

Translation

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THERMOMEMBRANE METHOD AND DEVICE

This invention pertains to a method to separate fluid mixtures consisting of at least two components, the fluid mixture being separated through contact with a selectively adsorbing membrane in conjunction with a porous transport matrix utilizing basic kinetic concentration effects in combination with thermal desorption of the sorbates.

Furthermore, this invention pertains to a device to separate a fluid mixture consisting of at least two components comprising a carbon membrane adjacent to or on one surface of a porous transport matrix, the membrane being adjacent to a first operating zone and another surface of the transport matrix, which surface is spatially removed from the membrane, being arranged adjacent to a second operating zone as well as devices to heat the surface and/or a part of the transport matrix which is adjacent to the second operating zone.

This invention also pertains to the use of the above-mentioned method or of the specified device to clean polluted inflowing or outflowing air, to concentrate a component from process gases, in particular hydrogen and/or to separate air.

The separation of fluid mixtures into their components represents a very significant field of technology from an economic viewpoint. It extends from the extraction of individual components of the mixture in their purest forms

to the production of product mixtures containing a least one component in concentrated form, relative to its contents in the initial mixture. Typical operational areas include the recovery of solvent vapours, the extraction of hydrocarbons and/or hydrogen from appropriate mixtures, for example following crack processes ("rectisorption processes") but also the separation of permanent gases from natural sources or technical processes, such as the separation of oxygen and nitrogen from air or the recovery of hydrogen from ammonia/hydrogen mixtures during the Haber-Bosch process or in other technical process gases.

As well, the cleaning of harmful, polluting or even toxic components from air or outflowing air requires that individual components be separated from complex fluid mixtures. In recent years such cleaning processes have become increasingly significant, such as in the cleaning of the air in industrial production facilities, e.g. in the super-clean rooms of the semi-conductor industry, or also in the feeding of purified ambient air into the interior of motor vehicles.

The separation of gas and gas/vapour mixtures as well as the separation of individual components from such mixtures is usually done technically through adsorption or recently, in conjunction with the development of selective membranes, also using permeation processes.

Adsorption utilizes the capacity of porous solids with large surfaces, such as activated charcoal, silica gel, and aluminium silicates, to concentrate gases and vapours

contained in small concentrations in gas mixtures and, therefore, to separate them from the mixture.

Essentially, all known adsorption processes consist of two operating steps: adsorption and desorption. Both processes can be carried out discontinuously with stationary adsorbent layers and continuously in the countercurrent process. Adsorption usually takes place at the lowest temperatures possible because high temperatures reduce the adsorption capacity of the adsorption agent. As a rule, desorption takes place at higher temperatures at which the loaded adsorption agent is freed of the adsorbed adsorbate thermally through the injection of super-heated steam.

Pressure swing adsorption (PSA) was developed to separate permanent gases. In this process, adsorption, once again using activated charcoal in particular, is carried out from the mixture at high pressures of up to almost 10 bar because at such high pressures the gas with the higher boiling point is adsorbed better than the gas with the lower boiling point. A precise separation, for example of hydrogen and carbon monoxide, or of hydrogen and methane, can be achieved. The adsorbent is regenerated, i.e. the more strongly adsorbed gas components are desorbed, by means of a reduction in pressure in parallel flow and subsequent rinsing with low-pressure pure gas. In this discontinuous process, part of the pure gas extracted must be re-used for regeneration. PSA fluid separation is employed on an industrial scale but is too impracticable, as well as not economic enough, for many conceivable applications.

The so-called "BF process" was developed specifically to separate oxygen and nitrogen. This process utilizes the small difference in size between nitrogen and oxygen which takes effect when adsorption is carried out using such finely-pored adsorbents that the pore size is in the range of the critical molecular diameter. At that point the difference in molecular sizes has a great effect on the diffusion velocity in the adsorbent. It has been found, for example, that the velocity-determining step in the adsorption of oxygen from an oxygen/nitrogen mixture on carbon molecular sieves with pore diameters in the 0.5 nm to 0.7 nm range is the so-called surface diffusion, which depends on the molecular size and, in particular, on the electron density. Despite similar equilibrium loadings for nitrogen and oxygen, oxygen is adsorbed much more quickly. Accordingly, a discontinuous process has been proposed which is similar to the PSA process and in which air is passed through an adsorber charged with activated coke for a short period under light excess pressure. First the oxygen is adsorbed. The relevant oxygen-loaded adsorber is then evacuated in order to draw off the oxygen. Where two adsorbers in parallel connection are used, one of which is always loading and the other unloading, a quasi-continuous process can be carried out that delivers an oxygen-rich gas containing approximately 50 to 55% oxygen. If part of the desorbed rich gas is fed back to rinse the relevant parallel operating adsorber, an oxygen concentration of up to about 80% by volume can be achieved.

German patent DE 36 18 426 as well as EP 606 306 of Bergwerksverband GmbH [Mining Association PLC] describe the production of carbon molecular sieves such as are used in the PSA or BF processes to extract nitrogen from air. As a rule, high-density, especially finely-pored activated charcoal granulates with apparent densities greater than 500 g/l are used in these processes.

The membrane separation process based on the basic operation of permeation is another method to separate gases and gas/vapour mixtures as well as to concentrate individual components or to separate individual components from such mixtures. Partially permeable, selectively operating membranes are used in this method to separate complex gas or gas/vapour mixtures. In addition to made-to-measure synthetic polymers, the materials for the required fixed membranes also include, among others, inorganic materials, like porous glass or glass ceramic, graphite, graphite oxide, and similar materials.

It has also been proposed that oxygen-rich gases be obtained by means of air separation on membranes. A significant problem with this is the unfavourable volume operation in comparison to liquid phase applications.

US patent specification 4,349,356 describes a method to concentrate a component from a gas mixture on porous glass membranes in accordance with the principle of Knudsen diffusion. With this method the gas mixture is fed to the membrane in the form of a pulse and the permeated gases

are suctioned off at specific time intervals. The enrichment factor is both time and pore size dependent, the motive force once again being the pressure difference. Adsorption processes play no role in the method described in US 4,349,356.

Separation processes using a combination of adsorption and membrane separation mechanisms are also known in the prior art.

A continuously operating gas separation process at membranes is described in EP 428 052 for example. In this method a semi-permeable composite membrane is used which consists of a thin porous substrate covered with a porous adsorption material. The basic function of the porous substrate is to guarantee a mechanical carrier and a defined pore size for the porous membrane precipitated on it.

The gas separation process described in EP 428 052 is based essentially on the pressure difference applied, i.e. on the fact that the fluid mixtures is pressed on the membrane under high pressure, parts of the fluid mixture being adsorbed selectively on the composite membrane and reaching the other side as a result of surface flow where they are suctioned off in a partial vacuum or desorbed through a reduction in the pressure. The carrier substrate does not affect these processes, it is inert. A low thickness of the composite membrane, less than 20 μm , is essential for this process to be implementable, because

otherwise the permeation velocities of the adsorbed components are too low.

An essential disadvantage of this process of the prior art is that the concentration of species which it is difficult to desorb (e.g. water, compounds with high boiling points, like xylene, naphthalene, SO_2 , H_2SO_4 , etc.) reduce the selectivities considerably. For example, the fluid mixtures used must be virtually free of water because water occupies the adsorption sites on carbon membranes, reducing greatly the selectivity and permeability of such systems. In order to remove the water, pressure gradients that are definitely higher and that increase in the course of the process must be developed in order to remove the adsorbed water. Substances with high boiling points virtually cannot be removed at room temperature and poison the membrane successively. This restricts very greatly the area of application of membranes like those described in EP 428 052. For example, partial vacuums of up to -50 mbar must be used to remove water in discontinuous processes, which is usually not possible in continuous processes for process-engineering reasons.

The use of analogous composite membranes to concentrate hydrogen is described in EP 582 184. In this patent, the membrane separation process described in EP 428 052 is used in combination with the traditional PSA process. In this case, too, the above disadvantages of membrane poisoning result.

US patent specification 5,649,996 describes a process to separate gases using molecular sieve membranes (MSM) made of activated charcoal fibres. In order to achieve the required selectivity and the higher separating sharpness, this process must be carried out at cryogenic temperatures of below -20°C . However, at such low temperatures, a much larger pressure gradient must be applied to the membrane in order to desorb the permeate. This restricts considerably both the applicability as well as the economic efficiency of this process. In addition, the gases are also precleaned in this process in order to keep water, substances with high boiling points, and other substances which it is difficult to desorb away from the membrane.

US patent specification 4,685,940 describes the manufacture and use of carbon membranes with defined pore sizes and distribution. They are used for the sieve-like separation of gas mixtures in accordance with the molecular diameter. The carbon membranes are precipitated on inert porous carriers. In this case, too, a pressure difference is established by means of the membrane. Furthermore, only two-component mixtures are used for separation with this method. However, the membranes described in US patents 5,649,996 and 4,685,940 are not suitable in the main for the method of this invention.

Consequently, there is a great need to make available membrane separation processes which overcome the prior-art disadvantages described, especially with respect to the selectivity of the membranes remaining unaltered for a long period.

In addition, a substantial and continuously increasing need for concentrated and pure gases make it absolutely necessary that the costs of the corresponding separation processes be reduced. Therefore, on account of their high energy costs, pressure gradient processes, particularly pressure swing processes, are especially disadvantageous for the compressing and decompressing of gases. As well, the recovery of educt gases from process gas mixtures of industrial production systems for the purpose of feeding them back into the production process is necessary and desirable both for economic as well as ecological reasons but depends basically on the investment and operating costs of the required separation processes. The technically equivalent case of the selective depletion of individual, for example harmful, components of a gas or gas/vapour mixture requires separation processes that are as inexpensive as possible.

As a result, there is a great need to make available an inexpensive separation process for the concentration or depletion of gases from appropriate mixtures.

In the most favourable case, such a process should combine the positive characteristics of traditional adsorption methods with the special characteristics of membrane separation processes, i.e. basically allow for high separation selectivity without a cost-intensive, spatially- and/or temporally-separate regeneration of the membrane or of the adsorbent being required.

Against this background, an essential problem of the invention is to make available a process to separate mixtures of the type described in Claim 1 that uses inexpensive means to create a continuous or quasi-continuous process for the extraction or separation of at least one fluid component.

The inventive process shall make possible a high selectivity and yield of the separation or concentration with low energy and construction costs.

A further essential problem of the invention is the provision of a device to separate fluid mixtures of the type described in Claim 13 which allow the above-mentioned separation processes to be realized.

Moreover, an essential problem of the invention is the creation of a device which, with a high degree of efficiency and the appropriate dimensions, allows one or more components to be separated from inflowing or outflowing air or from process gases.

The process-related problems are solved by the characteristics of Claim 1.

Advantageous embodiments of the inventive process are defined in the process subclaims.

The device-related problems are solved by the characteristics of Claim 8. Advantageous embodiments of the inventive device are defined in the device subclaims.

The inventive process for the separation of a fluid mixture consisting of at least two components is comprised of the following steps:

- contacting of the fluid mixture with a carbon membrane which is adjacent to the surface of a porous transport matrix (and preferably is applied to the latter) at a first lower temperature in a first operating zone, in which case at least one fluid component is adsorbed and at least one adsorbed component of the fluid mixture preferably permeates through the membrane;
- heating of a surface spatially distant from the membrane and/or part of the transport matrix to a second, higher temperature which facilitates the thermal desorption of adsorbed components in a second operating zone, producing a concentration gradient with respect to the at least one permeated component from the membrane surface through the transport matrix to the second operating zone;
- separate removal of the fluid mixture depleted by the at least one permeated component from the first operating zone and of the fluid mixture enriched by the at least one permeated component from the second operating zone.

The inventive device to separate a fluid mixture consisting of at least two components is comprised of a carbon membrane adjacent to a surface of a porous transport matrix, the membrane being adjacent to a first operating zone of the matrix and another surface of the transport

matrix which is spatially removed from the membrane being adjacent to a second operating zone, as well as of devices to heat the surface and/or a part of the transport matrix adjacent to the second operating zone.

The transport matrix for the inventive method or the device consists of porous material having adsorption properties similar to those of activated charcoal, normally porous activated charcoal itself. This can be used in any form, for example in the form of plates and/or tubes or also of bulk material. Especially preferred is the use of extrusion-moulded bodies. Their manufacture has been known for a long time in the prior art (in this regard see, for example, Fuel 1881, Vol. 60, pp. 817ff., DE 21 19 829, DE 36 18 426). Activated charcoal moulded parts are normally produced through the compression of coal/binder mixtures followed by sintering and steam activation.

Especially preferred as transport matrix material is sintered activated charcoal with a density of 0.2 - 1.8 g/l, preferably 0.6 - 1.2 g/l, and a BET surface greater than 200 m²/g, preferably greater than 500 m²/g, more preferably greater than 800 m²/g, especially preferably greater than 1000 m²/g, and most preferably greater than 1200 m²/g. Such sintered activated charcoal materials facilitate a high surface mobility of the adsorbed components. Furthermore, such activated charcoal material is especially suitable for the installation of drilled holes on the desorption side for the placement of electrical heat conductors for example.

However, a large number of other porous adsorbents might be used as transport matrix material, such as aluminosilicates, zeolites, silica gels of all kinds, etc. provided they guarantee the transport of the permeated components through the essentially identical molecular movement mechanism, particularly through surface flow.

In order to produce channels for the removal of the permeate/desorbate within the transport matrix, substances with low melting points, for example metals, can be embedded prior to compression of the coal/binder mixture. These substances melt during sintering and run out, producing the appropriate hollow spaces.

The transport matrix useable with the inventive method must be combined with an activated charcoal membrane which itself is preferably membranized on a surface. In this case, too, many methods have been known in the prior art for a long time.

In most cases, so-called CVD processes are used to produce carbon membranes. For this purpose the carrier, in the case of this invention the transport matrix, is treated with hydrocarbon-separating compounds at high temperatures (see G. Savage, Carbon-Carbon Composites, Chapman and Hall, London, 1993, p. 85 ff., US 3,960,769, US 3,979,330). Almost all known saturated and unsaturated hydrocarbons with sufficient volatility are suitable as hydrocarbon-separating compounds. Examples of these are methane, ethane, ethylene, acetylene, linear and branched alkanes, alkenes, and alkynes with carbon numbers of C_{1-20} ,

aromatic hydrocarbons like benzene, naphthalene, etc., single and multiple alkyl-, alkenyl-, and alkynyl-substituted aromates such as toluene, xylene, cresol, styrene, etc., and the like. These are used in CDV and CVI processes, usually in low concentrations in an inert gas such as N_2 , argon, or the like. It is also possible to add hydrogen to the relevant separation gas mixtures.

In order to distribute the precipitated activated charcoal membrane more uniformly on the matrix, the so-called CVI process (Chemical Vapour Infiltration, for example, see also W. Benzinger et al., Carbon 1996, 34, p. 1465), which is described in the literature and is well-known to the experts, is used in the standard manner, in which during precipitation of the membrane the decomposition gases are suctioned onto the surface of the transport matrix by means of a continuous vacuum ("forced flow CVI"). This results in an essentially homogeneous pore structure being maintained in the activated charcoal membrane. This homogenization of the pore structure by means of forced flow CVI also increases the mechanical strength of the membrane. Optionally, after the CVI membranization, a further sintering step can be carried out at temperatures up to $1200^{\circ}C$ in order to further stabilize the homogenization and strength of the membrane.

As well, where the permeability of the resulting membrane is too low, the pore system can be expanded subsequently by wetting the membrane briefly with an oxidizing agent, e.g. HNO_3 , and then treating it thermally.

In this invention, a fluid mixture to be separated is brought into contact in a first operating zone with the activated charcoal membrane at a first lower temperature. On account of the molecular-kinetic and thermodynamic characteristics of the membrane surface, preferably at least one component is adsorbed at the membrane, this means with higher selectivity than other fluid components. Depending on the nature of the component to be adsorbed, the selectivity of the adsorption can be increased through suitable pressure and temperature conditions. Low temperatures are to be preferred on the membrane surface, preferred are temperatures of minus 20°C to approximately 100°C, especially preferred is room temperature.

In accordance with a thermodynamically driven concentration equalization, as the packing of the surface increases the adsorbed molecules begin to migrate in the direction of the lower packing density as a result of transposition processes, some of them migrating into the pore channels on the surface of the membrane, passing through the membrane in this way.

As a rule, at least one of the adsorbed components will have a higher mobility than the other adsorbates and permeate preferentially through the membrane into the transport matrix. This capacity for preferred permeation is the essential factor in determining the selectivity of the separation on the membrane.

The transposition processes at adsorption sites are generally described as surface flow. Behind the membrane, the

permeated components distribute themselves on the adsorption sites of the pore system of the transport matrix. As long as there are free adsorption sites, they will be occupied by advancing molecules so that new adsorption sites are constantly becoming free on the membrane which are immediately re-occupied by molecules from the fluid mixture. This thermodynamically driven concentration equalization only comes to an end when a concentration equilibrium has been established, i.e. when all adsorption sites on the membrane and in the transport matrix are occupied.

Therefore, the transport matrix fulfils multiple functions: on the one hand, it promotes the transport of permeated species through the membrane without the components having to be desorbed immediately on the back of the membrane, while also maintaining the surface flow behind the membrane by guaranteeing an unbroken chain of adsorption sites. On the other hand, as a result of the large number of adsorption sites it operates as a kind of reservoir or interim storage for adsorbed components.

The transport matrix joins the first operating zone, which is adjacent to the membrane, with a second operating zone, which is spatially distant from the membrane adjacent to the transport matrix. For example, this can be the external surface opposite to the membrane side, or also a hollow channel, a drilled hole or the like in the transport matrix. In order to desorb the adsorbed components in the second operating zone, the invention provides that the boundary surface between the transport matrix and the

second operating zone and/or a part of the transport matrix adjacent to the second operating zone be heated in order to make available in this way the energy required for desorption of the sorbates.

This thermal energy can be made available in all sorts of ways, for example through heating with electrical heating conductors, induction heating, radiant heating pipes, tubular lamps, infra-red radiation, microwave radiation, passage of a heated gas or fluid over/partially through the transport matrix and similar measures known to the experts. Heating conductors jacketed with catalytically effective material can also be used with which, for example, adsorbed volatile, organic compounds are oxidized catalytically during desorption in specific applications. Especially preferred is direct heating of part of the transport matrix through attachment or installation of electrodes, provided the transport matrix is made of an electrically conductive material. Especially advantageous is direct electrical heating via installed electrodes with an activated charcoal matrix. Activated charcoal exhibits a (negative) electrical thermal conductivity coefficient which is very dependent on the temperature as a result of which a kind of electrical channel formation occurs in the transport matrix with the assistance of which a restricted area of the transport matrix can be heated very effectively, whereby the membrane layer is not heated in the main.

Depending on the nature of the desorbed components, the temperature applied for desorption is between 30 and 300°C, preferably between 50 and 150°C. Where the transport matrix

is heavily occupied with substances with high boiling points, a higher temperature, up to 500°C or more, can be used in individual cases (non-oxidative conditions).

The thermal desorption of adsorbed components from the transport matrix into the second operating zone results in new adsorption sites in the transport matrix being freed, disturbing the concentration equilibrium and re-stimulating the surface flow of sorbates from the membrane into the transport matrix in the course of the concentration equalization. In this way, discontinuous or continuous heating of one side of the transport matrix can produce a quasi-continuous surface flow of adsorbed components from the first into the second operating zone, resulting in a concentration of the adsorbed components from the fluid mixture in the first operating zone as well as in a corresponding concentration of these components in the second operating zone.

In this regard it has to be taken into account that the surface flow processes take place in addition to normal diffusion processes or parallel to them at the membrane and in the transport matrix. Consequently, the pore size of the membrane is not decisive for the separation effect. The pore sizes of the membrane are between 4 and 50 Å in diameter, preferably between 4 and 10 Å, those of the transport matrix up to 10 µm. The molecular diameters of adsorbed components are usually clearly smaller, therefore there is no molecular sieve type separation.

Rather, as a rule, almost all the species of the fluid mixture pass through the membrane in the course of diffusion and flow processes; however, the transport of adsorbed components by means of surface flow is many times faster, so that the separation effect of the inventive device or process in accordance with this invention is based essentially on kinetic effects.

The fundamental advantage of the invention lies in the use of thermal desorption, which, in view of the better energy balance, is not only more advantageous than pressure desorption, but also facilitates the removal of substances which it is difficult to desorb by means of pressure, such as water, substances with high boiling points, acids, etc. As a result, the service life and selectivity of inventive devices is clearly higher than the pressure desorption devices known from the prior art.

Thermodesorption can be combined with pressure desorption and/or supplemented with it in the inventive process and device in an advantageous manner. For this purpose, a partial vacuum must be added in the second operating zone if necessary.

The fluid mixture can also be fed into the first operating zone in the form of a pulse or alternation from excess pressure to negative pressure in order to remove non-permeating components from the membrane again or faster from the pores and the area before the membrane at which separation occurs.

The removal of fluid mixtures depleted of the preferably adsorbed components from the first operating zone after a certain contact period and of the correspondingly enriched fluids must be carried out on separate routes. In order to further increase the degree of concentration or depletion, the fluid mixtures can be brought in contact with other inventive devices in the sense of membranes connected in series. For example, the fluid mixture extracted from the first operating zone can be used as circulation gas to remove the depleted fluid mixture in the first operating zone of a membrane connected downstream and/or in parallel by managing it in a circuit. In the same way, the fluid mixture extracted from the second operating zone can be used to remove desorbed components from the second operating zone of a membrane device connected downstream and/or in parallel. Parallel supply of the flow to a large number of inventive membrane/transport matrix devices is also provided for and especially preferred in this invention.

Naturally, the inventive process and/or device can be used both to extract a gas depleted of at least one component from the first operating zone as well as to extract enriched fluid mixtures from the second operating zone. Depending on the separation problem and the properties of the fluid components as well as of the membrane, the expert will choose where the fluid mixture occurs that is of more interest to him.

The fluid mixture enriched with desorbed components can be removed from the second operating zone through the application of a partial vacuum by means of suction or by means

of passing a carrier gas, which carries the desorbed components with it, through the second operating zone.

The inventive process and device can be use for a large number of separation problems, for example the separation of permanent gases, such as the separation of air into N_2 and O_2 , the concentration of O_2 from air, the concentration or separation of hydrogen from industrial process gases, the concentration or separation of D_2 from H_2/D_2 -mixtures, the separation of volatile hydrocarbons from inflowing or outflowing air (air purification) and the like. It is also possible to dry gases and/or gas mixtures using the inventive method and/or device. In this regard, thermodesorption allows an almost quantitative separation of water in a very simple way.

It is also possible to separate gas/vapour mixtures or liquid mixtures using the invention.

In addition, the invention can be used to separate inert gases, to separate isotopes from mixtures containing fluid isotopes, to separate isomers, to dry compressed air as well as to extract and/or concentrate N_2 . The invention also provides for its being used as a preliminary stage in combination with a traditional pressure swing-adsorption process, for example for the extraction of oxygen from zeolites.

Depending on the application, the dimensions of inventive devices can be varied greatly. Small compact modules with car-battery low-voltage heating are conceivable for use as

interior air filters, e.g. in motor vehicles, correspondingly large technical systems are necessary to separate air into its main components.

Essential advantages of the inventive process or a corresponding device compared to the known art are found in its structural simplicity and low structural costs, above all, because there are no moveable parts in the potential compact design nor do separate regeneration or desorption devices have to be provided. Also advantageous is the high, design-based, mechanical stability, which also allows unstable species to be desorbed in a vacuum. Very high desorption temperatures can also be achieved without special materials or expensive insulations being required.

This invention shall be explained in more detail on the basis of the following examples of the device.

Description of the Figures:

Figure 1 shows the profile of an inventive transport matrix with a lamellar structure.

Figure 2 shows a perspective view of the transport matrix in Figure 1.

Figures 1 and 2 show a transport matrix consisting of a central plate 1 to which lamellar surfaces 2, both sides of which are arranged parallel to one another, are attached vertically to the plane of illustration. The main plane of the lamellar surfaces is vertical to the plane of

the central plate 1. The central plate 1 has channels 3 passing through it which form the second operating zone of the device. The lamellar surfaces 2 are membranized on the surface. This membranized surface is adjacent to the first operating zone which surrounds the exterior of the plate 1.

If electrodes are now attached to the central plate 1, for example on the two opposite sides (A, B) and electrical voltage is applied to them, the electric current flows through the central plate 1 in the shortest way, heating essentially only the second operating zone of the plate. In this way heating of the lamellar surfaces and, therefore also of the membrane, is largely prevented.

The fluid mixture is applied to the membranized lamellar surfaces from both sides, so that the permeating components can be removed subsequently from channels 3 of the central plate 1 following thermal desorption.

In another preferred embodiment of the inventive device, the channels 3 of the central plate 1 are sealed on one side, in which case a suction pipe socket made of material which does not conduct electricity can be attached to the other end.

C L A I M S:

. Process to separate a fluid mixture consisting of at least two components which is comprised of the following steps:

- contacting of the fluid mixture at a first, lower temperature in a first operating zone with a carbon membrane which is located adjacent to a surface of a porous transport matrix or applied to a surface of the matrix in which case at least one fluid component is adsorbed and at least one adsorbed component of the fluid mixture preferably permeates through the membrane;
- heating of a surface spatially distant from the membrane and/or a part of the porous transport matrix to a second, higher temperature which facilitates the thermal desorption of adsorbed components into a second operating zone, producing a concentration gradient with respect to the at least one permeated component from the membrane surface through the transport matrix to the second operating zone;
- separate removal of the fluid mixture depleted of the at least one permeated component from the first operating zone and of the fluid mixture enriched by the at least one permeated component from the second operating zone.

2. Process in accordance with Claim 1 **characterized by** the carbon membrane facilitating the permeation of the at least one adsorbed component and the



transport matrix the transport of the permeated component essentially by means of the same molecular movement mechanism.

3. Process in accordance with one of the preceding claims
characterized by the permeation and transport of the at least one of the permeated components essentially by means of surface flow of the adsorbed species.

4. Process in accordance with one of the preceding claims
characterized by the heating being carried out by means of an electrical heating conductor.

5. Process in accordance with one of the preceding claims
characterized by the heating of a part of the transport matrix by direct electrical heating.

6. Process in accordance with one of the preceding claims
characterized by continuous or discontinuous heating.

7. Process in accordance with one of the preceding claims
characterized by the fluid mixture enriched with the at least one of the preferably permeated components being removed continuously or discontinuously from the second operating zone, if necessary through the application of a pressure gradient.



8. Process in accordance with one of the preceding claims

characterized by the process steps of Claim 1 being carried out several times one after the other on several membrane/transport matrix structural assemblies connected in series behind one another.

9. Process in accordance with one of the preceding claims

characterized by the fluid mixture extracted from the first operating zone being used as circulation gas for the further depletion and/or removal of the depleted fluid mixture in the first operating zone of a process connected downstream.

10. Process in accordance with one of the preceding claims

characterized by the fluid mixture extracted in the second operating zone being used as circulation gas for the further concentration and/or removal of desorbed components in the second operating zone of a process connected downstream.

11. Process in accordance with one of the preceding claims

characterized by the fluid mixture depleted of permeated components being extracted from the first operating zone.



12. Process in accordance with one of the preceding claims

characterized by the fluid mixture enriched with permeated components being extracted from the second operating zone.

13. Device to separate a fluid mixture consisting of at least two components comprising a carbon membrane adjacent to or applied to a surface of a porous transport matrix, the membrane being adjacent to a first operating zone and another surface of the transport matrix, which surface is spatially removed from the membrane, being arranged adjacent to a second operating zone as well as devices to heat the surface and/or a part of the transport matrix which is adjacent to the second operating zone.

14. Device in accordance with Claim 13
characterized by the transport matrix being designed in the form of plates or pipes.

15. Device in accordance with one of Claims 13-14
characterized by the transport matrix being made of activated charcoal, in particular sintered activated charcoal with a BET surface greater than 200 m²/g, preferably greater than 500 m²/g, more preferably greater than 800 m²/g, especially preferably greater than 1000 m²/g, and most preferably greater than 1200 m²/g.

16. Device in accordance with one of Claims 13-15
characterized by the facilities to heat the desorption side of the transport matrix being comprised of radiant



heating pipes, a tubular lamp, an electrical heating conductor, an induction heating device, which can be installed in part of the transport matrix, or of direct electrical heating of an electrically conductive part of the transport matrix.

17. Device in accordance with one of Claims 13-16 **characterized by** devices for the supplying and removal of a fluid mixture being provided in a first operating zone and devices for the removal of a fluid mixture enriched with at least one component in a second operating zone.

18. Device to separate a fluid mixture **characterized by** several devices in accordance with of Claims 13-17 being operated in series.

19. Device in accordance with one of Claims 13-18 **characterized by** air being brought into contact with the membrane surface in the first operating zone and oxygen-enriched air being extracted in the second operating zone.

20. Device in accordance with one of Claims 13-19 **characterized by** the second operating zone being in the form of channels in a plate-shaped transport matrix which has lamellar surfaces, both sides of which are arranged in parallel vertical to the plane of the plates, to which the carbon membrane is applied.

21. Device in accordance with Claim 20 **characterized by** the current from a direct electrical heating device being conducted along the surfaces of the



transport matrix plates vertically to the main plane of the lamellae.

22. Use of the process and/or of the device in accordance with one of the preceding claims to clean polluted inflowing and outflowing air, especially the interiors of motor vehicles and the like.

23. Use of the process and/or of the device in accordance with one of the preceding claims to concentrate a component from process gases.

24. Use of the process and/or of the device in accordance with one of the preceding claims to concentrate hydrogen from fluid mixtures.

25. Use of the process and/or of the device in accordance with one of the preceding claims to separate air and/or to concentrate oxygen from air.

26. Use of the process and/or of the device in accordance with one of the preceding claims to dry gases and/or gas mixtures.

27. Use of the process and/or of the device in accordance with one of the preceding claims to separate inert gases.

28. Use of the process and/or of the device in accordance with one of the preceding claims to separate isotopes from mixtures containing fluid isotopes.



29. Use of the process and/or of the device in accordance with one of the preceding claims as a pre-concentration stage in combination with a pressure swing adsorber for the extraction of oxygen.