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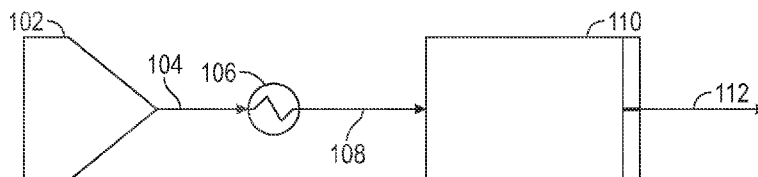


FIG. 1

(57) Abstract: A system (100) includes an exhaust gas source (102) that provides exhaust gas pollutants and an adsorbent-filled canister (110) downstream of the exhaust gas source (102) and configured to adsorb exhaust gas pollutants. The systems may further include a heat exchanger (106). A process (300) includes introducing exhaust gas comprising exhaust gas pollutants into a system (302) that includes an adsorbent-filled canister (110), such that the exhaust gas may flow through the adsorbent-filled canister (110) and the exhaust gas pollutants may be adsorbed into an adsorbent material in the adsorbent-filled canister (110) as adsorbed exhaust gas pollutants. A depleted exhaust gas may pass from the adsorbent-filled canister.



EMISSIONS REDUCTION FROM VEHICLES BY CONSUMING LOW CARBON FUEL BLENDS AND UTILIZING CARBON CAPTURE USING ADSORBENT MATERIAL

BACKGROUND

[0001] While complete combustion of fuels produces only carbon dioxide and water, engines are not completely efficient. In particular, internal combustion engines emit gaseous pollutants such as carbon monoxide, carbon dioxide, unburned hydrocarbons, and nitrogen oxides as well as solid pollutants such as particulate matter. As legislation has tightened the rules for vehicle emissions, new exhaust purification systems have been developed to reduce gaseous and particulate emissions. Most of the exhaust lines for internal combustion engines include one or more catalysts to reduce gaseous pollutants, while solid pollutants are removed by a particulate filter.

[0002] The transportation sector is one of the major sources of carbon dioxide gas emissions. In order to mitigate emissions from mobile sources, alternative energy sources are being used to power automobiles. Plug-in hybrid electric vehicles, electric vehicles, and hydrogen-powered vehicles are introduced at an increasing frequency and numbers; however, it will take decades to completely replace internal combustion engines. Besides, there are more than one billion internal combustion engine vehicles already on the road which will continue to emit carbon dioxide for a foreseeable future. Even a small reduction in carbon dioxide gas emissions from existing internal combustion engines can make an impact considering the sheer number of vehicles on the road. Furthermore, low-carbon fuels can be used for existing internal combustion engines without any modifications to the engines' configuration and therefore, can reduce carbon dioxide emissions further.

[0003] To improve air quality and meet emissions regulations, internal combustion engine systems include exhaust components that may be utilized to mitigate or reduce the amount of exhaust gas pollutants as compared to a system with an open exhaust line. Such components of an internal combustion engine system may include but are not limited to, catalytic converters, particulate filters, and systems to re-route a portion

of the exhaust gas, including the pollutants, back into the engine for further combustion (for example, engine gas recirculation).

[0004] Accordingly, there exists a need for innovations in reducing emissions from combustion engines.

SUMMARY

[0005] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0006] In one aspect, embodiments disclosed herein relate to an exhaust purification system including an exhaust gas source configured to provide an exhaust gas stream comprising at least one exhaust gas pollutant, optionally a heat exchanger unit configured to maintain a temperature of the exhaust gas stream in between 100 to 1000 °C, and a canister comprising at least one adsorbent-filled cartridge, and configured to adsorb the exhaust gas pollutant from the exhaust gas stream. The exhaust gas source, the heat exchanger unit and the canister are connected in series.

[0007] In another aspect, embodiments disclosed herein relate to a process of purifying an exhaust stream. The process includes introducing an exhaust gas stream comprising an exhaust gas pollutant into a heat exchanger unit, optionally cooling the exhaust gas stream in the heat exchanger unit to a pre-set temperature, feeding the exhaust gas stream from the heat exchanger unit to a canister, wherein the canister comprises at least one adsorbent-filled cartridge, capturing the exhaust gas pollutant in the adsorbent-filled cartridge, and releasing a clean exhaust gas stream from the canister.

[0008] Other aspects and advantages of the claimed subject matter will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0009] This section describes specific embodiments in detail with reference to the accompanying figures. Where the figures include like elements between them, the

elements are denoted by like reference numerals. They may be differentiated by letters appended to reference numerals. The use of the prime or “ ’ ” mark with a numeral indicates a like element in a different state of operation or condition than as previously referenced; however, other aspects remain the same.

[0010] FIG. 1 is a schematic of a conventional engine system coupled with an exhaust purification system in accordance with one or more embodiments.

[0011] FIG. 2A is a schematic of adsorbent materials containing cartridges in the adsorbent-filled canisters before use system in accordance with one or more embodiments.

[0012] FIG. 2B is a schematic of adsorbent materials containing cartridges in the adsorbent-filled canisters after use system in accordance with one or more embodiments.

[0013] FIG. 3 is a flow chart showing process steps for purifying an exhaust gas through the exhaust purification system in accordance with one or more embodiments.

[0014] FIG. 4 is a graph showing the EPA Federal Test Procedure in accordance with one or more embodiments.

[0015] FIG. 5 is a flow chart showing the emissions tested in the SWRI DEVCON™ automated driver system in accordance with one or more embodiments.

[0016] FIG. 6 is a bar chart of emissions reductions in a conventional internal combustion engine test vehicle in accordance with one or more embodiments.

[0017] FIG. 7 is a bar chart of emissions reductions in a FlexFuel test vehicle in accordance with one or more embodiments.

DETAILED DESCRIPTION

[0018] One or more embodiments of the present disclosure relate to a system that includes an adsorbent in an adsorbent-filled canister, which may be positioned along a line with an exhaust stream coming from an internal combustion engine, which is located downstream of the primary catalytic converter. The adsorbent-filled canister may be accessible through the exhaust piping and is downstream of and selectively fluidly coupled to the internal combustion engine.

[0019] Regardless of the efficiency of the engine and the fuel ratio, when an engine is consuming fuel, the fuel combusts and produces exhaust gas. Depending on the combustion efficiency of an internal combustion engine, and the quality of fuel being used, exhaust gas may comprise some amount of partially combusted products, and therefore exhaust gas pollutants. The presence of impurities in a fuel blend, carbon-chain length, fuel grade, as well as the efficiency of the internal combustion engine may all be important factors to determine the degree of pollutants in an exhaust stream.

[0020] As used herein “internal combustion engine” or “engine” refers to any type of motor using a fuel combustion process. The engine may be a spark engine or a compression engine. Types of engines include but are not limited to, a heavy fuel oil engine, a diesel engine, a generator, a gasoline engine, a two-stroke, a four-stroke, or a six-stroke engine. One skilled in the art would appreciate the vast array of internal combustion engines covered by this definition. Pollutants, incomplete or by-product reaction products can be found in the exhaust gas of an internal combustion engine.

[0021] An internal combustion engine may operate at a wide range of temperatures. An engine operating temperature range of a given engine is any suitable engine operating temperature for combusting fuel to create power, such as ranging from about 50 °C to about 1,500 °C. As a non-limiting example, combustion engines may operate at the lower end of the temperature operating range, and reaction engines may operate at the higher end of the temperature operating range.

[0022] An internal combustion engine operates at a range of pressures. In a non-limiting example, an internal combustion engine cylinder pressure may have a range of from about 600 pounds per square inch (psi) to about 2000 psi.

[0023] The exhaust gas passing from an internal combustion engine may pass at an elevated temperature. Non-limiting examples of an elevated temperature include a diesel fuel-burning engine having an exhaust temperature in a range of from about 100°C to about 700 °C, and a gasoline fuel-burning engine having an exhaust temperature in a range of from about 300 °C to about 950 °C.

[0024] The exhaust gas passing from an internal combustion engine may pass at elevated pressure. The exhaust pressure is greatest immediately after the exhaust gas passes from the combustion area and generally decreases in pressure as the exhaust gas passes through the exhaust piping. A gasoline fuel-burning engine may have an exhaust pressure in a range of from, for example, about 50 kilopascals (kPa) to about 600 kPa.

[0025] In one or more embodiments, when the engine is cold or malfunctioning, there is not enough heat from the exhaust to bring the catalyst in the catalytic converter to the operating temperature. Thus, one or more embodiments of the system or process described herein may be used to adsorb, store, or recycle exhaust gas pollutants from the engine exhaust gas when the catalyst in the catalytic converter is not operating at the catalyst operating temperature. When in conjunction with a gasoline engine, a catalytic converter operating temperature range may be greater than about 400°C. When used in conjunction with a diesel engine, a catalytic converter operating temperature range may be greater than about 200°C.

[0026] As shown in FIG. 1, an exhaust purification system 100 that may be used in an internal combustion engine includes an exhaust gas source 102, a first pipe 104, a heat exchanger 106, a second pipe 108, an adsorbent-filled canister 110, and a purified exhaust gas release pipe 112 – all connected in series and in fluid communication. The exhaust gas source 102 may include mainly hydrocarbon combustion products, impurities, partially combusted hydrocarbons, inorganic oxides, and solid particles. The first pipe 104 is positioned in between the exhaust gas source and the heat exchanger and feeds an exhaust gas to the heat exchanger to reduce the temperature of the exhaust gas such that the exhaust gas that is passing through the second pipe 108 and entering the adsorbent-filled canister 110 has a temperature ranging from 100 to 1000 °C.

[0027] The second pipe 108 is positioned in between the heat exchanger 106 and the adsorbent-filled canister 110 to feed a cooled exhaust gas to the adsorbent-filled canister 110. The adsorbent-filled canister 110 is filled with an adsorbent material that may adsorb chemicals selectively and release rest of the chemicals in the exhaust gas mixture to the atmosphere via the purified exhaust gas release pipe 112.

[0028] The exhaust purification system 100 may be used for the removal of exhaust gas pollutants from the exhaust gas. Non-limiting examples of the exhaust gas pollutants may be selected from a group consisting of carbon dioxide, carbon monoxide, nitrogen dioxide, nitrogen monoxide, particulate matter, and hydrocarbons. In one or more embodiments, the exhaust purification system 100 includes one adsorbent-filled canister 110 as shown in FIG. 1. The adsorbent-filled canister 110 is configured to adsorb exhaust gas pollutants produced from the exhaust gas source 102.

[0029] In one or more embodiments, the exhaust gas source may be a catalytic converter. The temperature of the exhaust gas passing through an outlet of a catalytic converter can be in a range from 500 to 1000 °C. The temperature of the exhaust gas may be reduced depending on the temperature tolerance of the adsorbent material. In an internal combustion engine, the exhaust gas stream may lose some heat while passing through the first pipe 104 and the second pipe 108. In one or more embodiments, the temperature of the exhaust gas stream entering the adsorbent-filled canister 110 may range from 150 to 250 °C. In one or more embodiments, the temperature of exhaust gas entering the adsorbent-filled canister 110 may be manipulated by changing the position of the adsorbent-filled canister 110 in the exhaust purification system 100.

[0030] In one or more embodiments, the exhaust purification system 100 may include two adsorbent-filled canisters 110. When there are two adsorbent-filled canisters, the upstream-most adsorbent-filled canister may be called a primary adsorbent-filled canister, and the one or more downstream adsorbent-filled canister may be named a secondary adsorbent-filled canister.

[0031] In one or more embodiments, the exhaust purification system 100 may include more than two adsorbent-filled canisters 110. When there are more than two

adsorbent-filled canisters, the upstream-most adsorbent-filled canister may be called a primary adsorbent-filled canister, and the second adsorbent-filled canister in line may be named as a first secondary adsorbent-filled canister, the next in line may be a second secondary adsorbent-filled canister, the next in line may be a third secondary adsorbent-filled canister, and so on, in series. The last canister in line may be configured to release a clean exhaust gas stream.

[0032] The adsorbent-filled canister 110 is configured to adsorb exhaust gas pollutants from the exhaust gas produced from the exhaust gas source 102 and passing through the first pipe 104, the heat exchanger 106, and the second pipe 108 to produce a depleted exhaust gas. As used herein, the term “adsorption” refers to a process where an “adsorbate,” meaning an atom, ion, molecule, charge, a portion of a molecule, or substance adsorbs, collects, or adheres to an “adsorbent.” The adsorbate is adsorbed into or onto the adsorbent. In one or more embodiments, adsorption may include absorption. As used herein, “absorption” refers to a chemical or physical phenomenon in which the molecules, atoms, and ions of the substance getting absorbed enters the bulk phase (gas, liquid or solid) of the material in which it is taken up. In one or more embodiments, the disclosed adsorbent material-filled cannister may capture 40-70% of carbon dioxide from the internal combustion engine combustion exhaust to capture carbon dioxide.

[0033] In one or more embodiments, a plurality of exhaust valves may be present to control fluid flow in the system. The exhaust valves may be one-way or two-way. In either case, the exhaust valves may be uni-directional. As used herein, the term “uni-directional” may refer to exhaust gas flowing in a single direction and back-flow being not allowed. A check or butterfly valve may perform a similar function and may be included in some embodiments.

[0034] In one or more embodiments, the exhaust purification system 100 may further comprise a filtration unit (not shown) positioned in between the exhaust gas source 102 and the first pipe 104. The filtration unit may be configured to remove solid particles from the exhaust stream before feeding it to the first pipe 104.

[0035] In one or more embodiments, the exhaust purification system 100 may further comprise a filtration unit (not shown) positioned in between the first pipe 104 and the

heat exchanger 106. The filtration unit may be configured to remove solid particles from the exhaust stream before feeding it to the heat exchanger 106.

[0036] In one or more embodiments, the exhaust purification system 100 may further comprise a filtration unit (not shown) positioned in between the heat exchanger 106 and the adsorbent-filled canister 110. The filtration unit may be configured to further remove any remaining solid particles from the exhaust stream before feeding it to the adsorbent-filled canister 110.

[0037] As noted above, a heat exchanger 106 is included in the system. The heat exchanger 106 may be any suitable heat exchanger commonly used in combustion engines. In one or more particular embodiments, the heat exchanger 106 is a radiator unit or a tubular exchanger.

[0038] The exhaust purification system 100 may be positioned in the back of a vehicle for easy access to the adsorbent-filled canister 110. Once the adsorbent is fully saturated by exhaust gas pollutants, the adsorbent-filled canister 110 may be replaced with a new adsorbent-filled canister.

[0039] FIG. 2A is a schematic of the adsorbent-filled canister in greater detail. As shown in the FIG. 2A, an adsorbent-filled canister 200 may be used as a carbon dioxide adsorption module and includes a canister 202, a set of cartridges 204, a plurality of spacers 206, an inlet connector 210, and an outlet connector 212. The adsorbent-filled canister 200 is designed such that it may be retrofitted in the back of any passenger or commercial vehicle. The set of cartridges 204 includes an adsorbent material that may selectively adsorb carbon dioxide gas. The plurality of spacers 206 may be utilized to position and protect the set of cartridges 204 from any external damage. The inlet connector 210 is used as a connection mechanism for the adsorbent-filled canister to enable an inlet to the adsorbent-filled canister in order to feed an exhaust gas stream to the canister. The inlet connector 210 is used as a connection mechanism for the adsorbent-filled canister to enable an outlet to the adsorbent-filled canister that may release a clean exhaust gas stream to the atmosphere through the outlet connector 212.

[0040] FIG. 2B is a schematic of the adsorbent-filled canister of FIG 2A after it has been used for a period of time in a combustion engine. As shown in the FIG. 2B, once

an exhaust gas is fed to the adsorbent-filled canister, carbon dioxide gas molecules 208 are adsorbed in the adsorbent materials in the set of cartridges 204.

[0041] The adsorbent-filled canister 200 may be a fixed or modular unit. When the adsorbent-filled canister 200 is modular, the unit may be uncoupled, removed, and replaced with the same type or another type of adsorbent-filled canister. The adsorbent-filled canister 200 may be configured to indicate its level of saturation, such as saturation with exhaust gas pollutants in one or more embodiments.

[0042] In one or more embodiments, the adsorbent-filled canister 200 with adsorbent material may be designed in such a way that the adsorbent may not be saturated with carbon dioxide until a full tank of the vehicle's fuel is combusted.

[0043] In one or more embodiments, the adsorbent may be a homogeneous substrate or a heterogeneous substrate (i.e., a mixture of substrates). In one or more embodiments, the adsorbent may be a Metal Organic Framework (MOF), Covalent Organic Framework (COF), or a hybrid material (as explained below). MOFs are composed of metal ions or clusters connected by organic ligands to form a three-dimensional porous structure. The resulting material has a high surface area and tunable pore size and shape, making it ideal for gas storage and separation, catalysis, and other applications. MOFs are often compared to zeolites, another type of porous material, but MOFs have a greater degree of structural diversity and flexibility. COFs are a class of porous materials in which organic molecules are linked together by covalent bonds to form a three-dimensional network. Like MOFs, COFs have a high surface area and tunable pore size, but they also have the advantage of being more stable and chemically robust than many other porous materials. COFs are currently being investigated for a variety of applications, including gas storage and catalysis. Both MOFs and COFs have a surface chemistry that can be modified to enhance their carbon dioxide storage properties.

[0044] The polymer backbone of the COFs is not particularly limited, and may be composed of light elements such as boron, carbon, nitrogen, oxygen, silicon and combinations thereof. The covalent organic framework may be composed of monomers that have been polymerized to form repeating units to make up the covalent organic framework. As such, the structure of the COFs may be determined by the

chemical structure of the monomers used and the extent of polymerization thereof. In some embodiments, the COF backbone may include at least one hydrophobic aromatic structure, such as a benzene ring.

[0045] The selection of the MOF or COF used depends on several factors including specific surface area, pore size distribution, stability, and selectivity for carbon dioxide over other gases. In general, MOFs and COFs with high surface area, large pore volumes, and narrow pore size distributions tend to be more effective for carbon dioxide capture. The stability of the MOF or COF is particularly important because carbon dioxide capture can occur at a variety of temperatures and pressures depending on the source of the carbon dioxide emissions. MOFs and COFs may be useful in various forms including as a thin film, sieve membrane, or hollow fiber membrane. Examples of MOFs that have suitable carbon dioxide capture capabilities include ZIF-7 membrane, ZIF-8 membrane, and HKUST-1 membrane. In this application, ZIF stands for zeolitic imidazolate framework. Examples of useful COFs include TpPa-1, COF-609, COF-5, and COF-103.

[0046] In some embodiments, the two adsorbent-filled canisters may contain the same material as each other. In other embodiments, the two adsorbent-filled canisters may contain different materials from each other. Each canister may contain a MOF, COF, or a hybrid material. As used herein, “hybrid materials” refer to adsorbents that are constructed of a combination of MOF and COF materials. Hybrid materials may demonstrate high carbon dioxide uptake due to high internal surface area relative to conventional, amine-based adsorbents. Using hybrid materials may allow for beneficial characteristics of each material to be utilized in a single situation. For example, installing MOFs and COFs in parallel may allow the MOFs to capture the water vapor to protect the COFs from contamination of water vapor while capturing carbon dioxide. Without wishing to be bound by any particular mechanism or theory, it is believed that hybrid materials demonstrate strong potential for tailoring to specific pollutants while withstanding harsh conditions, including high temperatures and pressures.

[0047] An effective MOF, COF, or hybrid material may exhibit high carbon dioxide selectivity, high carbon dioxide capture characteristics, a high tolerance to heat, moisture, and other exhaust gas pollutants, and low to no environmental toxicity in

case of leak. Developing MOFs and COFs for this specific application may allow for carbon capture in a light-weight, versatile, and environmentally-friendly approach to reducing vehicle emissions. Generally, MOFs and COFs are less dense and more lightweight compared to other adsorbents like activated carbon. This is because the components constructing the MOFs and COFs are lighter, including carbon, nitrogen, and oxygen, and have a highly porous structure with a low packing density. However, in some circumstances, MOFs and COFs can be more dense based on their specific materials and structure.

[0048] In one or more embodiments, the adsorbent may be used in powder form. When a powder form adsorbent is used, the adsorbent has an increased storage capacity compared to an adsorbent impregnated on a honeycomb structure.

[0049] In one or more embodiments, the adsorbent may be used in monolith form (attached to support), such as impregnated on honeycomb-shaped solid support. When an adsorbent in monolith form is used, exhaust system backpressure may be limited compared to an adsorbent in powder form. In one or more embodiments, the adsorbent may be used in the form of spheres, granules, extrudates, or as a coating on a substrate. In one or more embodiments, the form of the adsorbent used in the canister may be determined based on the storage capacity of the adsorbent-filled canister. As used herein, “storage capacity” refers to the void space, commonly expressed as the volume inside a canister that can be filled with adsorbent. In one or more embodiments, the form of the adsorbent used in the canister may be determined based on the adsorption capacity of the adsorbent. As used herein, “adsorption capacity” refers to the amount of adsorbate (exhaust gas impurities) taken up by the adsorbent per unit mass or volume of the adsorbent. In one or more embodiments, the form of the adsorbent used in the canister may be determined based on the structural stability of the adsorbent. In one or more embodiments, the form of the adsorbent used in the canister may be determined based on the process of adsorbent regeneration. As used herein, “adsorbent regeneration” refers to a wide variety of processes known to one skilled in the art to recover adsorbents to their original adsorption capacities. In one or more embodiments, the form of the adsorbent used in the canister may be determined based on the pressure differentials in the adsorbent-filled canister.

- [0050] In some instances, the adsorbent material may be a synthetically modified adsorbent. A synthetically modified adsorbent may include but is not limited to, solid support, or an adsorbent further functionalized with an additional adsorbent.
- [0051] In one or more embodiment, exhaust gas pollutants that are extracted from the exhaust gas may be stored in the adsorbent-filled canister under mild conditions. The adsorption of exhaust gas pollutants is typically conducted under mild conditions. “Mild conditions” may include a temperature in a range of less than about 50°C, such as from about 0°C to about 50°C. “Mild conditions” may include a pressure in a range of from about 0.7 bar to about 1.3 bar. The tailpipe may have a pressure of about 0.7 bar, and the exhaust just downstream of the catalytic converter may have a pressure of about 1.3 bar. The adsorbent may be stored in the mild condition pressure range at sea level and may be stored at a mild condition pressure range adjusted for altitude when at a higher altitude than sea level.
- [0052] In one or more embodiment, exhaust gas pollutants that are extracted from the exhaust gas may be stored in the adsorbent-filled canister under extreme conditions. “Extreme conditions” may include a temperature in a range of higher than about 50°C, such as from about 50°C to about 500°C. “Extreme conditions” may include a pressure in a range of from about 1.3 bar to about 20 bar.
- [0053] In yet another aspect, embodiments disclosed herein relate to a process for purifying an exhaust gas stream. FIG. 3 shows an embodiment process for removing exhaust gas pollutants. The process 300 shown in FIG. 3 may include introducing exhaust gas that contains exhaust gas pollutants into a system in step 302. The exhaust gas source that provides exhaust gas pollutants may be an internal combustion engine. In some embodiments, the internal combustion engine is an engine capable of operating using fuels with RONs above 90. In step 304, the process may include cooling the exhaust gas by exchanging heat with a heat exchanger.
- [0054] In some embodiments, introducing exhaust gas may occur during a cold-start condition, an engine malfunction, or at cold engine temperatures, and that may eliminate the need for reducing exhaust gas temperature with a heat exchanger. In one or more embodiments, exhaust gas introduction may occur during normal operation

of the internal combustion engine – which may require a heat exchanger to reduce the exhaust gas temperature.

[0055] In step 306, the process may include feeding the cooled exhaust gas into an adsorbent-filled canister. In step 308, the process may include capturing carbon dioxide gas molecules in adsorbent materials in a set of cartridges in the canister.

[0056] In step 310, the process may include releasing a purified exhaust gas in the atmosphere with a reduced carbon dioxide concentration. The exhaust gas pollutants adsorbed (captured) by the adsorbate may be maintained within the adsorbent-filled canister during and after the adsorption process. For example, the process may include maintaining the adsorbed exhaust gas pollutants in the adsorbent-filled canister.

[0057] In one or more embodiments, the process may include storing the exhaust gas pollutants in the adsorbent-filled cartridges in an adsorbent-filled canister unit within the system. Storage may be initiated upon introducing exhaust gas pollutants into the adsorbent-filled canister when the system is in use. Storage may continue when the system is not in use until exhaust gas pollutants are removed. When not actively in use, stored exhaust gas pollutants are maintained in the adsorbent-filled cartridges in the adsorbent-filled canister unit.

[0058] In one or more embodiments, the process may optionally include a cartridge removal step. In step 312, the process may include removing the exhaust gas pollutants from the system. In one or more embodiments, the exhaust gas pollutants may be removed from the system by physically removing the adsorbent-filled cartridges in the adsorbent-filled canister unit from the system. When the adsorbent-filled cartridges in the adsorbent-filled canister unit are modular, the adsorbent-filled cartridges in the adsorbent-filled canister unit may be removed manually, similar to a cartridge. In this way, the stored adsorbate may be collected and moved out of the system for further processing.

[0059] The amount of stored adsorbate in the adsorbent may be in a concentration range of from about 1 milligram (mg) of adsorbate per gram of adsorbent to about 10000 mg/g (adsorbate to adsorbent). The amount of stored adsorbate may depend on factors including, but not limited to, the type of adsorbent, the adsorbent form (powder or monolith), age of adsorbent, competitive adsorption among exhaust gas pollutants,

and partial pressures of the exhaust gas pollutants. The volume of adsorbent within an adsorbent-filled canister may vary, depending on the targeted efficiency and period between adsorption and removing exhaust gas pollutants.

[0060] In another aspect, embodiments disclosed herein relate to low carbon fuel blend compositions. Non-limiting exemplary fuel blends are described herein. Specifically, E0 Isooctane and E15 Methyl Tertiary Butyl Ether (E15 MTBE) may be suitable for achieving low-carbon emissions in accordance with one or more embodiments. The “E rating” refers to the number after the E in the naming sequence. The E rating discloses the percentage of ethanol within the blend. For example, E0 Isooctane does not contain ethanol and E15 MTBE contains 15% ethanol. The disclosed low-carbon fuel blends may be utilized to further reduce the emission from internal combustion engines.

[0061] Exemplary compositions of fuel blends in accordance with the present disclosure are shown below in Table 1. Additional characteristics of the fuel blends are shown below in Table 2.

Table 1: Volume percentages of various components of the fuel blends

Volume %	E15 MTBE	E0 Isooctane
n-Heptane	0	0
n-Butane	2.7	6.4
493 reformat	13.2	9.9
488 reformat	13.2	9.9
LSRN	8.8	6.6
J24 reformat	22.1	16.5
Pentane	8.8	6.6
MTBE	31.1	0
Isooctane		44.1

Table 2: Characteristics of the fuel blends

Characteristic	E15 MTBE	E0 Isooctane
RON	98.8	92.7
MON	92.5	89.5
Sensitivity	6.3	3.2
Density (g/L)	751.7	722.4
O2 %	6.50%	0.00%
TTW(g CO/ MJ fuel)	71.6	72.5

[0062] RON refers to the Research Octane Number. RON is determined by running the fuel in a test engine with a variable compression ratio under controlled conditions, and comparing the results with those for mixtures of isooctane and n-heptane. MON refers to the Motor Octane Number. MON is determined at 900 rpm engine speed instead of the 600 rpm for RON. MON testing uses a similar test engine to that used in RON

testing, but with a preheated fuel mixture, higher engine speed, and variable ignition timing to further stress the knock resistance of the fuel. The sensitivity refers to the Octane Sensitivity, which is the difference between the RON and the MON.

[0063] In one or more embodiments, the disclosed low carbon fuel blend composition may reduce the carbon dioxide emissions by 2 to 20%. In some embodiments, using E0 isooctane may reduce carbon dioxide emissions by approximately 15%. In other embodiments, E15 MTBE may reduce carbon dioxide emissions by approximately 13%. This data resulted from the SWRI laboratory testing shown in the example below.

[0064] In one or more embodiments, the combination of the adsorbent-filled canister and the low carbon fuel composition may capture at least 70% of the total emission, more preferably, may result in a reduction of up to 76% carbon dioxide reductions.

EXAMPLE

[0065] The two fuel blends were tested using the SWRI DEVCON™ automated driver system with two different standard commercial vehicles. Each fuel blend was created in small batches in the laboratory. The SWRI DEVCON™ automated driver system was developed by SWRI to provide computer control of vehicle speed to improve accuracy of testing engine behavior under driving conditions. One of the vehicles used for testing contained a conventional internal combustion engine. This vehicle is the Hyundai Elantra. The other vehicle used for testing, specifically a Nissan Frontier, contained a FlexFuel engine capable of operating with 85% ethanol by volume. The automated driver system eliminated driver errors and ensured consistent engine operating parameters between the two vehicles. The emissions were measured for each vehicle using the present claims. The emissions without the use of the present claims were also measured.

[0066] FIG. 4 shows the EPA Federal Testing Procedure (EPA FTP-75) used for the study. In this procedure, different phases of the engine are operated for a given amount of time and emissions are tested based off of these phases. A cold start phase 410 is operated for 505 seconds. A cold stabilized phase 420 is operated for 864 seconds. A hot soak phase 430 is operated for 505 seconds.

[0067] FIG. 5 shows a flow chart of the emissions tested in this study. The tested emissions include THC, CO, NO_x, CO₂, and O₂ 520 directly out of the engine 510. The tested emissions include THC, CO, NO_x, CO₂, and O₂ 540 directly out of the close-coupled three way catalyst (CC TWC) unit 530. The tested emissions include THC, CO, NO_x, CO₂, O₂, NMHC, and CO 560 directly out of the underbody three way catalyst (TWC) unit 550. As shown in FIG. 5, “raw” refers to the direct readings that were taken for each compound. “CVS” in FIG. 5 refers to the common emission dilution equipment used to measure pollution from vehicles by diluting a sample.

[0068] The SWRI laboratory testing included an assessment on the necessary equipment required for production of the fuel blends.

[0069] In Fig. 6, the emission reduction resulting from each tested fuel blend during each testing phase is shown in the Hyundai testing vehicle. In Fig. 7, the emission reduction resulting from each tested fuel blend during each testing phase is shown in the Nissan testing vehicle. Both figures consistently demonstrate that the two selected fuel blends are superior at reducing emissions compared to the other tested fuel blends.

[0070] Embodiments of the present disclosure may provide at least one of the following advantages. The absorbent materials contained in a cartridge may be replaced easily in a fuel filling station. While the vehicle is parked for filling fuel the saturated cartridge may easily be replaced with a new one. The saturated cartridges may be taken to a central processing area where they are regenerated using pressure or temperature and may be sent back to the fuel stations for exchange with saturated cartridges. The disclosed adsorbent-filled canister system including adsorbent-filled cartridges may be used for reducing carbon dioxide emissions in the atmosphere. The disclosed adsorbent-filled canister system may enable existing internal combustion engines to compete with alternative energy vehicles such as fuel cells, EVs, and PHEVs, and prolong the use of petroleum-based fuels due to its reduced environmental footprint utilizing the adsorbent materials filled adsorbent-filled canister. The easily replaceable, the adsorbent-filled canister may help overcome the complexity of reducing Scope 3 emissions. The disclosed adsorbent-filled canister system may also reduce the time to remove captured carbon dioxide using

conventional methodologies. The disclosed adsorbent-filled canister system may decrease the additional weight on the car by avoiding carbon dioxide compression, cooling, and compression systems used in conventional carbon capture systems. It may also reduce the time and reduce the cost of retrofitting fleets since the cartridges may be easily removable. The combined application of adsorbent-filled cartridges in a adsorbent-filled canister system and feeding a low carbon fuel blend may further reduce the carbon emissions from the vehicle.

[0071] As used here and in the appended claims, the words “comprise,” “has,” and “include” and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps.

[0072] “Optionally” means that the subsequently described event or circumstances may or may not occur. The description includes instances where the event or circumstance occurs and instances where it does not occur.

[0073] When the word “approximately” or “about” are used, this term may mean that there can be a variance in value of up to $\pm 10\%$, of up to 5% , of up to 2% , of up to 1% , of up to 0.5% , of up to 0.1% , or up to 0.01% .

[0074] Ranges may be expressed as from about one particular value to about another particular value, inclusive. When such a range is expressed, it should be understood that another one or more embodiments is from the one particular value to the other particular value, along with all particular values and combinations thereof within the range.

[0075] While one or more embodiments of the present disclosure have been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised, which do not depart from the scope of the disclosure. Accordingly, the scope of the disclosure should be limited only by the attached claims.

CLAIMS

What is claimed:

1. An exhaust purification system, comprising:
an exhaust gas source configured to provide an exhaust gas stream comprising at least one exhaust gas pollutant;
optionally a heat exchanger unit configured to maintain a temperature of the exhaust gas stream in between 100 to 1000 °C; and
a canister comprising at least one adsorbent-filled cartridge, and configured to adsorb the exhaust gas pollutant from the exhaust gas stream;
wherein the exhaust gas source, the heat exchanger unit and the canister are connected in series.
2. The exhaust purification system of claim 1, wherein the exhaust gas source is an internal combustion engine.
3. The exhaust purification system of claim 1 or 2, wherein the exhaust gas stream is produced by combustion of a low carbon fuel blend in an internal combustion engine.
4. The exhaust purification system of any preceding claim, wherein the low carbon fuel blend is E0 Isooctane.
5. The exhaust purification system of any preceding claim, wherein the low carbon fuel blend is E15 Methyl Tertiary Butyl Ether.
6. The exhaust purification system of any preceding claim, wherein the at least one exhaust gas pollutant in the exhaust gas stream is carbon dioxide.
7. The exhaust purification system of any preceding claim, wherein the exhaust gas stream comprises an oxide of nitrogen.
8. The exhaust purification system of any preceding claim, wherein the exhaust gas pollutant in the exhaust gas stream is selected from a group consisting of: carbon dioxide, carbon monoxide, nitrogen, nitrogen monoxide, nitrogen dioxide, hydrocarbons, particulate matter, and a mixture thereof.

9. The exhaust purification system of any preceding claim, wherein the canister is replaceable.
10. The exhaust purification system of any preceding claim, wherein the heat exchanger unit is a tubular heat exchanger.
11. The exhaust purification system of any preceding claim, wherein the exhaust purification system comprises a plurality of adsorbent-filled cartridges.
12. The exhaust purification system of claim 11, wherein the plurality of adsorbent-filled cartridges is separated by a plurality of spacers in the canister.
13. The exhaust purification system of claim 12, wherein the plurality of adsorbent-filled cartridges comprise metal organic frameworks, covalent organic frameworks, or a combination thereof.
14. The exhaust purification system of any one of claims 11-13, wherein the plurality of adsorbent-filled cartridges is configured to selectively adsorb carbon dioxide from the exhaust gas stream.
15. The exhaust purification system of any preceding claim, wherein the canister comprises:
 - an inlet connector configured to introduce the exhaust gas stream into the canister; and
 - an outlet connector configured to release a clean exhaust gas stream from the canister.
16. The exhaust purification system of any preceding claim, wherein the exhaust purification system comprises a first canister configured to feed the exhaust gas stream from the heat exchanger unit and a last canister configured to release a clean exhaust gas stream.
17. The exhaust purification system of any preceding claim, further comprises a filtration unit positioned in between the heat exchanger unit and the canister.
18. The exhaust purification system of any preceding claim, wherein the exhaust gas source, heat exchanger, and canister are connected via a plurality of pipes.
19. A process of purifying an exhaust stream, the process comprising:

introducing an exhaust gas stream comprising an exhaust gas pollutant into a heat exchanger unit;
optionally cooling the exhaust gas stream in the heat exchanger unit to a pre-set temperature;
feeding the exhaust gas stream from the heat exchanger unit to a canister, wherein the canister comprises at least one adsorbent-filled cartridge;
capturing the exhaust gas pollutant in the adsorbent-filled cartridge; and
releasing a clean exhaust gas stream from the canister.

20. The process of claim 19, wherein the exhaust gas stream is produced by combustion of a low carbon fuel blend in an internal combustion engine.
21. The process of claim 19 or 20, wherein the low carbon fuel blend is E0 Isooctane.
22. The process of claim 19 any one of claims 19-21, wherein the low carbon fuel blend is E15 Methyl Tertiary Butyl Ether.
23. The process of any one of claim 19-22, further comprises removing captured exhaust gas pollutants from the exhaust gas stream.
24. The process of any one of claims 19-23, further comprises replacing the canister when the adsorbent-filled cartridge in the canister is saturated with the exhaust gas pollutant.
25. The process of any one of claims 19-25, wherein the adsorbent-filled cartridge comprises metal organic frameworks, covalent organic frameworks, or a combination thereof.

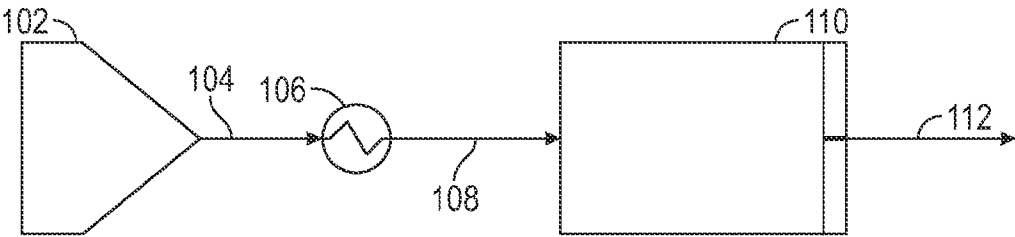


FIG. 1

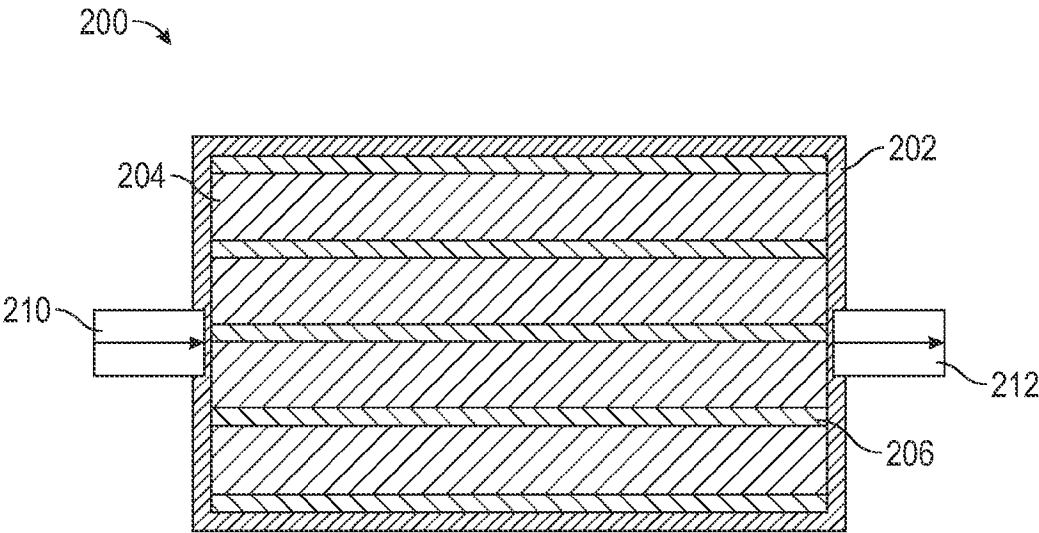


FIG. 2A

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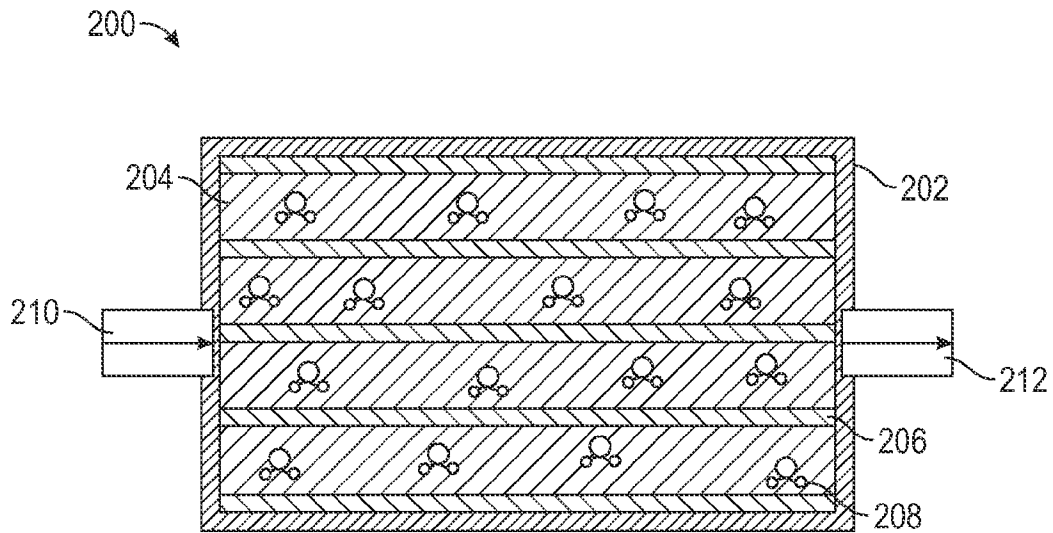


FIG. 2B

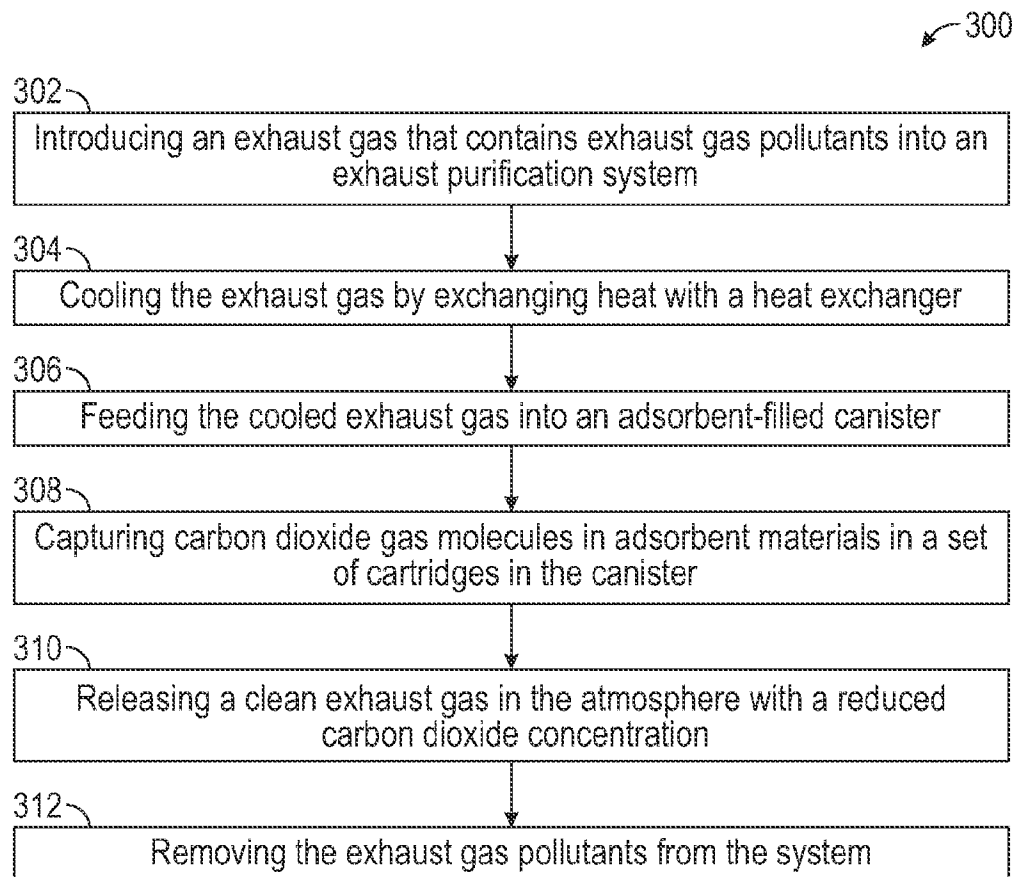


FIG. 3

EPA Federal Test Procedure (FTP)
Duration = 1874 Seconds, Distance = 11.04 Miles, Average Speed = 21.19 mph

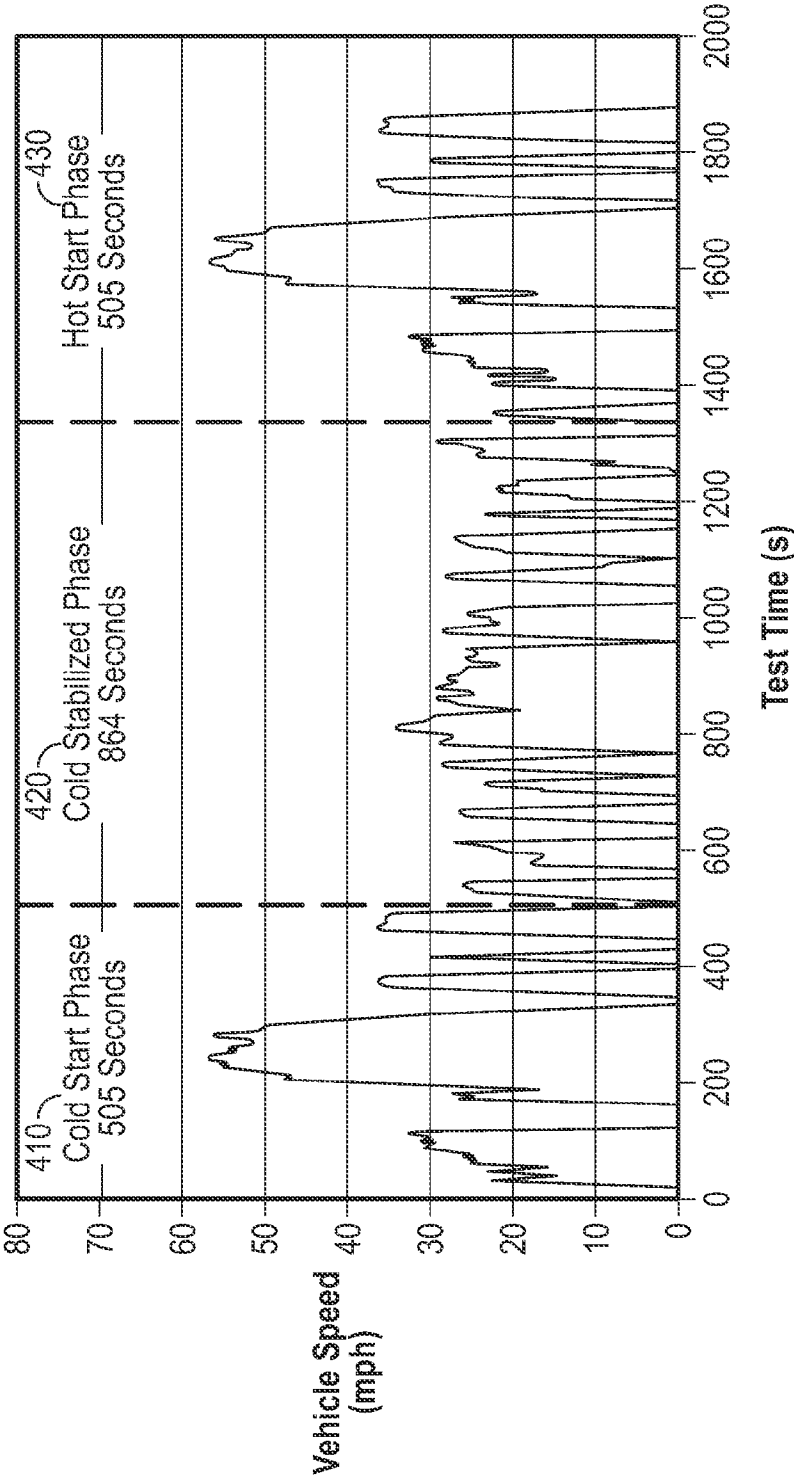


FIG. 4

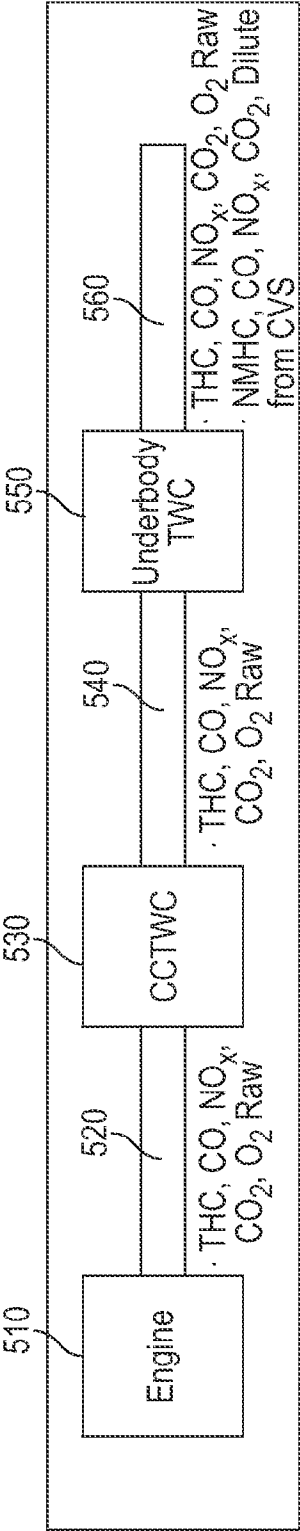


FIG. 5

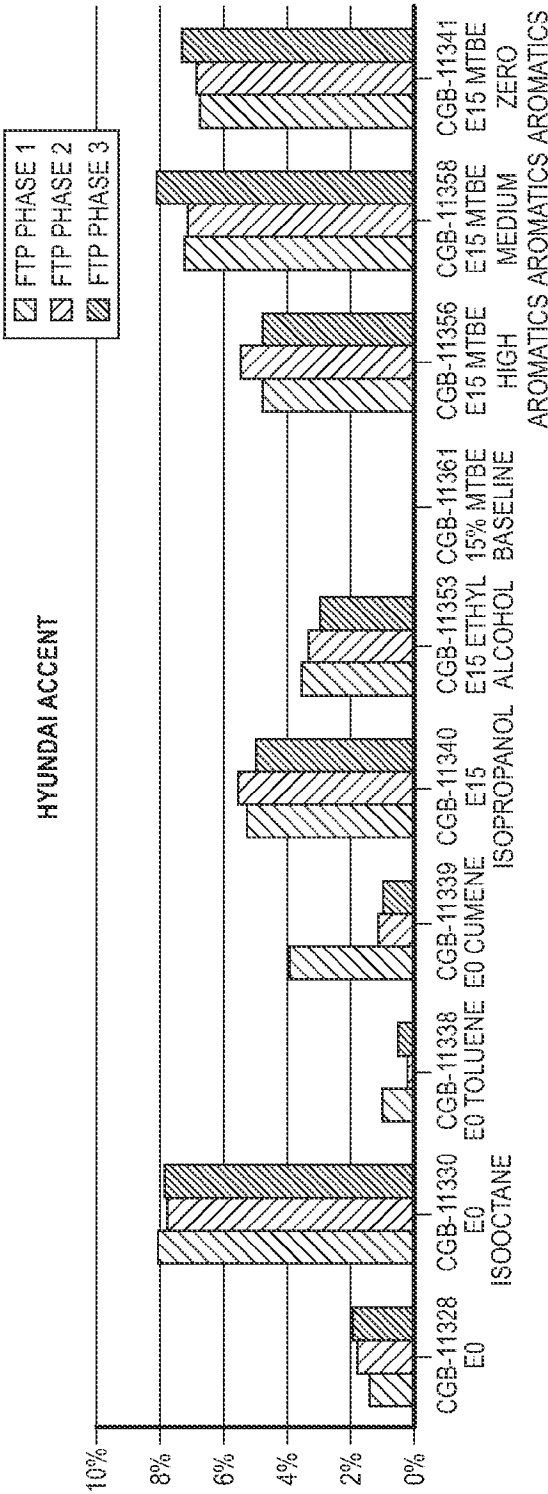


FIG. 6

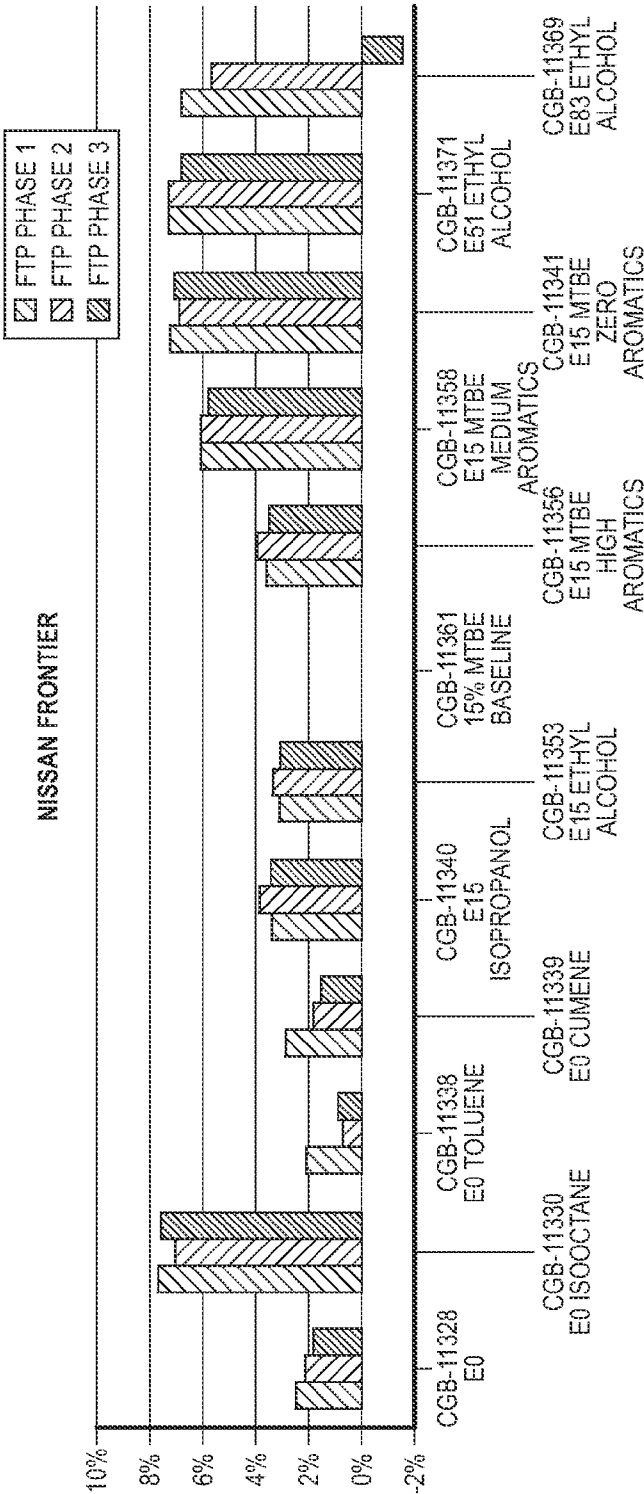


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2023/026787

A. CLASSIFICATION OF SUBJECT MATTER

INV. F01N3/02 F01N3/08

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)

F01N

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/100165 A1 (SAUDI ARABIAN OIL CO [SA]; ARAMCO SERVICES CO [US] ET AL.) 26 July 2012 (2012-07-26) pages 7-10; claims 1-25; figures 1-4 -----	1-25
X	DE 10 2016 219301 A1 (AUDI AG [DE]) 5 April 2018 (2018-04-05) paragraphs [0042] - [0045]; claims 1-4; figure 1 -----	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

22 September 2023

Date of mailing of the international search report

02/10/2023

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/026787

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