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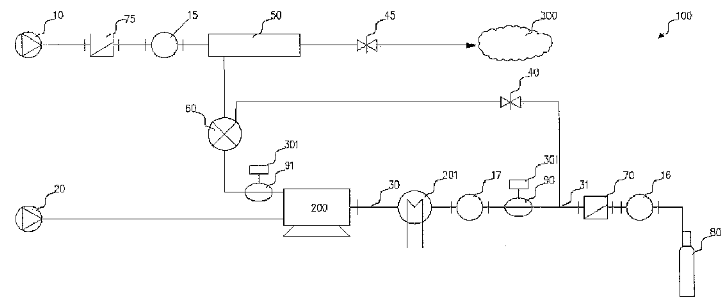

Fig.1

(57) **Abstract:** Kit (100) for an internal combustion engine (200) comprising an air intake (10) and a fuel intake (20), a recirculation valve of the exhaust smoke (40) produced by the engine (200), a gas separation device (50) suitable for separating incoming air into two volumes, one of which is rich in molecular oxygen, and directing it towards a gas mixing device (60) which mixes it with said recirculation exhaust smoke coming from said exhaust smoke recirculation valve (40).

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KIT FOR AN INTERNAL COMBUSTION ENGINE

The present invention relates to a kit for an internal combustion engine.

Kits on board vehicles are known in the state of the art, for treating exhaust smoke including carbon dioxide emitted by an internal combustion engine of a vehicle. These kits are used for treating exhaust smoke from the vehicle's engine to reduce the amount of carbon dioxide emitted by the engine into the atmosphere. These kits include selective capturing means for extracting carbon dioxide from the exhaust smoke such as, for example, adsorbent materials or materials with a selective permeability, means for compressing a volume of carbon dioxide extracted and finally means for storing the carbon dioxide thus compressed and/or liquefied on board the vehicle.

Unfortunately, the known apparatuses do not function efficiently and considerable difficulties remain which result in one or more drawbacks, such as the persistence of a considerable quantity of carbon dioxide in the exhaust smoke of the vehicle, an excessively high operating temperature of the engine, problems with corrosion due to the presence of liquid condensates that are generated inside the apparatus, the need for carrying out very close periodic maintenance operations of the selective capturing means, the considerable increase in the weight of the vehicle, thus decreasing its efficiency, storage means which have a very large volume with respect to the space available on the vehicle, and which are particularly energy-intensive as they must be kept either at low temperatures to keep the carbon dioxide in liquid phase or at particularly high pressures in order to be able to store sufficient quantities in the gaseous phase in acceptable volumes.

Recirculation apparatuses of a percentage of exhaust smoke of the engine are also known, which are suitable for reducing the operating temperatures of the internal combustion engine of the vehicle and reducing nitrogen oxide emissions. These recirculation apparatuses do not allow there to be a concentration of carbon dioxide in the exhaust gases suitable for allowing their storage.

One of the objectives of the present invention is to provide a kit for an internal combustion engine which allows the separation and/or storage of the carbon dioxide produced by said engine to be more effective and efficient and to drastically reduce the amount emitted into the atmosphere with the exhaust smoke.

Other objectives of the present invention, associated with the provision of the kit, are a reduction in the presence of liquid condensates in the exhaust smoke, together with a reduction in the periodic maintenance operations, in the weight and volumetric dimensions of the confinement and storage means of the exhaust gases, making the engine more energy efficient.

According to the invention this objective is achieved with a kit according to claim 1.

A further objective of the present invention is to provide a method which makes it possible to make the separation and/or storage of the carbon dioxide produced by said engine more effective and efficient and to drastically reduce the amount emitted into the atmosphere with the exhaust smoke.

Another objective of the present invention is to provide a method which allows a reduction in the presence of liquid condensates in the exhaust smoke, in periodic maintenance operations, together with a drastic decrease in the weight and volumetric dimensions of the confinement and storage means of the exhaust gases, making the kit that implements the method itself more energy efficient.

According to the invention this further objective is achieved with a method according to claim 10.

Other features are provided in the dependent claims.

In accordance with the present invention, the term "air" as used herein in the description and claims, refers to any gaseous mixture prevalently comprising (at least 98% by volume on an anhydrous basis) molecular oxygen and molecular nitrogen, whether it be present in nature or deriving from natural air by filtration, purification or partial separation of the components. According to what is reported in literature, the normal composition of air in the atmosphere at sea level comprises oxygen and nitrogen in a volumetric ratio of about 21/79. For the purposes of the present application, enriched air is considered to be air with an oxygen content > 23% v/v and depleted air with an oxygen content of < 19% v/v.

In accordance with the present invention, the volumes of fluids as reported herein in the description and claims, are intended indifferently as such or referring to an arbitrary unit of time in the case of flows and processes or methods conducted in continuous.

In the description of the embodiments of the present invention, the use of the terms "comprising" and "containing" indicates that the options described, for example relating to the steps of a method or a process or the components of a product or device, are not necessarily exhaustive. It is important to note, however, that embodiments of the invention should also be considered as being within the scope of the present patent application, wherein the term "comprising" referring to the options described, for example relating to the phases of a method or a process or the components of a product or device, should be interpreted as "essentially consisting of" or "consisting of", even if not explicitly stated.

The characteristics and advantages of the present invention will appear more evident from the following description, provided for illustrative and non-limiting purposes, referring to the attached schematic drawings in which:

Figure 1 is a diagram of an installation of a kit according to the present invention;

Figure 2 is a diagram of an installation of the kit according to a first alternative.

With reference to the above-mentioned figures and in particular to Figure 1, a kit 100 is shown for an internal combustion engine 200 of a vehicle designed for storing carbon dioxide produced by the internal combustion engine 200 on board the vehicle.

The kit 100 for the internal combustion engine 200 of the vehicle is an installation mounted in fluid communication with the internal combustion engine 200. A part of the kit 100 is mounted upstream of the internal combustion engine 200, another part of the kit 100 is mounted downstream of the internal combustion engine

200.

As shown in particular in Figure 1, the kit 100 comprises an air intake 10 and a fuel intake 20 mounted upstream.

The air that is received from the air intake 10 is atmospheric air and substantially comprises molecular oxygen and molecular nitrogen, i.e. an original percentage by volume of molecular oxygen and an original percentage by volume of molecular nitrogen. Typically from atmospheric measurements, the original percentage by volume of molecular oxygen in anhydrous air ranges from 20 to 22%, for example 21%, whereas the original percentage by volume of molecular nitrogen ranges from 78 to 80%, for example 79%. As is well known to skilled persons in the field, small variations in these percentages are possible depending on the environmental and geographical characteristics of the site where the measurement is effected.

The air intake 10 and fuel intake 20 are connected in fluid communication with the internal combustion engine 200.

Fuel input at the fuel intake 20 refers to any fuel used for internal combustion engines 200 such as gas oil, methane, LPG or gasoline.

The internal combustion engine 200 produces an exhaust smoke comprising carbon dioxide. The combustion reaction can be represented in simplified form with the following formula:

$$2C_xH_y + \left(2x + \frac{y}{2}\right)O_2 \rightarrow 2xCO_2 + yH_2O$$

with x greater than or equal to 1 and y normally ranging from x and 4x,

wherein C_xH_y, for example C_8H_{18}, represents a generic hydrocarbon forming the fuel which is fed to the internal combustion engine 200 from the fuel intake 20, O_2 is molecular oxygen which is inserted into the internal combustion engine 200 from the air intake 10, CO_2 is carbon dioxide, H_2O is molecular water. The elements of the formula are multiplied by the respective stoichiometric chemical reaction factors.

The exhaust smoke coming out of the internal combustion engine 200 substantially comprises molecular nitrogen, carbon dioxide and water vapour. It can also comprise lower quantities (usually less than 1%) of nitrogen oxides and unburned hydrocarbons, in addition to any residual molecular oxygen.

The exhaust smoke is then channelled into an outlet duct 30 of the kit 100.

The outlet conduit 30 is connected in fluid communication with an exhaust smoke recirculation valve 40 of the kit 100.

The exhaust smoke recirculation valve 40 directs a fraction of the exhaust smoke, which is recirculation exhaust smoke, again towards the internal combustion engine 200 and directs another fraction of the exhaust smoke, which is discharge exhaust smoke, towards an exhaust duct 31 of the kit 100. The exhaust duct 31 can also be called discharge duct 31.

The exhaust smoke recirculation valve 40 allows the recirculation exhaust smoke to be directed various times according to a multiplicity of operating cycles, or continuously.

According to the present invention, said exhaust smoke recirculation valve 40 can be a two-way valve positioned upstream of said mixing device 60, preferably coupled with a second two-way valve downstream of the exhaust duct 31 and upstream of the possible compressor 70, which acts directly on the flow of the recirculation exhaust smoke and indirectly regulates, by difference, the flow of the discharge exhaust smoke. Alternatively, said valve 40 can be a three-way valve (or equivalent device), positioned at the separation point of the streams of said recirculation exhaust smoke and said discharge exhaust smoke, which can act on both flows of said streams. Said valve 40 is preferably driven by a suitable control unit capable of managing the transient phase from the moment the engine is started until reaching regime conditions. Control units of the above-mentioned type are commercially available or easily derivable, with normal engineering methods, from known or commercially available devices. Said control unit can be the control unit 301 shown in figures 1, 2 or 3.

Downstream of the internal combustion engine 200, an energy recovery device 201 can be optionally provided, which can be, for example, a heat exchanger for recovering a part of the heat from the exhaust smoke, or a device for recovering the kinetic energy of the gas, such as, for example, a turbine connected to a dynamo for producing electricity, or to a compressor in the case of turbocharged vehicles.

According to a particular aspect of the present invention, both of the above-mentioned devices, thermal and mechanical, can also be present.

Downstream of the energy recovery device 201, a device 17 is preferably inserted for the possible discharge of water and/or other condensates of the kit 100. Said discharge device 17 is arranged between the internal combustion engine 200 and the recirculation valve of the exhaust smoke 40 and advantageously allows at least a fraction of the water produced by the internal combustion in the internal combustion engine 200, to be discharged.

Downstream of the internal combustion engine 200, a gas sensor 90 can be present which, in the engines of vehicles such as for example gasoline cars, is, for example, a lambda probe, which measures the presence of molecular oxygen in the exhaust smoke. The gas sensor 90 is logically connected with a control unit 301 of the vehicle which regulates the mixture ratio between air and fuel entering within an optimum efficiency range depending on the characteristics of the internal combustion engine 200 and the catalyst possibly present. In the case of gasoline engines, the control unit 301 controls the flow of fuel entering from the fuel intake 20, based on the flow of air entering from the air intake 10.

Upstream of the internal combustion engine 200, the kit 100 comprises a gas separation device 50 and a gas mixer 60.

The gas separation device 50 is arranged in fluid communication between the air intake 10 and the internal combustion engine 200 through said gas mixer 60.

The gas separation device 50 receives incoming air from the air intake 10. The gas separation device 50 separates the incoming air into two volumes of air: a first volume of air and a second volume of air.

The first volume of air is enriched with molecular oxygen, the first volume of air in fact comprises a first percentage by volume of molecular oxygen and a first percentage by volume of molecular nitrogen. The first percentage by volume of molecular oxygen is higher than the original percentage by volume of molecular oxygen of the incoming air and the first percentage by volume of molecular nitrogen is lower than the original percentage by volume of molecular nitrogen of the incoming air.

The second volume of air is impoverished in molecular oxygen, the second volume of air in fact comprises a second percentage by volume of molecular oxygen and a second percentage by volume of molecular nitrogen. The second percentage by volume of molecular oxygen is lower than the original percentage by volume of molecular oxygen of the incoming air and the second percentage by volume of molecular nitrogen is higher than the original percentage by volume of molecular nitrogen of the incoming air.

The gas separation device 50 directs the first volume of air enriched with molecular oxygen towards the mixing device 60.

The gas separation device 50 directs the second volume of air impoverished in molecular oxygen outwards, into the atmosphere.

The gas separation device 50 can be a polymeric separation membrane, a membrane made of ceramic material or a membrane of another nature. Devices of this type are known and commercially available for other applications.

In particular, the gas separation device 50 can be composed of hollow fiber membranes comprising a plurality of hollow fibers. The incoming air enters the hollow fibers and the gases included in the incoming air are separated due to different diffusion rates and different dimensions of the molecules. Normally, in commercially available membrane devices, molecular oxygen travels faster than nitrogen through the membrane. The first volume of air, enriched in molecular oxygen, exits from one side of the gas separation device 50, and the second volume of air (impoverished) enriched in molecular nitrogen and low in molecular oxygen, exits from the other side.

The use of flat or rolled membranes is also provided.

When the gas separation device 50 is a membrane, the first volume of air can be enriched with molecular oxygen passing, for example, from the atmospheric percentage 21% to the first percentage of 50% by volume of molecular oxygen. Preferred concentrations of molecular oxygen in said first volume of air are greater than 25% and preferably range from 30 to 90%, more preferably from 40 to 70%, by volume.

Correspondingly, the second volume of air enriched with molecular nitrogen and impoverished in molecular oxygen preferably comprises a percentage by volume of molecular nitrogen higher than 83%, preferably equal to or higher than 90% and lower than 99%.

The separation membranes operate advantageously better by pre-compressing the incoming air coming from the air intake 10 by means of a compressor device 75.

In general, it is possible to provide that the compressor device 75 is arranged upstream of the gas separation device 50 to compress the air arriving from the air intake 10.

It is also advantageous to provide for a water discharge device 15 to be positioned downstream of the compressor device 75. The water discharge device 15 is arranged in fluid communication downstream of the compressor device 75 and allows at least a percentage of water vapour to be discharged, that condenses from the incoming air coming from the air intake 10 after the compressor device 75. The water discharge device 15 is a water-vapor condensate drain.

Preferably, the incoming air is compressed at pressures ranging from 0.2 MPa to 1.5 MPa.

In the presence of the compressor device 75, a decompression valve 45 is mounted at the outlet of the gas separation device 50, which decompresses the second volume of air impoverished in molecular oxygen, releasing it towards the outside, into the atmosphere 300. Alternatively, at the outlet of the gas separation device 50, on the discharge line of said second volume of air into the atmosphere, a device for recovering the kinetic energy of the gas (not shown in the figures) can be present, following expansion, to produce, for example, electric energy by means of a dynamo or mechanical energy by means of a turbo compressor.

According to a particular embodiment of the present invention, it is possible for said gas separation device 50 to comprise various membranes in series, interspersed with compression devices, in order to obtain a greater enrichment in oxygen of said first volume of air. A person skilled in the field selects, according to methods known in the gas separation technology on a semipermeable membrane, the optimal combination of membranes and compressors, and also the pressure values acting on each membrane, in order to obtain the desired level of oxygen enrichment of the first volume of air.

The first volume of air, enriched with molecular oxygen, is sent by the gas separation device 50 towards the gas mixer 60. Said first volume of air may or may not be under pressure.

The gas mixing device 60 is arranged in fluid communication between the gas separation device 50 and the internal combustion engine 200.

Furthermore, the gas mixing device 60 is connected in fluid communication with the recirculation valve 40 of the exhaust smoke coming from the internal combustion engine 200.

The gas mixing device 60 mixes the first volume of air with the recirculation exhaust smoke coming from the exhaust smoke recirculation valve 40, generating a gas mixture.

The gas mixture comprises a percentage by volume of molecular oxygen close to the original atmospheric percentage by volume of molecular oxygen, wherein close to refers to a percentage by volume of molecular oxygen close to the atmospheric value, or within a range of percentages by volume of molecular oxygen so as to allow the optimum functioning of the internal combustion engine 200 or within an optimum efficiency range of the catalyst of the vehicle, particularly in terms of good mechanical performances and low production of nitrogen oxides at the same time. The range of percentages by volume of molecular oxygen so as to allow the functioning of the internal combustion engine 200 or to optimize the efficiency of the catalyst of the vehicle, depends on the technical characteristics of the internal combustion engine 200 or of the catalyst, and can be determined by the skilled person in the field based on the information provided by the manufacturers. It is normally lower than 22%, preferably ranging from 18 to 22% by volume with respect to the total volume of the gas mixture.

The gas mixing device 60 sends the gas mixture to the internal combustion engine 200.

In order to advantageously monitor the percentage by volume of molecular oxygen of the gas mixture sent to the internal combustion engine 200 by the gas mixing device 60, the presence of a gas sensor 91 is preferably provided.

In this preferred case, the gas sensor 91 is arranged in fluid communication between the mixing device 60 and the internal combustion engine 200.

The gas sensor 91 measures at least a percentage by volume of molecular oxygen of the gas mixture leaving the gas mixing device 60.

The gas sensor 91 and the valve 40 are in logical communication with a control unit 301 of the vehicle. The gas sensor 91 will regulate the flow of the recirculating exhaust smoke by acting on the recirculation valve 40 through the control unit 301 so as to ensure the required percentage of oxygen.

For Otto cycle combustion engines (gasoline engines), the control unit 301, in logical connection with the gas sensor 90 downstream of the engine 200, preferably also regulates the flow of fuel coming from the fuel intake 20. In this way, the control unit 301 regulates the mixing ratio between air and fuel, i.e. between comburent and fuel in such a way that the internal combustion engine 200 can operate efficiently or the catalyst of the vehicle can operate efficiently.

Even more advantageously, in order to reduce the carbon dioxide released into the environment by the system comprising said kit 100 and said motor 200, there is preferably the provision that, downstream of the exhaust duct 31, the kit 100 also comprises a compressor device 70, a water discharge device 16 and a storage device 80 of the compressed gas.

The water discharge device 16 is arranged in fluid communication downstream of the compressor device 70. The water discharge device 16 discharges at least a percentage of water volume from the exhaust smoke coming from the exhaust duct 31 and directed towards the storage tank 80.

The water discharge device 16 is a condensate drain.

The compressor device 70 is arranged in fluid communication with the exhaust duct 31 and the water discharge device 16.

The compressor device 70 compresses the discharge exhaust smoke coming out of the exhaust duct 31.

Advantageously, the water discharge device 16 allows the volume of water sent to the storage device 80 to be reduced, significantly reducing the risk of clogging and/or corrosion.

Advantageously, the storage device 80 stores the discharge exhaust smoke compressed by the compressor device 70.

The storage device 80 comprises at least one tank which allows the compressed exhaust smokes to be stored by means of the compressor device 70. This tank can possibly be filled with adsorbent material suitable for facilitating the storage of CO_2, increasing its storable volumes or allowing a lower storage pressure.

Advantageously, the presence in the exhaust smokes of a high concentration of CO_2, obtained by means of the kit and the method in accordance with the present invention, allows large quantities of gaseous carbon dioxide to be stored by simple compression in volumes reasonably compatible with transporting on board a vehicle, thus avoiding the use of heavy and energy-intensive chillers, otherwise necessary for bringing the smokes to the liquefaction temperature of the carbon dioxide and thus allowing it to be stored in the liquid state. Once filled, the storage device tank 80 can then be emptied at service stations set up for the purpose, or it can be replaced with an empty tank, transferring the full tank outside the vehicle for subsequent discharge and treatment of the gas contained therein.

An object of the present invention is also to provide a method for reducing the emission of carbon dioxide produced by an internal combustion engine 200, preferably by compression and storage in a suitable storage device 80, said engine preferably being mounted on a vehicle.

The method is implemented by the kit 100 mounted in fluid communication with the internal combustion engine 200.

The method comprises a series of steps which are described hereunder in succession, but which operate simultaneously when the engine 200 is under regime conditions: a step for receiving incoming air from the air intake 10 and receiving fuel from the fuel intake 20; a gas separation step by means of the gas separation device 50 to separate the incoming air in the first volume of air enriched with molecular oxygen and in the second volume of air impoverished in molecular oxygen.

There is subsequently a mixing step by means of the gas mixing device 60 which mixes the first volume of air enriched with molecular oxygen and coming from the gas separation device 50 with the recirculation exhaust smoke coming from the exhaust smoke recirculation valve 40.

In succession, there is a step for sending the gas mixture leaving the gas mixing device 60 and fuel towards the internal combustion engine 200.

The method subsequently comprises a step for channelling the exhaust smoke comprising carbon dioxide produced by the internal combustion engine 200 in the outlet duct 30.

The method comprises a step for intercepting the recirculation exhaust smoke, causing it to recirculate a part of the exhaust smoke towards the internal combustion engine 200 by means of the exhaust smoke recirculation valve 40 and the gas mixer 60, and allowing the remaining part, as discharge exhaust smoke, to pass towards the exhaust duct 31 of the kit 100.

Once under regime conditions, the amount of recirculation exhaust smoke that is recycled to the engine 200 preferably represents from 30 to 85%, more preferably from 35 to 75% by volume. In a particularly preferred embodiment, the amount of recirculation exhaust smoke that is recycled to the engine 200 represents from 40 to 70% by volume, with respect to the total volume of exhaust smokes coming out of the engine through the duct 30.

Under regime conditions, according to the method of the present invention, the composition, on an anhydrous basis, of the exhaust smoke coming out of the engine 200 (coinciding with the composition of the discharge and recirculation exhaust smoke), preferably comprises a carbon dioxide content ranging from 25 to 90% by volume, more preferably from 40 to 80% by volume, even more preferably from 60 to 80 % by volume, with respect to the total volume of anhydrous exhaust gas.

The method, even more advantageously, also preferably comprises an additional subsequent compression step of the discharge exhaust smoke by means of the compressor device 70. Subsequently, according to this preferred embodiment, the method comprises a step for storing the discharge exhaust smoke compressed by the compressor device 70 by means of the storage device 80.

The kit 100 advantageously enables the carbon dioxide produced by an internal combustion engine to be stored simply and effectively, preferably on board a vehicle, and drastically reduces the amount of this gas emitted into the atmosphere.

The kit 100 advantageously reduces the presence of liquid condensates, decreases periodic maintenance operations, drastically decreases the weight and the volume of the storage device 80, making the storage of the carbon dioxide produced by the engine 200 more energy efficient.

Advantageously, the use of air enriched with molecular oxygen allows the percentages of molecular nitrogen to be reduced and the fraction of carbon dioxide in the exhaust gases to be increased, allowing a greater quantity of carbon dioxide to be stored in the storage device 80 on board the vehicle at the same pressure. Alternatively, and even more advantageously, the kit 100 and the method in accordance with the present invention allow high quantities of carbon dioxide to be stored on board at considerably reduced pressures with respect to vehicles not equipped with the kit, thus advantageously reducing the weight of the necessary pressure containers, and the energy consumption for the compression. In this way, it is possible to guarantee adequate travel autonomy of the vehicle before unloading and/or treating the gas, without substantially modifying the mechanical and operating characteristics of the internal combustion engine 200.

As an alternative to a motor vehicle it is possible to mount the kit 100 with any internal combustion engine 200 of any vehicle.

Again as an alternative, it is possible to provide that the kit 100 can be mounted with any internal combustion engine 200, even an internal combustion engine 200 which is not mounted with a vehicle, for example a stationary internal combustion engine.

Advantageously, the kit 100 for this type of use allows it to be very small in size compared to the state of the prior art, also drastically reducing carbon dioxide emissions from the exhaust smoke into the external environment.

It is alternatively possible to provide that for diesel engines 200 there is no gas sensor 90 or relative control unit for carburetion control.

Alternatively, it is possible to provide that the kit 100 be equipped with a single control unit, suitably programmed, for the various regulation functions of the quantities of air and fuel being supplied and the recirculation smoke.

Again alternatively, the gas separation device 50 can be composed of PSA (Pressure Swing Adsorption) modules. The PSA modules selectively absorb under pressure, one of the two components present in the air entering from the air intake 10. In this case, the incoming air is pre-compressed by means of the compressor device 75 up to pressures preferably ranging from 0,2 to 1 MPa. The PSA modules can produce the first volume of air considerably enriched with oxygen with the first percentage by volume of molecular oxygen of around 90% and over, expelling the second volume of air impoverished in oxygen into the atmosphere.

Alternatively, for industrial applications which are not vehicle-related, but which comprise internal combustion engines 200, it is possible to provide that the gas separation device 50 separate the first volume of air rich in molecular oxygen from the second volume of air poor in molecular oxygen through a fractional distillation process. The air entering from the air intake 10 must be cooled until liquefied, so as to be subsequently distilled. Also for kits 100 mounted with internal combustion engines 200 of any type, it can be provided that the gas separation device 50 be a membrane or a plurality of membranes or can be PSA modules.

Again alternatively, there can be the provision that the kit 100 does not mount any compressor device 75 and that the air entering from the air intake 10 directly reaches the gas separation device 50. In this alternative, the weight of the kit 100 advantageously decreases due to the fact of not having the compressor device 75 which pre-compresses the incoming air.

In this latter alternative, where there is no compressor device 75 upstream of the gas separation device 50, it is possible to advantageously provide that the kit 100 comprise the insertion of a vacuum pump between the gas separation device 50 and the motor internal combustion 200 for directing a sufficient flow of air towards the engine.

In a further alternative, it can also be provided that the compressor device 75 functions without the water discharge device 15 when the gas separation device 50 does not have contraindications to the presence of water.

A possible variant of the kit in accordance with the present invention provides that there is no water discharge device 16 mounted upstream of the compressor device 70 of the exhaust smoke. In this further alternative, the compressor device 70 is arranged in fluid communication between the exhaust duct 31 and the storage device 80.

In an alternative embodiment of the present invention, the exhaust smoke of the engine 200, comprising a high percentage of carbon dioxide with respect to the traditional engine exhaust, is partly (for example from 10 to 90%, preferably from 15 to 60%) compressed and stored in the tank of the device 80, whereas the remaining part is discharged into the atmosphere. It is thus possible to obtain an advantageous compromise which allows a significant portion of the discharge exhaust smoke to be stored using reasonable volumes and pressures of the storage device 80 (in relation to the volumes available on the vehicle), while allowing a satisfactory autonomy of the vehicle modified with the Kit 100, before discharging and/or treating stored exhaust smoke.

In a further variant of the method in accordance with the present invention, the discharge exhaust smoke, comprising a high concentration of CO_2, after compression, can be cooled with a cooling system, before or after loading into the tank 80, at the liquefaction temperature of the CO_2 so as to allow uncondensed nitrogen to be discharged, and obtaining even more concentrated CO_2 and possibly in the liquid state. With the method of the present invention, it is therefore possible to sequester the CO_2 produced by the exhaust of an engine 200, with the use of significantly reduced volumes and pressures compared to the methods known in the art, and with a considerable energy saving.

The diagram shown in Figure 2 represents a further alternative embodiment in accordance with the present invention, wherein the kit 100 comprises a second gas separation device 51 arranged in fluid communication between the compressor device 70 and the storage device 80. The second gas separation device 51 receives the discharge exhaust smoke compressed by the compressor device 70. The second gas separation device 51 further separates the compressed exhaust smoke at the inlet into two volumes of gas: a first volume of gas and a second volume of gas. The first volume of gas comprises a third percentage by volume of molecular nitrogen and the second volume of gas comprises a fourth percentage by volume of molecular nitrogen. The fourth percentage by volume of molecular nitrogen of the second volume of gas is higher than the third percentage by volume of molecular nitrogen of the first volume of gas, in this way, even more advantageously, the percentage by volume of molecular nitrogen present in the first volume of compressed gas to be sent to the storage device 80, is reduced even more, further reducing the volume of the tank of the storage device 80 necessary for the same amount of carbon dioxide stored. The second gas separation device 51 directs this latter first volume of compressed gas towards the storage device 80. According to this further alternative of the kit and method in accordance with the present invention, the discharge exhaust gas is first compressed up to pressures not higher than 2 MPa and preferably ranging from 0.2 to 1.5 MPa, in the compressor 70 positioned upstream of the second gas separation device 51, and subsequently compressed up to the final storage pressure, for example ranging from 10 to 20 MPa, by means of a further compressor device 71, situated downstream of the second gas separation device 51 and before the storage device 80.

Alternatively, it can also be provided that downstream of the exhaust duct 31, the kit 100 does not comprise any water discharge device 16, compressor device 70 or storage device 80. In this alternative, the exhaust smoke with a low concentration of molecular nitrogen and an increased concentration of carbon dioxide emitted by the exhaust duct 31 can advantageously be treated with other methods for separating and/or confining the carbon dioxide and the other harmful components contained in the exhaust gas, such as nitrogen oxides and particulate, such as, for example, absorption or adsorption on materials suitable for the purpose.

EXAMPLES

As an example, let us consider a vehicle such as a gasoline powered car. An average fuel consumption of approximately 2.3 kg/h can be reasonably assumed. In order for the automobile's internal combustion engine 200 to efficiently burn this fuel flow, about 5.5 Nm^3/h of molecular oxygen is required, wherein Nm^3/h represents a flow measured in cubic meters normalized every hour. Normalized cubic meters refer to a corresponding quantity of substance that occupies a volume of one cubic meter under normal conditions, that is, at the conventional temperature values of 0°C (273.15 K) and absolute pressure of 101 kPa (1 atm). The kit 100 of the present invention is assembled, equipped with a storage device with the internal combustion engine 200, fueled with gasoline, of the car and the values of the observables of the kit 100 of the present invention are estimated.

It can be reasonably assumed that the storage device (80) has a volume of 100 liters and a maximum operating pressure of 20 MPa. Under these conditions a volume of exhaust gas equal to 20 Nm^3 can be recovered. In the following examples, the compressed discharge exhaust smoke which is stored by the storage device 80 does not consider the water, as it is assumed to be completely discharged by the water discharge devices 16 and 17. It is also considered that the other components of the compressed discharge exhaust smoke, such as, for example, molecular oxygen, are present in traces of less than 1% by volume.

Example 1

According to a first example, with reference to figure 1, the gas separation device 50 is a molecular oxygen and nitrogen separation membrane, series PRISM® Model PA4050-N1, supplied by Airproduct. The first volume of air leaving the gas separation device 50 and directed towards the mixing device 60, has a flow-rate of 18.5 Nm^3/h and comprises a first percentage of 30% by volume of molecular oxygen equal to a flow-rate of 5.5 Nm^3/h and a first percentage of 70% by volume of molecular nitrogen equal to a flow-rate of 13.0 Nm^3/h.

In order to bring the composition of the feeding comburent gas to the engine to an oxygen content of 21 % by volume (the same concentration as atmospheric air), a stream of 7.9 Nm^3/h of exhaust gas is recirculated back from the exhaust duct 31, through the valve 40, to the mixing device 60.

According to this first example, the compressed discharge exhaust smoke which is stored by the storage device 80 has a flow-rate of 16.6 Nm^3/h and comprises a percentage of 22.2% by volume of carbon dioxide equal to a flow-rate of 3.7 Nm^3/h and a percentage of 77.8% by volume of molecular nitrogen equal to a flow-rate of 13.0 Nm^3/h. Based on these results and assuming a continuous and constant operation of the motor vehicle and the transfer of the whole compressed discharge exhaust smoke into the storage tank 80, the filling of the latter at a maximum pressure of 20 MPa would take place in 70 minutes. After this time, the storage tank (80) can be emptied or replaced at a specialized facility, for subsequent treatment of the sequestered CO_2.

Example 2

According to a second example, the gas separation device 50 is a molecular oxygen and nitrogen separation membrane, series PRISM® Model PA4030-N1, supplied by Airproduct. The first volume of air leaving the gas separation device 50 and directed towards the mixing device 60, has a flow-rate of 13.9 Nm^3/h and comprises a first percentage of 40% by volume of molecular oxygen equal to a flow-rate of 5.5 Nm^3/h and a first percentage of 60% by volume of molecular nitrogen equal to a flow-rate of 8.4 Nm^3/h.

In order to bring the composition of the feeding comburent gas to the engine to an oxygen content of 21 % by volume, a stream of 12.5 Nm^3/h of exhaust gas is recirculated back from the exhaust duct 31, through the valve 40, to the mixing device 60.

According to this second example, the compressed discharge exhaust smoke which is stored by the storage device 80 has a flow-rate of 12.0 Nm^3/h and comprises a percentage of 30.8% by volume of carbon dioxide equal to a flow-rate of 3.7 Nm^3/h and a percentage of 69.2% by volume of molecular nitrogen equal to a flow-rate of 8.4 Nm^3/h. Based on these results and assuming a continuous and constant operation of the motor vehicle and the transfer of the whole compressed discharge exhaust smoke into the storage tank 80, the filling of the latter at a maximum pressure of 20 MPa would take place in 100 minutes. After this time, the storage tank (80) can be emptied or replaced at a specialized facility, for subsequent treatment of the sequestered CO_2.

Example 3

According to a third example, the gas separation device 50 is a molecular oxygen and nitrogen separation membrane, series PRISM® Model PA4050-P3, supplied by Airproduct. The first volume of air leaving the gas separation device 50 and directed towards the mixing device 60, has a flow-rate of 11.0 Nm^3/h and comprises a first percentage of 50% by volume of molecular oxygen equal to a flow-rate of 5.5 Nm^3/h and a first percentage of 50% by volume of molecular nitrogen equal to a flow-rate of 5.5 Nm^3/h.

In order to bring the composition of the feeding comburent gas to the engine to an oxygen content of 21 % by volume, a stream of 15.3 Nm^3/h of exhaust gas is recirculated back from the exhaust duct 31, through the valve 40, to the mixing device 60.

According to this third example, the compressed discharge exhaust smoke which is stored by the storage device 80 has a flow-rate of 9.2 Nm^3/h and comprises a percentage of 40.0% by volume of carbon dioxide equal to a flow-rate of 3.7 Nm^3/h and a percentage of 60.0% by volume of molecular nitrogen equal to a flow-rate of 5.5 Nm^3/h. Based on these results and assuming a continuous and constant operation of the motor vehicle and the transfer of the whole compressed discharge exhaust smoke into the storage tank 80, the filling of the latter at a maximum pressure of 20 MPa would take place in 130 minutes, corresponding to a significant vehicle autonomy. After this time, the storage tank (80) can be emptied or replaced at a specialized facility, for subsequent treatment of the sequestered CO_2.

Example 4

According to a fourth example, with reference to figure 2, the first gas separation device 50 is a molecular oxygen and nitrogen separation membrane, series PRISM® Model PA4050-P3, supplied by Airproduct.

The first volume of air leaving the first gas separation device 50 and directed towards the mixing device 60, has a flow-rate of 11.0 Nm^3/h and comprises a first percentage of 50% by volume of molecular oxygen equal to a flow-rate of 5.5 Nm^3/h and a first percentage of 50% by volume of molecular nitrogen equal to a flow-rate of 5.5 Nm^3/h. Similarly to previous example 3, a stream of 12.5 Nm^3/h of exhaust gas is recirculated back from the exhaust duct 31, through the valve 40, to the mixing device 60, in order to bring the oxygen content of the feeding comburent stream to 21 % by volume.

According to this fourth example, the discharge exhaust smoke is compressed and sent to a second gas separation device 51. This second gas separation device 51 is a gas separation membrane, series PRISM® Model PA3030-N1, supplied by Airproduct.

The discharge exhaust smoke leaving the condensate separator 16 and directed towards the second gas separation device 51, has a flow-rate of 9.2 Nm^3/h of discharge exhaust smoke comprising a percentage of 40.0% by volume of carbon dioxide equal to a flow-rate of 4.0 Nm^3/h and a percentage of 60.0% by volume of molecular nitrogen equal to a flow-rate of 5.2 Nm^3/h.

The first volume of gas leaving the gas separation device 51 and directed towards the compressor 71 for storage in the tank 80 has a flow-rate of 4.0 Nm^3/h and comprises a first percentage of 73% by volume of carbon dioxide equal to a flow-rate of 2.9 Nm^3/h and a first percentage of 27% by volume of molecular nitrogen equal to a flow-rate of 1.1 Nm^3/h. The first volume of gas leaving the gas separation device 51 contains a quantity of CO_2 which is equal to 81% with respect to that produced by the internal combustion engine.

Based on these results and assuming a continuous and constant operation of the motor vehicle and the transfer of the whole compressed discharge exhaust smoke into the storage tank 80, the filling of the latter at a maximum pressure of 20 MPa would take place in 300 minutes. After this time, the storage tank (80) can be emptied or replaced at a specialized facility, for subsequent treatment of the sequestered CO_2.

The invention thus conceived can undergo numerous modifications and variations, all of which are within the scope of the inventive concept; furthermore, all the details can be replaced by technically equivalent elements. In practice, the materials used, as also the dimensions, can vary according to technical requirements.

CLAIMS

1. Kit (100) for an internal combustion engine (200) producing an exhaust smoke comprising carbon dioxide, said kit (100) being mounted in fluid communication with said internal combustion engine (200), said kit (100) comprising:

- an air intake (10) and a fuel intake (20), said air comprising an original percentage by volume of molecular oxygen and an original percentage by volume of molecular nitrogen,

- an outlet duct (30) of said exhaust smoke of said engine (200), said outlet duct (30) being connected in fluid communication with an exhaust smoke recirculation valve (40) able to direct a fraction of said exhaust smoke, which is recirculation exhaust smoke, towards said internal combustion engine (200) and another fraction of said exhaust smoke, which is discharge exhaust smoke, towards an exhaust duct (31) of said kit (100),

characterized in that said kit (100) comprises:

- a gas separation device (50) and a gas mixer device (60), said gas separation device (50) being arranged in fluid communication between said air intake (10) and said gas mixer device (60), and said gas mixer device (60) being arranged in fluid communication between said gas separation device (50) and said internal combustion engine (200), and being also connected in fluid communication with said exhaust smoke recirculation valve (40),

wherein:

- said gas separation device (50) is adapted to separate said incoming air from the intake (10) in two volumes of air, one of which is a first volume of air comprising a first percentage by volume of molecular oxygen and a first percentage by volume of molecular nitrogen, where said first percentage by volume of molecular oxygen is greater than the original percentage by volume of molecular oxygen of the incoming air and where said first percentage by volume of molecular nitrogen is smaller than the original percentage by volume of molecular nitrogen of the incoming air, said gas separation device (50) being adapted to direct said first volume of air towards the gas mixer device (60), and

- said gas mixer device (60) is adapted to mix said first volume of air with said recirculation exhaust smoke coming from said exhaust smoke recirculation valve (40) generating a mixture of gas, said gas mixer device (60) being adapted to send said gas mixture towards the internal combustion engine (200).

2. Kit (100) according to claim 1, characterized in that it comprises a compressor device (70) arranged in fluid communication downstream of said exhaust duct (31) and a storage device (80) arranged in fluid communication downstream of said compressor device (70), said compressor device (70) being able to compress said discharge exhaust smoke, said storage device (80) being adapted to store said compressed discharge exhaust smoke.

3. Kit (100) according to any one of the claims 1 or 2, characterized in that it comprises a gas sensor (91) arranged in fluid communication between said gas mixer device (60) and said internal combustion engine (200), said gas sensor (91) being adapted to measure at

least a percentage by volume of molecular oxygen of said gas mixture outgoing from said gas mixer device (60), said gas sensor (91) being in logic communication with a control unit (301) of the vehicle, where said control unit (301) being able to regulate the flow of the recirculation exhaust smoke outgoing from the exhaust smoke recirculation valve (40).

4. Kit (100) according to any one of the claims 1 to 3, characterized in that it comprises a compressor device (75) arranged upstream of said gas separation device (50), said compressor device (75) being adapted to compress said air incoming from said air intake (10).

5. Kit (100) according to any one of the claims 1 to 4, characterized in that it comprises a water evacuation device (15) arranged in fluid communication between said air intake (10) and said gas separation device (50), said water evacuation device (15) adapted to evacuate at least a percentage by volume of water from the incoming air coming from said air intake (10).

6. Kit (100) according to any one of the claims 1 to 5, characterized in that it comprises a water discharge device (17) arranged in fluid communication between said internal combustion engine (200) and said exhaust smoke recirculation valve (40).

7. Kit (100) according to any one of the claims 2 to 6, characterized in that it comprises a second gas separation device (51) arranged in fluid communication between said compressor device (70) and said storage device (80), said second gas separation device (51) being adapted to receive said discharge exhaust smoke compressed by said compressor device (70), said second gas separation device (51) being adapted to separate

said incoming compressed exhaust smoke in two gas volumes, a first volume of gas and a second volume of gas, where the first volume of gas comprises a third percentage by volume of molecular nitrogen and where the second volume of gas comprises a fourth percentage by volume of molecular nitrogen, where the fourth percentage by volume of molecular nitrogen of the second volume of gas is greater than the third percentage by volume of molecular nitrogen of the first volume of gas, said second gas separation device (51) being adapted to direct said first volume of gas towards said storage device (80).

8. Method for reducing the emission of carbon dioxide produced by an internal combustion engine (200), said method being implemented by a kit (100) mounted in fluid communication with said internal combustion engine (200), said method comprising a series of successive steps,

- a step of receiving incoming air from an air intake (10) of the kit (100) and of receiving fuel from a fuel intake (20) of the kit (100), said air comprising an original percentage by volume of molecular oxygen and an original percentage by volume of molecular nitrogen,

- a step of combustion of said fuel in said internal combustion engine (200) with production of an exhaust smoke comprising carbon dioxide,

- a step of channelling said exhaust smoke comprising carbon dioxide produced by said internal combustion engine (200) in an outlet duct (30) of the kit (100),

- a step of intercepting a fraction of said exhaust smoke, which is a recirculation exhaust smoke, making it recirculate towards said internal combustion engine (200) by means of an exhaust smoke recirculation valve (40) of the kit (10) and letting through another fraction of said exhaust smoke, which is discharge exhaust smoke, towards an exhaust duct (31) of the kit (100),

characterized in that said method comprises

- a step of gas separation by a gas separation device (50) of the kit (100), said step of gas separation being between said step of receiving incoming air and said step of sending air towards said internal combustion engine (200), wherein said gas separation device (50) separates said incoming air in two air volumes, one of which is a first volume of air comprising a first percentage by volume of molecular oxygen and a first percentage by volume of molecular nitrogen, wherein said first percentage by volume of molecular oxygen is greater than the original percentage by volume of molecular oxygen of the incoming air and wherein said first percentage by volume of molecular nitrogen is smaller than the original percentage by volume of molecular nitrogen of the incoming air,

- a step of mixing by means of a gas mixing device (60) which mixes said first volume of air coming from said gas separation device (50) with said recirculation exhaust smoke coming from said exhausting smoke recirculation valve (40) to obtain a gas mixture, said mixing step being subsequent to said step of gas separation,

- a step of sending said gas mixture and said fuel towards the internal combustion engine (200).

9. Method according to claim 8, characterized in that it comprises

- a step of compressing said discharge exhaust smoke by means of a compressor device (70) of the kit (100), said compressing step being subsequent to said intercepting step,

- a step of storing said exhaust smoke being evacuated by said compressor device (70) by means of a storage device (80) of the kit (100), wherein said storage step is subsequent to said compression step.

10. Method according to either claim 8 or 9, characterized in that it comprises

- a step of measuring at least a percentage by volume of molecular oxygen of said gas mixture outgoint from said gas mixing device (60) by means of a gas sensor (91) of the kit (100) arranged in fluid communication between said gas mixer device (60) and said internal combustion engine (200),

- a step of communicating said measure of said at least a percentage of molecular by volume of oxygen of said gas mixture outgoing from the gas mixer device (60) to a control unit (301) of the vehicle,

- a step of regulating by the control unit (301) of the recirculation exhaust smoke flow outgoing from the exhaust smoke recirculation valve (40).

11. Method according to anyone of claims 8 to 10, characterized in that, under regime conditions, the amount of recirculation exhaust smoke that is recycled to the engine 200 through the valve 40 and the mixing device 60, represents from 30 to 85%, preferably from 35 to 75% by volume, more preferably from 40 to 70% by volume, with respect to the total volume of exhaust smokes coming out of the engine through the duct 30

12. Method according to any one of the claims 8 to

11, characterized in that it comprises

- a step of compressing said incoming air from said air intake (10) by means of a compressor device (75) of the kit (100) arranged upstream of said gas separation device (50), wherein said compression step precedes said gas separation step.

13. Method according to any one of the claims 8 to 12, characterized in that it comprises

- a step of evacuating at least a percentage by volume of water from the incoming air coming from said air intake (10) by means of a water discharge device (15) of the kit (100) arranged in fluid communication between said air intake (10) and said gas separation device (50), wherein said evacuating step is subsequent to said step of receiving incoming air.

14. Method according to claim 9, characterized in that it comprises

- a step of discharging at least a percentage by volume of water from the outgoing gas to said compressor device (70, 75) of the kit (100) by means of a water evacuation device (15, 16) arranged in fluid communication downstream of said compressor device (70, 75).

15. Method according to any one of the claims 8 to 14, characterized in that it comprises a step of post-combustion discharge of at least a percentage by volume of water from exhaust smokes outgoing from said internal combustion engine (200) by means of a water discharge device (17) arranged in fluid communication between said internal combustion engine (200) and said exhaust smoke recirculation valve (40), wherein said step of post-combustion discharge is between said step of channelling

said exhaust smoke and said step of intercepting said recirculation exhaust smoke.

16. Method according to any one of the claims 9 to 15, characterized in that it comprises

- a second step of gas separation by means of a second gas separation device (51) of the kit (100) arranged in fluid communication between said compressor device (70) and said storage device (80), said second step of gas separation being before the storage step, said second gas separation device (51) receives said discharge exhaust smoke compressed by said compressor device (70), said second gas separation device (51) being adapted to separate said incoming compressed exhaust smoke in two volumes of gas, a first volume of gas and a second volume of gas, wherein the first volume of gas comprises a third percentage by volume of molecular nitrogen and wherein the second volume of gas comprises a fourth percentage by volume of molecular nitrogen, wherein the fourth percentage by volume of molecular nitrogen of the second volume of gas is greater than the third percentage by volume of molecular nitrogen of the first volume of gas, said second gas separation device (51) directs said first volume of gas towards said storage device (80).

17. Method according to any one of the preceding claims from 8 to 16, wherein said step of mixing by means of a gas mixer device (60) produces a mixture of gas in which the percentage by volume of molecular oxygen is close to the original atmospheric percentage by volume of molecular oxygen, preferably comprised between 18 and 22 % by volume.

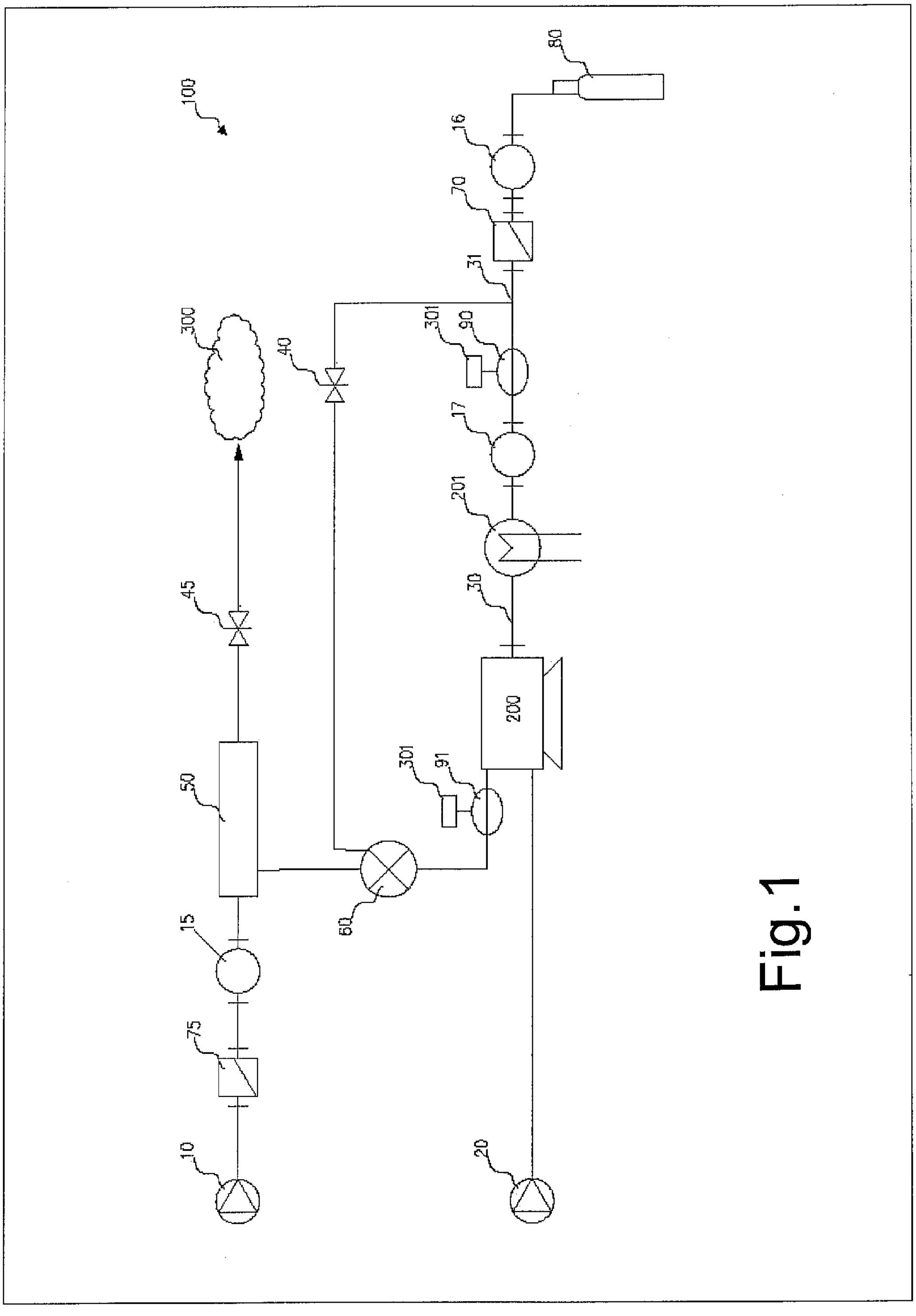
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Fig.1

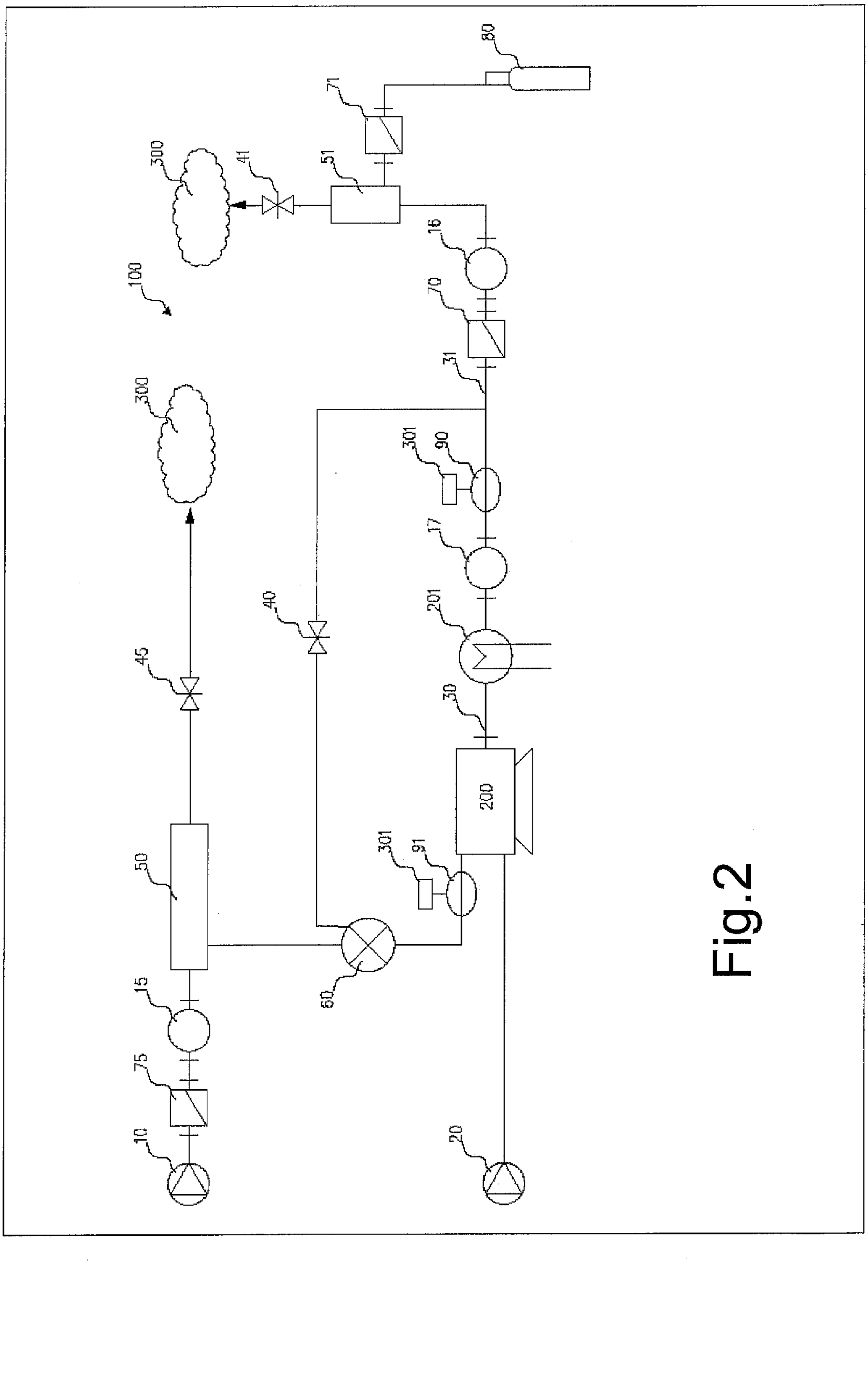
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Fig.2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/056359

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D53/22 F02M35/10 F02M25/12 F02M26/13
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D F02M F01N F02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 November 2019	22/11/2019

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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