system prior to being fed into the collection reservoir **44**. As illustrated, a circulation pump **46** recycles at least part of the solvent from the collection reservoir **44** back into the enzymatic reaction column **14**.

Referring now to Fig 4, which represents another embodiment of the present invention, the biofiltration and enzymatic chambers **12**, **14** are arranged as part of a reactor unit. In this embodiment, the biofiltration chamber **12** is provided with the effluent gas inlet stream **16** and the effluent gas passes through the support media **18**. At the upper portion of the biofiltration chamber, there is provided a collection plate **47** which is perforated to allow the partially cleansed gas **32** to be gathered to then enter the enzymatic chamber **14**. The partially cleansed gas **32** is preferably fed into the enzymatic chamber via a stream line, but may alternatively pass by other openings or conduits between the two chambers **12**, **14**.

The enzymatic chamber **14** receives the incoming partially cleansed gas **32** preferably at a bottom part thereof and by means of a distributor plate **48**. The distributor plate **48** enables the incoming gas to be well distributed and diffused among the packing **34** within the enzymatic chamber **14**. The solvent **36** and the enzymes enable the CO_2 by-product in the gas to be dissolved and converted into hydrogen and bicarbonate ions. The apparatus **10** also is able to withdraw the rich ion solution from the enzymatic chamber **12**. Preferably, there is an collection tank **49** arranged to collect the used solvent, which has become an ion rich solution.

Preferably, the ion rich solution is employed to increase the efficiency of the apparatus or to benefit from the ions in a variety of ways. For instance, the ion rich solution may be regenerated using a variety of systems, such as an ion exchanger type system (not illustrated) or a precipitation system (not illustrated). The regenerated solvent may then be recycled back to the enzymatic chamber **14**.

Furthermore, the ion rich solution may be converted using conversion means into a buffer solution to be added in desired quantities to the effluent gas **16** or to the biofiltration chamber **12** itself. Some micro-organisms may be sensitive to low pH levels and such a buffer solution may thus facilitate prolific and advantageous microbial growth. The buffer solution may be made in a number of ways using a number of conversion means. For example, the solvent may contain an amine-compound, which reacts with the hydrogen ions to remove them from solution to thereby raise the pH of the solution. In this case, therefore, the ion rich solution maintains a modestly basic pH, and thus may be provided directly to the effluent gas **16** just prior to its entering into the biofiltration chamber **12**, or to the effluent gas in a pre-treatment. The bicarbonate ion-based buffer solution may be quite useful in promoting certain types of microbial growth. Alternatively, when the solvent does not contain compounds that react readily with the hydrogen ions, the ion rich solution is acidic and may be subjected to treatments to convert it to a basic buffer solution. Additions of compounds such as amines or appropriate bases, or elements such as calcium and the like in an appropriate form, are among the conversion means that may be employed to convert the ion rich solution into a buffer solution.

It may also be desirable to selectively use the ion rich solution for both recycling and buffering. Especially when the incoming effluent gas **16** fluctuates in composition, it is preferable to control the amount of buffering solution used for the biofiltration chamber **12**. When the VOCs include acidic compounds, such as acetic acid for example, it may be particularly preferred to use the buffer solution.

A particular advantage of the apparatus **10** is that it enables a comprehensive management of VOCs and their degradation products, found in effluent gases. The apparatus **10** not only metabolizes VOCs via digestion by micro-organisms of a full range of substrates, and enables the capture of CO_2, but also assures the management of the CO_2 gas by-product emitted by the biofiltration chamber **12**.

The Gas Purification Process

The gas purification process may be appreciated by referring to Fig 1 and the following description.

The gas purification process for purifying effluent gas **16** containing volatile organic compounds (VOCs) allows the management of emissions of VOCs and carbon dioxide (CO_2). The process includes the consecutive steps of:

- degrading the VOCs contained in the effluent gas by biofiltration, thereby producing a partially cleansed gas containing CO_2 gas by-product;
- dissolving the CO_2 gas by-product and catalyzing the hydration reaction of the CO_2 gas by-product into bicarbonate ions and hydrogen ions using enzymes, whereby the CO_2 gas by-product is removed from the partially cleansed gas; and
- separating the bicarbonate and hydrogen ions from the partially cleansed gas to produce an ion rich solution and a purified gas.

Preferably, the step of degrading the VOCs is performed in the biofiltration chamber **12** as illustrated in Fig 1, 2 or 4. The step of dissolving the CO_2 gas by-product and catalyzing the hydration reaction is preferably performed in the enzymatic chamber **14** as illustrated in Fig 1 or 4. The step of separating the ions from the purified gas **40** also preferably occurs in the enzymatic chamber **14**. Alternatively, arrangements other than the preferred embodiments illustrated in Figs 1, 2 and 3 may be used to perform the process of the present invention.

Experimental Pilot Apparatus

Referring to Fig 1, an experimental pilot apparatus was constructed to perform experimentation regarding this new technology. The pollutant effluent gas **16** entering the purification apparatus **10** was simulated by an effluent simulation unit **50**. Effluent gases were simulated in the effluent simulating unit **50**, wherein compressed air **52** was fed to the simulation unit **50** and split into first **54** and second **56** streams. Valves **58** were provided for regulating the proportion of compressed air in each stream. The first stream **54** was percolated through a VOC simulator **60**. The second stream **56** was fed into the bottom of a humidifier column **62**. A humidified air stream **64** exited the top of the humidifier column **62** and fed into a mixing zone **66** along with the VOC-containing gas **68** from the VOC simulator **60**. The mixing of streams **64** and **68** produced the simulated effluent gas stream **16**, which was fed into the bottom of the biofiltration chamber **12**.

Examples

Trials with this experimental pilot apparatus were performed to degrade VOCs issuing from the timber industry, such as formaldehyde, methanol, alpha-pinene and hexanal. Different degrees of oxidation of these products were observed. An increased amount of CO_2 was observed at the entrance of the enzymatic chamber **14** when components of this nature were introduced into the biofiltration chamber **12**. The absence of the contaminants resulted in a decrease in CO_2 at the entrance of the enzymatic chamber **14**. The results of this trial are represented hereafter. Different mixtures of volatile organic components were used in order to simulate different concentrations of the principle VOCs produced by the wood/timber industry. Drying of the lignocellulosic fiber, high temperature pressing of composite wood panels and cooling of these panels at the exit of the pressing are the main sources of these pollutants. Different mixtures were tested over four weeks of operation.

TABLE 1: Mixture of volatile organic compounds used

Schedule in Days	**Tested Mixture**
0 to 14	No. 600
15 to 16	No. 900
17 to 21	No. 300
22	No. 900
23 to 28	No. 600
29 to 30	No. 0

Mixture No. 300 had 300 ppm methanol at the entrance of the biofiltration chamber, whereas mixture Nos. 600 and 900 had 600 ppm and 900 ppm of methanol respectively. The mixtures also had, at most, approximately 60 ppm formaldehyde, 250 ppm acetic acid, 150 ppm phenol, 125 ppm hexanal, 50 ppm alpha-pinene at the entrance of the biofiltration chamber.

During 30 days, four mixtures were tested alternately. Each of these mixtures contained variable concentrations of the above-mentioned VOCs. The average percents of degradation for some specific VOCs are presented in Table 2.

TABLE 2: Rate of degradation of volatile compounds

Volatile compounds	Concentration at the exit of the biofiltration chamber	Percent of degradation
Formaldehyde	4,5 to 9,5 ppm	91 to 100%
Methanol	350 to 1250 ppm	30 to 96%
Alpha-pinene	0,2 to 0,75 ppm	30 to 80%
Hexanal	0,1 to 0,9 ppm	95 to 99%

The average carbon dioxide concentration measured at the exit of the biofiltration chamber was 428 ppm $\pm$ 32 ppm. The mixture No. 0, containing no organic compounds, was used during the two last days of the experimental phase and a decrease in the concentration of carbon dioxide at the exit of the biofiltration chamber was observed. This also translated into a decrease in the performance of the enzymatic chamber since the performance of the enzymatic chamber is a function of the concentration of CO_2 present in the apparatus.

In conclusion, the apparatus and process have great potential, since they are able to transform VOCs, conforming not only to the norms relating to such rejected effluent gases but also to the policies put in place in accordance with the Kyoto protocol.

While one preferred embodiment of the invention was described above and illustrated in the Figs, the invention is not limited to these embodiments and many modifications may be made by a person skilled in the art while staying within the scope of what the inventor actually invented.

CLAIMS

1. A gas purification apparatus for purifying effluent gas containing volatile organic compounds (VOCs) by managing emissions of VOCs and carbon dioxide (CO_2), comprising:

- a biofiltration chamber containing support media having disposed thereon micro-organisms suitable for performing degradation reactions of the VOCs and producing CO_2 gas by-product, the biofiltration chamber having an inlet for receiving the effluent gas and an outlet for releasing a partially cleansed gas containing the CO_2 gas by-product; and
- an enzymatic chamber having a gas inlet in fluid connection with the outlet of the biofiltration chamber for receiving therefrom the partially cleansed gas, said enzymatic chamber containing enzymes capable of catalysing the hydration reaction of CO_2 into bicarbonate ions and hydrogen ions, said enzymatic chamber having also a liquid inlet for receiving a solvent to dissolve said CO_2 gas by-product, a gas outlet for releasing a purified gas and a liquid outlet for releasing an ion rich solution;

whereby the gas purification apparatus reduces the amounts of VOCs and CO_2 by-product to produce the purified gas.

2. The gas purification apparatus of claim 1, wherein the inlet of the biofiltration chamber is provided at a bottom part thereof and the outlet of the biofiltration chamber is provided at a top part thereof.

3. The gas purification apparatus of claim 2, wherein the biofiltration chamber has a liquid outlet for releasing condensation and liquid run-off.

4. The gas purification apparatus of claim 1, wherein the gas inlet of the enzymatic chamber is provided at a bottom part thereof and the liquid inlet is provided at a top part thereof, thereby enabling the partially cleansed gas and the solvent to flow counter-currently with respect to each other.

5. The gas purification apparatus of claim 1, further comprising a collection reservoir in fluid connection with the liquid outlet of the enzymatic chamber for collecting the ion rich solution.

6. The gas purification apparatus of claim 1, further comprising a regeneration unit having an inlet for receiving the ion rich solution, the regeneration unit regenerating the ion rich solution to produce a regenerated solvent, the regeneration unit also having an outlet in fluid connection with the liquid inlet of the enzymatic chamber for recycling the solvent thereto.

7. The gas purification apparatus of claim 1, further comprising a conversion unit receiving the ion rich solution from the liquid outlet of the enzymatic chamber and converting the same into a buffer solution, said conversion unit having an outlet in fluid connection with the biofiltration chamber for feeding the buffer solution therein.

8. The gas purification apparatus of claim 1, wherein the support media of the micro-organisms are chosen from the group consisting of bark, peels, wood chips, synthetic packing, rocks and combinations thereof.

9. The gas purification apparatus of claim 1, wherein a plurality of different mirco-organisms are provided on the support media for degrading a variety of VOCs.

10. The gas purification apparatus of claim 9, wherein the plurality of different micro-organisms comprise bacteria and/or fungi.

11. The gas purification apparatus of claim 1, wherein the enzymatic chamber is provided with a packing on which the enzymes are immobilized.

12. The gas purification apparatus of claim 11, wherein the enzymes include carbonic anhydrase.

13. A gas purification process for purifying effluent gas containing volatile organic compounds (VOCs) by managing emissions of VOCs and carbon dioxide (CO_2), the process comprising the consecutive steps of:

- degrading the VOCs contained in the effluent gas by biofiltration, thereby producing a partially cleansed gas containing CO_2 gas by-product;
- dissolving the CO_2 gas by-product and catalyzing the hydration reaction of the CO_2 gas by-product into bicarbonate ions and hydrogen ions using enzymes, whereby the CO_2 gas by-product is removed from the partially cleansed gas; and
- separating the bicarbonate and hydrogen ions from the partially cleansed gas to produce an ion rich solution and a purified gas.

14. The gas purification process of claim 13, comprising the additional steps of:

- regenerating the ion rich solution by at least partially removing the hydrogen and bicarbonate ions therefrom to produce a regenerated solvent; and
- recycling the regenerated solvent to dissolve the CO_2 gas by-product.

15. The gas purification process of claim 14, wherein the step of regenerating the ion rich solution includes at least one of the following steps:

- performing an ionic exchange; and
- precipitating the bicarbonate and hydrogen ions.

16. The gas purification process of claim 13, comprising the additional steps of:

- converting at least part of the ion rich solution into a buffer solution; and
- providing the buffer solution in the step of degrading the VOCs by biofiltration to thereby buffer said biofiltration.

17. The gas purification process of any one of claims 13 to 16, wherein the partially cleansed gas contains the CO_2 gas by-product and residual non degraded VOCs.

18. The gas purification process of any one of claims 13 to 17 for purifying effluent gas containing volatile organic compounds (VOCs) produced by wood or timber industry.

19. The gas purification process of any one of claims 13 to18, wherein the VOCs are selected from the group consisting of formaldehyde, phenol, alpha-pinene, hexanal, methanol and acetic acid.

20. The gas purification process of claim 19, wherein the concentrations of the VOCs in the effluent gas are at most 60 ppm for formaldehyde, at most 150 ppm for phenol, at most 50 ppm for alpha-pinene, at most 125 ppm for hexanal and at most 250 ppm for acetic acid.

21. The gas purification process of any one of claims 13 to 20, comprising collecting the partially cleansed gas using a collection plate having perforations prior to the step of dissolving the CO_2 gas by-product and catalyzing the hydration reaction of the CO_2 gas by-product into the bicarbonate ions and the hydrogen ions using the enzymes.

22. The gas purification apparatus of any one of claims 1 to 12, wherein the partially cleansed gas contains the CO_2 gas by-product and residual non degraded VOCs.

23. The gas purification apparatus of any one of claims 1 to 12 and 22 for purifying effluent gas containing volatile organic compounds (VOCs) produced by wood or timber industry.

24. The gas purification apparatus of any one of claims 1 to 12, 22 and 23, wherein the VOCs are selected from the group consisting of formaldehyde, phenol, alpha-pinene, hexanal, methanol and acetic acid.

25. The gas purification apparatus of claim 24, wherein the concentrations of the VOCs in the effluent gas are at most 60 ppm for formaldehyde, at most 150 ppm for phenol, at most 50 ppm for alpha-pinene, at most 125 ppm for hexanal and at most 250 ppm for acetic acid.

26. The gas purification apparatus of any one of claims 1 to 12 and 22 to 25, further comprising a humidificiation column upstream of the biofiltration chamber for humidifying the effluent gas prior to entry into the biofiltration chamber.

27. The gas purification apparatus of any one of claims 1 to 12 and 22 to 26, wherein the biofiltration unit further comprises a collector provided upstream of the outlet of the biofiltration unit.

28. The gas purification apparatus of claim 27, wherein the collector is a collection plate having perforations.

29. The gas purification apparatus of any one of claims 1 to 12 and 22 to 28, wherein the biofiltration chamber and the enzymatic chamber are provided in a single reactor structure, the biofiltration chamber being arranged below the enzymatic chamber.

30. The gas purification apparatus of claim 29, wherein the biofiltration chamber comprises a collection plate having perforations provided upstream of the outlet of the biofiltration chamber.

31. The gas purification apparatus of claim 30, wherein the enzymatic chamber comprises a distributor plate at a bottom part thereof for distributing

the partially cleansed gas within the enzymatic chamber; and the collection reservoir is provided within the single reactor structure below the distributor plate and above the biofiltration chamber.

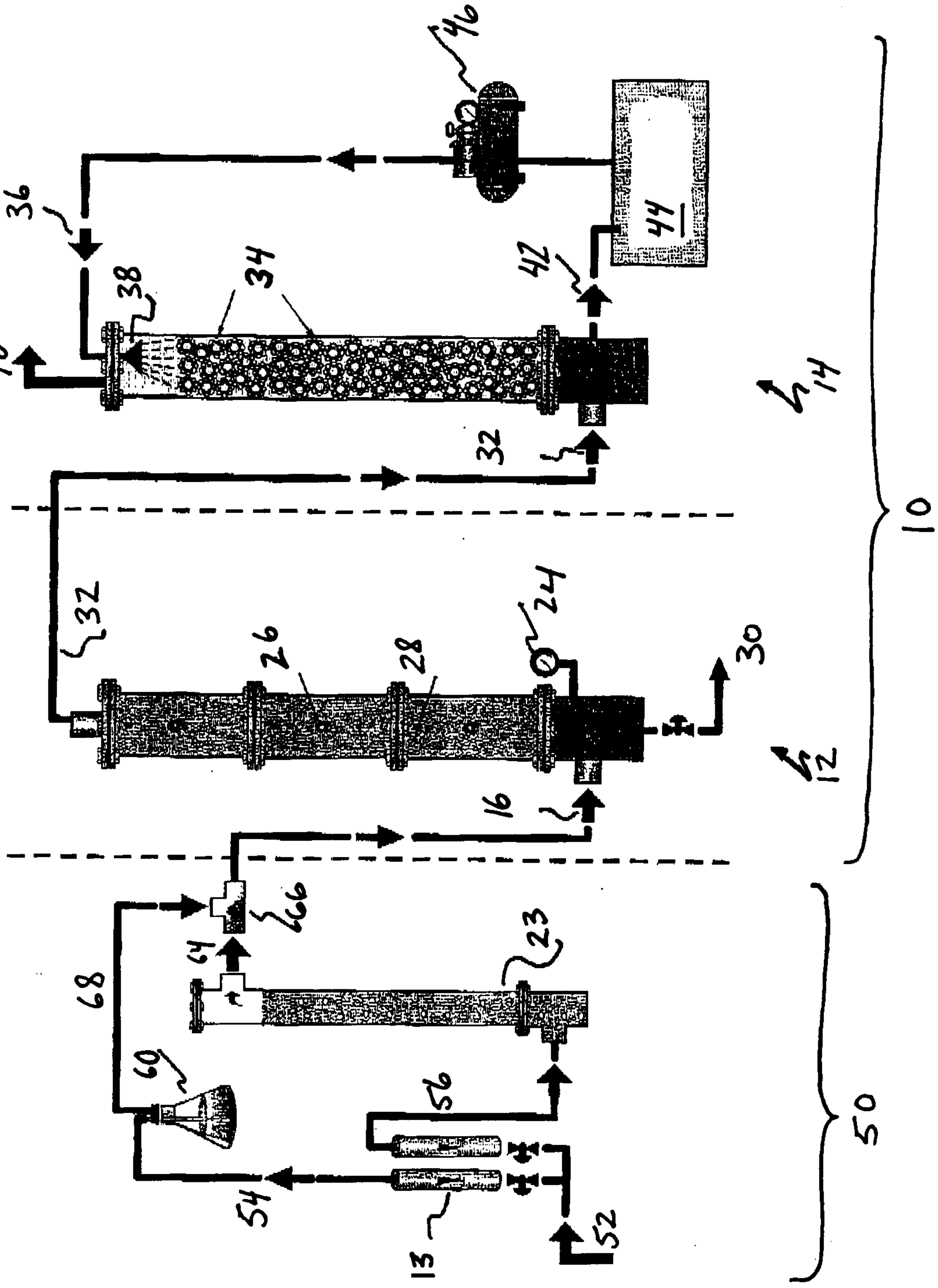

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Figure 1

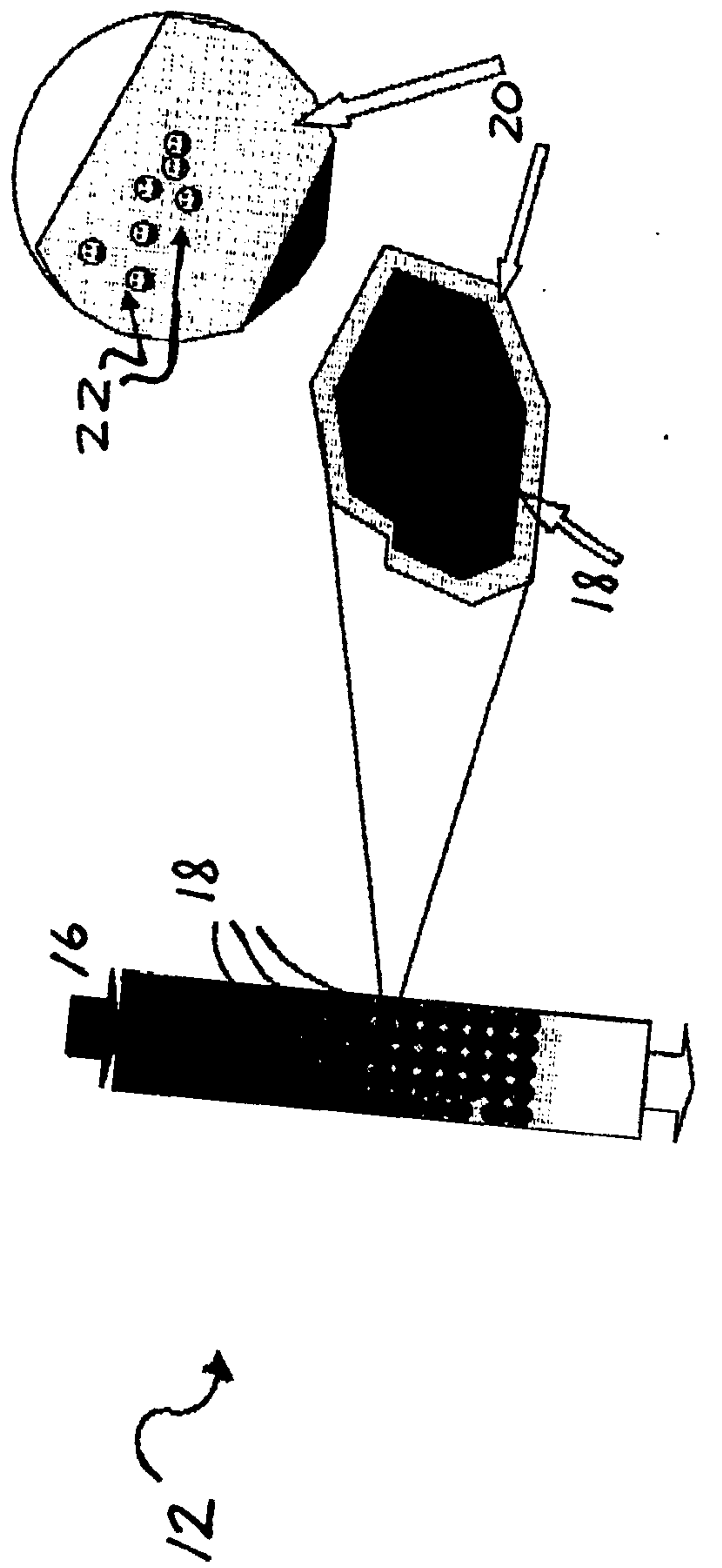
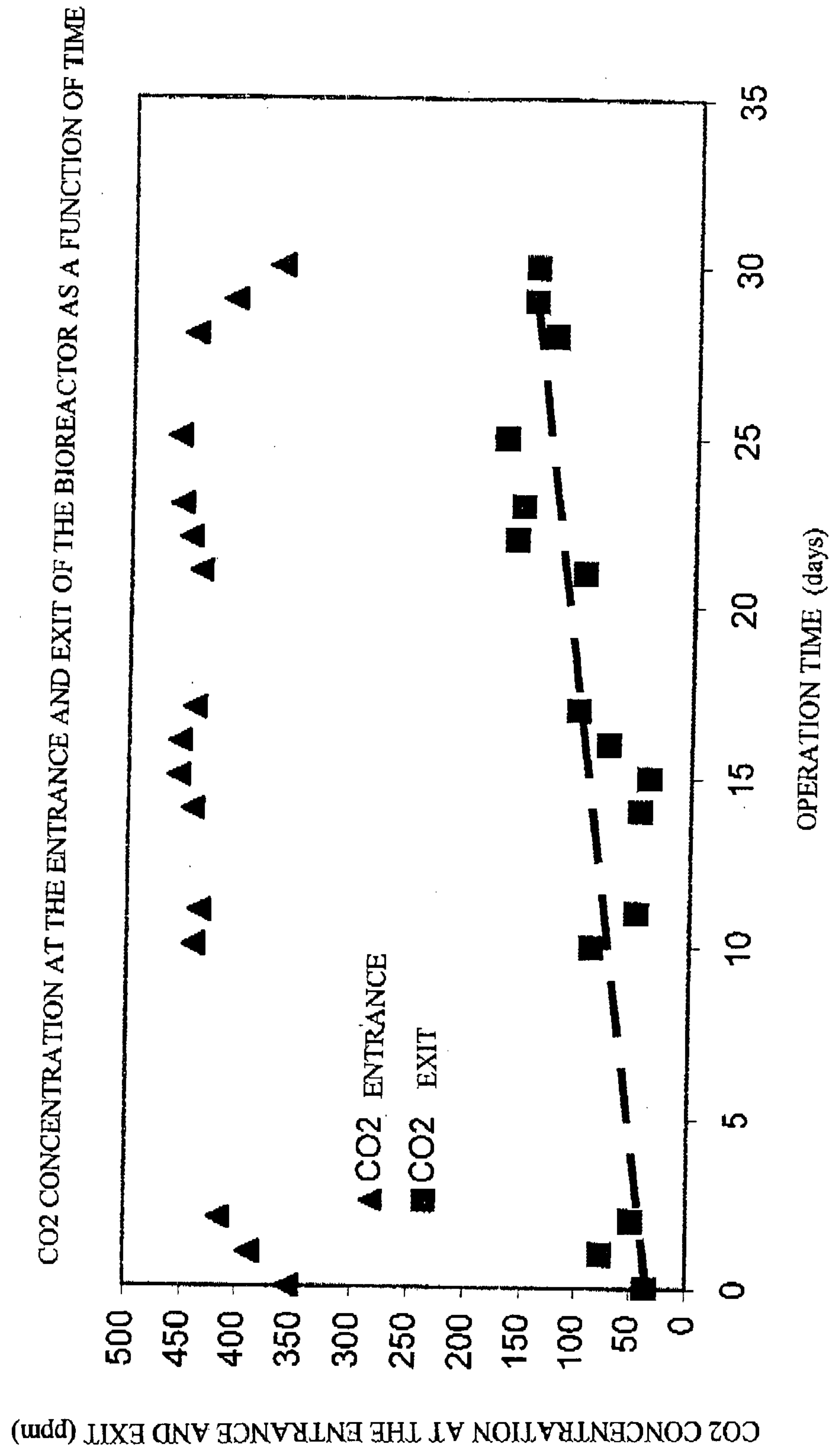


Figure 2

Figure 3


CO2 CONCENTRATION AT THE ENTRANCE AND EXIT OF THE BIOREACTOR AS A FUNCTION OF TIME
CO2 ENTRANCE
CO2 EXIT
CO2 CONCENTRATION AT THE ENTRANCE AND EXIT (ppm)
500
450
400
350
300
250
200
150
100
50
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0
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25
30
35
OPERATION TIME (days)

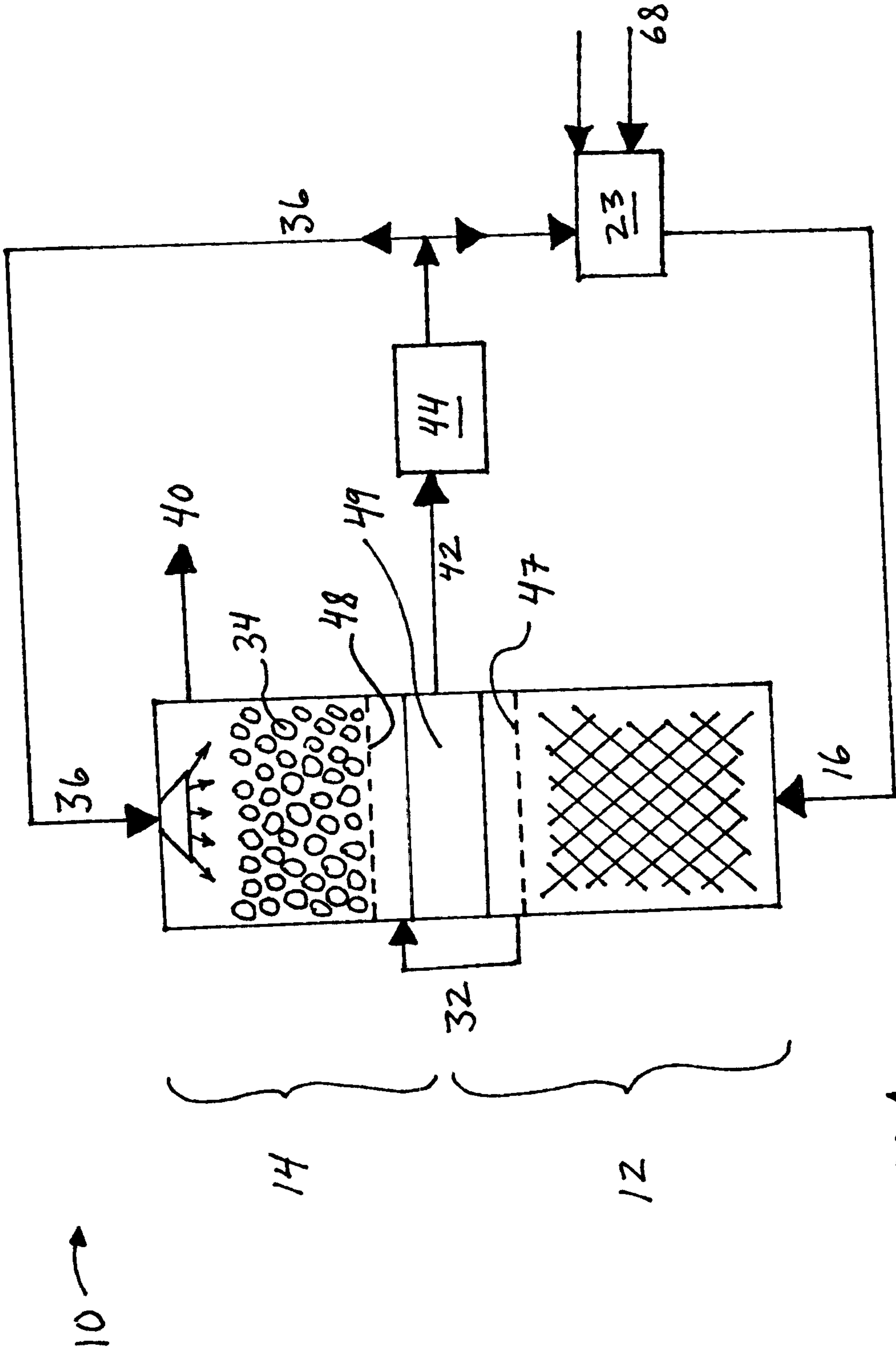
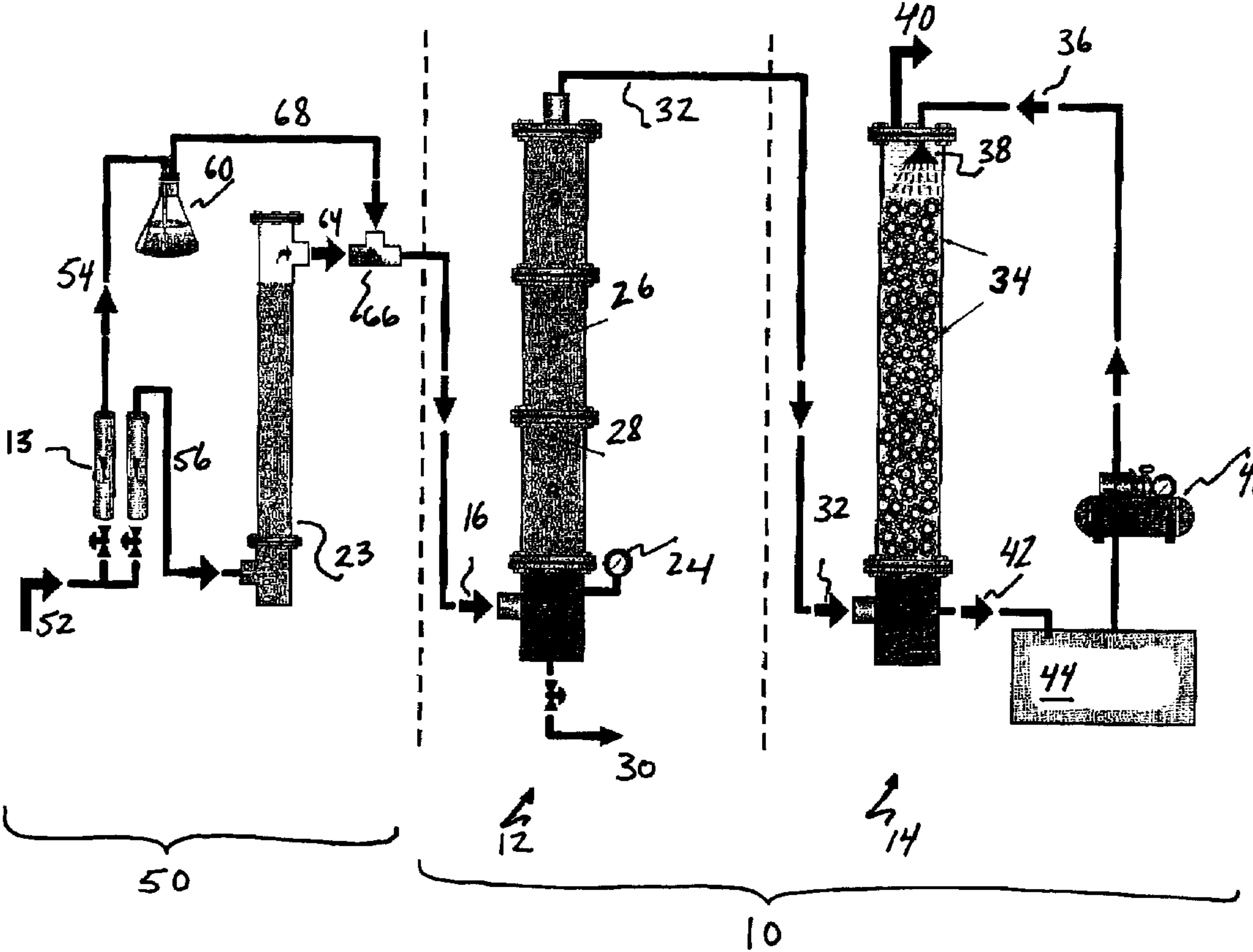


FIGURE 4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