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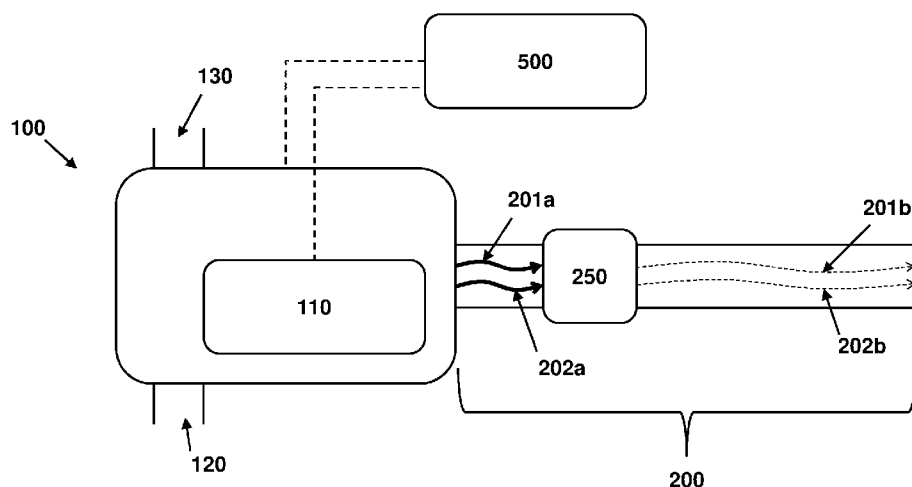


FIG 1

(57) Abstract: An internal combustion engine (100) comprises an exhaust line (200) for transporting the exhaust gas produced by the internal combustion engine (100) through a selective catalyst reactor (SCR) (250), arranged for using NO_x (202a) as an unburnt fuel reducing agent to reduce the amount of unburnt fuel (201a) emitted by the internal combustion engine (100). The internal combustion engine (100) comprises a control module (500) arranged for controlling the NO_x control system (110) in such a way that the amount of unburnt fuel (201a) produced by the internal combustion engine (100) is matched with a controlled amount of NO_x (202a) produced by the internal combustion engine (100), such that a stoichiometric ratio between unburnt fuel (201a) and NO_x (202a) is obtained in the exhaust gas upstream of the SCR (250). The control module (500) is arranged for controlling the internal combustion engine (100) to increase the amount of unburnt fuel (201a) in the exhaust gas upstream of the SCR (250) when the amount of NO_x (202a) required

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TITLE: NO_x and CO₂ reduction with Hydrogen or Ammonia

DESCRIPTION

5 Field of invention

The invention relates to an internal combustion engine producing exhaust gas with a given amount of unburnt fuel in dependence of operating conditions.

10 Description of the prior art

In strategies to reduce carbon emission, upcoming fuel concepts contemplate the use of low carbon fuels, e.g. H₂ or NH₃ as a fuel source. In practice these zero carbon fuels often are used in mixed form, e.g. mixed with carbon fuel, in particular
15 diesel fuel to have at least a fraction of these carbon fuels available. This balances handling and energy density optimizations, and also serves to provide (improved) ignition conditions e.g. by adding a pilot quantity of diesel. However, small fractions e.g. 2-4% of injected fuel may remain unburnt due to the imperfectness of homogenous combustion. Operating an internal combustion engine with premix
20 fuel may in particular lead to incomplete combustion due to e.g. incomplete mixing, wall quenching or slow flame propagation.

A traditional method to eliminate unburnt fuel that enters the exhaust line, is by oxidizing it which may be assisted by a catalyst, e.g. a 3 way catalyst. However, catalysts operate best above a specific light-off temperature and therefore
25 may require additional heaters, which in turn may lower the energy efficiency of the internal combustion engine when used unrestricted and the oxidation of unburnt fuel adds to an energy cost that is undesired.

The invention aims to provide an improved way of treatment of unburnt fuel, in particular the reduction of the emission to the environment.

30

Summary of the invention

In one aspect, it is aimed to provide an internal combustion engine arranged for reducing the amount of unburnt fuel in the exhaust gas emitted by the internal

combustion engine by using NO_x produced by the internal combustion engine as an unburnt fuel reducing agent. To this end it is proposed to provide an internal combustion engine producing exhaust gas with a given amount of unburnt fuel in dependence of operating conditions, that comprises an NO_x control system such as
5 an exhaust gas recirculation (EGR) system or an engine management system arranged for controlling the ignition timing and/or injection timing of the internal combustion engine. The NO_x control system is arranged for controlling the amount of NO_x in the exhaust gas produced by the internal combustion engine within a control range defined as having a minimum controllable amount of NO_x
10 and a maximum controllable amount of NO_x.

The internal combustion engine further comprises an exhaust line for transporting the exhaust gas produced by the internal combustion engine through a selective catalyst reductor (SCR), arranged for using NO_x as an unburnt fuel reducing agent to reduce the amount of unburnt fuel emitted by the internal
15 combustion engine.

The internal combustion engine further comprises an unburnt fuel control module arranged for controlling the NO_x control system in such a way that the given amount of unburnt fuel produced by the internal combustion engine is matched with a controlled amount of NO_x produced by the internal combustion
20 engine, such that a stoichiometric ratio between unburnt fuel and NO_x is obtained in the exhaust gas upstream of the SCR.

Secondly, the unburnt fuel control module is arranged for controlling the internal combustion engine to increase the amount of unburnt fuel in the exhaust gas upstream of the SCR when the amount of NO_x required to obtain the
25 stoichiometric ratio between NO_x and unburnt fuel in the exhaust gas upstream the SCR is smaller than the minimum controllable amount of NO_x.

In another aspect of the invention, the internal combustion engine may additionally comprise an oxidation catalyst unit, arranged for burning off excess unburnt fuel in the exhaust gas downstream of the SCR when the amount of NO_x
30 required to obtain the stoichiometric ratio upstream of the SCR is larger than the maximum controllable amount of NO_x.

The internal combustion engine may further comprise one or multiple sensor means for measuring the amount of NO_x and/or unburnt fuel in the exhaust line, to provide sensor information to the unburnt fuel control module. It is

observed, that many other solutions have been developed to reduce the emission of NO_x, including exhaust lines comprising various types of catalytic devices, arranged for converting nitrous oxides into harmless diatomic nitrogen (N₂) and water (H₂O) with the use of a catalyst agent, such as urea or ammonia. However
5 engines typically are equipped with engine management systems arranged to control the production of NO_x during combustion, for instance by controlling the fuel injection timing or ignition timing to reduce pressure and temperature during combustion. Also, engines can be equipped with an exhaust gas recirculation (EGR) system, to recirculate parts of the exhaust gas back into the engine. The
10 recirculated exhaust gas lowers the in-cylinder temperature by absorbing heat during combustion, thereby inhibiting the production of NO_x. These NO_x control systems however do not take into account a given amount of unburnt fuel. Besides limiting or preventing the emission of NO_x by internal combustion engines because of its proven detrimental effects, the invention takes a different approach
15 and find a way to use NO_x in a productive way where it is used as an unburnt fuel reducing agent for a selective catalytic reactor (SCR), by controlling an NO_x control system in such a way that simultaneously eliminates all unburnt fuel and nitrous oxides emitted by an internal combustion engine. In this way, the invention may create possibilities for higher overall NO_x reduction, also at lower exhaust gas
20 temperatures because the unburned fuel that is used as NO_x reducing reactant is already in a well-mixed and gaseous state, compared to current SCR systems where the reactant is often injected in liquid state just in front of the SCR catalyst, where it has to evaporate, decompose & mix in a limited time & space.

25 BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be further elucidated in the figures:

Figure 1 shows an embodiment of an internal combustion engine arranged
30 for reducing the emission of unburnt fuel;
Figure 2 shows a second embodiment of the invention;
Figure 3 shows a third embodiment of the invention;
Figure 4 shows a graph depicting various operating ranges of the invention.

DETAILED DESCRIPTION

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of
5 ordinary skill in the art to which this disclosure belongs as read in the context of the description and drawings. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly
10 so defined herein. In some instances, detailed descriptions of well-known devices and methods may be omitted so as not to obscure the description of the present systems and methods. Terminology used for describing particular embodiments is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context
15 clearly indicates otherwise. The term "and/or" includes any and all combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising" specify the presence of stated features but do not preclude the presence or addition of one or more other features.

While example embodiments are shown for systems and methods, also
20 alternative ways may be envisaged by those skilled in the art having the benefit of the present disclosure for achieving a similar function and result. E.g. some components may be combined or split up into one or more alternative components. Finally, these embodiments are intended to be merely illustrative of the present system and should not be construed as limiting the appended claims to any
25 particular embodiment or group of embodiments. Thus, while the present system has been described in particular detail with reference to specific exemplary embodiments thereof, it should also be appreciated that numerous modifications and alternative embodiments may be devised by those having ordinary skill in the art without departing from the scope of the present systems as set forth in the
30 claims that follow. The specification and drawings are accordingly to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims.

Any reference signs in the claims do not limit their scope; several "means" may be represented by the same or different item(s) or implemented structure or

function; any of the disclosed devices or portions thereof may be combined together or separated into further portions unless specifically stated otherwise. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to advantage.

5 Turning now to Figure 1, there is illustrated an embodiment of an internal combustion engine 100 producing exhaust gas with a given amount of unburnt fuel 201a in dependence of engine operating conditions. The internal combustion engine 100 comprises an air intake 120, a fuel intake 130, and an NO_x control system 110. The NO_x control system 110 is arranged for producing a controlled amount of NO_x 10 202a in the exhaust gas produced by the internal combustion engine 100 within a minimum and maximum controllable amount of NO_x. The NO_x control system 110 may for instance be an exhaust gas recirculation (EGR) system and/or an engine management system arranged for controlling the ignition timing and/or injection timing of the internal combustion engine 100.

15 The internal combustion engine 100 further comprises an exhaust line 200 for transporting the exhaust gas from the internal combustion engine 100 through a selective catalytic reactor (SCR) 250. The exhaust line 200 comprises exhaust gas with the given amount of unburnt fuel 201a and the controlled amount of NO_x 202a upstream of the SCR 250.

20 The SCR 250 is arranged for using the controlled amount of NO_x 202a as an unburnt fuel reducing agent to reduce the given amount of unburnt fuel 201a emitted by the internal combustion engine 100. Accordingly, the exhaust line 200 comprises exhaust gas with a second amount of unburnt fuel 201b and a second amount of NO_x 202b downstream of the SCR, smaller than, respectively, the given 25 amount of unburnt fuel 201a and the controlled amount of NO_x 202b upstream of the SCR 250.

 The internal combustion engine 100 further comprises an unburnt fuel control module 500, arranged for controlling the NO_x control system 110 to match the given amount of unburnt fuel 201a produced by the internal combustion engine 30 100 with the controlled amount of NO_x 202a produced by the internal combustion engine 100, such that a stoichiometric ratio is obtained between NO_x and unburnt fuel in the exhaust gas upstream of the SCR. The unburnt fuel control module 500 is further arranged for controlling the internal combustion engine 100 to increase the given amount of unburnt fuel 201a in the exhaust gas upstream of the SCR

when the given amount of unburnt fuel in a particular engine state is too small to be compensated by the actual production of NO_x required to obtain the stoichiometric ratio between the unburnt fuel and NO_x in the exhaust gas upstream of the SCR. In this case the required amount of NO_x may be too small to
5 be controlled by the NO_x control system because the amount of NO_x produced by the internal combustion engine is already at a minimum. This situation might for instance occur at high load conditions or in cases where limited NO_x reducing capability is available, i.e. hot ambient conditions.

Typically, when combustion efficiency is low the given amount of unburnt
10 fuel 201a is large with respect to the amount of NO_x produced in-cylinder during combustion, and vice versa for high combustion efficiencies, thereby possibly leading to a self-stabilizing effect. Additionally, the ratio between the given amount of unburnt fuel 201a and the amount of NO_x produced in-cylinder could be adjusted by an engine management system controlling engine operating conditions such as
15 ignition and injection timing, air-fuel ratio and, in case of automatic transmission, engine load and running speed, e.g. by late post injection, to increase the amount of unburnt fuel delivered to the exhaust. In this way, the amount of unburnt fuel in the exhaust gas upstream of the SCR can be increased when the amount of NO_x required to obtain the stoichiometric ratio between NO_x and unburnt fuel in the
20 exhaust gas upstream of the SCR is smaller than the minimum controllable amount of NO_x. Alternatively, the given amount of unburnt fuel 201a could be increased by injecting additional fuel directly into the SCR 250 or into the exhaust line 200 upstream of the SCR 250, as further discussed in the below in relation with Figure 2.

25 The given amount of fuel can be determined in several ways:
Determination of both unburned fuel 201a & NO_x quantities 202a produced by the internal combustion engine by a sensor that directly measures the unburnt fuel & NO_x quantity. Alternatively either unburnt fuel and/or NO_x quantity may be derived from look-up tables or models based on mapping of the engine states, based
30 on other sensed variables, e.g. lambda sensor, exhaust gas temperature sensor.
The given amount need not be quantitatively measured, since the unburnt fuel control module may include an adaptive control that increases NO_x 202a, measured with NO_x sensor, from a minimum value until NO_x 202b, also measured with NO_x sensor, starts to increase, when all unburnt fuel is used. In this way the

given amount of unburnt fuel produced by the internal combustion engine can be matched with a controlled amount of NO_x produced by the internal combustion engine, such that a stoichiometric ratio is obtained between NO_x and unburnt fuel in the exhaust gas upstream of the SCR.

5

Figure 2 shows a second embodiment of the internal combustion engine 100 of Figure 1, additionally comprising a fuel injection unit 240 arranged for injecting fuel into the exhaust line 200 upstream of the SCR 250. Additional fuel is injected to increase the given amount of unburnt fuel 201a in the exhaust gas upstream of the SCR 250, to match the controlled amount of NO_x 202a in the exhaust gas upstream of the SCR 250 when the amount of NO_x 202a produced by the internal combustion engine is too high to obtain a stoichiometric ratio with the given amount of unburnt fuel 201a and cannot be controlled to a lower value in the particular operative engine state, i.e. at high load conditions or in cases where limited NO_x reducing capability is available, i.e. hot ambient conditions, because the required amount of NO_x for obtaining the stoichiometric ratio is still smaller than the minimum controllable amount of NO_x of the NO_x control system 110. In the shown embodiment, the fuel injection unit 240 may be controlled by the unburnt fuel control module 500, however the fuel injection unit 240 may also be controlled by e.g. an intrinsic fuel injection controller or the engine management system of the internal combustion engine 100 in order to reduce the NO_x fraction in the exhaust gas further. The fuel injection unit 240 may be provided with fuel e.g. by being fluidly connected to a fuel reservoir 135 shared with the internal combustion engine 100 or to a separate fuel reservoir or by having an intrinsic fuel reservoir.

The fuel injected by the fuel injection unit 240 may be identical to the fuel used by the internal combustion engine 100 or may be of a different type or composition than the fuel used by the internal combustion engine 100, possibly supplemented with fuel additives that can be used as a reactant with NO_x. Potentially, the fuel injected by the fuel injection unit 240 may not be suitable or preferable for combustion by the internal combustion engine 100, but rather be of a specific type or composition preferable for being used as a catalyst agent to reduce NO_x, e.g. comprising hydrogen (H₂) or ammonia (NH₃). Alternatively, the internal combustion engine 100 may be arranged for combustion of fuels comprising, at

least in part, a fuel or fuel additive that is preferable for being used as a catalyst to reduce NO_x, such as fuels or fuel additives comprising hydrogen (H₂) or ammonia (NH₃).

Figure 3 shows a third embodiment of the internal combustion engine 100 of Figure 1, additionally comprising an oxidation catalyst unit 260 for burning off excess unburnt fuel 201c in the exhaust gas downstream of the SCR 250 when the amount of NO_x required to obtain the stoichiometric ratio between NO_x and unburnt fuel in the exhaust gas upstream of the SCR 250 is larger than the maximum actual amount of NO_x of the NO_x control system 110. This typically occurs at low engine loads where the lower combustion temperatures lead to typically higher unburned fuel 201a quantities and low NO_x 201b. The oxidation catalyst unit 260 may be a diesel oxidation catalyst (DOC), e.g. in case the internal combustion engine 100 is operated with a fuel comprising diesel. Alternatively, the oxidation catalyst unit 260 may be an ammonia slip catalyst (ASC), e.g. in case the internal combustion engine 100 is operated with a fuel comprising ammonia (NH₃).

As conceivable by a person skilled in the art, other types of oxidation catalyst units may be used to suit various types of fuels the internal combustion engine 100 could be operated with. Similarly, multiple and different types of oxidation catalyst units may be arranged in the exhaust line 200 to burn off excess unburnt fuel 201c in the exhaust gas downstream of the SCR 250.

The oxidation catalyst unit 260 may be continuously activated or may be controlled, e.g. by the unburnt fuel control module 500 or by the engine management system of the internal combustion engine 100. As shown in Figure 3, the internal combustion engine 100 may comprise an unburnt fuel sensor means 265 for measuring the amount of unburnt fuel 201c in the exhaust gas downstream of the SCR 250 and upstream of the oxidation catalyst unit 260. The unburnt fuel sensor means 265 may be arranged to provide information to the unburnt fuel control module 500 such that the unburnt fuel control module 500 is able to control the oxidation catalyst unit 260 in dependence of the information from the unburnt fuel sensor means 265.

Of course, any features belonging to the embodiments depicted in figures 1-3 may be combined in various ways to create other embodiments of the invention, as deemed suitable and beneficial by the skilled person.

Figure 4 shows a graph depicting various operating conditions of the invention. The graph shows an idealized linear (constant) relation between NO_x and unburnt fuel, which corresponds to the stoichiometric ratio between NO_x and unburnt fuel. The stoichiometric ratio is dependent on the types of fuel the internal combustion engine is operated with. Instead of a linear ratio, the stoichiometric ratio may also be non-linear or non-constant over time, e.g. due to variations in the composition of the fuel or the unburnt fuel, caused e.g. by degradation or temperature effects. The unburnt fuel control module may accordingly be arranged to compensate for any variations or offsets in the stoichiometric ratio between the unburnt fuel and NO_x .

The graph in Figure 4 shows that the amount of NO_x produced by the internal combustion engine can be controlled by the NO_x control system, within a first NO_x control range (I) defined as ranging between a minimum controllable amount of NO_x ($\text{NO}_x\text{-min}$) and a maximum controllable amount of NO_x ($\text{NO}_x\text{-max}$), to match the stoichiometric line which corresponds to the stoichiometric ratio between unburnt fuel and NO_x . The minimum and maximum controllable amount of NO_x may be dependent on engine operating conditions, e.g. at higher loads the minimum NO_x ($\text{NO}_x\text{-min}$) that can be generated will increase, which may be part of the input for the unburnt fuel module. The NO_x level may also be detected by an NO_x sensor.

Within this first NO_x control range (I), all NO_x and all unburnt fuel produced by the internal combustion engine can simultaneously be eliminated from the exhaust gas by the SCR.

In the area of the graph corresponding to NO_x amounts smaller than $\text{NO}_x\text{-min}$, the amount of NO_x produced by the internal combustion engine cannot be controlled small enough by the NO_x control system to match the given amount of unburnt fuel produced by the internal combustion engine to obtain the stoichiometric ratio. In that non-controllable second range (II), i.e. the range stoichiometrically corresponding to lower amounts of NO_x than a minimum amount $\text{NO}_x\text{-min}$, the amount of unburnt fuel in the exhaust gas upstream of the SCR is increased by the unburnt fuel control module, so that the amount of NO_x required to obtain the stoichiometric ratio is brought back to a controllable amount that is within the minimum and maximum controllable amount.

In the area of the graph corresponding to NO_x amounts larger than NO_x-max, the amount of NO_x produced by the internal combustion engine cannot be increased enough by the NO_x control system to match the given amount of unburnt fuel produced by the internal combustion engine to obtain the stoichiometric ratio.

- 5 In that third non-controllable range (III), i.e. the range stoichiometrically corresponding to higher amounts of unburnt fuel, the maximum controllable amount of NO_x (NO_x-max) is fully used as a reactant with a matching amount of unburnt fuel by the SCR to eliminate all NO_x and a partial amount of unburnt fuel. Next, the excess amount of unburnt fuel downstream of the SCR is burnt off by an
- 10 oxidation catalyst unit.

CLAIMS

1. An internal combustion engine producing exhaust gas with an amount of unburnt fuel in dependence of engine operating conditions, comprising:
 - an NO_x control system arranged for controlling the amount of NO_x in
5 the exhaust gas produced by the internal combustion engine between a minimum and maximum controllable amount of NO_x;
 - an exhaust line for transporting the exhaust gas from the internal combustion engine through a selective catalytic reactor (SCR); and
 - a control module, arranged for controlling the NO_x control system to
10 match the amount of unburnt fuel produced by the internal combustion engine with a controlled amount of NO_x produced by the internal combustion engine, such that a stoichiometric ratio is obtained between NO_x and unburnt fuel in the exhaust gas upstream of the SCR;
- 15 whereas the control module is arranged for controlling the internal combustion engine to increase the amount of unburnt fuel in the exhaust gas upstream of the SCR when the amount of NO_x required to obtain the stoichiometric ratio between NO_x and unburnt fuel in the exhaust gas upstream of the SCR is smaller than the minimum
20 controllable amount of NO_x; and
whereas the SCR is arranged for using the NO_x as an unburnt fuel reducing agent to reduce the unburnt fuel emitted by the internal combustion engine.
2. Internal combustion engine according to claim 1, whereas the NO_x control
25 system is an exhaust gas recirculation system and/or an engine management system arranged for controlling the ignition timing and/or injection timing of the internal combustion engine.
3. Internal combustion engine according to any preceding claim, whereas the
30 internal combustion engine is arranged for increasing the amount of unburnt fuel in the exhaust gas upstream of the SCR by injecting fuel in the exhaust line upstream of the SCR.
4. Internal combustion engine according to any preceding claim, whereas the exhaust line comprises an oxidation catalyst unit, for burning off excess unburnt fuel in the exhaust gas downstream of the SCR when the amount of

NO_x required to obtain the stoichiometric ratio between NO_x and unburnt fuel in the exhaust gas upstream of the SCR is larger than the maximum controllable amount of NO_x.

5. Internal combustion engine according to any preceding claim, whereas the
5 amount of unburnt fuel produced by the internal combustion engine is derived from a model of the internal combustion engine and/or from sensor output from the internal combustion engine, as input to the control module.

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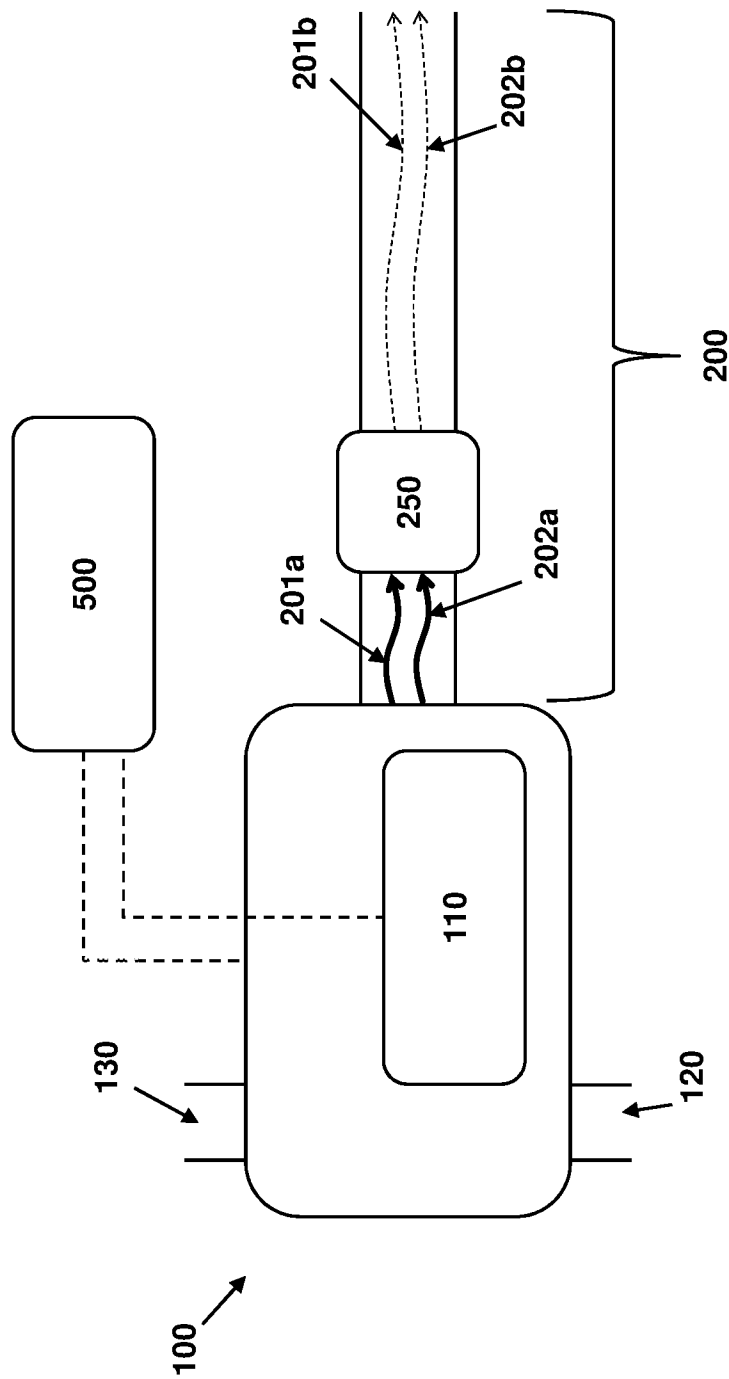


FIG 1

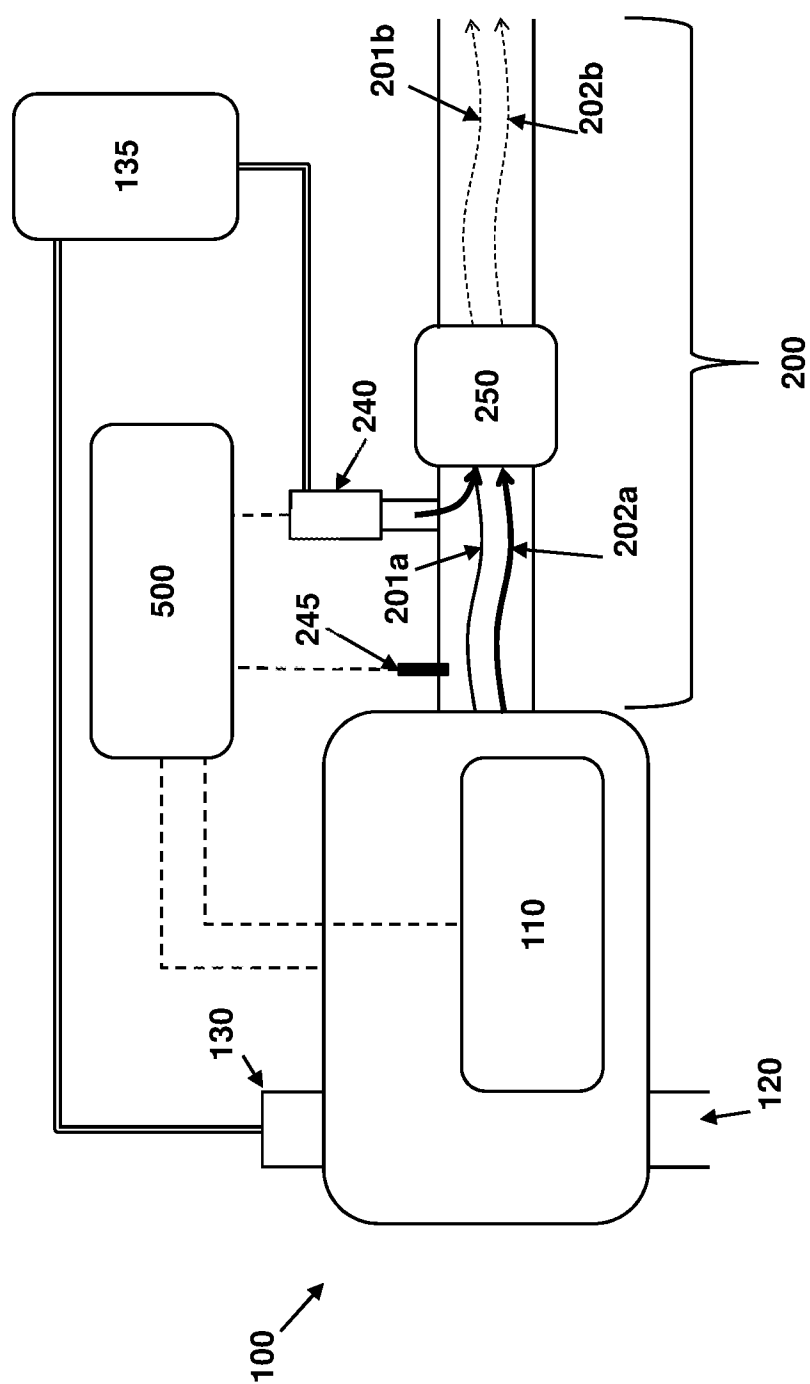


FIG 2

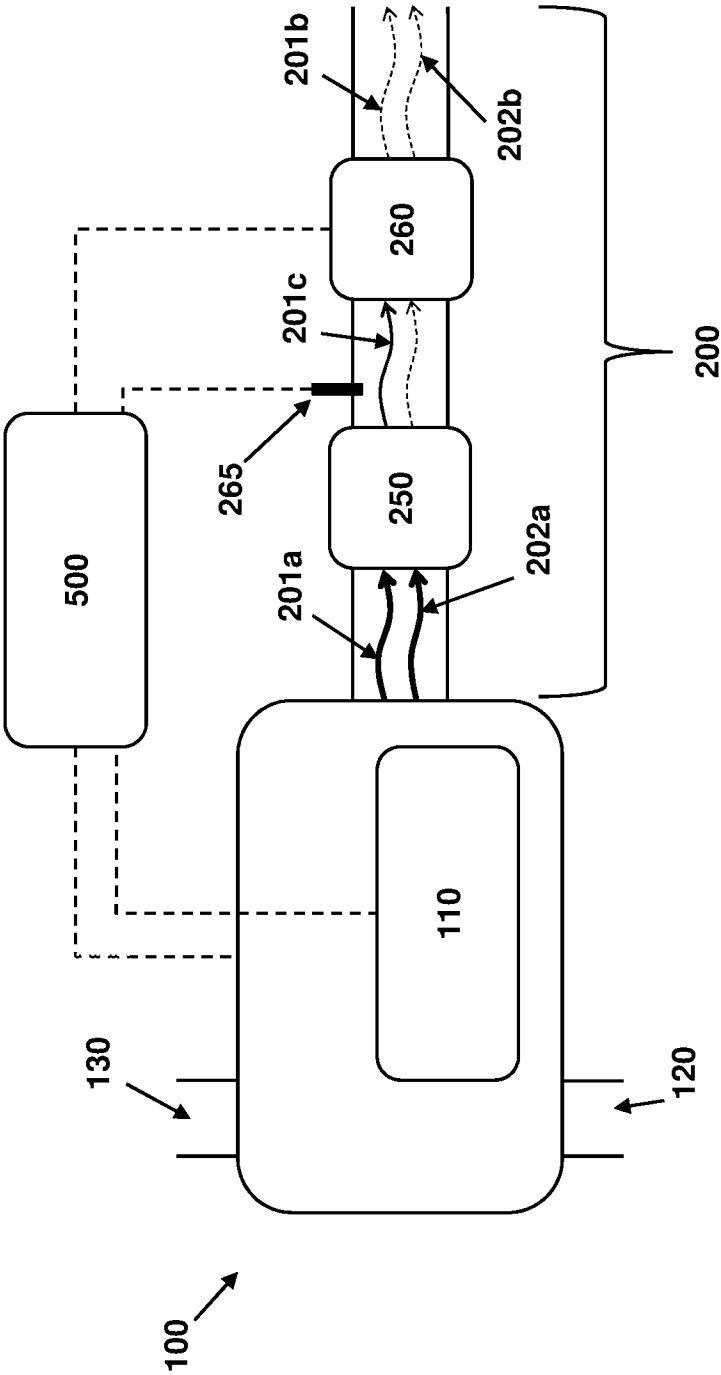


FIG 3

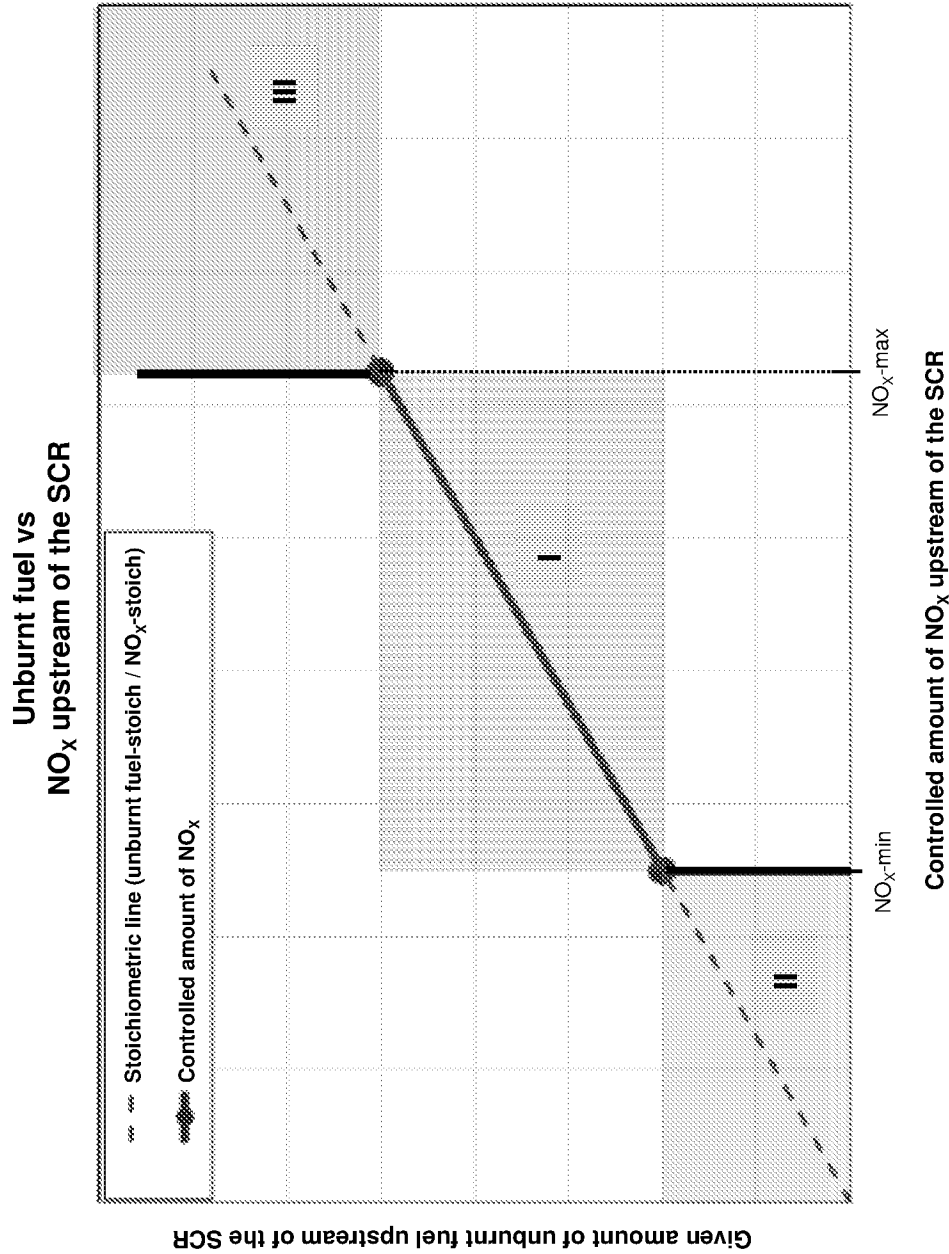


FIG 4

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER INV. F01N3/20 F01N3/10 F02D41/14 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F01N F02D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/248876 A1 (TAXON MORSE N [US]) 9 November 2006 (2006-11-09) paragraphs [0006], [0049], [0050] claims 2-8 figures 1-3 -----	1-5
A	FR 2 892 766 A1 (RENAULT SAS [FR]) 4 May 2007 (2007-05-04) page 6, line 13 - page 10, line 20 figure 1 -----	1-5
A	EP 3 073 083 A1 (TOYOTA MOTOR CO LTD [JP]) 28 September 2016 (2016-09-28) paragraph [0067] claim 1 figures 1, 6 -----	1-5
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 14 September 2021		Date of mailing of the international search report 14/10/2021
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Ikas, Gerhard

INTERNATIONAL SEARCH REPORT

Information on patent family members

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