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(54) Apparatus and method for treating gas to be delivered to a combustion process in an internal combustion engine

(57) The invention relates to an Apparatus for treating gas to be delivered to a combustion process in an internal combustion engine comprises a canister (16) having an inlet (18) for introducing gas (12), an outlet (20) for allowing gas (14) to flow out, a permeable zeolite based charge (22) arranged between the inlet and the outlet and being able to absorb and desorb water. The apparatus further comprises a first temperature sensor (24) arranged in thermal contact with the zeolite based charge, a second temperature sensor (26) that is arranged upstream of the canister, and a control unit (28) that is adapted to determine whether the charge is in an absorbing state, a desorbing state or in a transition state between the absorbing state and the desorbing state, based on signals of the first temperature sensor and the second temperature sensor, and to control an amount of recirculated exhaust gas based on the determined state. Further disclosed is a method utilizing said apparatus

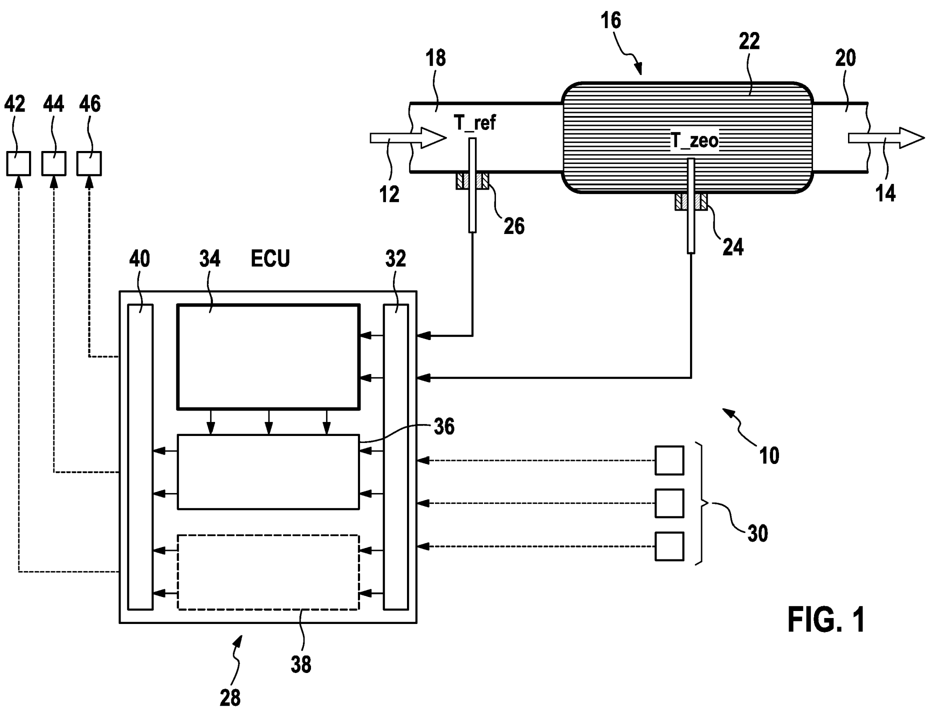

FIG. 1

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Description

Prior Art

[0001] The present invention relates to an apparatus for treating gas to be delivered to a combustion process in an internal combustion engine according to the preamble of claim 1 and to a respective method according to the independent method claim.

[0002] Such an apparatus comprises a canister having an inlet for introducing gas into the canister, an outlet for allowing gas to flow out of the canister and a permeable zeolite based charge arranged between the inlet and the outlet and being able to absorb and desorb water. The method comprises piping gas through such a canister. Zeolites are microporous aluminosilicate minerals commonly used in a wide range of applications because of the high adsorbent capacity for water and because of low production costs.

[0003] Such an apparatus and such a method are known from the document JP 2006-226149A. This document shows an exhaust gas recirculation system having such a canister arranged between the exhaust line and a pump in an exhaust gas recirculation line. The canister serves for separating steam from other exhaust gas constituents. In one embodiment, only the steam is transmitted to the intake side of the engine.

[0004] The characterizing features of both the independent apparatus claim and the independent method claim distinguish the present invention over the prior art mentioned at the outset.

[0005] In addition to the features mentioned at the outset, the apparatus according to the present invention further comprises a first temperature sensor arranged in thermal contact with the zeolite based charge, a means for providing a temperature at the canister inlet, and a control unit that is adapted to determine whether the charge is in an absorbing state, in a desorbing state or in a transition state between the absorbing state and the desorbing state, based on signals of the first temperature sensor and the means for providing a temperature at the canister inlet, and which control unit is further adapted to control an amount of recirculated exhaust gas based on the determined state.

[0006] Accordingly, the method of the present invention further comprises determining whether the charge is in an absorbing state, in a desorbing state or in a transition state between the absorbing state and the desorbing state, and controlling an amount of recirculated exhaust gas based on the determined state, wherein the step of determining is based on evaluating signals of a first temperature sensor and a means for providing a temperature at the canister inlet, the first temperature sensor being arranged in thermal contact with the zeolite based charge.

[0007] The present invention is of particular advantage in so called low pressure exhaust gas recirculation systems (LP-EGR). By using this terminology, different EGR-systems used with turbocharged internal combustion engines are distinguished from each other. Exhaust gas recirculation is, in general, a well known emission control technology that provides a significant NOx-emission reduction of internal combustion engines for automotive application, in particular for Diesel engines and for other lean burn engines. Commonly used is a so called high pressure EGR (HP-EGR), where the exhaust gas is taken from a position upstream of the turbine, cooled down and mixed with compressed air downstream the compressor of the turbocharger.

[0008] With a LP-EGR, the exhaust gas to be recirculated is drawn downstream of the turbine and exhaust gas treatment devices such as an oxidation catalyst and/or a particulate filter and/or a NOx-storage catalyst, cooled down and then introduced into the intake air upstream the compressor. LP-EGR is preferred over a standalone HP-EGR because of a higher NOx-reduction capability, lower temperatures of the recirculated gas, a lesser particulate content and a higher potential of enthalpy recovery via the turbocharger. LP-EGR may be used in combination with HP-EGR.

[0009] However, an unwanted side effect of using high LP-EGR ratios, i.e. a high content of recirculated exhaust gas in a combustion chamber charge, is a significant introduction of water vapor from the exhaust system to the air system. The exhaust gas contains water vapor since water is one of the end products of the combustion. This side effect strongly increases the absolute humidity of the gas mixture in the engine air system, which may lead to water condensation on piping surfaces, heat exchanger fins and the like in the air system. Such condensed water may be siphoned into the combustion chamber, where it may lead to engine failure due to overpressure in said chamber. Further, such liquid water may impact on the compressor impeller, causing pitting, corrosion etc.

[0010] Accordingly, the safe operation of the engine during all driving conditions requires an LP-EGR ratio limitation in operating points where a condensation may occur. Said limitation strongly depends on environmental conditions such as ambient temperature, humidity and altitude. Further, said limitation strongly depends on engine and EGR-system operating conditions such as piping wall temperature, gas temperature, boost pressure and the like, and the driving profile. The engine and LP-EGR/air system control unit (ECU) has to be programmed to execute algorithms to estimate condensation and react with proper limitation to LP-EGR-ratio. This limitation applies mainly to cold environmental conditions, engine heat-up after cold start and warm engine conditions with high boost pressure. As a result, the theoretical NOx-reduction potential of LP-EGR in the cold start homologation cycles and real world driving profiles is strongly decreased.

[0011] By determining whether the zeolite charge is in an absorbing state, a desorbing state or in a transition state between the absorbing state and the desorbing state, the present invention allows to determine more precisely whether there is a risk of condensed water in the air system. For instance, the risk is smaller in situations where the Zeolite hydrates, i.e. absorbs water from the gas flowing through the zeolite. Accordingly, the limitations on the EGR, in particular limitations on the LP-EGR may be lowered or relaxed in such situations. The present invention allows controlling the amount or the load of water in the air system for internal combustion engines, in particular for Diesel engines, in particular for Diesel engines equipped with an LP-EGR-system. Thereby, an extended use of LP-EGR is possible by fine monitoring the presence and/or risk of condensing water in the air system, which extended use leads inherently to a further reduction of NOx-emissions.

[0012] A side effect of the adsorption of water (hydrating) and the desorption of water (dehydrating) by zeolites is a strong energy exchange. Zeolite structure hydration is exothermic and vice-versa, water release from the zeolite is coupled with an inherent endothermia. Although this phenomenon is as such known, said exothermia / endothermia have not been utilized in the field of engines. This applies in particular in the field of EGR and even more particular, in the field of LP-EGR.

[0013] By using the temperature sensors for sensing the exothermia and/or endothermia of the Zeolite, the state of the zeolite can be sensed with simple means that are robust enough for an automotive use. The combination of said exothermia and/or endothermia with the temperature sensors provides feedback and information about water load in the air system, which allows safe and rational use of EGR, in particular of LP-EGR, in all vehicle operating conditions.

[0014] Zeolite exothermia induced by dew formation in cold engine conditions helps to heat up the intake air rapidly, which reduces the HC and CO emissions during warm up.

[0015] Endothermia, during zeolite desorption phases, e.g. during warm engine operation and low boost pressure helps to cool intake air, thereby improving intercooler efficiency with the benefit of reducing NOx-emissions.

[0016] These advantages apply to both the device aspects and the method aspects of the present invention.

[0017] With regard to the apparatus aspects, it is preferred that the canister comprises a zeolite based charge that is a zeolite based brick having more or less straight flow-through channels or that the canister comprises a charge that is based on tightly packed zeolite based pellets.

[0018] The apparatus preferably comprises further an EGR-System for an engine, an air system and an exhaust system, a turbocharger and one or more exhaust gas treatment devices that are located downstream of the charger's turbine in the exhaust system, wherein a branch-off for drawing exhaust gas off is located downstream of the exhaust gas treatment devices and a pipe conducting the drawn off exhaust gas to a junction in the air system for mixing the drawn off exhaust gas with fresh intake air.

[0019] Preferably, the pipe between the branch-off and the junction comprises a cooling device which cools the drawn off exhaust gas, and an EGR-valve that is controlled by the control unit.

[0020] Preferably, the apparatus comprises a pipe, which connects the exhaust system upstream of the turbine with the air system downstream of the compressor and which comprises a cooling device which cools the exhaust gas recirculated through the pipe.

[0021] The apparatus preferably comprises a further EGR-valve that is located in the intake system upstream of the junction where the pipe joins the air system and a further valve that is located in the exhaust system downstream of the branch-off, wherein both valves are controlled by the control unit.

[0022] It is further preferred that the canister with the first temperature sensor is installed in one of a first installation position, a second installation position, and a third installation position, wherein the first installation position is located between the branch-off and the EGR-valve, the second installation position is located in or downstream of the junction and upstream of the compressor, and the third installation position is located downstream of the compressor and upstream of the EGR-valve.

[0023] It is further preferred that the means for providing the temperature at the canister inlet comprises a second temperature sensor that is arranged upstream of the canister, in particular, without any device that might cause an unwanted deviation between the temperature at the second temperature sensor and the temperature at the canister inlet.

[0024] With regard to method aspects of the invention, it is preferred that the difference between a reference temperature T_{ref} determined with a means for providing a temperature at the catalyst inlet and the zeolite temperature T_{zeo} measured with the first temperature sensor is evaluated and three working states are detected, wherein a first working state is characterized in that the temperature T_{zeo} of the zeolite is greater than the gas reference temperature T_{ref} and wherein the control unit estimates the water load, i.e. the mass of water absorbed by the zeolite, and calculates the remaining adsorbing potential, and wherein the control unit calculates an LP-EGR condensation limitation correction, and wherein the control unit calculates the heat-up capacity of the zeolite in its present state of water load, and wherein the second working state is characterized in that the temperature T_{zeo} of the zeolite is comparable to the gas reference temperature T_{ref} and wherein this state is used for learning and adaptation of the mentioned water load and water unload models concerning the zeolite, and wherein a third working state is characterized in that the temperature T_{zeo} of the zeolite is lower than the gas reference temperature T_{ref} and that in this state the control unit estimates the remaining water load, i.e. the mass of water released by the zeolite and the control unit calculates an

LP-EGR condensation limitation correction and that the control unit calculates correction factors to evaluate the proper LP-EGR condensation limitation, and that the control unit calculates the cooling capacity of the zeolite in its present state of water load.

[0025] It is further preferred that the step of determining is based on evaluating signals of a first temperature sensor, and of a second temperature sensor, which is arranged at the catalyst inlet.

[0026] Further features, possible uses and advantages of the invention will become apparent from the ensuing description of the exemplary embodiments of the invention, which are shown in the drawings. All the features described or shown are the subject of the invention on their own or in arbitrary combination, regardless of how they are summarized in the claims or of their dependency and regardless of how they are worded or shown in the specification and the drawings, respectively.

[0027] In the drawings:

Figure 1 shows an embodiment of the apparatus according to the present invention;

Figure 2a shows an embodiment of the canister;

Figure 2b shows a further embodiment of the canister;

Figure 3 shows possible installation positions of the canister and temperature sensors within an LP-EGR-System;

Figure 4 shows a state machine that is run by the control unit and which represents preferred embodiments of method aspects of the present invention; and

Figure 5 shows an extended use of LP-EGR after a cold start and during a particular driving profile.

[0028] Figure 1 schematically depicts an apparatus 10 for treating gas to be delivered to a combustion process in an internal combustion engine. The apparatus comprises a canister 16 having an inlet 18 for introducing gas 12, an outlet 20 for allowing gas 14 to flow out, and a permeable zeolite based charge 22 arranged between the inlet and the outlet and being able to absorb and desorb water. Between the inlet and the outlet, the canister is tightly closed. It comprises no further gas flow openings.

[0029] The gas 12 entering the canister 16 is exhaust gas of a combustion process, e.g. exhaust gas of an engine, or a mixture of exhaust gas with air. The gas 14 leaving the canister is fed to the intake side of the combustion process. By interacting with the zeolite charge 22, the gas 12 is converted into the gas 14, which will in general comprise more or less water than the gas 12, depending on whether the charge 22 is in a desorbing or an adsorbing state.

[0030] Further, the apparatus 10 comprises a first temperature sensor 24 arranged in thermal contact with the zeolite based charge 22, a second temperature sensor 26 that is arranged upstream of the canister, and a control unit 28 that is adapted to determine whether the charge 22 is in an absorbing state, a desorbing state, or in a transition state between the absorbing state and the desorbing state, based on signals of the first temperature sensor 24 and the second temperature sensor 26. The control unit is further adapted to control an amount of recirculated exhaust gas based on the determined state.

[0031] The control unit 28 may be a control unit which controls only the exhaust gas recirculation or may be a control unit that controls other parameters of the combustion process, too. In the depicted embodiment, the control unit is of the latter type. Signals of further sensors 30 that provide other parameters are fed to the control unit, too. The input signals are conditioned in an acquisition and conditioning section 32 of the control unit.

[0032] Further, the depicted control unit comprises a canister state evaluation section 34, an EGR-control section 36 which preferably includes an EGR-limitation and a section 38 representing other engine control functions. These sections represent both hardware and software aspects of said control functions. Output signals of the sections 36 and 38 are conditioned in an output stage 40 and fed to actuators for controlling the combustion process, e.g. to actuators 42, 44, 46. The actuator 42 is an EGR-valve adapted and arranged to control the amount of recirculated exhaust gas. The other actuators may be further EGR-valves used in the system. Further actuators may be injection valves, or a variable geometry turbocharger, etc.

[0033] In this context, the control unit 28 is adapted, in particular programmed to determine whether the zeolite charge 22 is in an absorbing state, a desorbing state or in a transition state between the absorbing state and the desorbing state, and to control an amount of recirculated exhaust gas based on the determined state. The step of determining is based on evaluating signals of the first temperature sensor 24 and the second temperature sensor 26. The determination is made in the section 34. The result of the determination is further processed in the section 36.

[0034] The second temperature sensor 26 provides a temperature at the canister inlet, i.e. a signal representing said temperature. This second temperature may be a temperature sensor that is already installed on the engine layout so the invention does not need an additional invention-specific second temperature sensor. The second temperature sensor is an embodiment of a means for providing a canister inlet temperature. Another embodiment of such a means is a control unit that is adapted, in particular programmed to calculate values of said temperature at the canister inlet by using a mathematical temperature model and input signals from other sensors, e.g. for engine coolant temperature, suction air temperature, load and rpm. This applies not only to the subject of the figures, but to the invention in general.

[0035] Figure 2 shows two embodiments of the canister 16. The canister 16a comprises a zeolite based charge that is a zeolite based brick having more or less straight flow-through channels. The canister 16b comprises a charge that is based on tightly packed zeolite based pellets. The circular cross sections on the right represent one possible cross section geometry; however, other geometries with straight or curved boundaries are also possible.

[0036] Figure 3 shows possible installation positions of the canister 16 and the temperature sensor 26 within an LP-EGR-System. An engine 48 is equipped with an air system 50 and an exhaust system 52.

[0037] A turbocharger comprises a turbine 54 driven by exhaust gas and a compressor 56 driven by the turbine. One or more exhaust gas treatment devices 58, e. g. an oxidation catalyst and/or a particulate filter and/or a NOx-storage catalyst are located downstream of the turbine in the exhaust system.

[0038] At a branch-off 60 that is located downstream of the exhaust gas treatment devices 58, exhaust gas may be drawn from the exhaust system and piped to a junction 62 in the air system 50, where the exhaust gas is mixed with fresh intake air. The pipe between the branch-off 60 and the junction 62 may comprise a cooling device 64 which cools the drawn off exhaust gas, and an EGR-valve 42 that is controlled by the control unit 28. Such an exhaust gas recirculation path represents a LP-EGR, while the pipe 68, which connects the exhaust system upstream of the turbine 54 with the air system downstream of the compressor, represents a HP-EGR. The pipe 68 may comprise a cooling device 70 which cools the exhaust gas recirculated through the pipe 68. A further EGR-valve 44 is located in the intake system upstream of the junction where the pipe 68 joins the air system 50. A further valve 46 is located in the exhaust system 52 downstream of the branch-off 60. The valves 42, 44 and 46 are controlled by the control unit 28. The canister 16 with the first temperature sensor 24 and the second temperature sensor 26 is preferably installed in one of the first installation position 72, the second installation position 74 and the third installation position 78.

[0039] The first installation position 72 is located between the branch-off 60 and the EGR-valve 42, preferably downstream of a cooling device 64, if such a device is present. In the first installation position, there is an increased risk of condensation due to a cooling effect. Condensed water will be absorbed by the canister.

[0040] The second installation position 74 is located in or downstream of the junction 62 and upstream of the compressor 56. In the second installation position, there is an increased risk of condensation due to a cooling effect that arises from mixing with fresh air. Condensed water will be absorbed by the canister.

[0041] The third installation position 78 is downstream of the compressor 56 and upstream of the EGR-valve 44, preferably downstream of a cooling device 80, if such a device is present. In the third installation position, there is an increased risk of condensation due to a cooling effect and pressure increase. Condensed water will be absorbed by the canister.

[0042] Figure 4 shows a state machine that is a program run by the control unit 28 and which represents preferred embodiments of method aspects of the present invention. The state machine stores the status of the zeolite at a given time and operates on input to change the status and/or cause an action or output to take place for a given change.

[0043] The core of the control method is the evaluation of the difference between the reference temperature T_ref measured with the second temperature sensor 26 or determined otherwise and the zeolite temperature T_zeo measured with the first temperature sensor 24. During the vehicle operation, three working states are possible and can be detected by the control unit 28. Each detected state enables inherent specific functions and is represented in figure 4 as one block of a state machine.

[0044] A first block 82 represents the state ADSORBING. This working state is characterized in that the temperature T_zeo of the zeolite is greater than the gas reference temperature T_ref. By taking the body thermal inertia via a model calculation into account, the control unit detects the zeolite exothermia and recognizes accordingly that the zeolite is in an adsorbing state. In this state, where T_zeo is greater than T_ref, the difference delta_T = (T_zeo·- T_ref) is used to estimate the adsorbing water mass flow. The value of delta_T is a function f of the adsorbing water mass flow. Preferably, the following functionalities are enabled:

[0045] The control unit estimates the water load. i.e. the mass of water absorbed by the zeolite and calculates the remaining adsorbing potential. This is preferably accomplished on the basis of an Observer and integration algorithm of measured delta_T.

[0046] Further, the control unit calculates an LP-EGR condensation limitation correction. Based on results of the calculated remaining adsorbing potential, the control unit calculates correction factors to relax the steady state LP-EGR limitation.

[0047] Even further, the control unit calculates the heat-up capacity of the zeolite in its present state of water load. The calculated heat-up capacity can be used during engine warm-up to evaluate the air system rapid heat-up potential via zeolite exothermia.

[0048] A second block 84 represents the state SATURATED. This working state is characterized in that the temperature T_zeo of the zeolite is comparable to the gas reference temperature T_ref, that is, T_zeo is about to be equal to T_ref. In other words, if the temperature T_zeo of the zeolite and the reference temperature T_ref are comparable, the transition state SATURATED is detected. Preferably, the following functionalities are enabled: By taking in account the body thermal inertia, this state is preferably used for learning and adaptation of the mentioned water load and water unload models concerning the zeolite.

[0049] A third block 86 represents the state DESORBING. This working state is characterized in that the temperature T_zeo of the zeolite is lower than the gas reference temperature T_ref. By taking in account the body thermal inertia (via model), zeolite endothermia is detected and the state DESORBING is detected. In this state, the difference delta_T= (T_zeo -T_ref) is used to estimate the released water vapor mass flow. Preferably, the following functionalities are enabled:

[0050] The control unit estimates the remaining water load, i.e. the mass of water released by the zeolite and. This is preferably accomplished on the basis of an observer and integration algorithm of measured delta_T. In other words: the control unit models the unloading of water from the zeolite.

[0051] Further, the control unit calculates an LP-EGR condensation limitation correction. Based on results of the calculated released water from the canister, the control unit calculates correction factors to evaluate the proper LP-EGR condensation limitation.

[0052] Even further, the control unit calculates the cooling capacity of the zeolite in its present state of water load. The calculated cooling / heat-up capacity can be used to improve intake air cooling via zeolite endothermia.

[0053] The state machine stores the status of the zeolite at a given time and operates on input to change the status between the states ADSORBING and SATURATED (in both directions), and between the states SATURATED and DESORBING and/or cause an action or output to take place for a given change.

[0054] Figure 5 shows an extended use of LP-EGR after a cold start and during a particular driving profile. In particular, figure 5a shows vehicle speed 90 and engine coolant temperature 92 during the New European Driving Cycle (NEDC). Figure 5b shows LP-EGR-ratios over time corresponding to the driving cycle of figure 5a.

[0055] The continuous lines in figure 5b shows LP-EGR-ratios with limitations due to a risk of condensing water in the air system. One can see that the EGR is limited to zero within the first 300 seconds after the engine start and that the EGR is at least reduced in the interval between t = about 300 second and t = about 380 seconds and further in the interval between t = about 860 seconds and t = about 1040 seconds.

[0056] The dashed line shows EGR ratios in said intervals which are allowed by utilizing the present invention. The fact that the dashed line lies above the continuous line means that the invention allows higher EGR-ratios and an earlier activation of the EGR after a cold start. This effect is due to the relaxed EGR-limitation that becomes possible with the present invention. As a result, the NOx-emissions during said intervals are decreased.

Claims

1. Apparatus for treating gas to be delivered to a combustion process in an internal combustion engine, the apparatus comprising a canister (16) having an inlet (18) for introducing gas (12), an outlet (20) for allowing gas (14) to flow out, a permeable zeolite based charge (22) arranged between the inlet and the outlet and being able to absorb and desorb water, **characterized in that** the apparatus further comprises a first temperature sensor (24) arranged in thermal contact with the zeolite based charge, a means for providing the temperature at the canister inlet, and a control unit (28) that is adapted to determine whether the charge is in an absorbing state, a desorbing state or in a transition state between the absorbing state and the desorbing state, based on signals of the first temperature sensor and the means for providing the temperature at the canister inlet, and to control an amount of recirculated exhaust gas based on the determined state.

2. The apparatus of claim 1, **characterized in that** the canister (16a) comprises a zeolite based charge that is a zeolite based brick having more or less straight flow-through channels.

3. The apparatus of claim 1, **characterized in that** the canister (16b) comprises a charge that is based on tightly packed zeolite based pellets.

4. The apparatus of any of claims 1 to 3, the apparatus further comprising an EGR-System for an engine (48), an air system (50) and an exhaust system (52), a turbocharger and one or more exhaust gas treatment devices (58), that are located downstream of the charger's turbine in the exhaust system, wherein a branch-off (60) for drawing exhaust gas off is located downstream of the exhaust gas treatment devices (58) and a pipe conducting the drawn off exhaust gas to a junction (62) in the air system (50) for mixing the drawn off exhaust gas with fresh intake air

5. The apparatus of claim 6, **characterized in that** the pipe between the branch-off (60) and the junction (62) comprises a cooling device (64) which cools the drawn off exhaust gas, and an EGR-valve (42) that is controlled by the control unit (28).

6. The apparatus of claim 7, **characterized by** a pipe (68), which connects the exhaust system upstream of the turbine (54) with the air system downstream of the compressor and which comprises a cooling device (70) which cools the exhaust gas recirculated through the pipe (68).

7. The apparatus of claim 8, **characterized by** a further EGR-valve (44) that is located in the intake system

upstream of the junction where the pipe (68) joins the air system (50) and by a further valve (46) that is located in the exhaust system (52) downstream of the branch-off (60), wherein both valves (44) and (46) are controlled by the control unit (28).

8. The apparatus of any preceding apparatus claim, **characterized in that** the canister (16) with the first temperature sensor (24) (26) is installed in one of a first installation position (72), a second installation position (74), and a third installation position (78), wherein the first installation position (72) is located between the branch-off (60) and the EGR-valve (42), the second installation position is located in or downstream of the junction (62) and upstream of the compressor, and the third installation position is located downstream of the compressor and upstream of the EGR-valve (44).

9. The apparatus of any of the preceding claims, **characterized in that** the means for providing the temperature at the canister inlet comprises or is a second temperature sensor (26) that is arranged upstream of the canister.

10. Method for treating gas to be delivered to a combustion process in an internal combustion engine, the method comprising, piping gas through a canister (16) having an inlet (18) for introducing gas, an outlet (20) for allowing gas to flow out, a permeable zeolite based charge (22) arranged between the inlet and the outlet and being able to absorb and desorb water, **characterized in that** the method further comprises determining whether the charge is in an absorbing state, a desorbing state or in a transition state between the absorbing state and the desorbing state, and controlling an amount of recirculated exhaust gas based on the determined state, wherein the step of determining is based on evaluating signals of a first temperature sensor (24) and a means for providing a temperature at the canister inlet, the first temperature sensor being arranged in thermal contact with the zeolite based charge

11. The method of claim 10, **characterized in that** the difference between a reference temperature T_ref determined with a means for providing a temperature at the canister inlet and the zeolite temperature T_zeo measured with the first temperature sensor (24) is evaluated and three working states are detected, wherein a first working state is **characterized in that** the temperature T_zeo of the zeolite is greater than the gas reference temperature T_ref and wherein the control unit (28) estimates the water load. i.e. the mass of water absorbed by the zeolite and calculates the remaining adsorbing potential, and wherein the control unit calculates an LP-EGR condensation limitation correction, and wherein the control unit calculates the heat-up capacity of the zeolite in its present state of water load, and wherein the second working state is **characterized in that** the temperature T_zeo of the zeolite is comparable to the gas reference temperature T_ref and wherein this state is used for learning and adaptation of the mentioned water load and water unload models concerning the zeolite, and wherein a third working state is **characterized in that** the temperature T_zeo of the zeolite is lower than the gas reference temperature T_ref and that in this state the control unit estimates the remaining water load, i.e. the mass of water released by the zeolite and the control unit calculates an LP-EGR condensation limitation correction and that the control unit calculates correction factors to evaluate the proper LP-EGR condensation limitation, and that the control unit calculates the cooling capacity of the zeolite in its present state of water load.

12. The method of claim 10 or 11, **characterized in that** the step of determining is based on evaluating signals of a first temperature sensor (24) and a second temperature senor(26) arranged at the catalyst inlet.

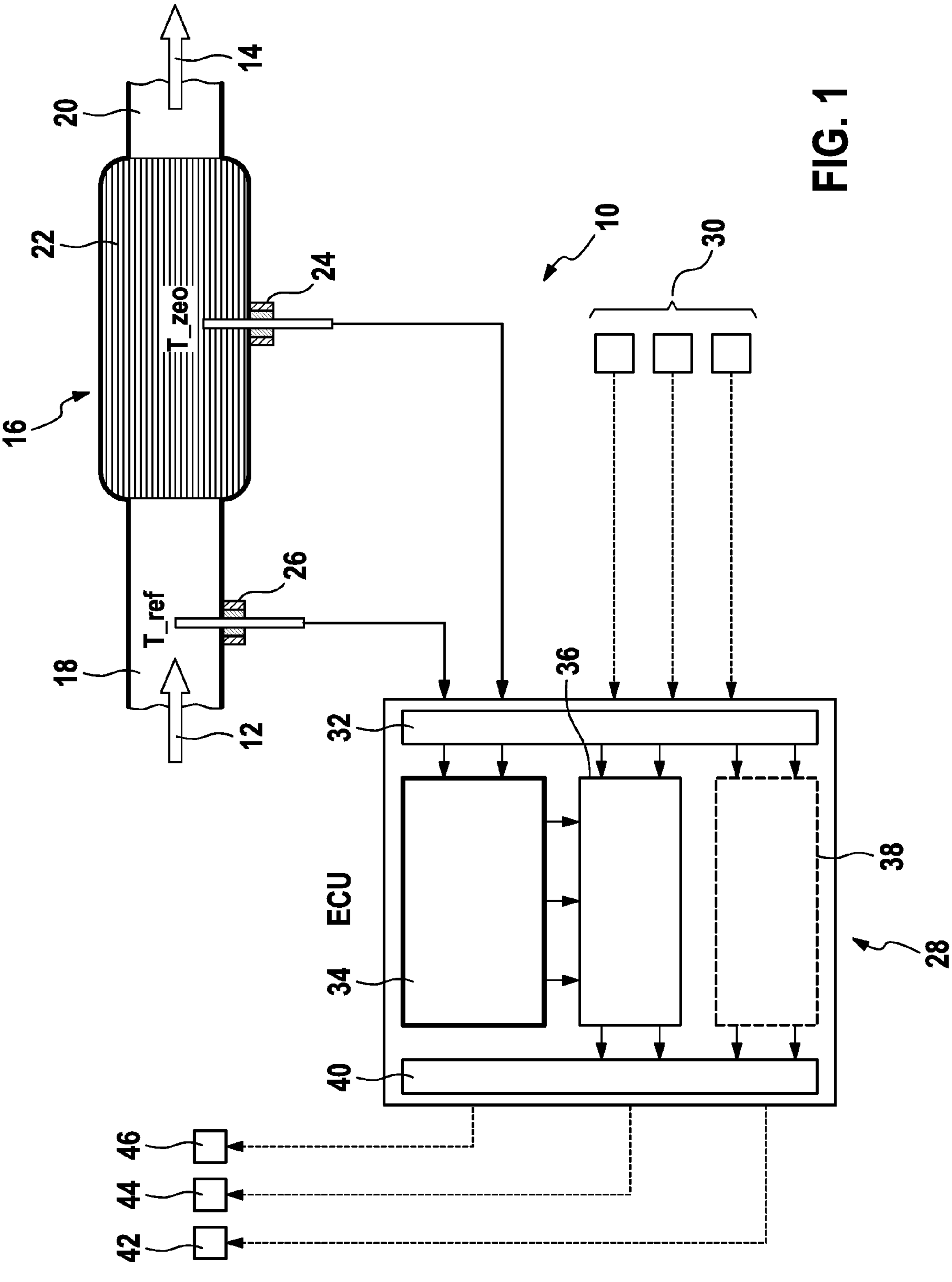


FIG. 1

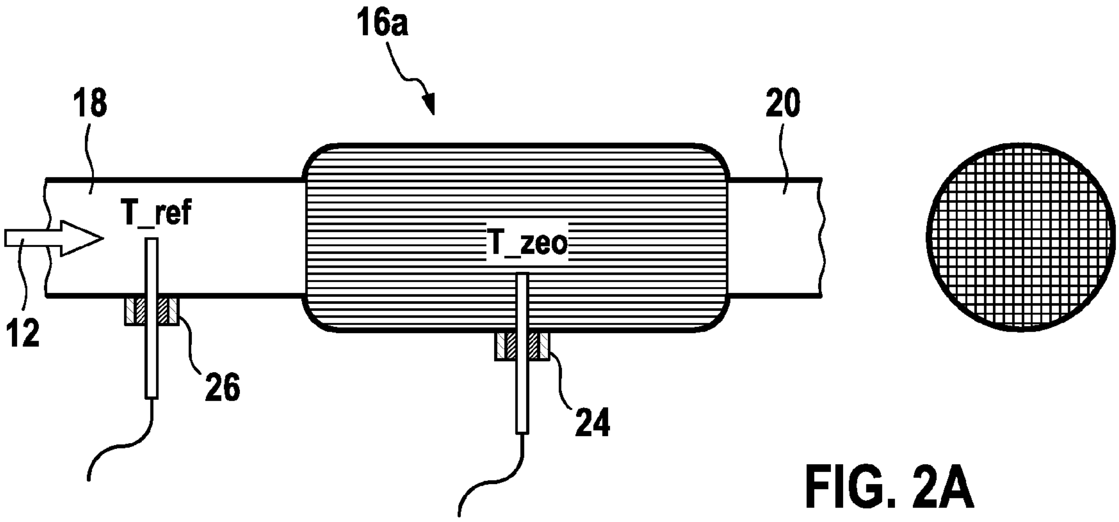


FIG. 2A

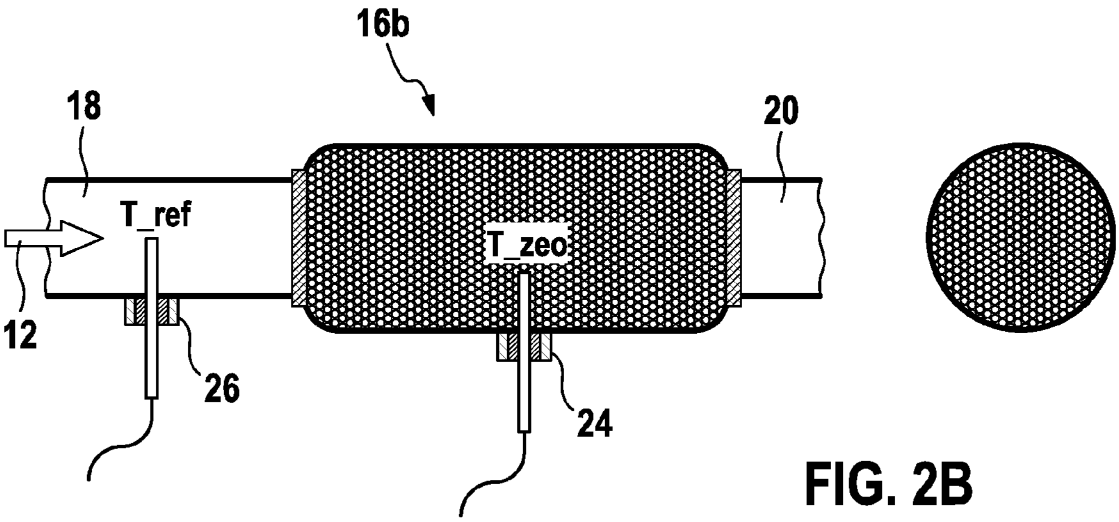
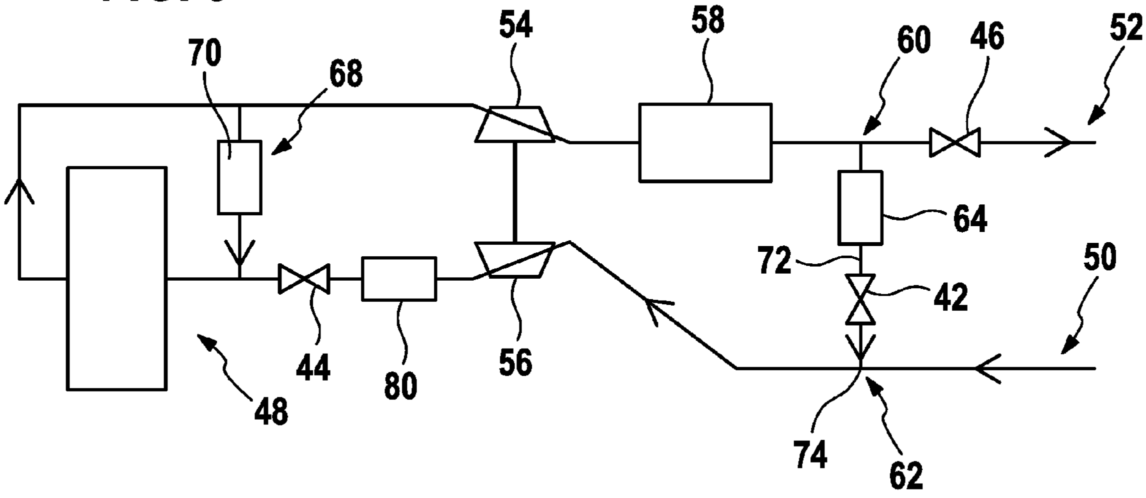


FIG. 2B

FIG. 3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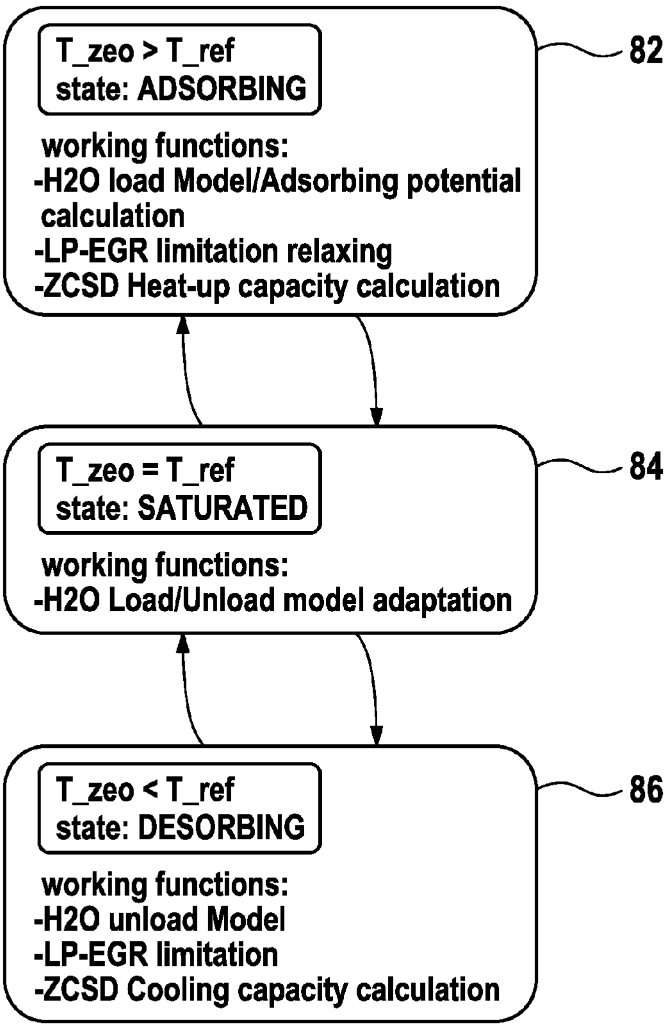
62

FIG. 4


T_zeo > T_ref
state: ADSORBING
working functions:
-H2O load Model/Adsorbing potential calculation
-LP-EGR limitation relaxing
-ZCSD Heat-up capacity calculation
82
T_zeo = T_ref
state: SATURATED
working functions:
-H2O Load/Unload model adaptation
84
T_zeo < T_ref
state: DESORBING
working functions:
-H2O unload Model
-LP-EGR limitation
-ZCSD Cooling capacity calculation
86

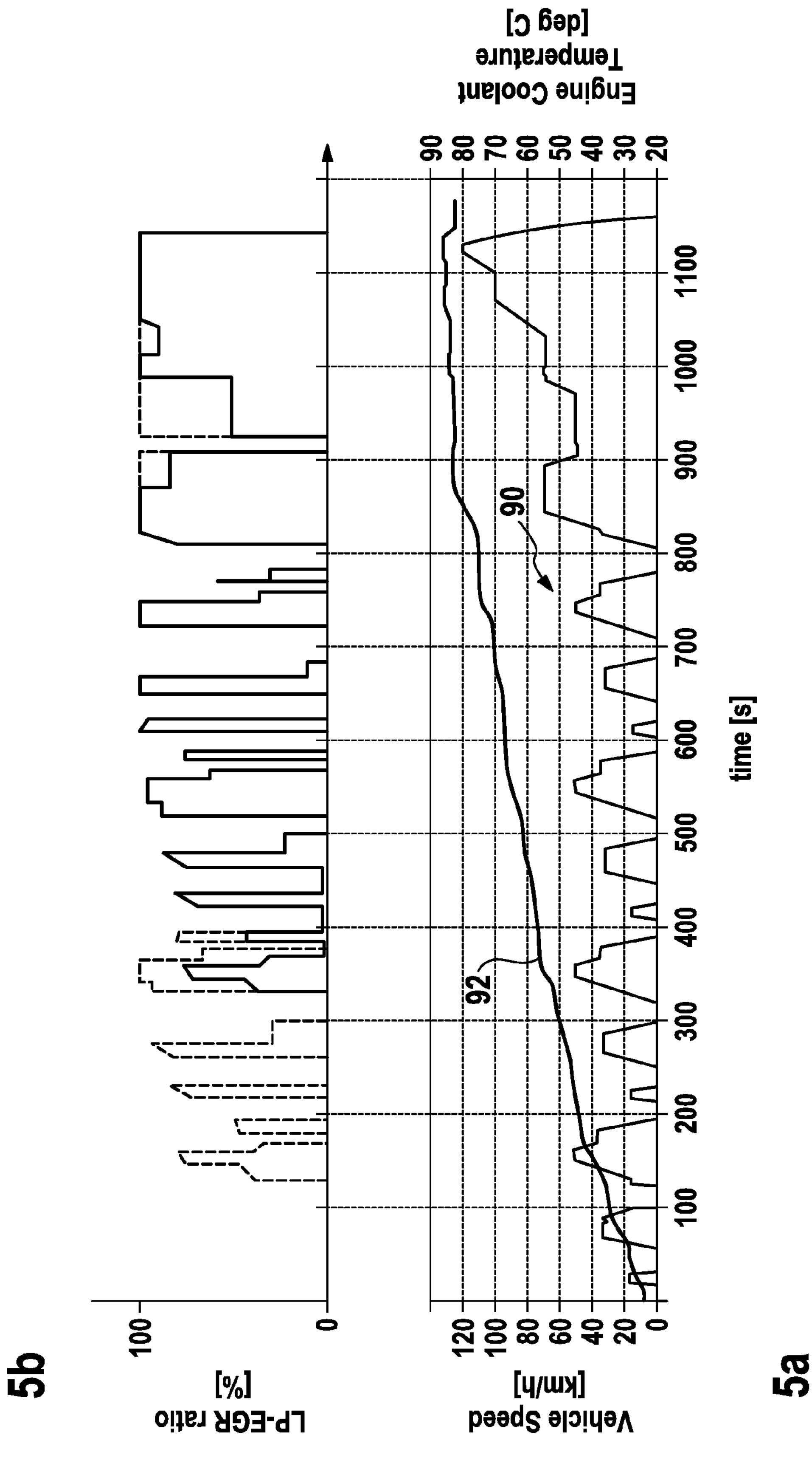

5b
LP-EGR ratio
[%]
100
0
5a
Vehicle Speed
[km/h]
120
100
80
60
40
20
0
Engine Coolant
Temperature
[deg C]
90
80
70
60
50
40
30
20
time [s]
100
200
300
400
500
600
700
800
900
1000
1100
90
92

FIG. 5

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EUROPEAN SEARCH REPORT

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EP 14 17 3283

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 September 2014	Juvenelle, Cyril

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Place of search	Date of completion of the search	Examiner
Munich	25 September 2014	Juvenelle, Cyril

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