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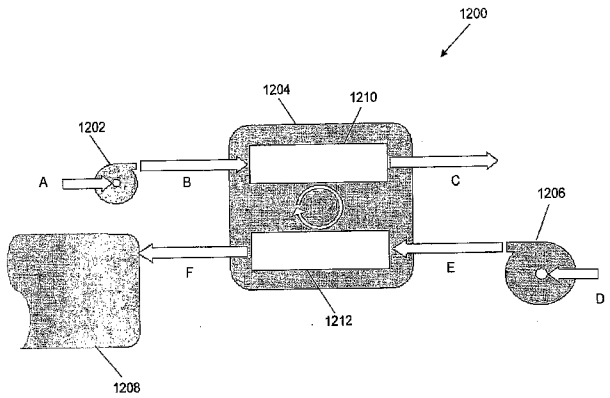
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(54) Title: ADSORPTIVE INTERCOOLER



(57) Abstract: Embodiments of an intercooler, and systems comprising the intercooler, are disclosed, which can be configured to cool a compressed gas stream (e.g. from a supercharger or turbocharger) by desorption of a fluid or a fluid component, such as water. The intercooler can be recharged by adsorbing atmospheric water from a recharge stream. Flow through the intercooler can be cycled so that an adsorptive element in the intercooler is periodically exposed to the compressed gas stream and the recharge stream. For example, the adsorptive element can be positioned within a rotor that is rotated to cycle flow through the adsorptive element. The intercooler can include more than one adsorptive element such that cooling and recharge occur simultaneously. Certain embodiments include rotary, fast cycle intercoolers. In this way, the intercooler can be configured to substantially-continuously cool the compressed gas stream. Due to the cooling effect of desorption, the intercooler can, under certain conditions, cool the compressed gas to a temperature lower than the temperature of the ambient environment.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ADSORPTIVE INTERCOOLER

FIELD

[001] This disclosure relates generally to cooling devices, such as cooling devices that can be used as intercoolers in air intake compression systems.

BACKGROUND

[002] Air intake compression systems, such as superchargers and turbochargers, have long been used to improve the performance of internal combustion engines. These systems operate by compressing the intake air delivered to the combustion cylinders to pressures greater than ambient. Increasing the intake air pressure allows a greater amount of fuel to be injected into the cylinders, according to the applicable fuel-to-air ratio. This leads to more powerful detonations and increased power output. Pressurizing intake air also provides the engine with a constant supply of combustion gas, allowing for consistent performance even at high altitudes. One common use for air intake compression systems has been to increase the power output of engines in performance vehicles. These systems also can be used in small, fuel-efficient engines, so that their performance approaches that of larger, less fuel-efficient engines. Deployment of turbocharged and supercharged engines can lead to an overall increase in fuel efficiency for a given class of vehicle.

[003] The most common types of air intake compression systems are superchargers and turbochargers, and both are used with internal combustion engines. Superchargers generally are powered by the engine's drive mechanism, while turbochargers generally are powered by the engine's exhaust. In addition to improving the performance of internal combustion engines, air intake compression systems also can be used with other combustion devices. For example, large forced air blowers have been used in industrial combustion devices to produce more uniform combustion and to improve combustion performance. Boilers and furnaces, when run at greater-than-ambient feed air pressures, are known to exhibit more efficient heat exchange and more complete utilization of the fuel's stored energy.

[004] As intake air is compressed in an air intake compression system, its temperature rises. The density of hot, compressed air is less than that of cooler, compressed air. Lower densities reduce the amount of air that can be introduced into a combustion device. Thus, the heating that occurs in an air intake compression system can decrease the system's performance. This problem is sometimes addressed by incorporating an intercooler into the air intake compression system. An intercooler is a cooling device positioned after the compression device and before the combustion device. In addition to increasing the amount of air delivered to the combustion device, an intercooler can help to standardize the properties of the intake air, such as the temperature and the partial pressure of water, which may otherwise vary due to atmospheric conditions. This is particularly useful for industrial processes in which predictable combustion is important, such as the combustion of coal for power generation.

[005] In some engines, intake air temperature and pressure are monitored to determine a quantity of fuel to inject, such that the fuel-to-air ratio of the intake charge to be injected into the cylinder remains relatively fixed. As intake air pressure rises due to the effects of supercharging or turbocharging, the amount of fuel injected per cylinder rises proportionately. This leads to more powerful detonations and increased power. However, there are limits to the extent of compression practicable using traditional fuels. As the cylinder pressure increases, so does the tendency of the air/fuel mixture to auto-ignite causing a phenomenon known as "knock." High air-fuel temperature is one of the major contributors to knock. An intercooler effectively lowers the intake air temperature, which lowers the air-fuel mix temperature in the combustion chamber and reduces the occurrence of knock. In addition, recent publications have indicated that lower combustion temperatures result in a reduction in certain harmful engine emissions.

[006] Compression ignition engines (i.e., diesel engines) also benefit from the increased intake air pressure associated with supercharging or turbocharging. It is generally accepted that intercooling is required to obtain the maximum benefit from diesel engine supercharging or turbocharging. With intercooling, less fuel can be injected per cylinder of pressurized air resulting in improved fuel economy in non-peak portions of the driving cycle. Recent advances in emission control

strategies have demonstrated that higher intake air pressures also may offset timing changes made to the engine and thereby reduce NO_x levels in the exhaust.

[007] Several types of intercoolers are known. For example, charge air intercoolers (a type of air-to-air heat exchanger) utilize the heat capacity of ambient-temperature air to cool the compressed intake air leaving the compression device. Charge air intercoolers require a heat exchanger, which typically is a portion of an existing engine radiator or a separate standalone device. Ambient air enters one side of a heat-exchange interface and hot, compressed air enters the other side of the heat-exchange interface. Charge air intercoolers are limited by the ambient air temperature and by the inefficiencies of the heat-exchange interface.

[008] Liquid-to-air intercoolers typically are significantly more effective at cooling compressed intake air than charge air intercoolers. There are many configurations of conventional liquid-to-air intercoolers. One such configuration includes a heat exchanger or radiator over which ambient air flows to cool a liquid therein. After passing through the heat exchanger or radiator, the liquid then circulates via a pump to a second heat exchanger where it cools the compressed intake air. Although effective, liquid-to-air intercooler systems typically include multiple individual components, such as liquid pumps and multiple heat exchangers, and hence are undesirably large.

SUMMARY

[009] Disclosed herein are embodiments of an intercooler system and embodiments of a vehicle incorporating the intercooler system. Some of the disclosed embodiments include an intercooler and a combustion device (e.g., an internal combustion engine). Some embodiments also include a compressor (e.g., a supercharger or a turbocharger), which can be configured to generate a compressed gas stream. The intercooler can be configured to cool the compressed gas stream before it passes to the combustion device. In some embodiments, the intercooler is configured to cycle flow through an adsorptive element through a cycle comprising a recharge stream and the compressed gas stream. The adsorptive element can adsorb atmospheric water from the recharge stream and then desorb atmospheric water into the compressed gas stream to cool the compressed gas stream. Some

embodiments further include a conduit for routing ambient air into the intercooler as the recharge stream and/or a conduit for routing exhaust from the combustion device into the intercooler as the recharge stream.

[010] Flow through the adsorptive element can be cycled using a variety of components and configurations. For example, in some embodiments, the adsorptive element is positioned within a rotor and the intercooler is configured to cycle flow through the adsorptive element by rotating the rotor. In other embodiments, the adsorptive element is substantially stationary. Some embodiments include more than one adsorptive element. In embodiments that include a first adsorptive element and a second adsorptive element, the intercooler can be configured to cycle flow such that at a first time, the first adsorptive element receives the recharge stream and the second adsorptive element receives the compressed gas stream, and at a second time, the second adsorptive element receives the recharge stream and the first adsorptive element receives the compressed gas stream. With multiple adsorptive elements, it is possible for the intercooler to substantially-continuously cool the compressed gas stream. Alternatively, the intercooler can be configured to intermittently cool the compressed gas stream, such as only during period of high power demand.

[011] In embodiments having multiple adsorptive elements, reflux can be used to reduce the pressurization energy demand. For example, some embodiments include a reflux channel for equilibrating the pressure in two adsorptive elements as they transition between adsorbing atmospheric water from the recharge stream (at low pressure) and desorbing atmospheric water into the compressed gas stream (at high pressure).

[012] In disclosed intercooler embodiments, the adsorptive element includes an adsorbent material, such as alumina, silica, a molecular sieve or a combination or derivative thereof. For example, the adsorptive element can include an aluminum-silicate molecular sieve, a titanium-silicate molecular sieve or a combination or derivative thereof. In some embodiments, the adsorptive element includes synthetic zeolite Y with a calcium counter ion or derivative thereof. The adsorptive element can include an adsorbent material capable of reversibly adsorbing from about 20% to about 50% of its weight in water at about ambient

temperature, about ambient pressure and a relative humidity of about 80%. In some embodiments, the adsorptive element includes an adsorbent material capable of reversibly adsorbing from about 15% to about 50% of its weight in water at about ambient temperature, about ambient pressure and a relative humidity of about 10%.

[013] The adsorbent material can be arranged in a variety of structures. In some embodiments, the adsorptive element includes a laminate comprising the adsorbent material and a support material. Suitable support materials include, for example, fiberglass, ceramic fibers, a metallic woven wire mesh, expanded metal, embossed metal and derivatives and combination thereof. The support material can be selected to have a thermal conductivity at room temperature from about 20 to about 1000 W/(m·°C). The support material also can have a specific surface area from about 5,000 m^2/m^3 to about 30,000 m^2/m^3. In some embodiments, the adsorptive element includes multiple layers of laminate separated by spacers. Like the support material, the spacers can have a thermal conductivity at room temperature from about 20 to about 1000 W/(m·°C). Gas flow channels can be formed between the multiple layers of laminate and at least a portion of the multiple layers of laminate can include ventilation apertures to allow gas flow from one gas flow channel to an adjacent gas flow channel.

[014] Some disclosed adsorptive intercooler embodiments are configured to wet adsorbent material within the adsorptive element with a liquid other than atmospheric water. For example, some embodiments include a liquid-injection device for wetting adsorbent material. The liquid-injection device can be configured, for example, to wet the adsorbent material with air-conditioning condensate. This liquid can supplement or replace atmospheric water.

[015] Use of the disclosed intercooler system can have many advantages. For example, the system may increase the fuel economy of a combustion device by a percentage from about 5% to about 17%, increase the power of a combustion device by a percentage from about 40% to about 105%, and/or decrease NO_x emissions from a combustion device by a percentage from about 30% to about 70%.

[016] Also disclosed are embodiments of an intercooling method. These embodiments can include cooling a compressed gas stream by flowing the compressed gas stream through an adsorptive element, and routing the compressed

gas stream exiting the adsorptive element to a combustion device (e.g., an internal combustion engine). Some embodiments also include recharging the adsorptive element. Recharging the adsorptive element can include flowing a recharge stream through the adsorptive element, such as a recharge stream comprising ambient air or a recharge stream comprising exhaust from the combustion device. The recharge stream can be at substantially the same temperature as the ambient environment when it enters the adsorptive element. After it is introduced, the adsorptive element can adsorb atmospheric water from the recharge stream. Cooling the compressed gas stream then can occur by desorption of atmospheric water into the compressed gas stream from the adsorptive element. Some embodiments include substantially-continuously cooling the compressed gas stream. Other embodiments include intermittently cooling the compressed gas stream. The temperature difference between the compressed gas stream entering the adsorptive element and the compressed gas stream exiting the adsorptive element can be, for example, from about 40 °C to about 120 °C. Due to the cooling effect of desorption, some embodiments include cooling the compressed gas stream to a temperature lower than the temperature of the ambient environment.

[017] Just as desorption of water causes cooling, adsorption of water causes heating. Thus, the adsorptive element may increase in temperature while it is being recharged by adsorption of atmospheric water. Some embodiments include cooling the adsorptive element after or while the adsorptive element adsorbs atmospheric water from the recharge stream. Cooling the adsorptive element can include, for example, flowing the recharge stream through the adsorptive element after the adsorptive element is fully loaded with water.

BRIEF DESCRIPTION OF THE DRAWINGS

[018] FIG. 1 is a schematic representation of an intercooler having a single, fixed-position adsorptive element between a compressor and a combustion device.

[019] FIG. 2 is a schematic representation of an intercooler having a first fixed-position adsorptive element and a second fixed-position adsorptive element between a compressor and a combustion device.

[020] FIG. 3A is a perspective view of a rotary intercooler embodiment.

[021] FIG. 3B is a cross-sectional view of the rotary intercooler embodiment shown in FIG. 3A taken along the line 3B-3B.

[022] FIG. 4 is a cross-sectional view of a rotary intercooler embodiment including reflux.

[023] FIG. 5 is a schematic representation of the stages experienced by an adsorptive element in a rotary intercooler embodiment including reflux.

[024] FIG. 6 is a schematic representation of an air-compression system including an embodiment of the disclosed intercooler configured to extract water from ambient air.

[025] FIG. 7 is a schematic representation of a supercharged system including an embodiment of the disclosed intercooler configured to extract water from ambient air.

[026] FIG. 8 is a schematic representation of a turbocharged system including an embodiment of the disclosed intercooler configured to extract water from ambient air.

[027] FIG. 9 is a schematic representation of an air-compression system including an embodiment of the disclosed intercooler configured to receive air-conditioning condensate.

[028] FIG. 10 is a schematic representation of an air-compression system including an embodiment of the disclosed intercooler configured to receive exhaust condensate.

[029] FIG. 11 is a schematic representation of a blower system for a boiler including an embodiment of the disclosed intercooler configured to extract water from ambient air.

[030] FIG. 12 is a schematic representation of an air-compression system including an embodiment of the disclosed intercooler configured to extract water from a recharge stream introduced by a blower.

[031] FIG. 13 is a plot of water uptake versus partial pressure of water for alumina at four different temperatures representing the inlet and outlet temperatures of a recharge stream and a compressed air stream flowing through an embodiment of the disclosed intercooler.

[032] FIG. 14 is a plot of air inlet temperature versus % loss or gain in horsepower for an internal combustion engine.

[033] FIG. 15 is a plot of wall temperature and gas temperature at different positions along the length of an adsorptive element in an embodiment of the disclosed intercooler undergoing desorption in a batch process.

[034] FIG. 16 is a plot of wall temperature and gas temperature at different positions along the length of an adsorptive element in an embodiment of the disclosed intercooler undergoing adsorption in a continuous process.

[035] FIG. 17 is a plot of wall temperature and gas temperature at different positions along the length of an adsorptive element in an embodiment of the disclosed intercooler undergoing desorption in a continuous process.

[036] FIG. 18A is a plot of water loading at 25 °C of several different adsorbent materials at different partial pressures of water.

[037] FIG. 18B is a plot of water loading at 100 °C of several different adsorbent materials at different partial pressures of water.

DETAILED DESCRIPTION

[038] Unless otherwise explained, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The singular terms "a," "an," and "the" include plural referents unless the context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise. The term "includes" means "comprises." The separations described herein can be partial, substantial or complete separations unless indicated otherwise. All percentages recited herein are weight percentages unless indicated otherwise. All patents and publications mentioned herein are incorporated by reference in their entirety, unless otherwise indicated. In case of conflict, the present specification, including explanations of terms, will control. The materials, methods, and examples recited herein are illustrative only and not intended to be limiting. Although the disclosed embodiments are described primarily with reference to cooling compressed air, it should be understood that such embodiments also can be used to cool other gases, including oxygen-enriched gases. Similarly, although the disclosed

embodiments are described primarily with reference to adsorbing water, it should be understood that such embodiments also can be used to adsorb other fluid components.

[039] The following terms may be abbreviated in this disclosure: centipoise (cps), centimeter (cm), cubic centimeter (cc), cubic foot per minute (CFM), cycles per minute (cpm), Engelhard titanium silicate molecular sieve (ETS), Engelhard chabazite molecular sieve (EXS), foot-pound (ft-lb), horsepower (HP), hour (hr), joule (J), infrared (IR), kilowatt (kW), liter (L), meter (m), micrometer (μm), millimeter (mm), millimeter mercury (mmHg), nanometer (nm), newton-meter (Nm), revolution per minute (rpm), standard liter per minute (SLPM), synthetic zeolite Y with a calcium counter ion (Ca-Y), volt (V), and watt (W).

[040] Disclosed herein are embodiments of an intercooler for use in air intake compression systems, embodiments of an air intake compression system incorporating the disclosed intercooler, embodiments of a vehicle incorporating the disclosed intercooler and embodiments of a method for improving combustion performance by air intake compression with intercooling. The disclosed intercooler embodiments include one or more adsorptive element. For example, some embodiments include one or more adsorptive element configured to reversibly adsorb water. Such an adsorptive element can be used to cyclically adsorb atmospheric water and subsequently desorb such water into compressed intake air, such as compressed intake air from a turbocharger or supercharger. The desorption process cools and increases the density of the compressed intake air. In some embodiments, heat-exchange is used to achieve additional cooling.

[041] The disclosed intercooler embodiments may reduce or eliminate the need for pumps and heat-exchange devices associated with conventional intercoolers, such as charge air intercoolers and liquid-to-air intercoolers. Without these extra components, the disclosed embodiments typically occupy significantly less space than conventional intercoolers. Thus, some of the disclosed embodiments are particularly suitable for use in environments with a limited amount of available space, such as under the hood of a vehicle.

[042] The disclosed intercooler system provides many beneficial combustion effects. For example, some embodiments may increase the fuel

economy of a combustion device by a percentage from about 5% to about 20%, such as from about 5% to about 17% or from about 5% to about 12%. Some embodiments also may increase the power of a combustion device by a percentage from about 30% to about 110%, such as from about 40% to about 105% or from about 50% to about 100%. Finally, some embodiments may decrease NO_x emissions from a combustion device by a percentage from about 20% to about 80%, such as from about 30% to about 70% or from about 40% to about 60%.

[043] In some cases, the disclosed intercooler embodiments are more efficient than charge air intercoolers and provide cooled, compressed intake air at temperatures that approach the temperatures previously achieved only by the use of more complex liquid-to-air intercoolers. For example, some embodiments provide cooled, compressed intake air at temperatures that may approach ambient air temperature. Furthermore, unlike conventional intercoolers, some of the disclosed intercooler embodiments are capable of lowering the temperature of the compressed intake air to temperatures lower than the ambient air temperature. This is possible due to the cooling effect of desorption. The temperature difference between the compressed air stream entering the adsorptive element and the compressed air stream exiting the adsorptive element can be, for example, from about 20 °C to about 200 °C, such as from about 40 °C to about 120 °C or from about 60 °C to about 100 °C.

[044] Some of the disclosed intercooler embodiments adsorb fluid components. For example, some embodiments adsorb at least some water from an atmospheric air stream. During the adsorption process, heat is released. At least a portion of such released heat may be removed from the intercooler by passing atmospheric air through or across the adsorptive element. Subsequent to the water adsorption step, the adsorptive element having the adsorbed water may receive relatively hot and dry compressed intake air exiting a compression device within the air intake compression system. The compression device can be, for example, a turbocharger or a supercharger. The relatively hot and dry compressed intake air stream typically causes desorption of at least a portion of the adsorbed component, such as water, from the adsorptive element. This results in cooling and densification

of the compressed intake air stream, thus allowing for a greater air mass charge for combustion.

[045] A description of exemplary adsorptive materials, forms, elements, and intercooler configurations follows. Additional details regarding adsorptive materials can be found in U.S. Patent Nos. 4,702,903, 4;801,308 and 5,082,473 and in U.S. Patent Application Publication No. 2002/0170436, all of which are incorporated herein by reference.

Adsorbent Materials

[046] Suitable adsorbent materials include any adsorbent materials useful for cooling a fluid stream according to described embodiments. Certain adsorbent materials for use in the adsorptive element of the disclosed intercooler embodiments may be chosen from adsorbent materials known for their capability to reversibly adsorb water (preferably in vapor form) from air streams. In particular embodiments, the adsorbent materials are capable of reversibly adsorbing from about 15% to about 50% of their weight in water at about ambient temperature, about ambient pressure and a relative humidity of about 80%. For example, the adsorbent materials can be capable of reversibly adsorbing from about 20% to about 50% or from about 25% to about 50% of their weight in water at these conditions. In some embodiments, the adsorbent materials are capable of reversibly adsorbing a significant quantity of water even under dry conditions. For example, the adsorbent materials can adsorb from about 10% to about 50%, from about 15% to about 50% or from about 20% to about 50% of their weight in water at about ambient temperature, about ambient pressure and a relative humidity of about 10%.

[047] The adsorbent material can be used in any suitable form, such as finely divided particles. Certain embodiments are facilitated by using adsorbents with a narrow, substantially-uniform size distribution. Adsorbent particle size can vary but such particles generally are less than about 10 μm in size, such as less than about 5 μm. Particle size can be selected to provide suitable macroporous diffusion.

[048] Exemplary adsorbent materials for use in embodiments of the disclosed intercooler include, without limitation, alumina, silica and molecular sieves. Exemplary molecular sieves include titanium-silicate molecular sieves and

aluminum-silicate molecular sieves. Exemplary titanium-silicate molecular sieves include ETS materials, such as ETS-10 and ETS-4 from Engelhard Corporation (Iselin, New Jersey). Exemplary aluminum-silicate molecular sieves include natural mineral zeolites, such as chabazite, and synthetic zeolites, such as synthetic zeolite Y. For example, the adsorbent material may be Ca-Y. In some embodiments, the adsorbent material begins as a precursor and is converted to another form or composition having useful adsorbent properties *in situ* after formation of the adsorptive element, such as after the adsorbent material is coated onto a support material. Some of the suitable adsorbent materials are zeolites, which typically are highly-crystalline, aluminum-silicate materials comprising $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedral units. Zeolites typically have silicon and aluminum joined by an oxygen bridge. Zeolites also typically have an overall negative charge, which requires positively charged counter ions, such as Na^+, K^+ and Ca^{2+}. Useful zeolites may be hydrophilic or hydrophobic.

[049] Useful properties of adsorbent materials include: (1) a high heat of adsorption for water, (2) a high level of water uptake under expected operating conditions, (3) a high dependency of water uptake on temperature variations, and (4) a low dependency of water uptake on water partial pressure under expected operating conditions. Factors (1) and (2) are desirable because the heat of adsorption for water and the amount of adsorbed water generally control the cooling amount achieved by desorption of water from a given quantity of adsorbent material. Factor (3) is desirable because temperature variations typically are used to drive the adsorption and desorption processes. Factor (4) is desirable because some embodiments are designed to operate consistently in environments with variable partial pressures of water. For any given application, none, some or all of these factors may be applicable. For example, if the intercooler is to be operated only in a high-humidity environment, factor (4) may not apply.

[050] FIGS. 18A and 18B show the water loading at 25 °C and 100 °C, respectively, of four different adsorbent materials (ETS, EXS, alumina and Ca-Y) at different partial pressures of water. As shown by the differences in water loading between FIG. 18A and FIG. 18B, the uptake of water by all four adsorbent materials generally is highly temperature dependent. Among the tested adsorbent materials,

however, EXS had the highest dependency of water uptake on temperature variations. This makes EXS a good candidate for use in intercooler embodiments used with heavy-duty diesel engines (e.g. marine engines). The super-boost turbochargers used in these engines generate compression ratios typically from about 3:1 to about 5:1. Thus, the compressed air is very hot (e.g., from about 240 °C to about 330 °C). In streetcars that are equipped with low-boost turbochargers, ETS is an advantageous adsorbent material. For example, an ETS intercooler system may cool down a compressed intake air stream at about 2 bar and about 130 °C to about ambient pressure and temperature. Ca-Y is a suitable candidate for high-boost applications in which the compressed air stream is at a pressure from about 2 to about 3 bar and a temperature from about 140 °C to about 220 °C.

[051] Some adsorbent materials are more suitable for low-humidity operation than others. For example, FIGS. 18A and 18B show that the water loading of alumina is much more dependent on the partial pressure of water than the water loading of ETS, EXS and Ca-Y. The ability to adsorb water in low-humidity environments can be important, for example, in vehicles that travel through a variety of environmental conditions. FIGS. 18A and 18B show that the water loading of ETS, EXS and Ca-Y is relatively constant and spikes downward only at extremely low partial pressures of water (e.g., partial pressures of water less than about 1 mmHg or less than about 0.5 mmHg). In contrast, the water loading of alumina decreases gradually as the partial pressure of water decreases. Assuming that the extremely low partial pressures of water that cause the rapid decline of water loading in ETS, EXS and Ca-Y are unlikely to be encountered under normal operating conditions, ETS, EXS and Ca-Y are better suited for consistent operation in variable-humidity environments than alumina. At high humidity (e.g., partial pressures of water greater than about 15 mmHg or greater than about 20 mmHg), alumina has higher water loading than ETS, EXS and Ca-Y. Thus, if humidity is controlled or if low humidity is unlikely (e.g., in certain stationary implementations) alumina may a desirable adsorbent material. It also may be advantageous to use, such as in discrete zones or as substantially homogeneous blends, combinations of these adsorbent materials in some implementations to take advantage of their different properties.

[052] In embodiments of the disclosed intercooler suitable for use in turbocharged or supercharged engines of the size range commonly in use in passenger cars and light trucks, the total quantity of adsorbent material may be, for example, from about 0.5 L to about 5 L, such as from about 1 L to about 4 L or from about 1.5 L to about 3 L. Such a quantity may be sufficient to result in adsorptive cooling of compressed intake air streams during periods of high engine output (such as accelerating between gear changes) to near-ambient or sub-ambient temperatures. Of course, much smaller and much larger quantities of adsorbent material also can be used depending on the specific implementation.

Adsorbent Forms

[053] As described in U.S. Patent Application Publication No. 2002/0170436, adsorbent material can be incorporated into the adsorptive element in a variety of forms. In some embodiments, the adsorbent material is granular or pelletized. In other embodiments, the adsorbent material is in a laminate form. Laminates can be rolled, stacked or otherwise arranged within the adsorptive element to provide the desired surface area and pressure drop. Spacers can be used to define a consistent separation between the laminate layers. Laminates generally minimize mass transfer resistances by providing a high surface-area-to-volume ratio and by providing a structure with a uniform, minimum thickness to support the adsorbent material. Methods for making suitable laminates generally involve forming a slurry, such as a slurry comprising a liquid suspending agent, a binder and an adsorbent material. This slurry then can be coated onto a support material. Alternatively, the support material can be admixed into the slurry.

[054] Inorganic material may be used as a binder. Although inorganic binders are typically inert, certain inorganic binders, such as clays, may be converted *in-situ* into a zeolite form so that they act as adsorbent materials. Additionally, high-molecular-weight materials can serve to improve laminate green strength (i.e., strength prior to firing). Flocculating agents also can be added to the slurries. Like high-molecular-weight materials, flocculating agents generally are used when the support material is admixed into the slurry. One example of a useful flocculating

agent is cationic starch. Cationic starch is particularly useful when the binder is colloidal silica

[055] A slurry can be applied to a support material by any suitable process. Exemplary processes include dip coating, electrophoretic deposition, etc.

[056] The support material can be either conducting or nonconducting. In some embodiments, the support material has a thermal conductivity at room temperature from about 10 to about 1000 W/(m·°C), such as from about 20 to about 1000 W/(m·°C) or from about 50 to about 1000 W/(m·°C). Higher thermal conductivity (and heat capacity in some cases) may serve to dissipate additional heat from the compressed intake air during cooling as well as to dissipate heat generated by adsorption of water during recharge.

[057] Additionally, support materials can be surface treated prior to deposition of the slurry, such as by oxidation, anodization, texturing, or a combination thereof. For example, metals typically are surface treated prior to electrophoretic deposition. Suitable surface-treated support materials include, without limitation, surface-treated metals (e.g., foils and meshes), surface-treated carbon fibers, surface-treated cellulosic materials, surface-treated polymeric materials, and combinations thereof. Surface treatment may serve a variety of purposes. For example, texturing may be used to provide favorable wetting and bonding properties. Surface treatment also can be used to control the orientation of macropores in the finished laminate.

[058] Electrophoretic deposition processes can include adding structures to the slurry designed to orient the adsorbent material. For example, long-chain polymeric fibers may be charged positively at one end and negatively at the other end and added to the slurry to orient in the field direction normal to the laminate surface. Suitable fibers may be, for example, about 0.1 to about 5 μm in diameter and about 1 to about 150 μm in length. The fibers may be located randomly in the coating, but also may be located in approximately a regular (e.g., hexagonal) pattern, such as by using electrostatic field gradients established by a template. Upon subsequent firing of the coating, the fibers can be removed (e.g., by volatilization, pyrolysis or combustion) to define opened, straight macropores. For example, if the

fibers are located in a regular pattern within the coating, they may define a columnar array of macropores with approximately equal spacing.

Adsorptive Element

[059] The adsorptive elements in the disclosed intercooler embodiments typically include a housing and an adsorbent material within the housing. The adsorptive elements can have a variety of shapes, but most often are elongated to maximize contact between air flowing through the adsorptive elements and the adsorbent material. In some embodiments, the shape of the adsorptive elements is closely related to the intercooler configuration. For example, in intercooler embodiments configured for rotary operation, the adsorptive elements can be shaped to fit within a rotor and/or to match the cross-sectional profile of the inlet and outlet ports in the stator.

[060] The adsorptive elements in the disclosed intercooler embodiments typically include micropores in the adsorbent material within which the adsorption takes place, flow channels that serve as the main conduits for air flow, and macropores to provide enhanced diffusive and convective access from the flow channels to the micropores. The dimensions of adsorptive elements used within the disclosed intercooler embodiments depend on a variety of factors, including the desired flow rate of compressed intake air, the anticipated operating conditions and the frequency of switching between recharge and cooling. In a typical vehicle implementation, the adsorptive elements include multiple laminate layers. Such adsorptive elements may, for example, have a flow channel length from about 2 cm to about 20 cm (e.g., from about 5 cm to about 15 cm), a channel gap height from about 25 μm to about 250 μm (e.g., from about 50 μm to about 150 μm), and an adsorbent coating thickness from about 25 μm to about 250 μm (e.g., from about 50 μm to about 150 μm) on one or both major surfaces.

[061] Support members can be made from a variety of materials, such as plastics, metals, glasses, ceramics, carbon, and combinations thereof. For example, flow channels may be formed between adjacent laminates that are separated by spacers. Similar to the support material, the spacers can be either conducting or nonconducting.

[062] In some applications, such as in disclosed intercooler embodiments placed onboard a vehicle, vibration and shock loading are much more frequent and severe than in stationary commercial applications. The use of laminates and spacers typically provides a structure that is more robust than a beaded or pelletized packed adsorber, and hence, provides additional benefits beyond size, weight, cost and pressure drop.

[063] For example, spirally-wound laminates can be contained in containment chambers. Mandrels can be used to hold a laminate in place and prevent mechanical degradation of the laminate, such as mechanical degradation caused by abrasion. The containment chamber and the mandrel can be made from a variety of materials, such as metals and metal alloys (e.g. stainless steel), ceramics and polymeric materials. In some embodiments, the containment chamber and/or the mandrel have a thermal conductivity at room temperature from about 10 to about 1000 W/(m·°C).

[064] Additional details regarding adsorptive elements can be found in U.S. Patent Nos. 4,702,903, 4,801,308 and 5,082,473 and in U.S. Patent Application Publication No. 2002/0170436, all of which are incorporated herein by reference.

Intercooler Configurations

[065] The disclosed intercooler embodiments can have a variety of configurations. Typical embodiments include at least one adsorptive element and at least one distribution system (e.g., a valve, rotary assembly, etc.) for routing flow through the adsorptive element(s). This subsection discusses arrangement of the adsorptive elements and other aspects of the configuration of embodiments of the disclosed intercooler.

[066] Embodiments of the disclosed intercooler can be configured for intermittent and/or substantially-continuous operation. For example, embodiments having only one adsorptive element can be configured such that the flow path of the compressed intake air is switched between a flow path through the adsorptive element and a flow path bypassing the adsorptive element. The bypass flow path can be used, for example, while the adsorptive element is being recharged. The adsorptive element can be engaged, for example, as soon as it is recharged, at a set

time interval, in response to an operator command or in response to some other signal. Possible signals include signals from sensors that detect engine stress. Embodiments that include only one adsorptive element also can be configured for substantially-continuous operation if water is routed to the adsorptive element from a source other than the atmosphere.

[067] Embodiments that include multiple adsorptive elements typically are better suited for substantially continuous operation than embodiments including only one adsorptive element. Multiple adsorptive elements can be switched between recharging and cooling such that the compressed intake air stream is substantially-continuously exposed to a non-exhausted adsorptive element. In embodiments including three or more adsorptive elements, all but one of the adsorptive elements can be recharging while the remaining adsorptive element is exposed to the compressed intake air stream. This configuration is particularly useful if the time it takes for the adsorptive elements to recharge is significantly greater than the time it takes for the adsorptive elements to desorb their water within the compressed intake air stream. Switching between multiple adsorptive elements can be performed, for example, at a set time interval or in response to a signal, such as a signal corresponding to the water content of an adsorptive element being recharged or an adsorptive element being exposed to compressed intake air. In humid environments, the switching may occur more rapidly than in dry environments because the adsorptive elements will require less time to recharge.

[068] In embodiments of the disclosed intercooler, the adsorptive elements can be fixed or movable. If the adsorptive elements are fixed, the embodiments can include at least one valve (e.g. a flapper valve, a solenoid valve or an actuating valve) for switching the flow of compressed intake air between adsorptive elements or between an adsorptive elements and a bypass. If the adsorptive elements are movable, the embodiments can include fixed inlet and outlet ports between which the adsorptive elements can be interchangeably positioned. In some embodiments, the adsorptive elements are held within a rotor and rotated relative to a stator defining inlet and outlet ports. One or more of the inlet and outlet ports can be used to carry the flow of compressed intake air while one or more other inlet and outlet ports carry a recharge stream (e.g., ambient air) for recharging the adsorptive

elements. Inlet and outlet ports that cause the compressed inlet air to bypass the adsorptive elements also can be included. The interface between the rotor and the stator, particularly around the inlet and outlet ports carrying the compressed intake air, can be configured to prevent leakage, such as by the incorporation of seals.

[069] FIG. 1 is a schematic representation of an intercooler 100 having a single, fixed-position adsorptive element 102 between a compressor 104 and a combustion device 106. The illustrated fixed-position adsorptive element 102 is elongated and includes an inlet conduit 108 at one end and an outlet conduit 110 at the opposite end. The flow into the inlet conduit 108 is controlled by a first valve 112 and can be switched between flow from a compressed air inlet conduit 114 and flow from an ambient air inlet conduit 116. Similarly, the flow exiting the outlet conduit 110 can be routed by a second valve 118 to a compressed air outlet conduit 120 or an exhaust conduit 122. When the compressed air is being cooled, a third valve 124 and a fourth valve 126 route the compressed air through the fixed-position adsorptive element 102. When the fixed-position adsorptive element 102 is recharging, the third valve 124 and the fourth valve 126 are switched to route the compressed intake air through a direct conduit 128 between the compressor 104 and the combustion device 106.

[070] FIG. 2 is a schematic representation of an intercooler 200 having a first fixed-position adsorptive element 202 and a second fixed-position adsorptive element 204 between a compressor 206 and a combustion device 208. The illustrated first fixed-position adsorptive element 202 is elongated and includes a first fixed-position adsorptive element inlet conduit 210 at one end and a first fixed-position adsorptive element outlet conduit 212 at the opposite end. The flow into the first fixed-position adsorptive element inlet conduit 210 is controlled by a first valve 214 and can be switched between flow from a first fixed-position adsorptive element compressed air inlet conduit 216 and flow from a first fixed-position adsorptive element ambient air inlet conduit 218. Similarly, the flow exiting the first fixed-position adsorptive element outlet conduit 212 can be routed by a second valve 220 to a first fixed-position adsorptive element compressed air outlet conduit 222 or a first fixed-position adsorptive element exhaust conduit 224. When the compressed air is being cooled, a third valve 226 and a fourth valve 228 route the compressed air

through the first fixed-position adsorptive element 202. When the first fixed-position adsorptive element 202 is recharging, the third valve 226 and the fourth valve 228 are switched to route the compressed intake air through a direct conduit 230 between the compressor 206 and the combustion device 208.

[071] Along the a direct conduit 230, after the third valve 226 and the fourth valve 228, a fifth valve 232 and a sixth valve 234 are positioned, respectively. When the first fixed-position adsorptive element 202 is recharging, the fifth valve 232 and the sixth valve 234 can be switched to route the compressed air through the second fixed-position adsorptive element 204. The compressed air travels from the fifth valve 232 through a second fixed-position adsorptive element compressed air inlet conduit 236, through a seventh valve 238, through a second fixed-position adsorptive element inlet conduit 240, through the second fixed-position adsorptive element 204, out a second fixed-position adsorptive element outlet conduit 242, through an eighth valve 244, through a second fixed-position adsorptive element compressed air outlet conduit 246, through the sixth valve 234 and back into the direct conduit 230. When the second fixed-position adsorptive element 204 is being recharged, intermediate valves 232, 234, 238 and 244 are switched to route ambient air from a second fixed-position adsorptive element ambient air inlet conduit 248, through the second fixed-position adsorptive element 204 and out a second fixed-position adsorptive element exhaust conduit 250.

[072] FIGS. 3A and 3B illustrate a rotary intercooler 300 having multiple movable adsorptive elements. The rotary intercooler 300 includes a main body 302, a compressed air inlet 304, a compressed air outlet 306, an ambient air inlet 308 and an ambient air outlet 310. FIG. 3B is a cross-sectional view through the main body 302 along the line 3B-3B. FIG. 3B shows an outer housing 312 around a rotor 314 having plural (eight in the illustrated embodiment) flow channels 316 defined therein. The rotor 314 is configured to rotate about an axis 318. Rotation of the rotor 314 causes different flow channels 316 to align with ports in a stator (not shown). Compressed air entering the main body 302 through the compressed air inlet 304 can be distributed to one or more ports. Similarly, ambient air entering the main body 302 through the ambient air inlet 308 can be distributed to one or more ports. For example, the compressed air can be distributed to one port and the

ambient air can be distributed to all remaining ports, such that ambient air flows through all of the flow channels 316 except the one flow channel that carries the compressed air. Each flow channel 316 can include an adsorptive element. In some embodiments, the rotor is rotated to cyclically pass compressed air and then ambient air through the adsorptive elements. The adsorptive elements can be configured to desorb water in the compressed air and then adsorb water from the ambient air. In this way, cooling of the compressed air can be substantially continuous.

[073] Although the embodiment shown in FIGS. 3A and 3B is cylindrical, other shapes also can be used. For many applications, the shape of the intercooler is determined by the available space. For example, in automobiles configured for air-to-air intercoolers, the available space may be rectangular.

[074] Some disclosed intercooler embodiments are configured to operate with reflux streams. The use of reflux streams complicates the valving, but can be useful to conserve compression power. FIG. 4 is a simplified cross-sectional diagram of an intercooler 400. The intercooler 400 includes a rotor containing adsorptive elements 402. The rotor rotates in the direction indicated by arrow 404 on a shaft 406. Within the stator supporting the rotor, there are two reflux channels 408. The reflux channels 408 create fluid connections between two adsorptive elements 402 on opposite sides of the rotor while the adsorptive elements 402 are in transition between adsorption and desorption stages. When an adsorptive element 402 is transitioning from receiving a high pressure feed to receiving a low pressure feed, it equilibrates via the reflux channels 408 with an adsorptive element on the opposite side of the rotor transitioning from receiving a low pressure feed to receiving a high pressure feed. Although some fluid is still exhausted to the atmosphere, the reflux stage reduces the overall pressurization energy demand of the system.

[075] FIG. 5 is a schematic representation of the stages experienced by an adsorptive element in a rotary intercooler embodiment including reflux. Each stage is represented by a box. The adsorptive element rotates through the stages in the order indicated by arrow 500. During a recharging stage 502, the adsorptive element receives a feed of ambient air and adsorbent material within the adsorptive element adsorbs water from the ambient air. The adsorptive element then rotates through a

first reflux stage 504, during which it is partially pressurized by equilibrating with another adsorptive element on the opposite end of a pair of reflux channels. Next, the adsorptive element rotates through two successive cooling stages 506, 508. During these stages, compressed air flows into the adsorptive element from a compression device (e.g., a turbocharger) and the adsorptive material in the adsorptive element desorbs water, thereby cooling the compressed air. The cooled, compressed air exits the adsorptive element and is routed into a combustion device (e.g., an engine). After the cooling stages 506, 508, the adsorptive element rotates through a second reflux stage 510. The adsorptive element, which contains pressurized air from the compression device, equilibrates with another adsorptive element at the first reflux stage 504. The remaining fluid in the adsorptive element then is exhausted as the adsorptive element rotates into a recharging stage 512 followed by the original recharging stage 502, as the cycle repeats itself.

[076] The embodiment illustrated in FIG. 5 includes only one pair of reflux stages. Additional energy can be saved by including more than one pair of reflux stages, such as two or three pairs. The valving for two additional reflux stages can be configured, for example, such that the reflux stage immediately after the reflux stage 510 equilibrates with the reflux stage immediately before the reflux stage 504 and the reflux stage after the reflux stage immediately after the reflux stage 510 equilibrates with the reflux stage before the reflux stage immediately before the reflux stage 504. Such a configuration provides for incremental pressurization and depressurization, and can be repeated for any number of reflux stages.

[077] As mentioned above, reflux stages complicate operation of the intercooler device, so they may not be appropriate for small-scale embodiments in which energy loss is of secondary importance to the cost and size of the equipment. In large scale operations, however, the energy savings may warrant the inclusion of reflux stages.

[078] Accordingly, many variants of rotary intercoolers will be evident to those skilled in the art. For example, details concerning the configuration of rotary adsorption devices can be found in U.S. Patent Nos. 6,051,050, 6,451,095 and 6,565,635, all of which are incorporated herein by reference.

Intercooler Implementations

[079] Embodiments of the disclosed intercooler can be deployed in a variety of systems. For example, some embodiments can be used as intermittent intercoolers for small engines, such as to provide an acceleration boost on demand without disrupting the fuel economy of the engine. These embodiments can, for example, include only one adsorbent bed that is cycled between adsorbing water from ambient air and desorbing water within a stream of compressed intake air. The switching can be performed, for example, using a bypass valve. In other configurations, multiple adsorbent beds are arranged to adsorb or desorb at various intervals, so as to provide substantially constant cooling of the compressed intake air. The adsorbent beds can be switched between adsorption and desorption, for example, by rotation of a rotary valve. This configuration is particularly suitable for use with large gas or diesel engines.

[080] The disclosed intercooler embodiments can be supplied with a fluid comprising water from a variety of sources other than ambient air. For example, the water can be adsorbed from the engine exhaust. In vehicle implementations, the adsorbent beds also can be wetted with air-conditioning condensate. Water also can be provided from a dedicated or shared water reservoir. Alternative sources of water are particularly useful to aid operation of some disclosed intercooler embodiments when the ambient air is relatively hot and/or dry. In some embodiments, all of the water is supplied from a source other than ambient air. This may eliminate the need for cycling between adsorption and desorption. For example, in embodiments having only a single adsorbent bed, the adsorbent bed can be wetted while exposed to the compressed intake air.

[081] In addition to improving engine performance, some embodiments of the disclosed intercooler can be used for emissions reduction. For example, many emissions-reducing devices operate more effectively when their intake is compressed and cooled. The disclosed intercooler embodiments can be positioned, for example, between compression devices and emissions-reducing devices along the exhaust stream exiting an engine.

[082] FIG. 6 is a schematic representation of a system 600 with air compression and cooling. The system 600 includes an air compressor 602, an

intercooler 604 and an engine 606. The air compressor 602 receives a feed of ambient air. This ambient air is compressed and routed into the intercooler 604, which cools the compressed air and sends it to the engine 606. The intercooler 604 is intermittently recharged with a recharge stream, which can be, for example, another stream of ambient air.

[083] FIG. 7 is a schematic representation of a supercharged system 700, including a supercharger 702, an intercooler 704 and an engine 706 with an intake manifold 708, cylinders 710 and an exhaust duct 712. The supercharger 702 receives a feed of ambient air. This ambient air is compressed and routed into the intercooler 704, which cools the compressed air and sends it to the intake manifold 708 of the engine 706. The intercooler 704 is intermittently recharged with a recharge stream, which can be, for example, another stream of ambient air.

[084] Superchargers, such as the supercharger shown in FIG. 7, can be mechanically or electronically driven. In a vehicle, air typically is supplied to the supercharger through an air intake duct located near the front of the vehicle or at another location where free-flowing ambient air is available. The supplied air is compressed and typically is delivered to the engine's air intake manifold via a short duct. As shown in FIG. 7, the disclosed intercooler can be located along this duct between the supercharger and the engine's air intake manifold.

[085] FIG. 8 is a schematic representation of a turbocharged system 800, including a turbocharger 802, an intercooler 804 and an engine 806 with an intake manifold 808, cylinders 810 and an exhaust duct 812. The turbocharger 802, which is positioned along the exhaust duct 812, receives a feed of ambient air. This ambient air is compressed and routed into the intercooler 804, which cools the compressed air and sends it to the intake manifold 808 of the engine 806. The intercooler 804 is intermittently recharged with a recharge stream, which can be, for example, another stream of ambient air.

[086] Typically, the only difference between a turbocharged system and a supercharged system is the power source for intake air compression. Superchargers typically are powered electrically or mechanically by the engine's drive mechanism. Turbochargers typically are powered by the energy of the escaping exhaust gas. In a typical turbocharger, at least one of the turbine blades is located in the exhaust

stream. The turbine blade in the exhaust stream is coupled to an air-compressor turbine blade using a direct shaft or gearbox. As the exhaust flows, it drives both turbines and intake air supplied from the air intake duct is compressed for delivery to the engine. The turbines typically connect to the exhaust gas flow at or near the point where it exits the engine. Thus, a duct typically is required to deliver the compressed intake air to the engine's intake manifold. As shown in FIG. 8, the disclosed intercooler 804 can be located along this duct between the turbocharger 802 and the engine's air intake manifold 808.

[087] The intercooler embodiments shown in FIGS. 6-8 extract water from, and thus are recharged by, ambient air. In other embodiments an alternative source of water is used to supplement or replace the water extracted from ambient air. The availability of an alternative source of water is particularly useful when the ambient air is relatively hot and/or dry, such as when the disclosed intercooler embodiments are operated in arid environments. An alternative source of water also may eliminate the need to take an adsorbent bed off-line for recharging. For example, water can be introduced into an adsorbent bed while compressed intake air is flowing through the adsorbent bed. In these embodiments, the pressure of the compressed intake air can be maintained, for example, by pumping the water through a one-way valve at a pressure greater than the pressure of the compressed intake air.

[088] FIG. 9 shows an air-compression system 900 including a compressor 902, an engine 904 and an intercooler 906 configured to receive condensate from an air-conditioner 908. FIG. 10 shows an air-compression system 1000 including a compressor 1002, an engine 1004 and an intercooler 1006 configured to receive condensate collected from the engine exhaust. The embodiments shown in FIGS. 9 and 10 also can include a reservoir to collect any excess water from the air conditioner 908 and the exhaust stream, respectively. Alternatively, a refillable reservoir may serve as the only alternate water source. Water from a source other than ambient air can be pumped from the source to the intercooler. When it reaches the intercooler, the water can be introduced, for example, by capillary action, soaking, misting, spraying or a combination thereof.

[089] FIG. 11 is a schematic representation of an embodiment of the disclosed intercooler used in a blower system for a boiler. The system 1100 includes a blower 1102, an intercooler 1104 and a boiler 1106. The blower 1102 receives a feed of ambient air. This ambient air is blown into the intercooler 1104, which cools the air and sends it to the boiler 1106. The intercooler 1104 is intermittently recharged with a recharge stream, which can be, for example, another stream of ambient air.

Intercooler Operation

[090] As discussed above, some embodiments of the disclosed intercooler are configured to reversibly adsorb and desorb water from air. These processes are affected by the properties of the air, including the temperature and the partial pressure of water. Lower temperatures and higher water content tend to increase the rate of adsorption. The water content of ambient air varies in wide range from about 0.05% by volume in very cold and dry conditions to about 5% by volume in very hot and humid conditions. As discussed above, however, some disclosed adsorbent materials (e.g., ETS, EXS and Ca-Y) are loaded with water relatively independently of water partial pressure. Other adsorbent materials (e.g., alumina) have a greater maximum water loading in humid conditions, but are highly dependent on the partial pressure of water.

[091] FIG. 12 shows one example of an intercooler system 1200, including a blower 1202 (e.g., an engine radiator fan), an intercooler 1204, a compressor 1206 (e.g., a turbocharger or supercharger), and an engine 1208. The intercooler 1204 includes a first adsorptive element 1210 being recharged with ambient air and a second adsorptive element 1212 cooling compressed intake air. Table 1 shows the pressure, temperature and relative humidity at points A-F in the system.

Table 1

Point	Pressure (bar)	Temperature (°C)	Relative Humidity
A	1.01	32	65%
B	1.10	32	65%
C	1.01	116	1.2%
D	1.01	32	65%
E	1.89	126	2.5%
F	1.80	42	100%

[092] As shown in FIG. 12, adsorption and desorption can occur simultaneously in separate adsorptive elements. The gas flows in which adsorption and desorption occur can travel through the intercooler in countercurrent or co-current directions.

[093] FIG. 13 is a plot of isotherms (water uptake versus partial pressure of water) for alumina at four different temperatures: trace A (32 °C), trace B (116 °C), trace C (126 °C) and trace D (42 °C). These four temperatures represent the temperature of the recharge stream entering an adsorptive element, the temperature of the recharge stream exiting the adsorptive element, the temperature of the compressed air stream entering the adsorptive element and the temperature of the compressed air stream exiting the adsorptive element, respectively, in one example of a cyclic adsorptive intercooling process. A schematic illustration of a cyclic intercooler is superimposed over the isotherms. Lines E and F represent the changes that occur during adsorption (recharge) and desorption (cooling), respectively. In the adsorption portion of the cycle (left side), a relatively low temperature and low pressure recharge stream from a radiator fan enters the adsorptive element. Upon exiting the adsorptive element, as system exhaust, the recharge stream has a lower partial pressure of water and a higher temperature than when it entered. Switching to the desorption portion of the cycle (right side), compressed air from a turbocharger enters the adsorptive element at relatively high temperature and pressure. When it exits the adsorptive element and heads to the engine intake, the compressed air has a higher partial pressure of water and a lower temperature than when it entered.

[094] Embodiments of the disclosed intercooler can operate by batch or continuous processes. Batch operation is useful, for example, in automobiles to provide a brief power boost on demand or in response to a signal. Batch processes can include, for example, slow loading of the adsorbent material (e.g., over a period of minutes) followed by a short cooling step (e.g., about 20 seconds). In some embodiments, each adsorptive element is subjected to from about 50 to about 500 seconds of adsorption (e.g., from about 10 to about 400 seconds or from about 150 to about 250 seconds) and from about 5 to about 100 seconds of desorption (e.g., from about 10 to about 50 seconds or from about 15 to about 25 seconds). In one

particular example, each adsorptive element is subjected to about 200 seconds of adsorption and about 20 seconds of desorption.

[095] Continuous operation is well-suited for applications that require a continuously increased power level. Continuous processes typically operate at faster cycle speeds than batch processes (e.g. about 30 cpm). In some embodiments, the cycle speed is greater than 5 cpm, typically greater than about 10 cpm and up to at least 50 cpm, such as from about 20 cpm to about 40 cpm or from about 25 cpm to about 35 cpm. In continuous processes, higher cycle speeds reduce the necessary size of the machine. The upper limit of the cycle speed may be determined by heat and mass transfer rates.

[096] In addition to cooling by desorption of water, some embodiments of the disclosed intercooler are configured to cool by heat exchange. If the compressed intake air is at a higher temperature than the adsorptive element, some heat exchange cooling will occur. The amount of heat exchange can be improved by increasing the heat capacity of the adsorptive element and increasing the thermal conductivity of the adsorptive element. Improving the heat capacity of the adsorptive element can include increasing the size of the adsorptive element, increasing the density of the adsorbent material and constructing the adsorptive element out of materials with high heat capacities. In some embodiments, the heat capacity of the overall adsorptive element at room temperature is from about 1.5 to about 5 J/(m^3·°C), such as from about 2 to about 4 J/(m^3·°C) or from about 2.5 to about 3.5 J/(m^3·°C).

[097] The thermal conductivity of the adsorptive element can be improved by constructing the adsorptive element out of materials with high thermal conductivities. For example, the adsorptive element can include a metal housing, a metal laminate support material and/or metal spacers between the laminate layers. Certain metals, such as aluminum, copper and silver and gold, have particularly high thermal conductivities and thus are especially useful for improving the rate of heat transfer. As mentioned above, the thermal conductivity of the housing, the support material and/or the spacers at room temperature can be from about 10 to about 1000 W/(m·°C), such as from about 20 to about 1000 W/(m·°C) or from about 50 to about 1000 W/(m·°C). To further improve heat transfer, the surface area of the support material within the adsorptive element can be from about 1,000 to about 30,000

m^2/m^3, such as from about 5,000 to about 30,000 m^2/m^3 or from about 10,000 to about 30,000 m^2/m^3.

[098] Lowering the temperature of the adsorptive element before it is introduced into the compressed feed air is useful for promoting cooling by heat exchange. After being heated by the compressed intake air and/or by adsorption of water during recharge, the adsorptive element can be allowed to return to ambient temperature. For example, an adsorptive element may become fully loaded with water after receiving a recharge stream at ambient temperature and then it may be cooled by continuing to pass the recharge stream through and/or around the adsorptive element.

[099] Adsorptive intercooling processes have several advantages over conventional intercooling processes. For example, adsorptive intercooling processes can achieve approach temperatures of zero without compromising heat transfer efficiency or intercooler size. This may immediately improve the engine horsepower by about 5%. Adsorptive intercooling processes also can achieve sub-ambient cooling under certain conditions. Factors that may affect the degree of cooling include, for example, the cycle speed, the heat transfer rate, the heat of adsorption of the adsorbent, and the pressure ratio between the compressed intake air and the recharge stream. Every 10 °C of sub-ambient intercooling typically improves the engine horsepower by about 2%. The relationship between air inlet temperature and % gain in horsepower is shown in FIG. 14. The disclosed intercooler embodiments generally also are smaller than conventional intercoolers. For example, conventional air-to-air intercoolers have a flat geometry to provide high surface area for higher heat transfer efficiency. The disclosed intercooler embodiments can have various geometries (e.g., flat or cylindrical) depending on the application. Finally, the disclosed adsorptive intercooling processes reduce the combustion temperatures and thereby reduce harmful emissions, such as NO_x emissions from diesel engines.

EXAMPLES

[0100] The following examples are provided to illustrate certain particular embodiments of the disclosure. It should be understood that additional

embodiments not limited to the particular features described are consistent with the following examples.

Example 1

[0101] This example describes modeling a batch process for intercooling in a compact automobile. A target intake flow capacity first was calculated for a Mazda Protégé 1.6 L (1,597 cc) engine. The engine was a 4 cylinder engine with a 78 mm bore, a 83.6 mm stroke, a compression ratio of 9, a volumetric efficiency at peak power of 85%, a power at 5,500 rpm of 78 kW (105 HP), and a power at 4,000 rpm of 107 ft-lb (145 Nm). Based on this information, the intake flow capacity was calculated as 135 CFM or 3,800 SLPM. This was rounded to 4,000 SLPM.

[0102] The modeling was performed with ADSIM software from Aspen Technology, Inc. (Cambridge, Massachusetts). It was assumed that a hot air stream (P = 1.7 bar, T = 90 °C, Flow = 4000 SLPM) must be cooled down to ambient for a period of 20 seconds. The adsorbent was assumed to be ETS. The heat of adsorption was estimated to be 25 kJ/mol. A sensitivity analysis on heat of adsorption showed nonlinear sensitivity. At high heat of adsorption values, the performance of the process decreases because the process becomes desorption limited. At very low heat of adsorptions, the cooling effect of the bed heat capacity is reduced because the adsorbed water content of the bed is removed too easily.

[0103] A simple two-step cycle including 200 seconds of adsorption and 20 seconds of desorption was assumed. The time interval for each step was estimated based on thermal swing magnitude, heat transfer coefficient, and process space velocity. A suitable intercooler configuration for this process likely will not be rotary, since the cycle is very simple. Instead, the batch intercooler cycle may be implemented using flapper or solenoid valves.

[0104] A structured bed bulk density of 350 g/L was assumed. The heat transfer coefficients used were the best achievable values using a metal mesh support structure. With respect to bed dimensions, a sensitivity analysis was completed on bed length. The bed length was found to be sensitive to space velocities, heat of adsorption, adsorbent capacity, shape of isotherms, process conditions, and other parameters. The bed length was highly dependent on the

duration of cooling (desorption) step. A bed length of 12 inches was found to be acceptable for a 20-second duration cooling step. The bed length was kept independent of capacity by changing the bed diameter for different applications. The estimated total structured adsorbent volume was from about 4 to about 6 L to cool down 4,000 SLPM of air to ambient in 20 seconds.

[0105] The temperature response of the bed during the desorption step exhibited a two-stage decay. FIG. 15 shows the bed profile of the modeled batch intercooler process. Trace A is the temperature of the compressed intake air at different points along the length of the adsorptive element. Trace B is the wall temperature at different points along the length of the adsorptive element. As shown in FIG. 15, the temperature of the adsorbent material and the compressed intake air lowers sharply shortly after entering the adsorptive element and then lowers more gradually until exiting the adsorptive element. By way of theory, the initial sharp decrease in temperature may be due to the cooling associated with extracting the heat of desorption of water. The more gradual decrease in temperature may then be caused by heat exchange between the hot gas and the structured adsorbent. During the adsorption step, the bed is cooled down by ambient air once the adsorption is complete. Then, during the desorption step, the hot air exchanges heat with the cold bed and cools down. The productivity of the process was about 40,000 v/v·hr. By the time the compressed intake air exits the adsorptive element its temperature has decreased to 25 °C according to the model.

[0106] Keeping the bed volume constant, shorter beds showed reduced performance because of the smaller desorption cooling heat transfer. However, longer beds were found to run into rate limitations since they have smaller diameters and higher space velocities. The bed aspect ratio was set to utilize most of the desorption cooling process. The heat exchange cooling process occurs in parallel to the desorption cooling process.

Example 2

[0107] This example describes modeling a continuous process for intercooling. Unless otherwise specified, all of the conditions assumed for the batch process also were assumed for the continuous process. The continuous process was

assumed to have a cycle speed of 20 cpm. The step sizes for adsorption and desorption were selected as 1.5 seconds. The intercooler was assumed to include two cycles with a 90° phase angle. Each cycle was assumed to include two adsorptive elements, so the machine included a total of four adsorptive elements. The preferred length of the adsorptive elements was shorter than in the batch process, but the width was increased to maintain the space velocity in a reasonable range. Each adsorptive element was assumed to be about 1.5 inches in diameter and about 6 inches in length.

[0108] FIGS. 16 and 17 show the bed profiles of the continuous process during adsorption and desorption, respectively. The desorption heat transfer profile of the adsorptive element was found to be less sharp than in the batch process. The desorption cooling process occurred over most of the bed length. The productivity of the process was as high as 90,000 v/v·hr. As shown in FIG. 17, a cold spot was formed in the bed during the adsorption step. The cold spot moved to the exit end of the bed during the desorption step reducing the temperature to sub-ambient levels. Upon exiting the desorption step, the compressed intake air had a temperature of 19 °C according to the model.

[0109] In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

We claim:

1. An intercooler system, comprising:

an intercooler comprising an adsorptive element configured to adsorb atmospheric water from a recharge stream and then to desorb atmospheric water into a compressed gas stream so as to cool the compressed gas stream, wherein the intercooler is configured to cycle flow through the adsorptive element through a cycle comprising the recharge stream and the compressed gas stream; and

a combustion device configured to receive the compressed gas stream exiting the intercooler.

2. The intercooler system according to claim 1 wherein the combustion device is an internal combustion engine.

3. The intercooler system according to claim 1 further comprising a conduit for routing ambient air into the intercooler as the recharge stream.

4. The intercooler system according to claim 1 further comprising a conduit for routing exhaust from the combustion device into the intercooler as the recharge stream.

5. The intercooler system according to claim 1 wherein the adsorptive element is substantially stationary.

6. The intercooler system according to claim 1 wherein the adsorptive element is positioned within a rotor and the intercooler is configured to cycle flow through the adsorptive element by rotating the rotor.

7. The intercooler system according to claim 1 wherein the adsorptive element is a first adsorptive element, the intercooler further comprises a second adsorptive element, and the intercooler is configured to cycle flow through the second adsorptive element such that at a first time, the first adsorptive element

receives the recharge stream and the second adsorptive element receives the compressed gas stream and at a second time, the second adsorptive element receives the recharge stream and the first adsorptive element receives the compressed gas stream.

8. The intercooler system according to claim 1 configured to substantially-continuously cool the compressed gas stream.

9. The intercooler system according to claim 1 configured to intermittently cool the compressed gas stream.

10. The intercooler system according to claim 1 wherein the intercooler increases the fuel economy of the combustion device by a percentage from about 5% to about 17%.

11. The intercooler system according to claim 1 wherein the intercooler increases the power of the combustion device by a percentage from about 40% to about 105%.

12. The intercooler system according to claim 1 wherein the intercooler decreases NO_x emissions from the combustion device by a percentage from about 30% to about 70%.

13. The intercooler system according to claim 1 wherein the adsorptive element comprises alumina, silica, a molecular sieve or a combination or derivative thereof.

14. The intercooler system according to claim 1 wherein the adsorptive element comprises an aluminum-silicate molecular sieve, a titanium-silicate molecular sieve or a combination or derivative thereof.

15. The intercooler system according to claim 1 wherein the adsorptive element comprises synthetic zeolite Y with a calcium counter ion or derivative thereof.

16. The intercooler system according to claim 1 wherein the adsorptive element comprises an adsorbent material capable of reversibly adsorbing from about 20% to about 50% of its weight in water at about ambient temperature, about ambient pressure and a relative humidity of about 80%.

17. The intercooler system according to claim 1 wherein the adsorptive element comprises an adsorbent material capable of reversibly adsorbing from about 15% to about 50% of its weight in water at about ambient temperature, about ambient pressure and a relative humidity of about 10%.

18. The intercooler system according to claim 1 wherein the adsorptive element is a first adsorptive element, and the intercooler further comprises a second adsorptive element and a reflux channel for equilibrating the pressure in the first adsorptive element and the second adsorptive element as the first adsorptive element and the second adsorptive element transition between adsorbing atmospheric water from the recharge stream and desorbing atmospheric water into the compressed gas stream.

19. The intercooler system according to claim 1 wherein the adsorptive element comprises a laminate comprising an adsorbent material and a support material.

20. The intercooler system according to claim 19 wherein the support material comprises fiberglass, ceramic fibers, a metallic woven wire mesh, expanded metal, embossed metal or a derivative or combination thereof.

21. The intercooler system according to claim 19 wherein the support material has a thermal conductivity at room temperature from about 20 to about 1000 W/(m·°C).

22. The intercooler system according to claim 19 wherein the specific surface area of the support material within the adsorptive element is from about 5,000 to about 30,000 m^2/m^3.

23. The intercooler system according to claim 1 wherein the adsorptive element comprises multiple layers of laminate separated by spacers.

24. The intercooler system according to claim 23 wherein the spacers have a thermal conductivity at room temperature from about 20 to about 1000 W/(m·°C).

25. The intercooler system according to claim 23 wherein gas flow channels are formed between the multiple layers of laminate and at least a portion of the multiple layers of laminate comprise ventilation apertures to allow gas flow from one gas flow channel to an adjacent gas flow channel.

26. The intercooler system according to claim 1 further comprising a liquid-injection device for wetting an adsorbent material within the adsorptive element.

27. The intercooler system according to claim 26 wherein the liquid-injection device is configured to wet the adsorbent material with air-conditioning condensate.

28. The intercooler system according to claim 1 further comprising a compressor for generating the compressed gas stream.

29. The intercooler system according to claim 28 wherein the compressor is a supercharger or a turbocharger.

30. A vehicle comprising the intercooler system according to claim 1.

31. An intercooler, comprising:

means for extracting heat energy from a compressed intake air flow to a combustion device by desorption of water from an adsorbent material within the compressed intake air flow; and

means for recharging the adsorbent material.

32. A system that increases the fuel economy of a combustion device by a percentage from about 5% to about 17%, comprising:

a compressor for generating a compressed gas stream; and

an intercooler comprising an adsorptive element configured to cool the compressed gas stream.

33. A system that increases the power of a combustion device by a percentage from about 40% to about 105%, comprising:

a compressor for generating a compressed gas stream; and

an intercooler comprising an adsorptive element configured to cool the compressed gas stream.

34. A system that decreases NO_x emissions from a combustion device by a percentage from about 30% to about 70%, comprising:

a compressor for generating a compressed gas stream; and

an intercooler comprising an adsorptive element configured to cool the compressed gas stream.

35. An intercooling method, comprising:

cooling a compressed gas stream by flowing the compressed gas stream through an adsorptive element such that atmospheric water is desorbed into the compressed gas stream; and

routing the compressed gas stream exiting the adsorptive element to a combustion device.

36. The intercooling method according to claim 35 further comprising generating the compressed gas stream with a supercharger or a turbocharger.

37. The intercooling method according to claim 35 wherein the combustion device is an internal combustion engine.

38. The intercooling method according to claim 35 wherein cooling the compressed gas stream comprises substantially-continuously cooling the compressed gas stream.

39. The intercooling method according to claim 35 wherein cooling the compressed gas stream comprises intermittently cooling the compressed gas stream.

40. The intercooling method according to claim 35 wherein cooling the compressed gas stream increases the fuel economy of the combustion device by a percentage from about 5% to about 17%.

41. The intercooling method according to claim 35 wherein cooling the compressed gas stream increases the power of the combustion device by a percentage from about 40% to about 105%.

42. The intercooling method according to claim 35 wherein cooling the compressed gas stream decreases NO_x emissions from the combustion device by a percentage from about 30% to about 70%.

43. The intercooling method according to claim 35 wherein cooling the compressed gas stream comprises cooling the compressed gas stream to a temperature lower than the temperature of the ambient environment.

44. The intercooling method according to claim 35 wherein the compressed gas stream is at a first temperature when it enters the adsorptive element and at a second temperature when it exits the adsorptive element and the first temperature is from about 40 °C to about 120 °C greater than the second temperature.

45. The intercooling method according to claim 44 wherein the adsorptive element is positioned within a rotor and cycling flow through the adsorptive element comprises rotating the rotor.

46. The intercooling method according to claim 44 wherein the adsorptive element is substantially stationary.

47. The intercooling method according to claim 35 further comprising recharging the adsorptive element by flowing a recharge stream through the adsorptive element, such that the adsorptive element adsorbs atmospheric water from the recharge stream.

48. The intercooling method according to claim 47 wherein the recharge stream comprises ambient air.

49. The intercooling method according to claim 47 wherein the recharge stream comprises exhaust from the combustion device.

50. The intercooling method according to claim 47 wherein the recharge stream is at substantially the same temperature as the ambient environment when it enters the adsorptive element.

51. The intercooling method according to claim 47 further comprising cycling flow through the adsorptive element through a cycle comprising the recharge stream and the compressed gas stream.

52. The intercooling method according to claim 51 wherein the adsorptive element is a first adsorptive element within an intercooler, the intercooler further comprises a second adsorptive element, and the method further comprises cycling flow through the second adsorptive element such that at a first time, the first adsorptive element receives the recharge stream and the second adsorptive element receives the compressed gas stream and at a second time, the second adsorptive element receives the recharge stream and the first adsorptive element receives the compressed gas stream.

53. The intercooler method according to claim 51 wherein the adsorptive element is a first adsorptive element within an intercooler, the intercooler further comprises a second adsorptive element, and the method further comprises equilibrating the pressure in the first adsorptive element and the second adsorptive element as the first adsorptive element and the second adsorptive element transition between adsorbing atmospheric water from the recharge stream and desorbing atmospheric water into the compressed gas stream.

54. The intercooling method according to claim 47 further comprising cooling the adsorptive element after or while the adsorptive element adsorbs atmospheric water from the recharge stream.

55. The intercooling method according to claim 54 wherein cooling the adsorptive element comprises flowing the recharge stream through the adsorptive element after the adsorptive element is fully loaded with water.

56. The intercooling method according to claim 47 further comprising introducing water other than atmospheric water into the adsorptive element.

57. The intercooling method according to claim 56 wherein the water other than atmospheric water is air-conditioning condensate.

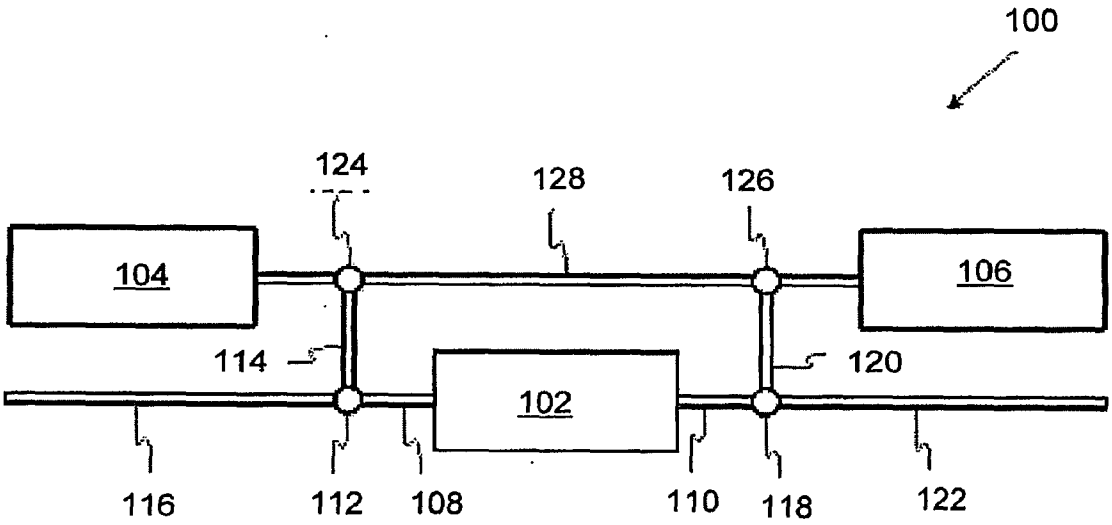

100
124
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118
122

FIG. 1

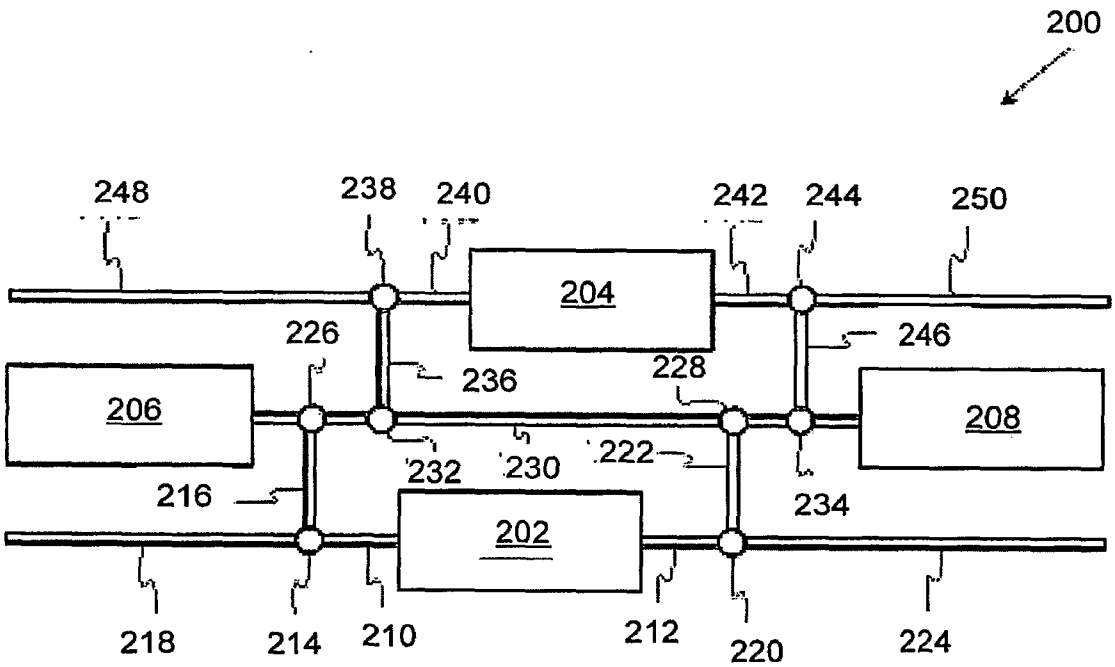

200
248
238
240
242
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250
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222
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212
220
224

FIG. 2

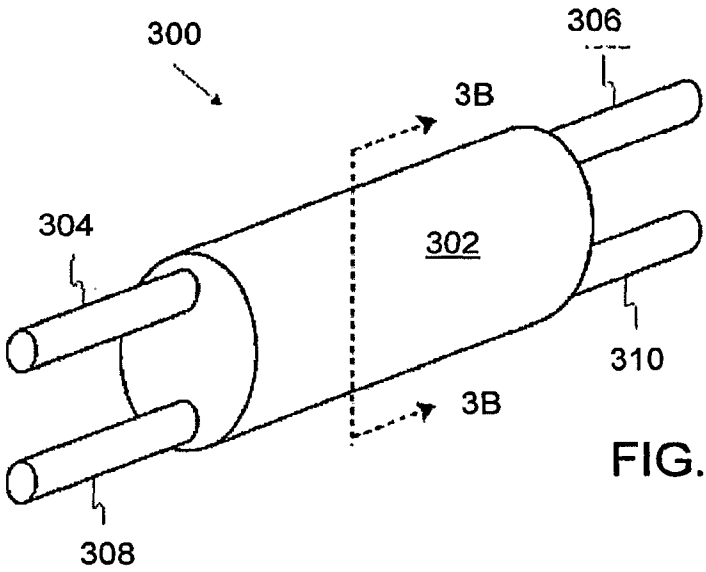


FIG. 3A

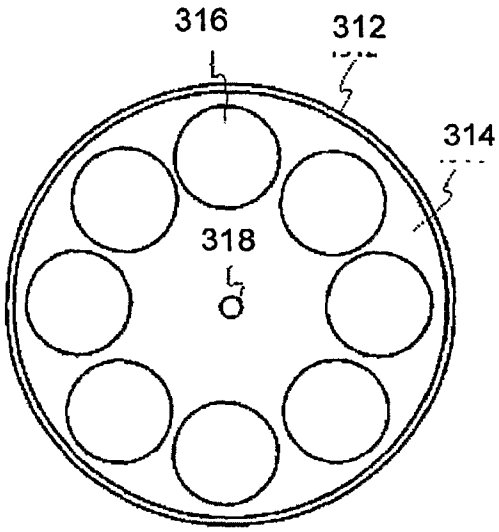


FIG. 3B

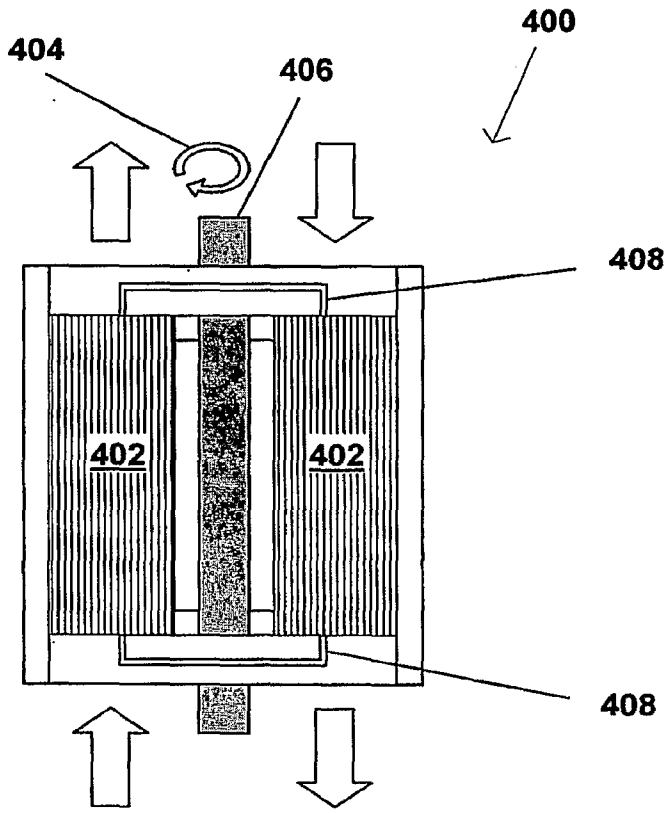


FIG. 4

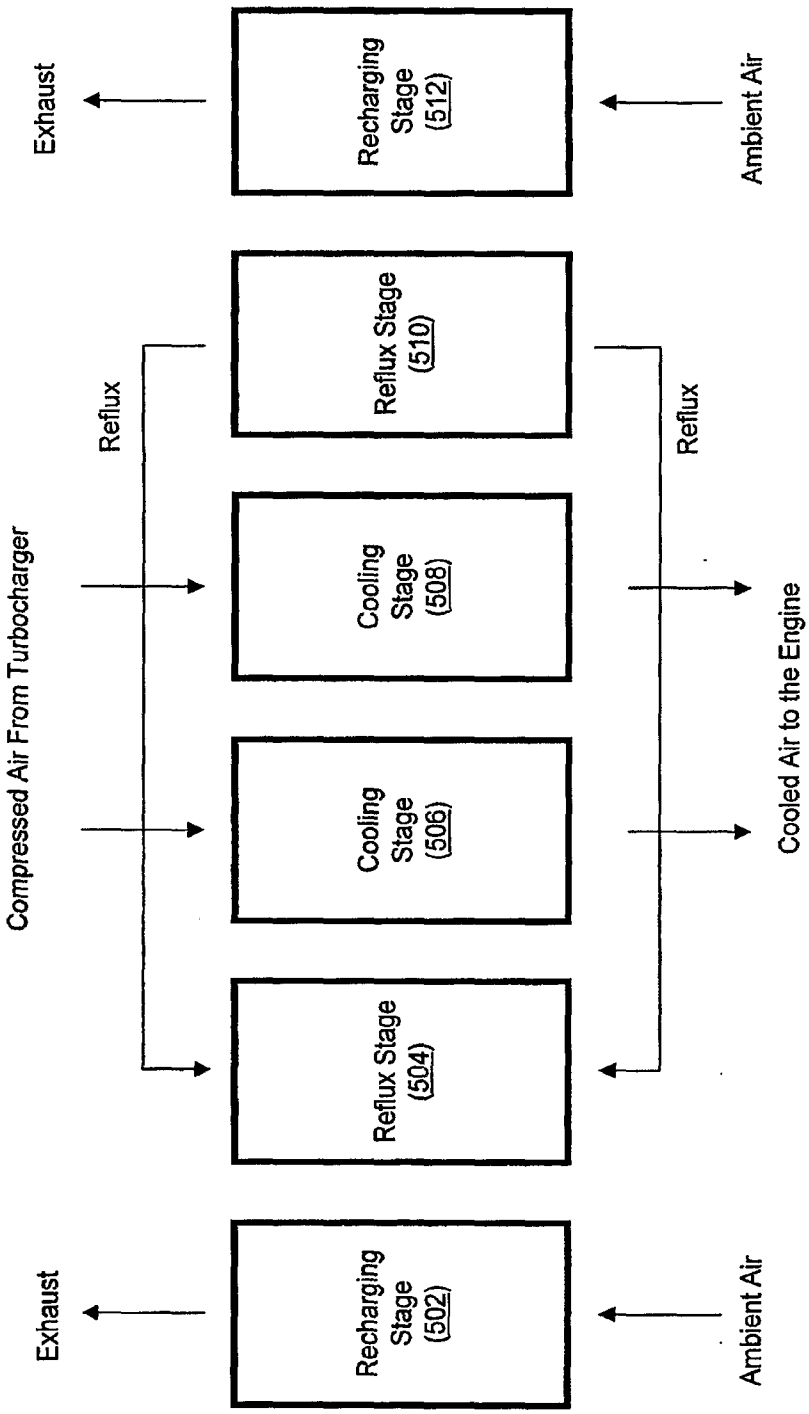

Exhaust
Recharging Stage (512)
Ambient Air
Reflux
Reflux Stage (510)
Reflux
Compressed Air From Turbocharger
Cooling Stage (508)
Cooling Stage (506)
Cooled Air to the Engine
Reflux Stage (504)
Exhaust
Recharging Stage (502)
Ambient Air
500

FIG. 5

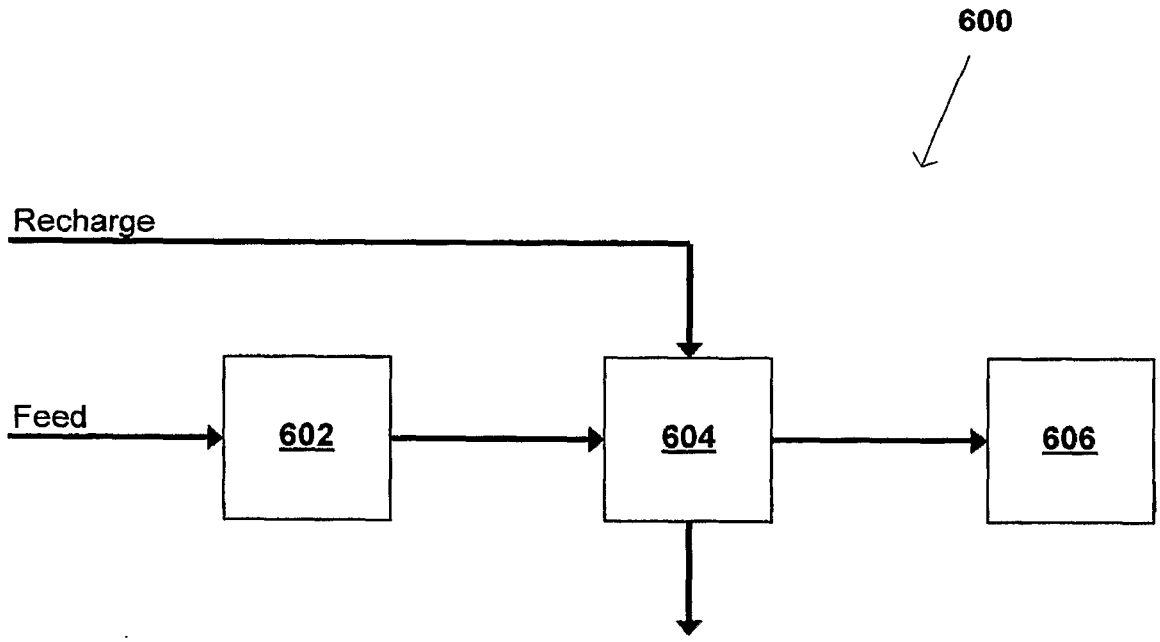


FIG. 6

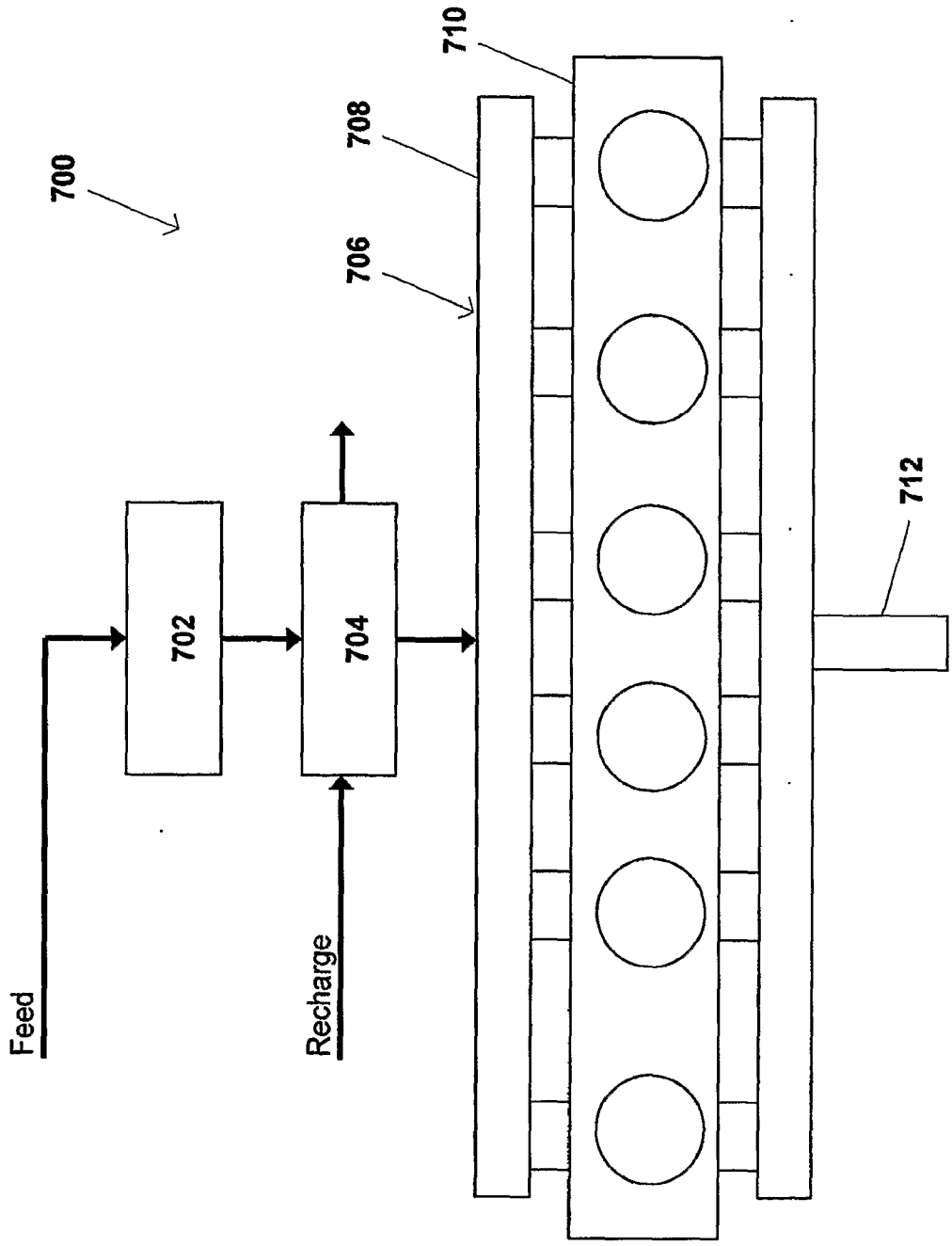


FIG. 7

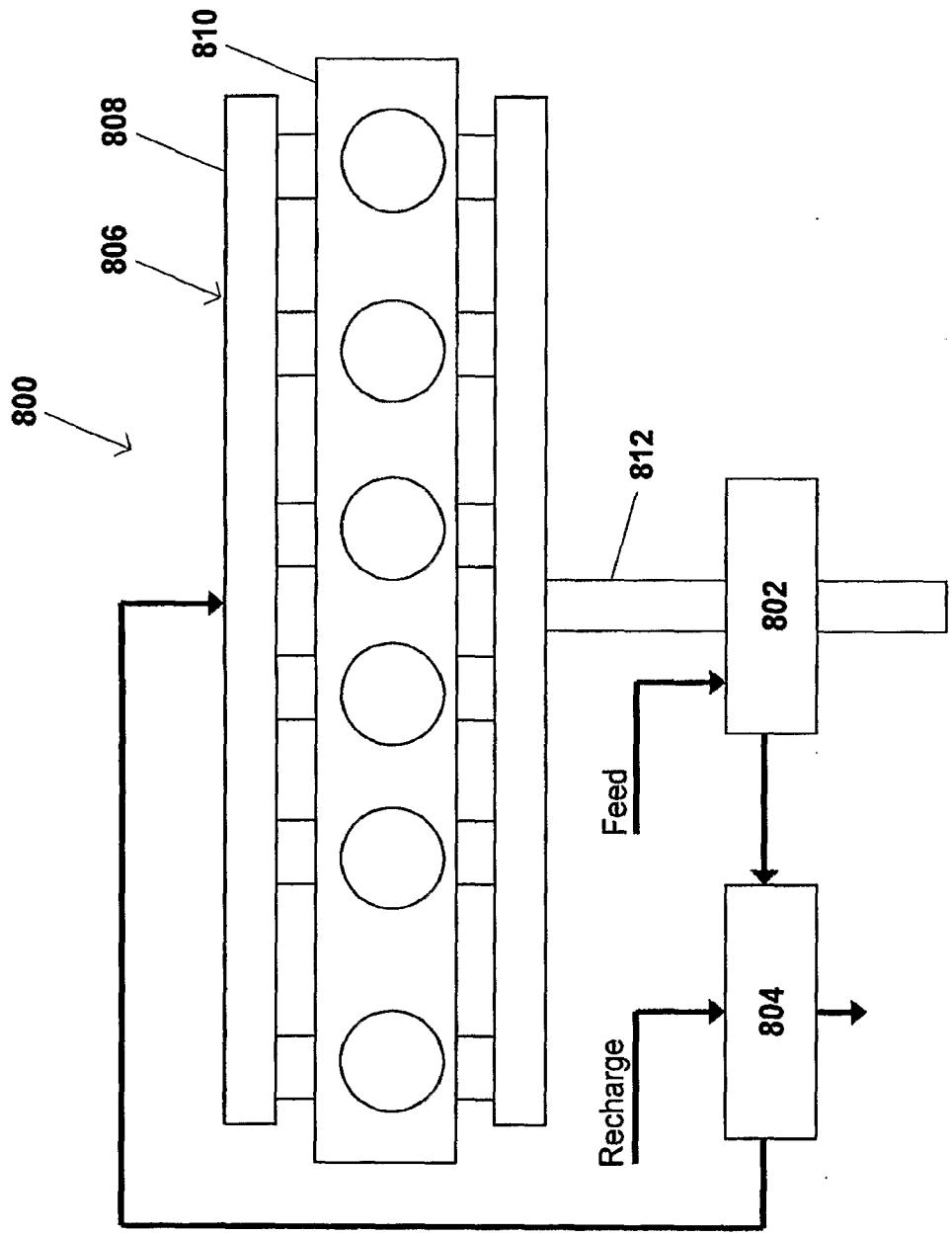


FIG. 8

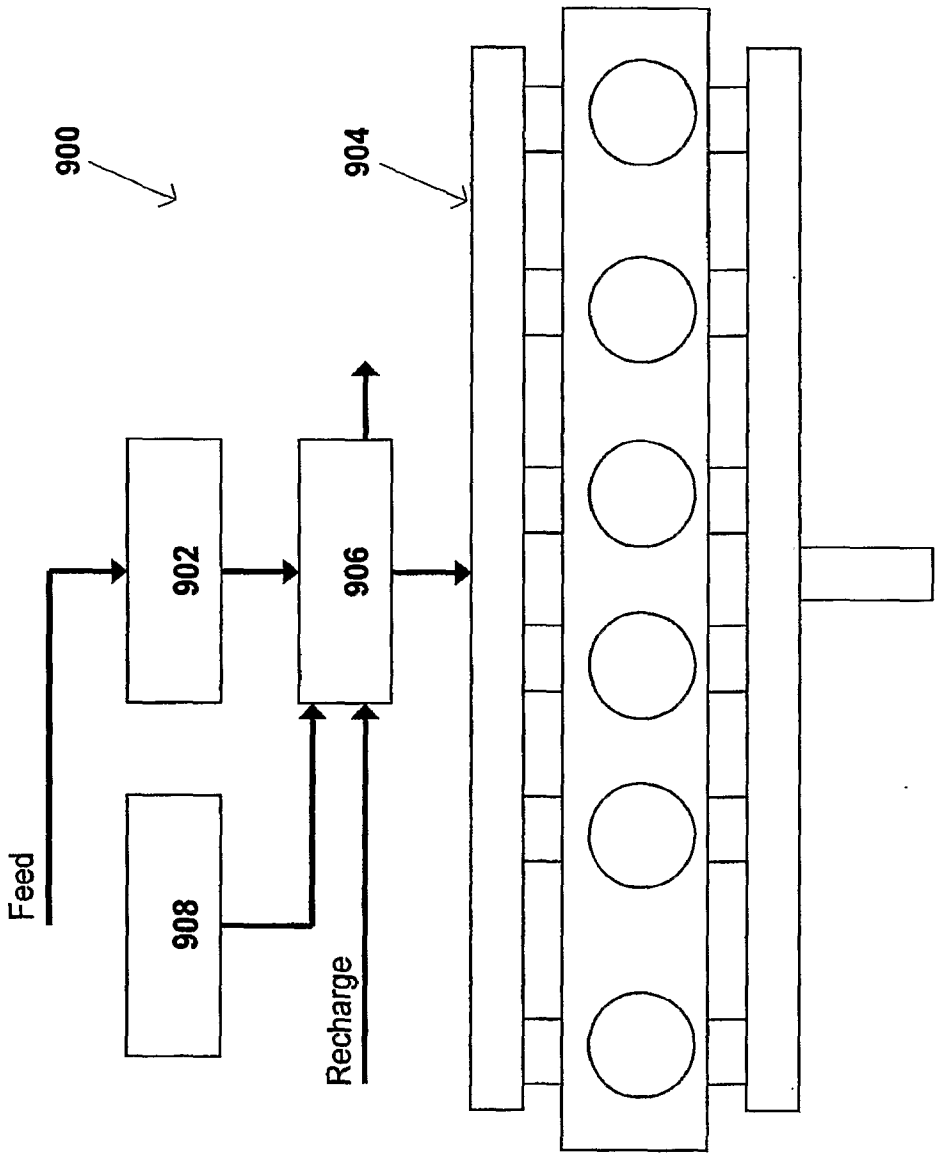


FIG. 9

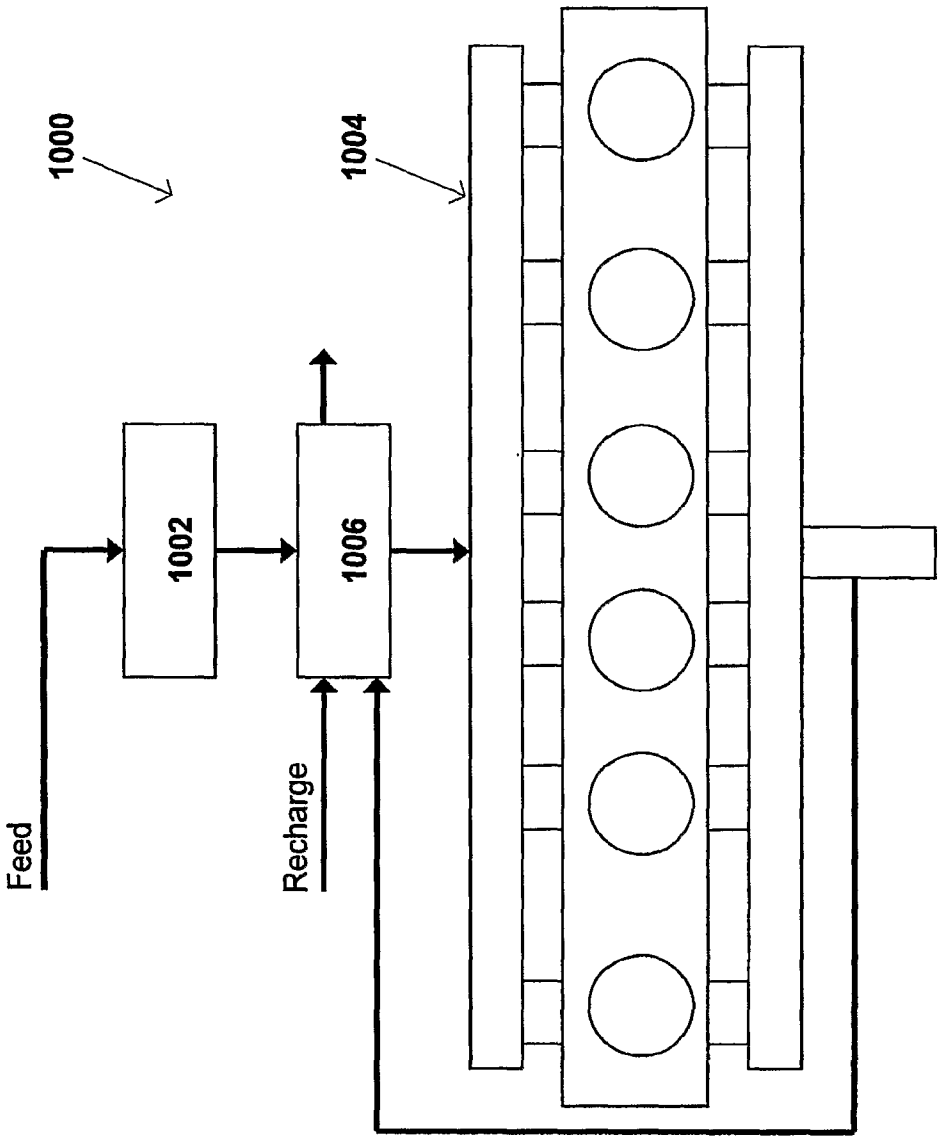


FIG. 10

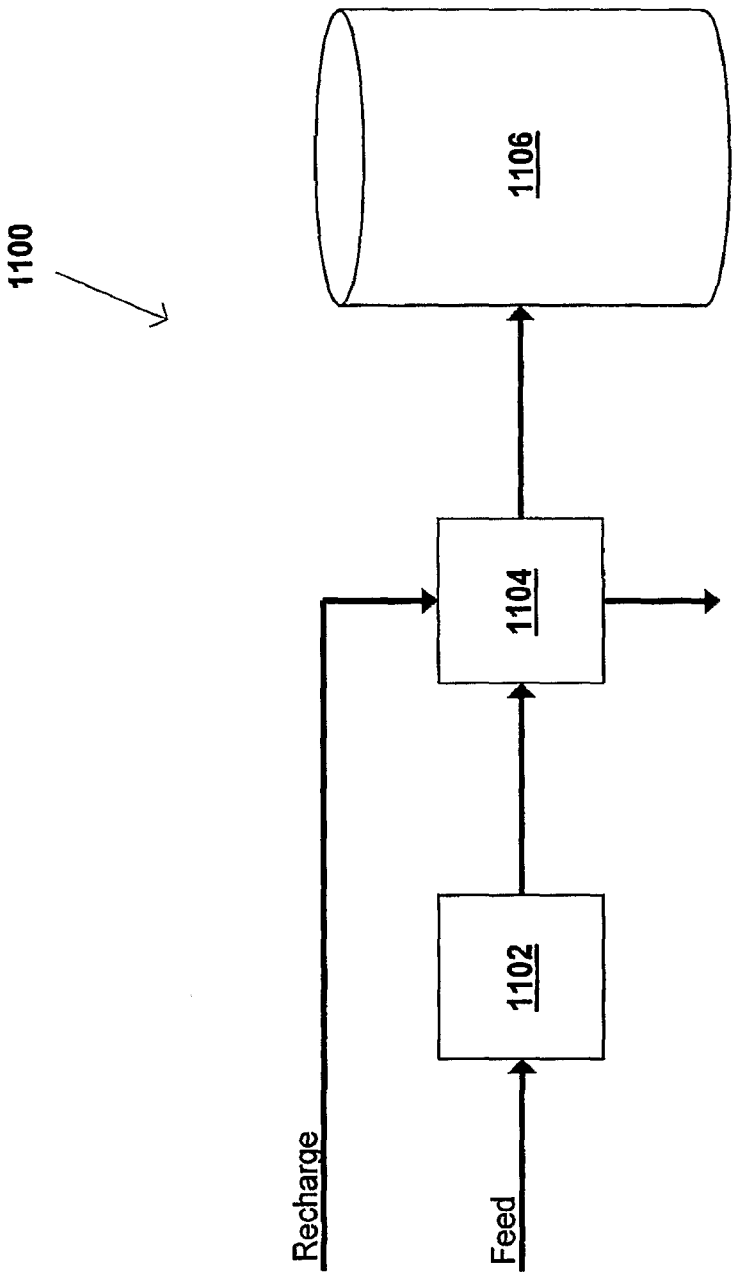


FIG. 11

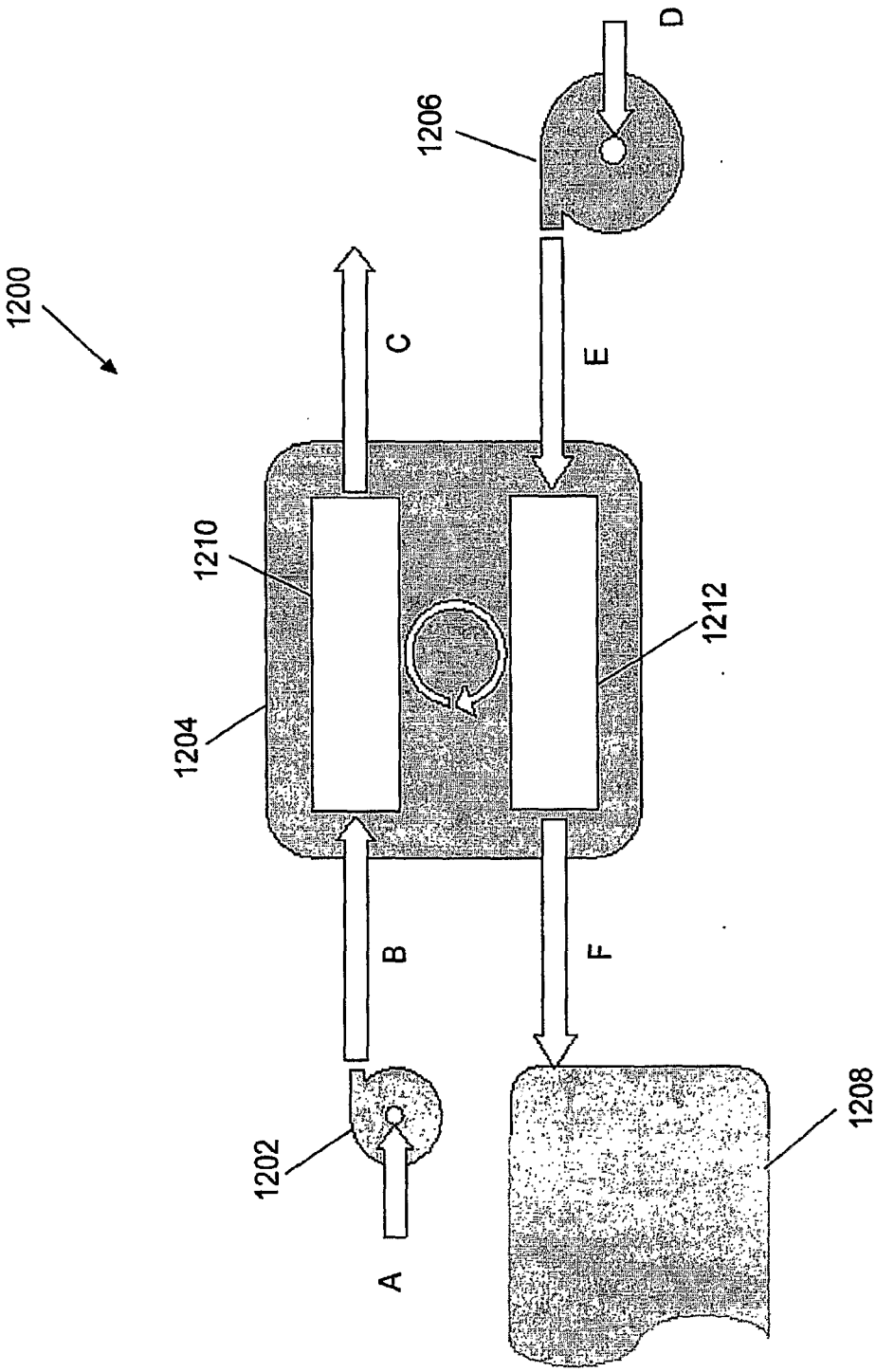


FIG. 12

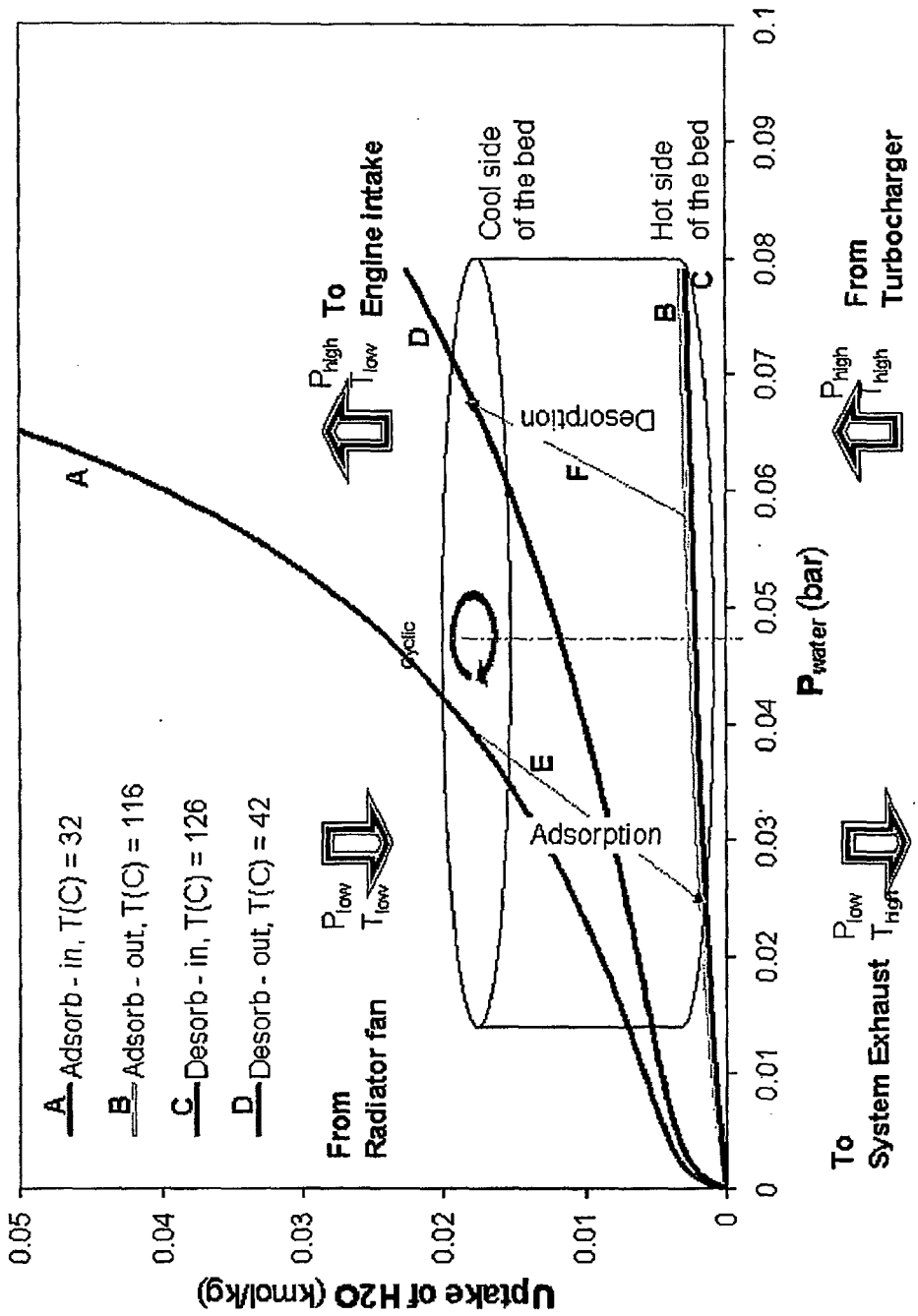

Uptake of H2O (kmol/kg)
0.05
0.04
0.03
0.02
0.01
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
P_{water} (bar)
A Adsorb - in, T(C) = 32
B Adsorb - out, T(C) = 116
C Desorb - in, T(C) = 126
D Desorb - out, T(C) = 42
From Radiator fan
P_{low} T_{low}
To System Exhaust
P_{low} T_{high}
P_{high} T_{low} To Engine intake
P_{high} T_{high} From Turbocharger
Cool side of the bed
Hot side of the bed
Adsorption
Desorption
cyclic
A
B
C
D
E
F

FIG. 13

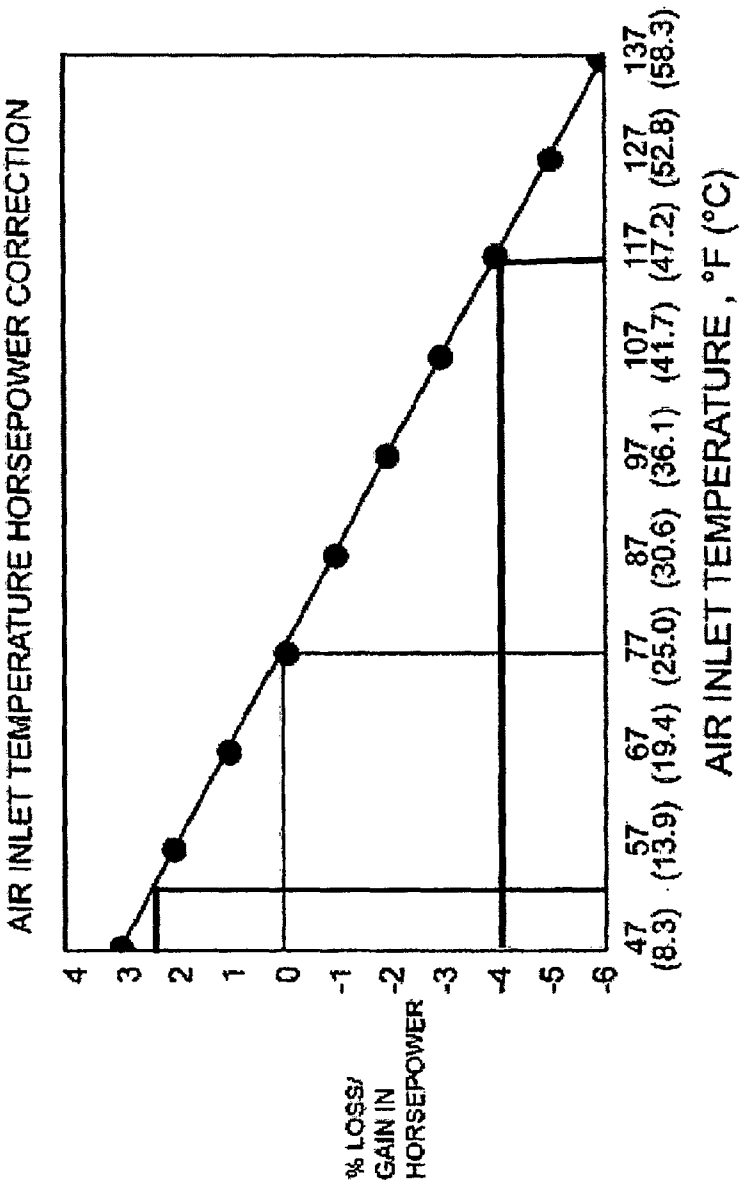

AIR INLET TEMPERATURE HORSEPOWER CORRECTION
% LOSS/ GAIN IN HORSEPOWER
4
3
2
1
0
-1
-2
-3
-4
-5
-6
47 (8.3)
57 (13.9)
67 (19.4)
77 (25.0)
87 (30.6)
97 (36.1)
107 (41.7)
117 (47.2)
127 (52.8)
137 (58.3)
AIR INLET TEMPERATURE , °F (°C)

FIG. 14

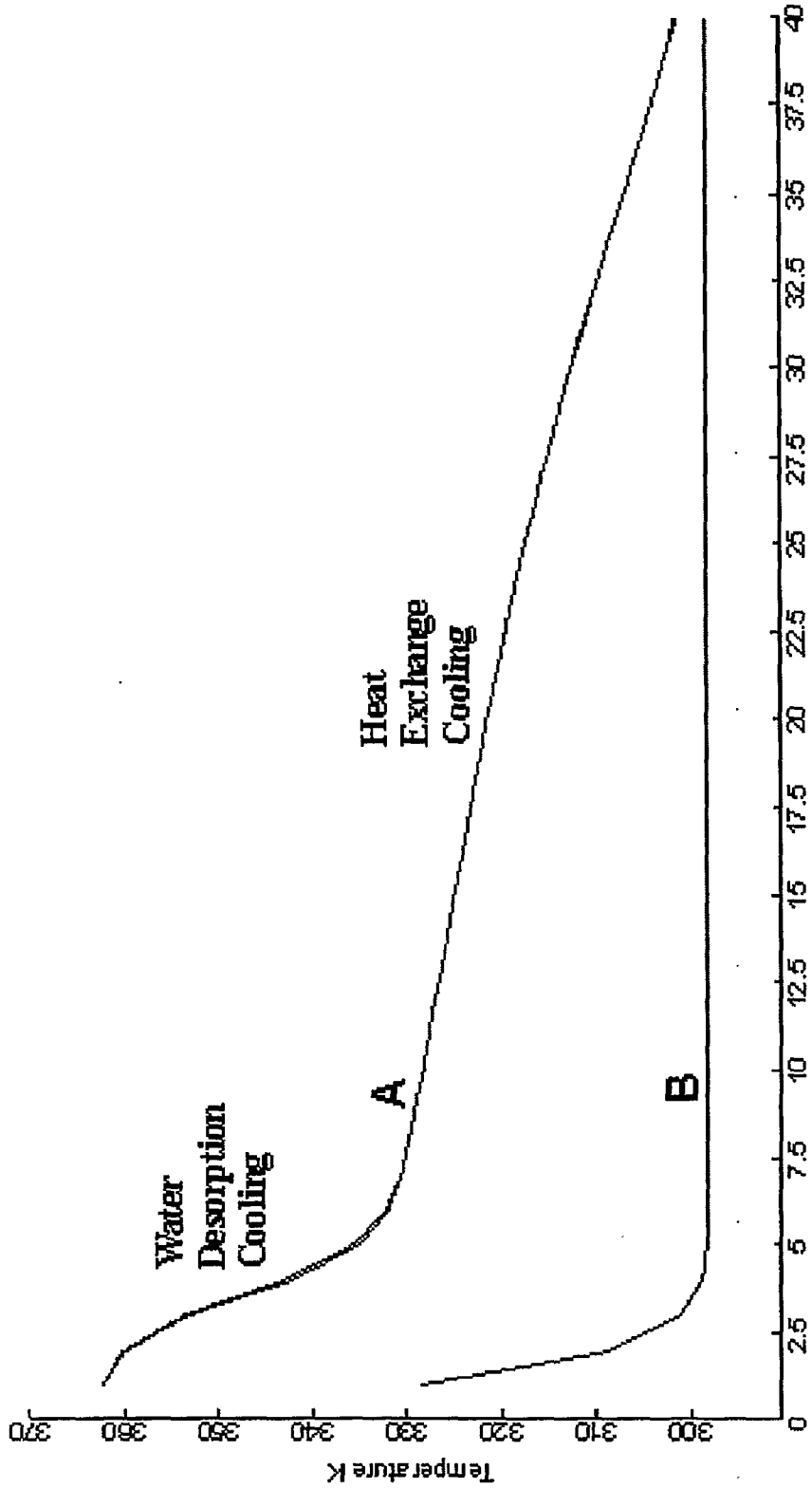

Water
Desorption
Cooling
A
Heat
Exchange
Cooling
B
Temperature K
300
310
320
330
340
350
360
370
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
27.5
30
32.5
35
37.5
40
Index

FIG. 15

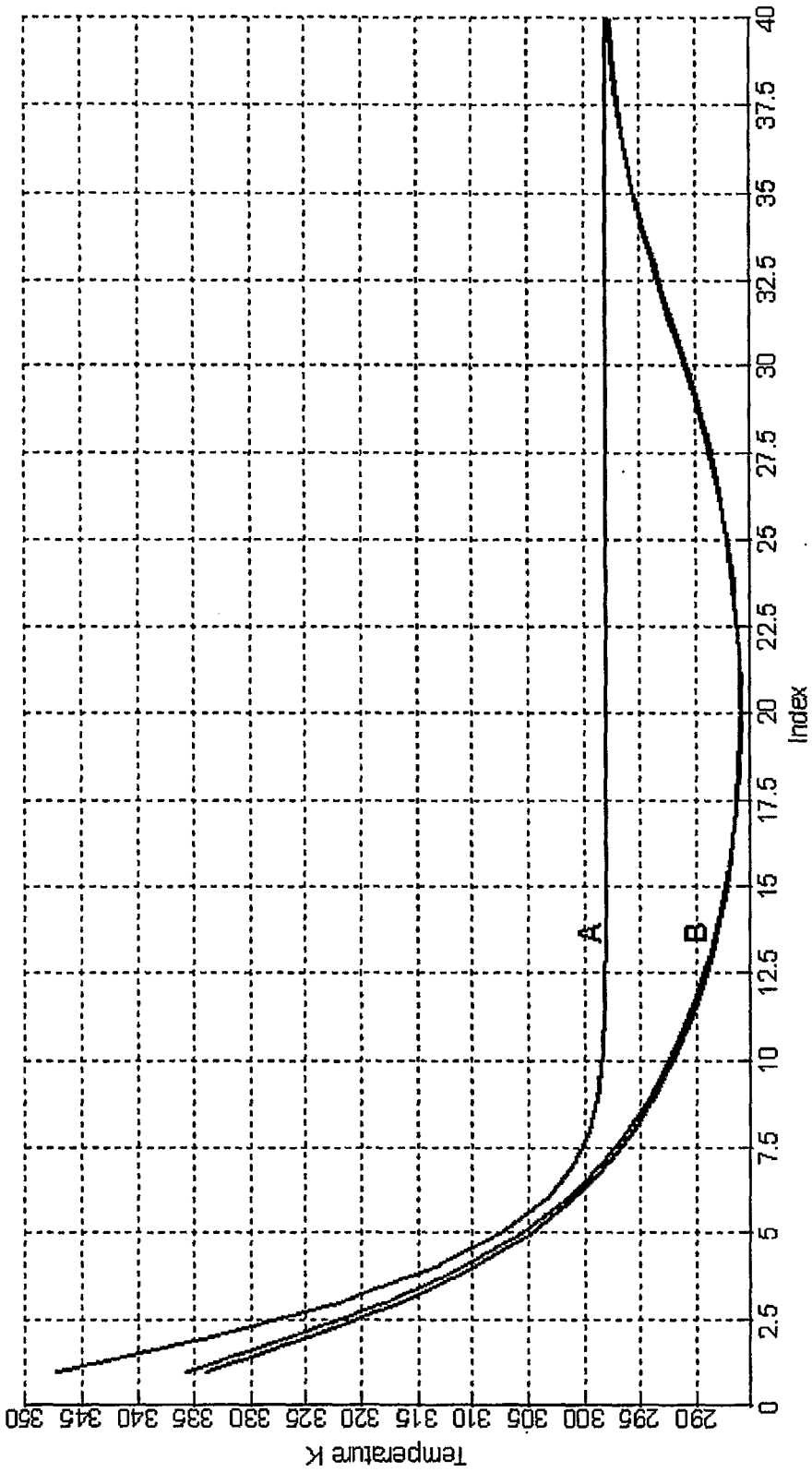

Temperature K
290 295 300 305 310 315 320 325 330 335 340 345 350
Index
0 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5 35 37.5 40
A
B

FIG. 16

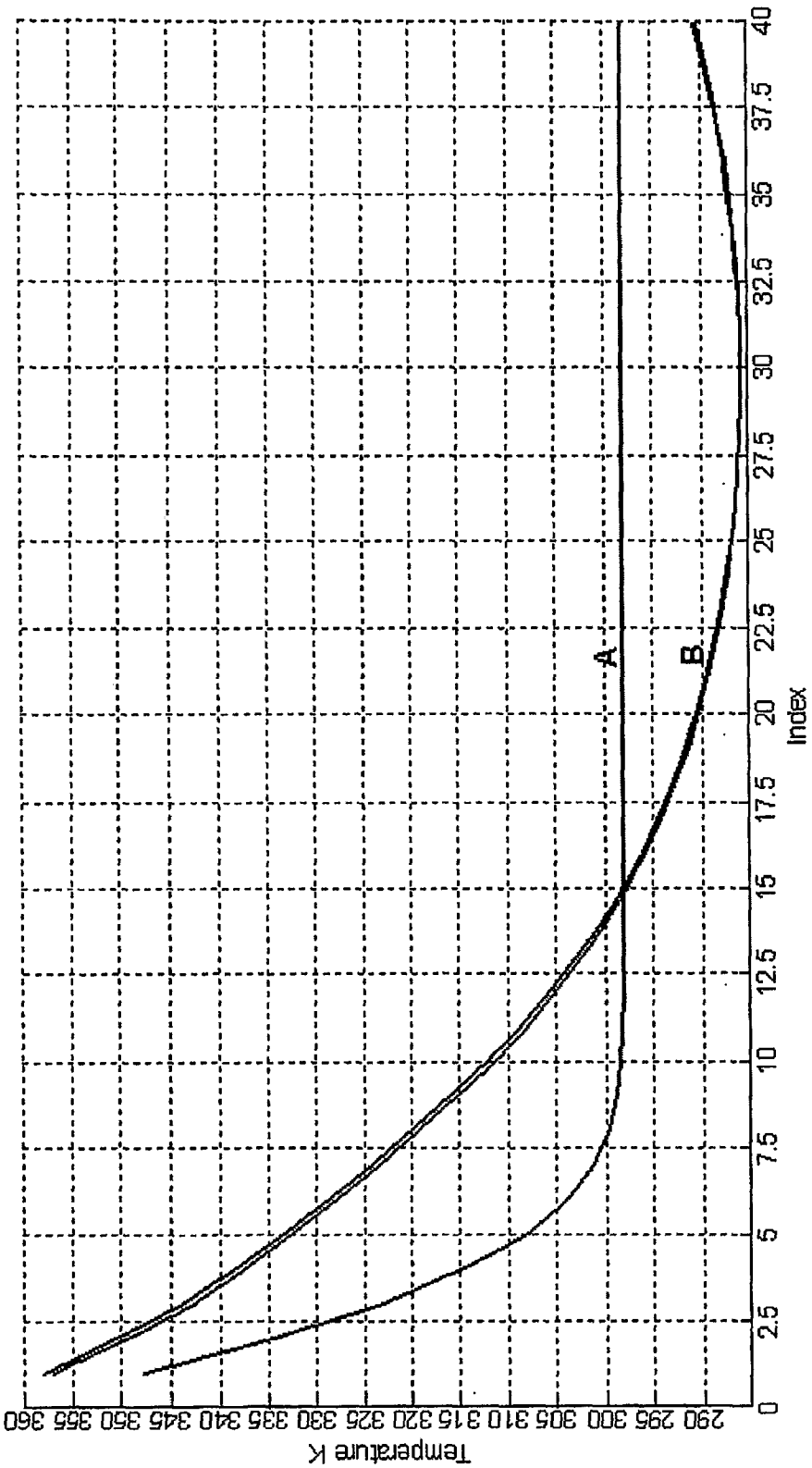

Temperature K
290 295 300 305 310 315 320 325 330 335 340 345 350 355 360
Index
0 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5 35 37.5 40
A
B

FIG. 17

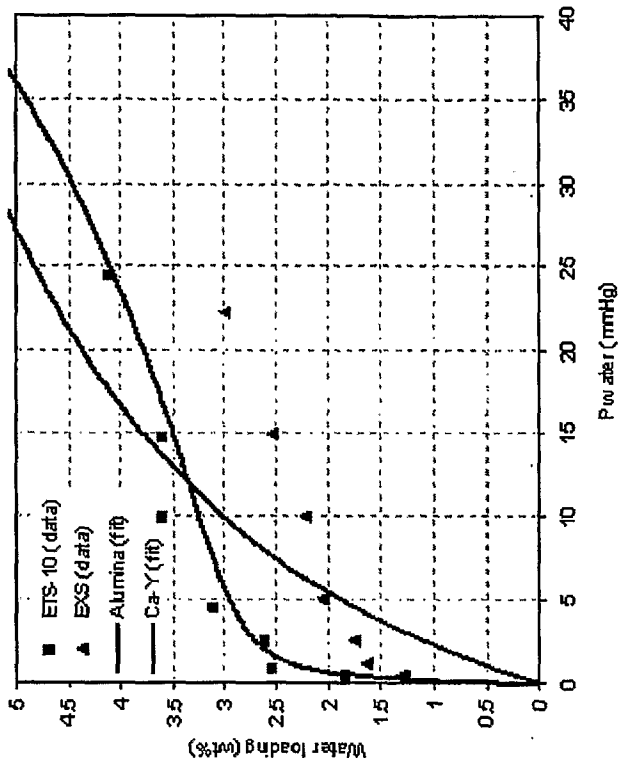


FIG. 18B

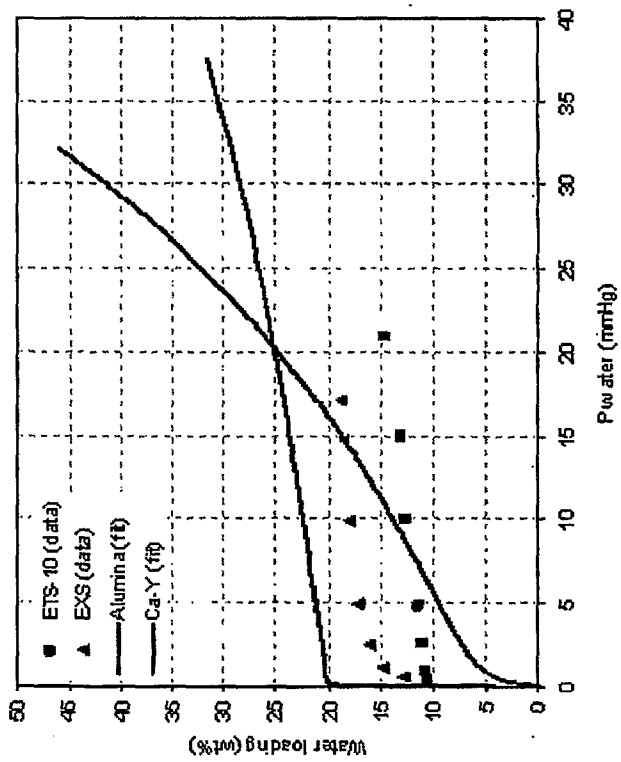


FIG. 18A

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/008643

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02B29/04 F02M25/028

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)
F02B F02M

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/016193 A1 (TARASINSKI NICOLAI [DE] ET AL) 27 January 2005 (2005-01-27) paragraphs [0017], [0033]	31
A		1-9, 13-30, 35-39, 43-57
A	US 6 352 068 B1 (JACOBSEN ARTHUR J [US]) 5 March 2002 (2002-03-05) abstract	1-9, 13-31, 35-39, 43-57

-/--

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

[X] 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 document 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	Date of mailing of the international search report
29 August 2007	05/09/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Yates, John

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/008643

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 141 293 A (CROOKS WILLIAM R) 21 July 1964 (1964-07-21) column 1, line 42 - line 46	1-9, 13-31, 35-39, 43-57
A	EP 0 081 716 A (DIAVIA SPA [IT]) 22 June 1983 (1983-06-22) abstract	1-9, 13-31, 35-39, 43-57
A	US 5 809 981 A (BERG-SONNE PETER [DK]) 22 September 1998 (1998-09-22) column 6, line 19 - line 55	1-9, 13-31, 35-39, 43-57
A	DE 199 18 591 A1 (FEV MOTORENTECH GMBH [DE]) 26 October 2000 (2000-10-26) abstract	1-9, 13-31, 35-39, 43-57
A	WO 03/001046 A (ALSTOM SWITZERLAND LTD [CH]; FRUTSCHI HANS ULRICH [CH]) 3 January 2003 (2003-01-03) abstract	1-9, 13-31, 35-39, 43-57
A	GB 1 496 548 A (BROWN TRACTORS LTD) 30 December 1977 (1977-12-30) page 2, line 16 - line 21	1-9, 13-31, 35-39, 43-57

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/008643

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 10-12,32-34,40-42
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 10-12,32-34,40-42

The non-searched claims claim a result to be achieved, rather then concrete technical features which would allow a meaningful search. The concrete techincal features which would lead to the result will presumably be in the other claims which have been included in the search.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.5), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2007/008643

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