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(19) **United States**(12) **Patent Application Publication****Kato et al.**(10) **Pub. No.: US 2008/0184701 A1**(43) **Pub. Date: Aug. 7, 2008**(54) **EXHAUST GAS PURIFYING DEVICE FOR
INTERNAL COMBUSTION ENGINE****Publication Classification**(51) **Int. Cl.**
F01N 3/10 (2006.01)(52) **U.S. Cl.** **60/299; 60/295**(75) Inventors: **Kenji Kato**, Shizuoka (JP);
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ABSTRACT

An NO_x-occluding and reducing catalyst 7 is arranged in an exhaust gas passage 2 of an engine 1 so as to occlude, reduce and purify NO_x contained in an exhaust gas. An H₂ sensor 33 is arranged in the exhaust gas passage on a downstream side of the NO_x-occluding and reducing catalyst 7 and a hydrogen component concentration of the exhaust gas is detected. When an amount of NO_x occluded in the NO_x-occluding and reducing catalyst is increased to a predetermined value, an electronic control unit (ECU) 30 of the engine operates the engine at a rich air-fuel ratio, and a regenerating operation, by which a rich air-fuel ratio exhaust gas is supplied to the NO_x-occluding and reducing catalyst, is executed so as to reduce and purify NO_x which is occluded in the NO_x-occluding and reducing catalyst. At the time of executing the regenerating operation, when the H₂ sensor 33 detects hydrogen components in the exhaust gas, ECU 30 finishes the regenerating operation. Due to the foregoing, it is possible to accurately judge the time for terminating the regenerating operation of the NO_x-occluding and reducing catalyst.

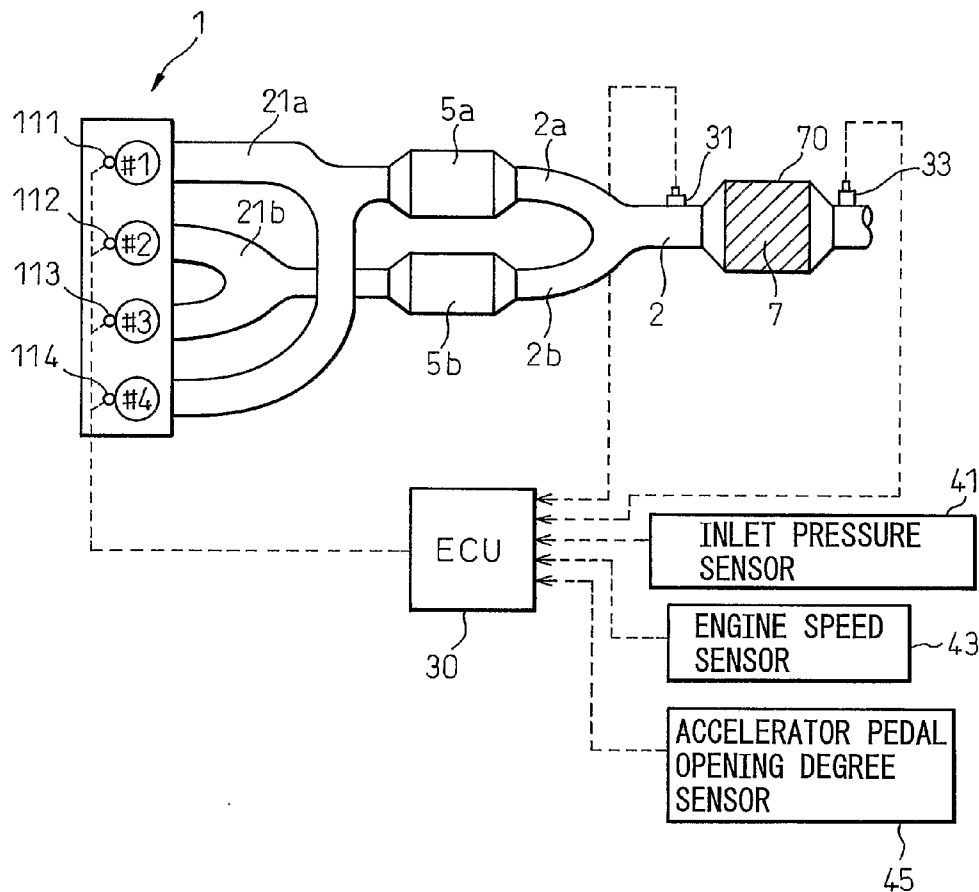


Fig.1

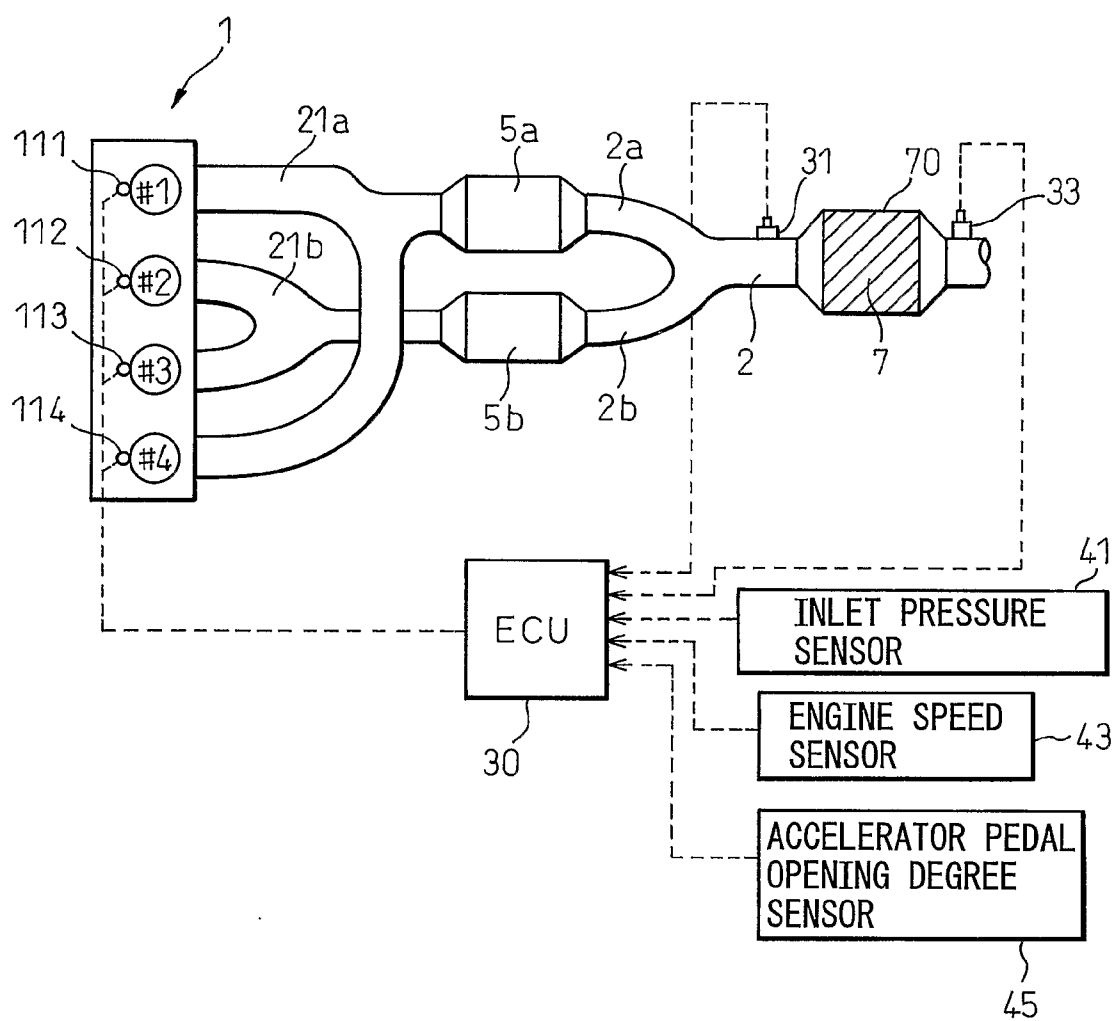


Fig.2

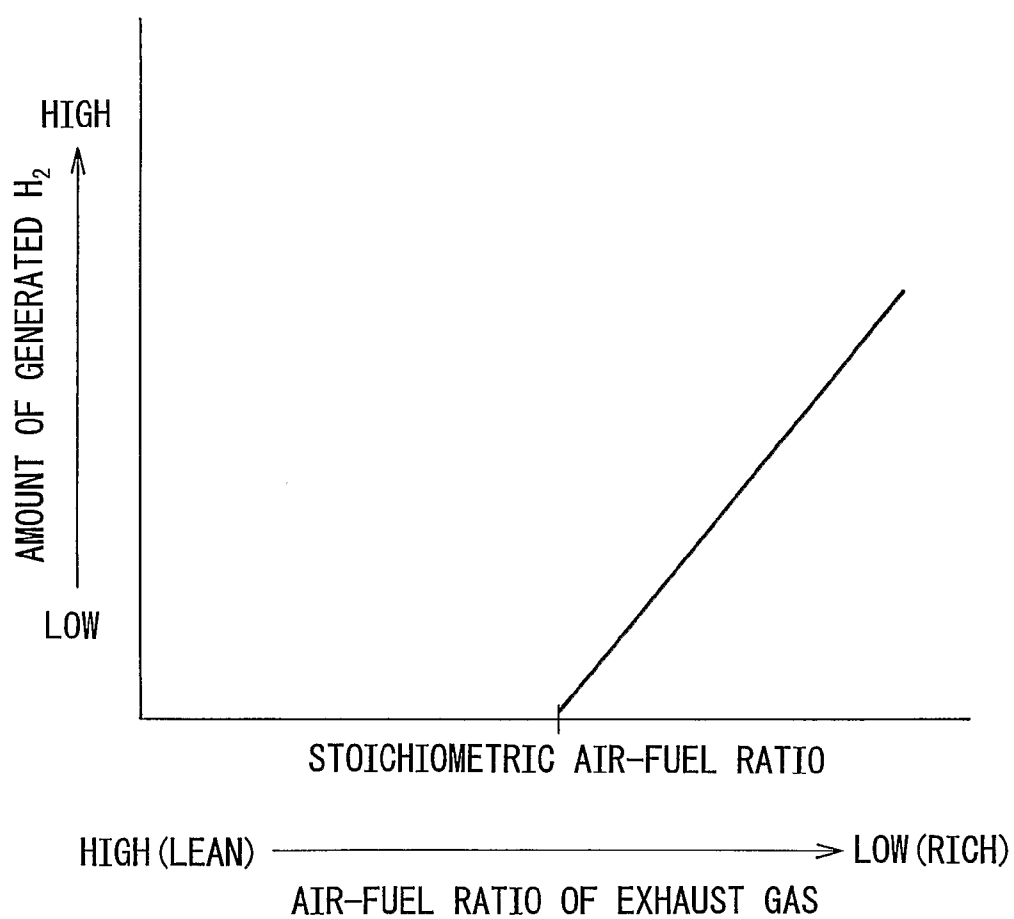


Fig.3

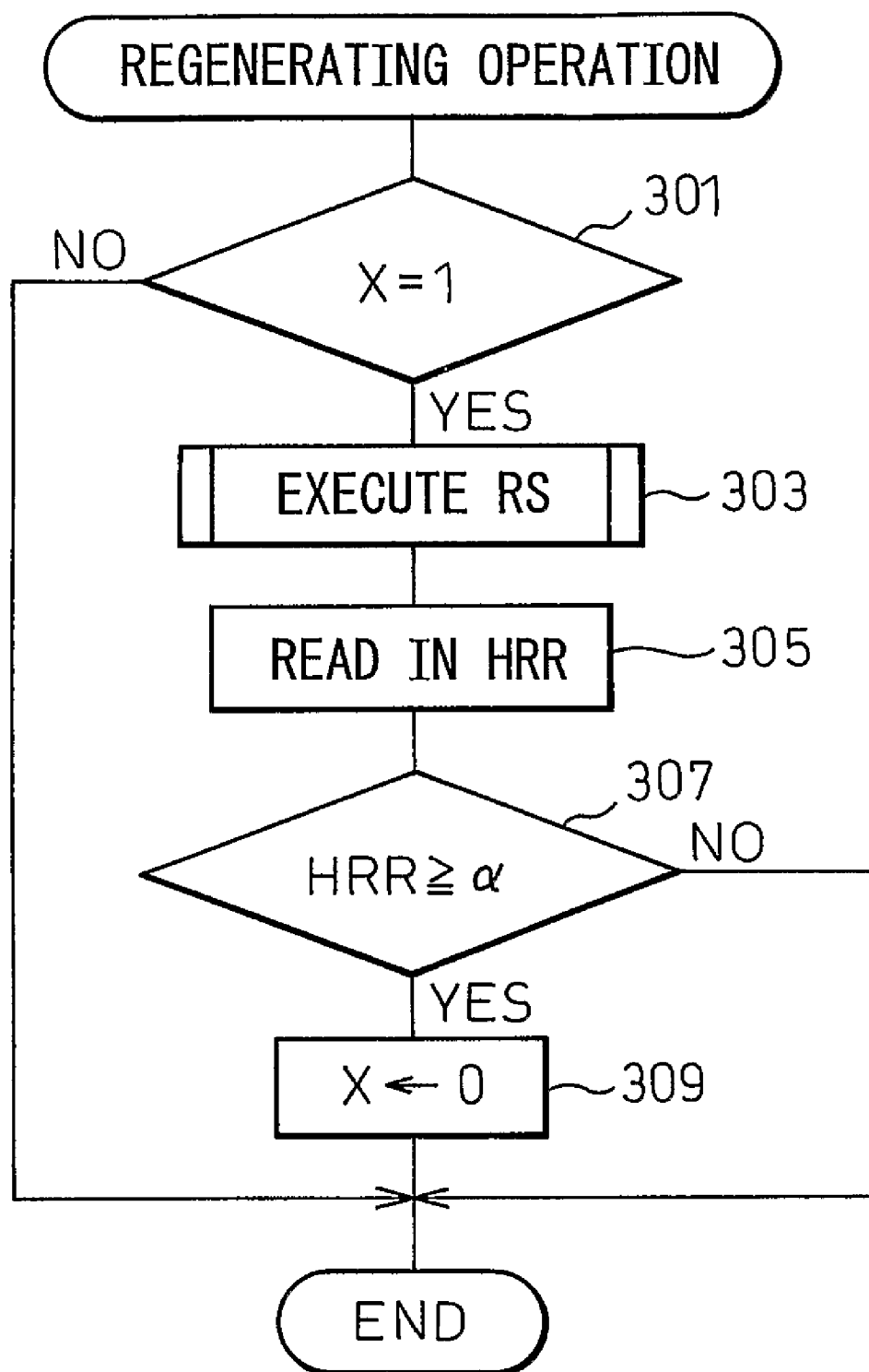


Fig.4

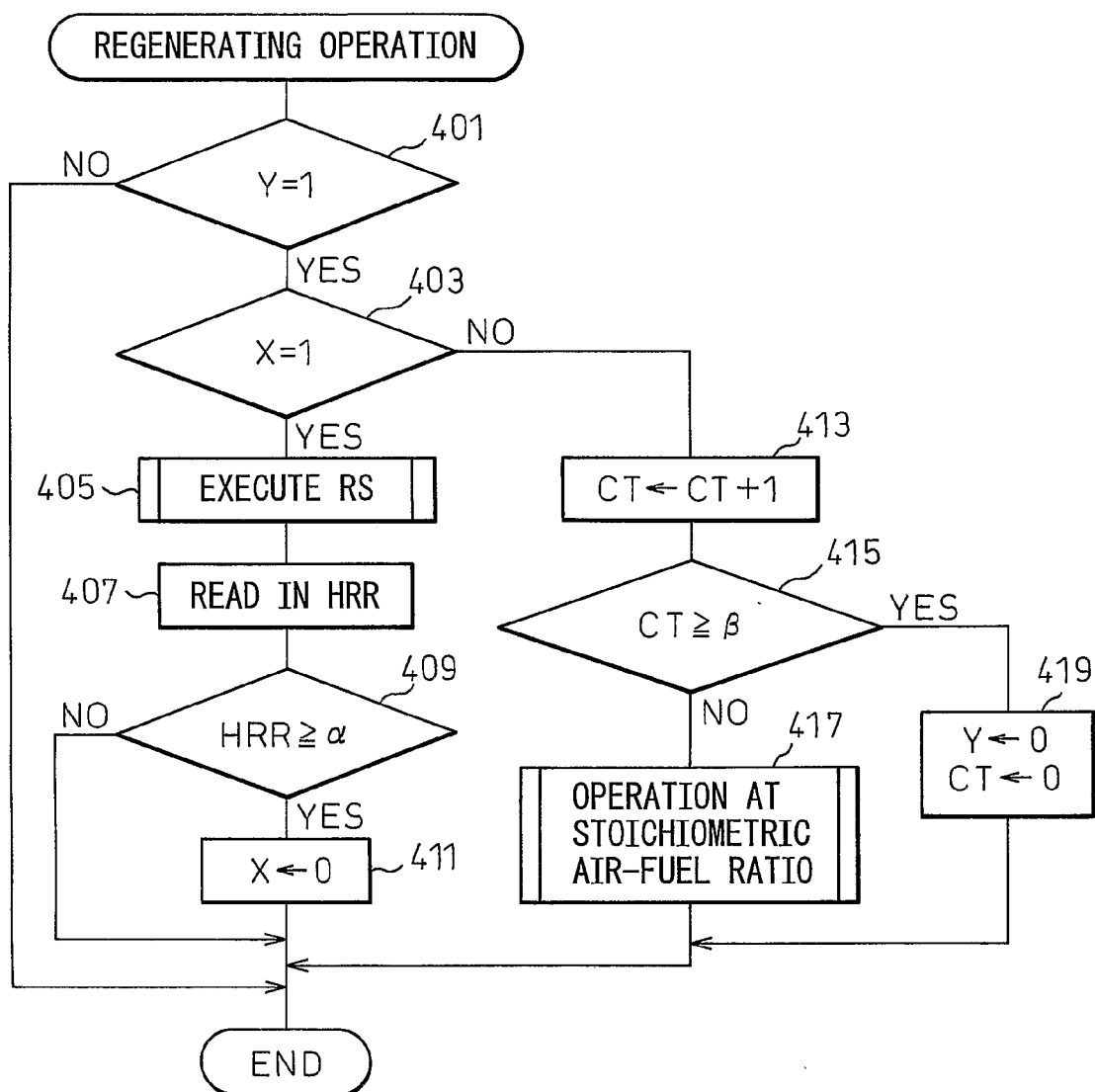


Fig. 5

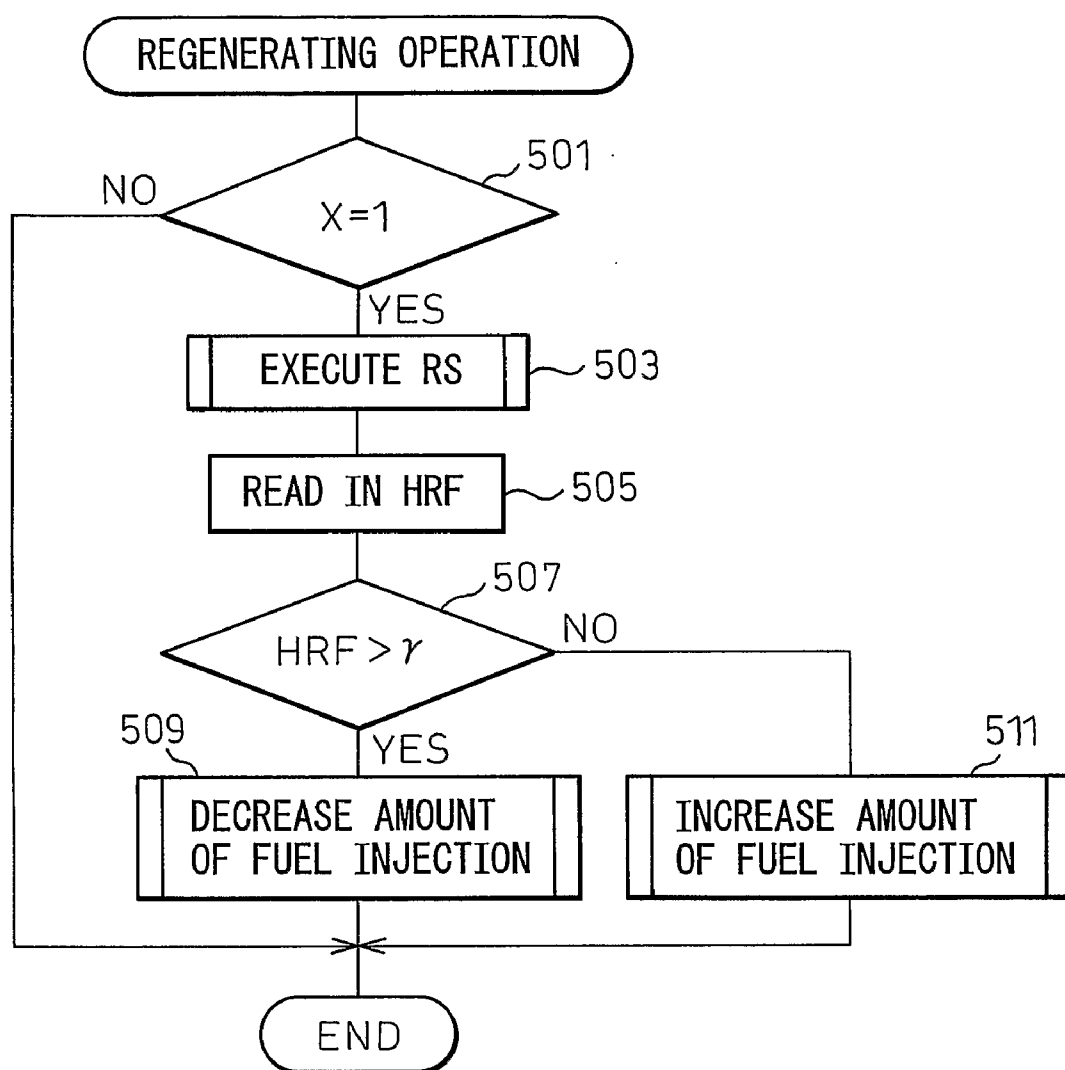


Fig.6

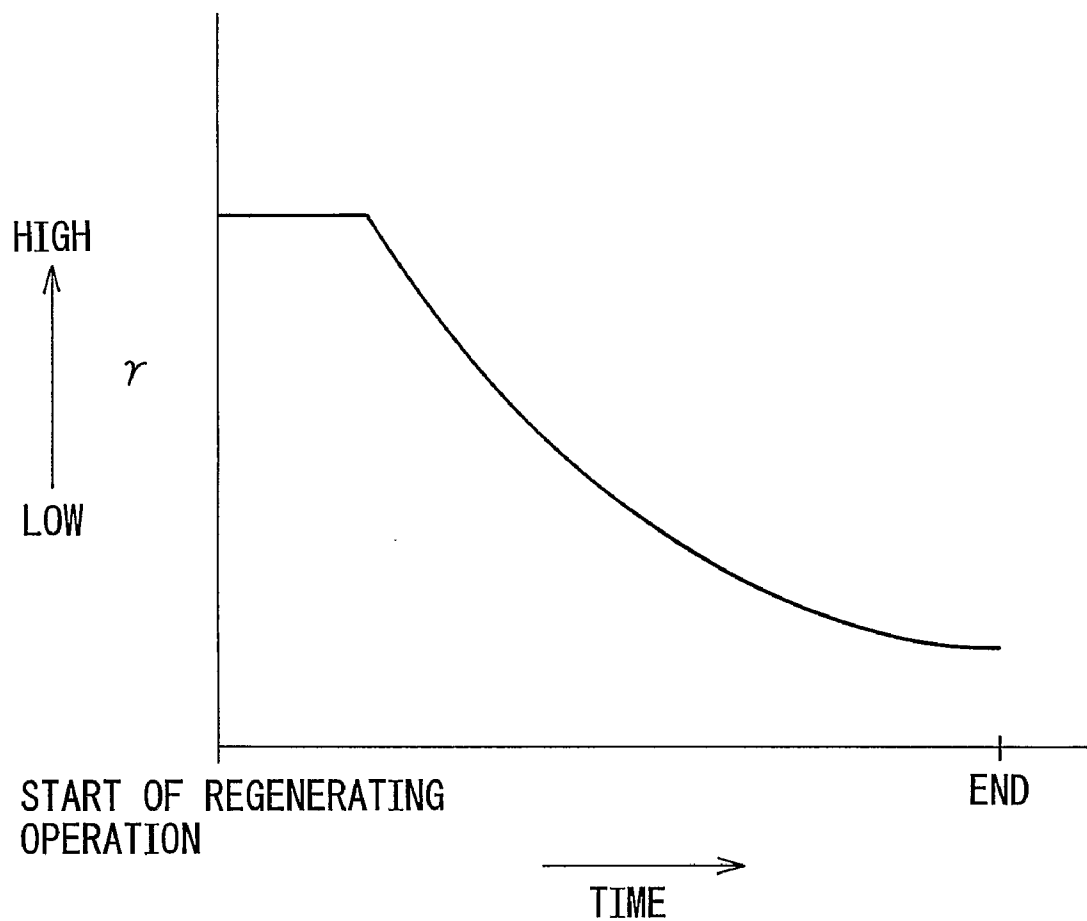


Fig.7

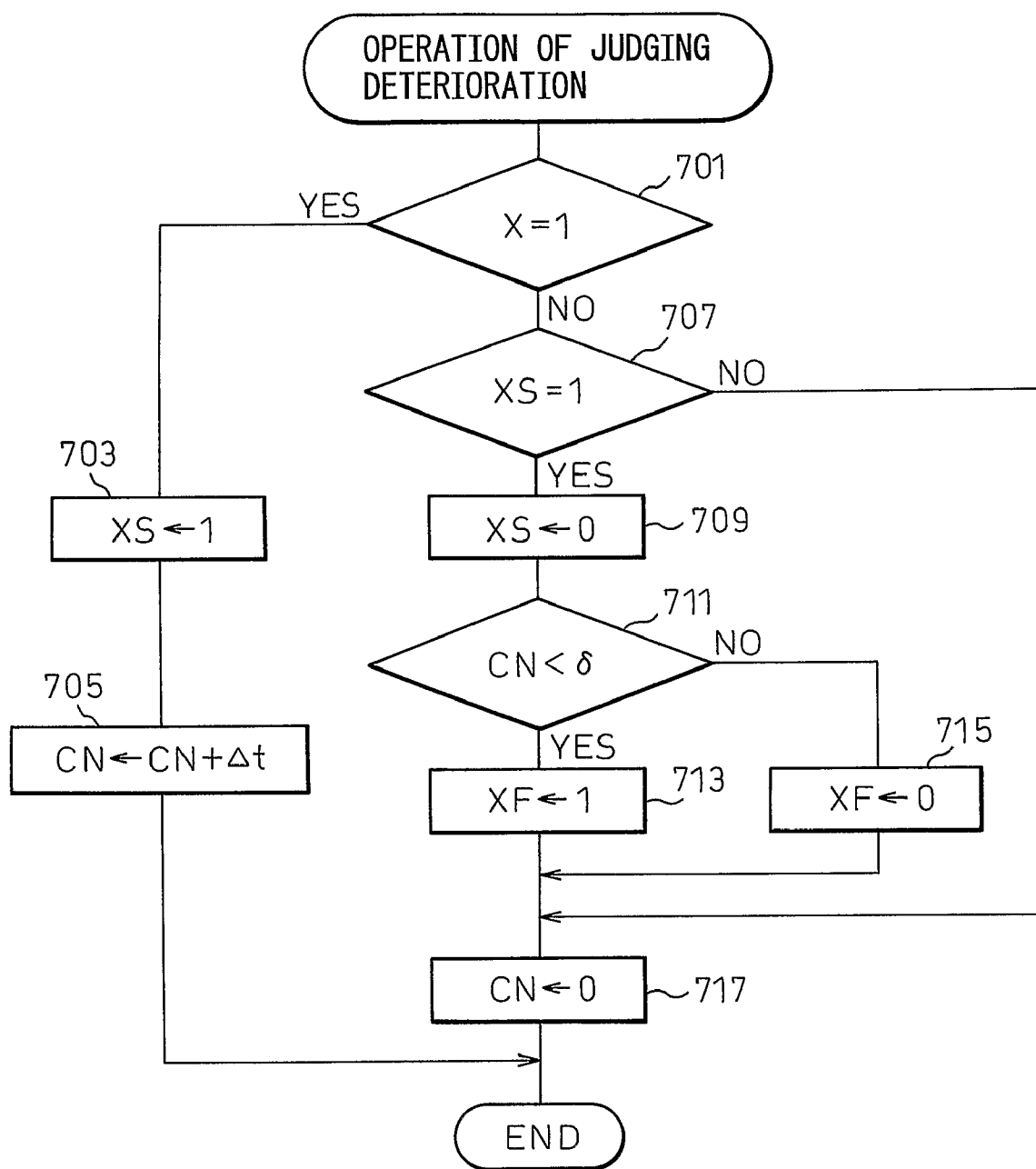


Fig.8

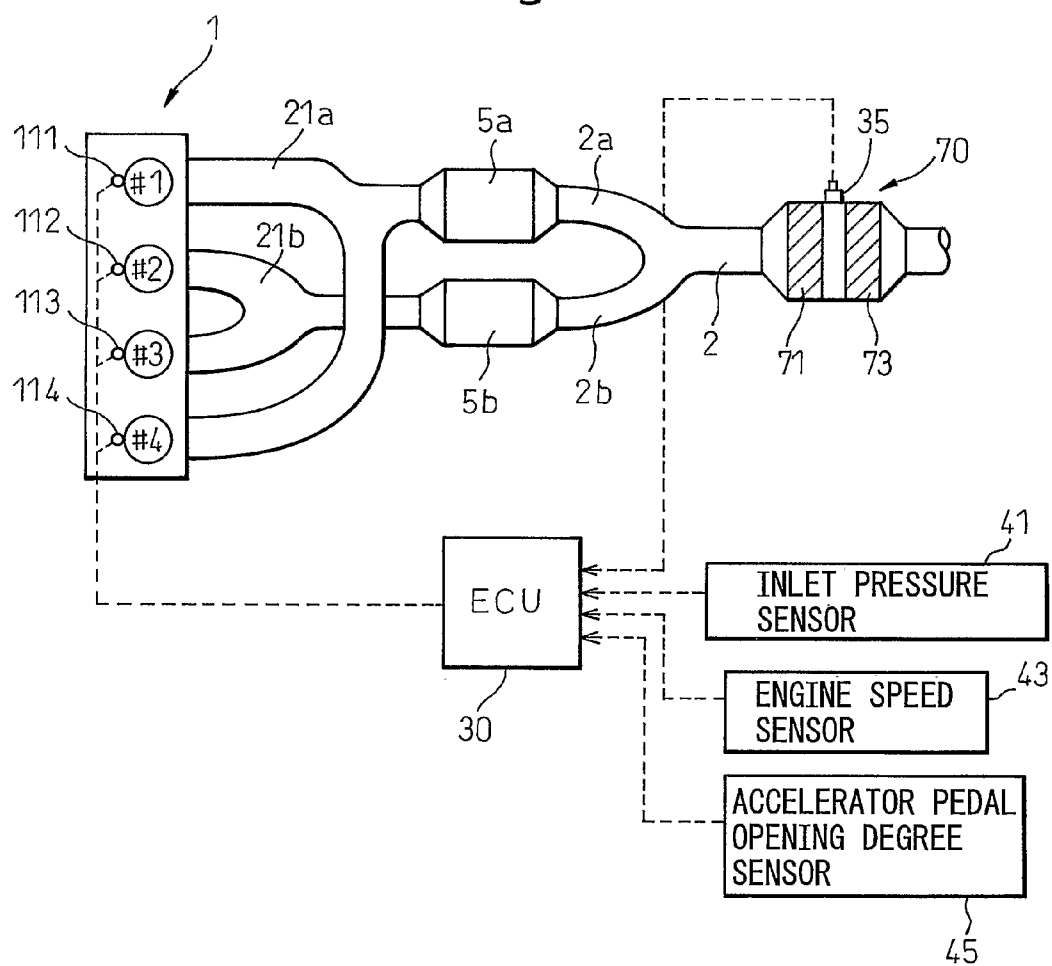
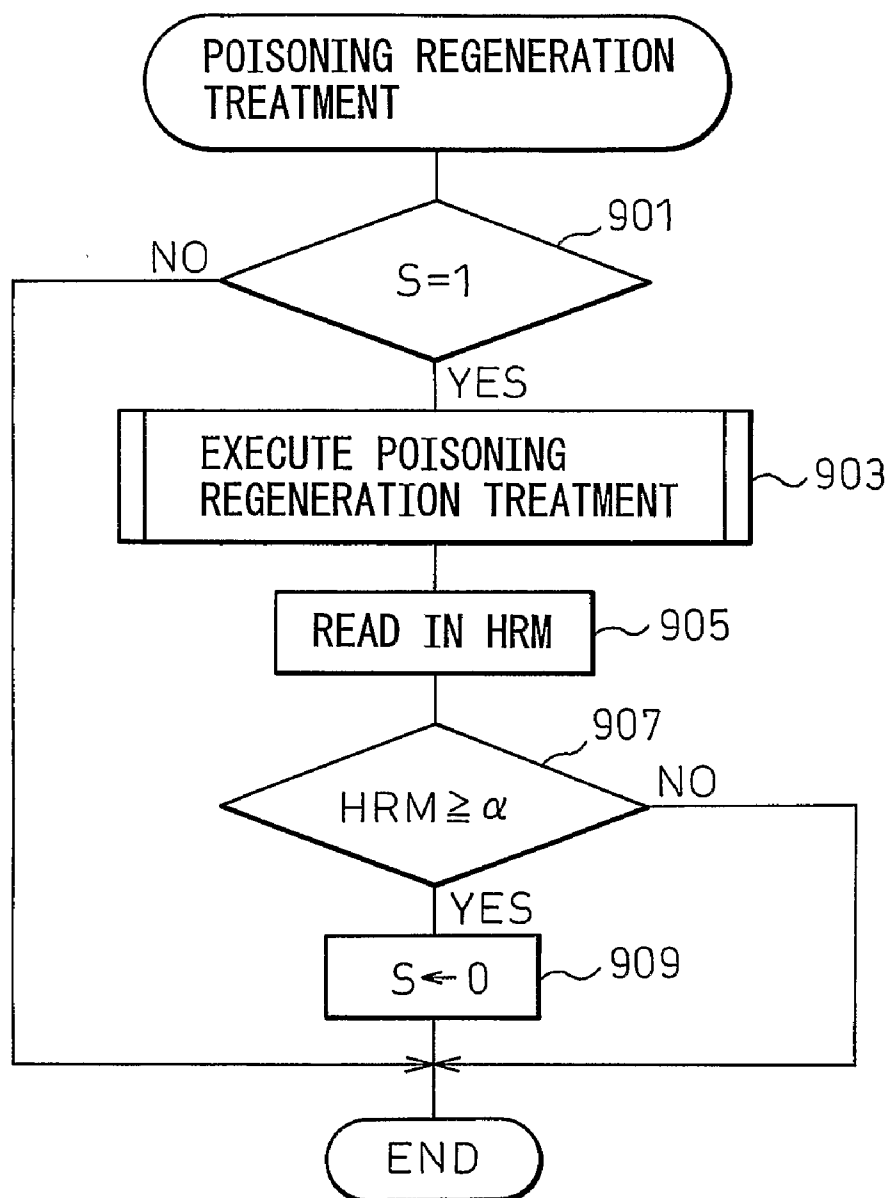


Fig.9



LIST OF REFERENCES

- 1 Engine body
- 2 Exhaust gas passage
- 5a, 5b Start catalyst
- 7, 71, 73 NO_x occluding and reducing catalyst
- 30 ECU (Electric control unit)
- 31, 33, 35 H₂ sensor
- 70 Converter

EXHAUST GAS PURIFYING DEVICE FOR INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

[0001] The present invention relates to an exhaust gas purifying device for an internal combustion engine. More particularly, the present invention relates to an exhaust gas purifying device for an internal combustion engine in which an NO_x occluding and reducing catalyst is used.

BACKGROUND ART

[0002] An exhaust gas purifying device for an internal combustion engine which includes an NO_x occluding and reducing catalyst is well known in the art. An NO_x occluding and reducing catalyst occludes NO_x components in the exhaust gas when the air-fuel ratio of exhaust gas flowing into the catalyst is lean and reduces NO_x occluded in the catalyst by reduction using the reducing component in the exhaust gas when the air-fuel ratio of the exhaust gas flowing into the catalyst is rich or stoichiometric air-fuel ratio. In this connection, the term "occlusion" used in this specification includes both the concept of adsorption and absorption.

[0003] When the air-fuel ratio is lean, an NO_x occluding and reducing catalyst occludes NO_x components, which are contained in the exhaust gas, in the occlusion material such as BaO, in the form of nitric acid ions. Therefore, when an amount of NO_x, which has been occluded in an NO_x occluding and reducing catalyst, is increased, the occlusion material is saturated with NO_x, and it becomes difficult for catalyst to occlude NO_x contained in the exhaust gas.

[0004] Therefore, in the exhaust gas purifying device in which an NO_x occluding and reducing catalyst is used, every time an amount of NO_x occluded in the NO_x occluding and reducing catalyst is increased, a rich spike operation is conducted in which exhaust gas of a rich air-fuel ratio is supplied to the NO_x occluding and reducing catalyst for a short period of time, so that NO_x occluded by the catalyst can be reduced and purified. This rich-spike technique is described in, for example, Japanese Patent Publication No. 2600492.

[0005] When the air-fuel ratio of the exhaust gas becomes a stoichiometric air-fuel ratio or a rich air-fuel ratio, an amount of reducing components such as CO and an amount of HC components contained in the exhaust gas are sharply increased. NO_x desorbed from the occlusion material of the NO_x occluding and reducing catalyst reacts with CO, HC and so forth and is reduced to N₂ and, therefore, the amount of NO_x occluded in the NO_x occluding and reducing catalyst decreases. Thus, it becomes possible for the NO_x occluding and reducing catalyst to occlude NO_x again under the condition of a lean air-fuel ratio.

[0006] As described above, the rich spike operation, which is conducted for the reduction and purification of NO_x occluded in the NO_x occluding and reducing catalyst (this reduction and purification of NO_x occluded in the NO_x occluding and reducing catalyst is hereinafter referred to as "regeneration of the NO_x occluding and reducing catalyst") is accompanied by the rich air-fuel ratio operation of an engine and also accompanied by the addition of fuel or a reducing agent into the exhaust gas. Accordingly, if the regenerating operation is continued even after the regenerating operation of the NO_x occluding and reducing catalyst has been com-

pleted, the fuel consumption of the engine is increased, or the emission is deteriorated by the discharge of the reducing agent.

[0007] Therefore, it is necessary to judge that the regeneration of the NO_x occluding and reducing catalyst has been completed, that is, it is necessary to judge that all of the occluded NO_x has been reduced and purified, and it is also necessary to complete the regenerating operation when the regeneration has been completed.

[0008] For this purpose, Japanese Patent Publication No. 2692380 discloses an exhaust gas purifying device in which an O₂ sensor is disposed on the downstream side of the exhaust gas passage of the NO_x occluding and reducing catalyst. The output of the O₂ sensor changes according to whether the air-fuel ratio of exhaust gas is rich or lean. According to the output of this O₂ sensor, the completion of the regeneration of the NO_x occluding and reducing catalyst is judged.

[0009] As described above, when exhaust gas of a rich air-fuel ratio flows into the NO_x occluding and reducing catalyst at the time of a rich spike operation, components such as HC, CO and so forth contained in the exhaust gas are consumed in order to reduce NO_x occluded in the NO_x occluding and reducing catalyst. In the other words, HC, CO and so forth are oxidized by oxygen contained in NO_x. Therefore, even when an exhaust gas of a rich air-fuel ratio flows into the NO_x occluding and reducing catalyst while NO_x is being reduced by the NO_x occluding and reducing catalyst, HC, CO and so forth are oxidized by oxygen, which has been desorbed from the NO_x occluding and reducing catalyst. Therefore, the air-fuel ratio of exhaust gas on the downstream side of the NO_x occluding and reducing catalyst is maintained at the stoichiometric air-fuel ratio. Then, when the regeneration of the NO_x occluding and reducing catalyst is completed and all NO_x is reduced, the components of HC, CO and so forth contained in the exhaust gas are not oxidized by the NO_x occluding and reducing catalyst. This causes the air-fuel ratio of exhaust gas on the downstream side of the NO_x occluding and reducing catalyst to become a rich air-fuel ratio which is the same as that on the upstream side.

[0010] That is, the air-fuel ratio of exhaust gas on the downstream side of the NO_x occluding and reducing catalyst does not become a rich air-fuel ratio right after the start of the rich spike operation but it is maintained at a value close to the stoichiometric air-fuel ratio, and when all of NO_x occluded in the NO_x occluding and reducing catalyst has been reduced, that is, only when the regeneration of the NO_x occluding and reducing catalyst has been completed, the air-fuel ratio of exhaust gas on the downstream side of the NO_x occluding and reducing catalyst is changed to a rich air-fuel.

[0011] According to the apparatus disclosed in Japanese Patent Publication No. 2692380, the completion of the regeneration of the NO_x occluding and reducing catalyst is judged as follows. An output of an O₂ sensor, which is disposed on the downstream side of the NO_x occluding and reducing catalyst, is monitored. When it is detected that an output of an O₂ sensor is changed from a stoichiometric air-fuel ratio to a rich air-fuel ratio at the time of the rich spike operation, it is judged that regeneration of the NO_x occluding and reducing catalyst is completed.

[0012] In this connection, hydrogen has a high reducing capacity compared with CO. Therefore, when an appropriate amount of hydrogen is supplied to the NO_x occluding and reducing catalyst at the time of reducing and purifying the

NO_x occluded in the NO_x occluding and reducing catalyst, a reducing rate of NO_x occluded in the NO_x occluding and reducing catalyst is increased, and NO_x can be effectively reduced and purified in a short period of time.

[0013] It is known that hydrogen is generated by the combustion of fuel in an engine when the air-fuel ratio is rich. Further, a method is known in which hydrogen from another source is added to exhaust gas in addition to hydrogen generated in the process of a rich air-fuel ratio operation of a usual engine.

[0014] For example, Japanese Unexamined Utility Model Publication (Kokai) No. 2002-47919 discloses a method in which the NO_x occlusion capacity of the NO_x occluding and reducing catalyst is judged by utilizing a reducing capacity of hydrogen which is a strong reducing agent.

[0015] As hydrogen has a high reducing capacity, if NO_x is occluded in the catalyst, hydrogen components in the exhaust gas flowing into the NO_x occluding and reducing catalyst are consumed by reacting with NO_x occluded in the catalyst and hydrogen components do not flow out onto the downstream side of the NO_x occluding and reducing catalyst as long as NO_x occluded in the NO_x occluding and reducing catalyst exists.

[0016] Accordingly, in the case where the exhaust gas of a rich air-fuel ratio containing hydrogen is supplied to the NO_x occluding and reducing catalyst, a point of time at which hydrogen starts flowing out into the exhaust gas on the downstream side of the NO_x occluding and reducing catalyst can be thought to be a point of time at which all of the NO_x occluded in the NO_x occluding and reducing catalyst has been reduced and purified. Accordingly, a period of time from the start of the rich spike operation to the detection of hydrogen components on the downstream side corresponds to the amount of NO_x occluded in the NO_x occluding and reducing catalyst. Accordingly, it can be judged that the longer this period of time, the larger the amount of NO_x occluded in the NO_x occluding and reducing catalyst.

[0017] The technique disclosed in Japanese Unexamined Patent Publication (Kokai) No. 2002-47919 utilizes the phenomenon explained above for judging the completion of the regeneration of the NO_x occluding and reducing catalyst.

[0018] In Japanese Unexamined Patent Publication (Kokai) No. 2002-47919, H₂ sensors for detecting hydrogen in the exhaust gas are disposed on both the upstream side and the downstream side of the NO_x occluding and reducing catalyst. At the time of reducing and purifying the occluded NO_x, according to a difference of time from the detection of hydrogen by the upstream H₂ sensor to the detection of hydrogen by downstream H₂ sensor, it is judged whether or not an amount of NO_x occluded in the NO_x occluding and reducing catalyst is decreased, that is, it is judged whether or not the NO_x occluding and reducing catalyst is deteriorated.

[0019] Japanese Unexamined Patent Publication (Kokai) No. 2003-120383 discloses a method for controlling the air-fuel ratio based on the concentration of hydrogen component in the exhaust gas of the internal combustion engine. In this publication, in order to prevent the occurrence of a case in which an error is caused in an output of an oxygen sensor disposed on the downstream side of a three way catalyst by hydrogen generated by the three way catalyst at the time of operation of a rich air-fuel ratio of a stoichiometric air-fuel ratio and, in order to prevent the occurrence of a case in which air-fuel ratio control is conducted according to the output of the oxygen sensor is affected by the error, a hydrogen sensor

is disposed on the downstream side of the three way catalyst and air-fuel ratio control is corrected based on the concentration of hydrogen components in the exhaust gas measured by the hydrogen sensor.

[0020] As explained above, in the case where the NO_x occluding and reducing catalyst is regenerated by the rich spike operation, in order to prevent an increase in the fuel consumption of an engine, it is necessary to accurately judge that the regeneration of the NO_x occluding and reducing catalyst has been completed.

[0021] However, as described in Japanese Patent Publication No. 2692380, when the time of the completion of the regeneration of the NO_x occluding and reducing catalyst is judged at the time of a rich spike operation based on the output of the oxygen sensor disposed on the downstream side of the NO_x occluding and reducing catalyst, it is difficult to accurately judge the time of the completion of the regeneration in some cases.

[0022] As explained later, in order to reduce NO_x by HC, CO and so forth in the exhaust gas at the time of a rich spike operation, it is necessary for the catalyst component such as platinum (Pt) contained in the NO_x occluding and reducing catalyst to function as a reducing catalyst. However, in the case where a large amount of HC components are contained in the exhaust gas, the HC components are adsorbed onto a surface of the catalyst. Therefore, the surface of the catalyst is covered with the HC components, and it becomes difficult for the catalyst components to function as a reducing catalyst, that is, a problem of covering is caused on the catalyst components.

[0023] Therefore, in the case where a large amount of HC components are contained in the rich air-fuel ratio exhaust gas supplied to the NO_x occluding and reducing catalyst at the time of rich spike operation, a portion of NO_x occluded in the NO_x occluding and reducing catalyst and a portion of HC components contained in the exhaust gas, without reacting each other, flow out to the downstream side of the NO_x occluding and reducing catalyst.

[0024] When HC components contained in the rich air-fuel ratio exhaust gas passes through the NO_x occluding and reducing catalyst without reacting with NO_x and flow out onto the downstream side of the catalyst as described above, the oxygen sensor disposed on the downstream side of the catalyst judges that the air-fuel ratio of the exhaust gas becomes rich. Therefore, when the completion of the regeneration of the NO_x occluding and reducing catalyst is judged according to the output of the oxygen sensor disposed on the downstream side of the catalyst as described in Japanese Patent Publication No. 2692380, problems may occur. Namely, although the regeneration is not actually completed, the air-fuel ratio of the exhaust gas detected by the oxygen sensor becomes a rich air-fuel ratio, and it is erroneously judged that the regeneration is completed, and the rich spike operation is terminated. When the regenerating operation is terminated while the regeneration of the NO_x occluding and reducing catalyst has not been sufficiently carried out, the NO_x occluding and reducing catalyst has to resume the occlusion of NO_x before the NO_x occlusion capacity thereof has not been sufficiently regenerated. This results in insufficient exhaust gas purification and deterioration of emission.

[0025] As described above, supplying hydrogen components is effective for the regeneration of the NO_x occluding and reducing catalyst. However, when the NO_x occluding and reducing catalyst is regenerated by supplying hydrogen com-

ponents to the NO_x-occluding and reducing catalyst, unless an appropriate amount of hydrogen components are supplied, it is difficult to sufficiently regenerate the NO_x occluding and reducing catalyst, and the exhaust gas can not be sufficiently purified.

[0026] According to the techniques disclosed in Japanese Unexamined Utility Model Publications (Kokai) No. 2002-47919 and 2003-120383, hydrogen components in the exhaust gas are detected by the H₂ sensors. However, no consideration is given to controlling an amount of H₂ components contained in the exhaust gas supplied to the catalyst at the time of regenerating the NO_x-occluding and reducing catalyst.

DISCLOSURE OF THE INVENTION

[0027] In view of the problems explained above, an object of the present invention is to provide an exhaust gas purifying device for an internal combustion engine in which an NO_x-occluding and reducing catalyst is appropriately regenerated even in the case where a relatively large amount of HC is contained in exhaust gas so that the exhaust gas can be sufficiently purified.

[0028] In order to achieve the above object, according to the invention described in claim 1, there is provided an exhaust gas purifying device for an internal combustion engine comprising: an NO_x-occluding and reducing catalyst disposed in an exhaust passage of an internal combustion engine, the NO_x-occluding and reducing catalyst occluding NO_x contained in exhaust gas by one of the absorption and the adsorption or by both the absorption and the adsorption when an air-fuel ratio of the exhaust gas flowing into the catalyst is lean, and reducing and purifying the occluded NO_x with a reducing component contained in the exhaust gas when an air-fuel ratio of the exhaust gas is a stoichiometric air-fuel ratio or a rich air-fuel ratio; and an H₂ sensor disposed in at least one of the exhaust gas passages on the inlet side and the outlet side of the NO_x-occluding and reducing catalyst for detecting a hydrogen component concentration of the exhaust gas, wherein the exhaust gas purifying device executes a regenerating operation in which the exhaust gas of a rich air-fuel ratio or a stoichiometric air-fuel ratio is supplied to the NO_x-occluding and reducing catalyst for a predetermined period of time when the NO_x-occluding and reducing catalyst is to reduce and purify the NO_x occluded in the NO_x-occluding and reducing catalyst and, during the regenerating operation, the exhaust gas purifying device controls the air-fuel ratio of the exhaust gas flowing into the NO_x-occluding and reducing catalyst based on the hydrogen component concentration in the exhaust gas detected by the H₂ sensor.

[0029] Namely, according to the invention described in claim 1, an air-fuel ratio of exhaust gas is controlled according to the hydrogen component concentration detected by the H₂ sensor disposed on at least one of the upstream side and the downstream side of the NO_x-occluding and reducing catalyst.

[0030] For example, as described later, when the hydrogen component concentration detected by the H₂ sensor disposed on the downstream side of the NO_x-occluding and reducing catalyst is used, it is possible to judge the completion time of the regenerating operation of the NO_x-occluding and reducing catalyst. Therefore, accordingly, the regenerating operation can be terminated at a time exactly the same as the completion of the regeneration of the NO_x-occluding and reducing catalyst and the air-fuel ratio of the exhaust gas can

be returned to a lean air-fuel ratio. Therefore, the NO_x-occluding and reducing catalyst can be appropriately regenerated.

[0031] The hydrogen component concentration in the exhaust gas changes in accordance with the air-fuel ratio of the exhaust gas. Accordingly, when the air-fuel ratio of the exhaust gas is controlled based on the hydrogen component concentration in the exhaust gas detected by the H₂ sensor disposed on the upstream side of the NO_x-occluding and reducing catalyst, for example, the hydrogen component concentration in the exhaust gas flowing into the NO_x-occluding and reducing catalyst can be controlled to be an appropriate value and an appropriate amount of hydrogen components can be supplied to the NO_x-occluding and reducing catalyst. Therefore, the NO_x-occluding and reducing catalyst can be appropriately regenerated.

[0032] According to the invention described in claim 2, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in an exhaust gas passage on an outlet side of the NO_x-occluding and reducing catalyst and, at the time of executing the regenerating operation, a time for terminating the regenerating operation is judged according to a hydrogen component concentration in the exhaust gas detected by the outlet side H₂ sensor.

[0033] According to the invention described in claim 2, the H₂ sensor is disposed at least on the outlet side (the downstream side) of the NO_x-occluding and reducing catalyst. When the rich spike operation for conducting the regeneration of the NO_x-occluding and reducing catalyst is started, as the air-fuel ratio of the exhaust gas flowing into the NO_x-occluding and reducing catalyst is made to be a rich air-fuel ratio, the hydrogen component concentration in the exhaust gas is increased.

[0034] However, as the reducing capability of hydrogen is very strong, when hydrogen flows into the NO_x-occluding and reducing catalyst, it can directly reduce NO_x without the assistance of the reducing catalyst. Therefore, even if a relatively large amount of HC components are contained in the exhaust gas and the covering of the catalyst, in which a catalyst surface is covered with HC, occurs and the function of the reducing catalyst is deteriorated, hydrogen contained in the exhaust gas is consumed by reacting with NO_x.

[0035] Therefore, even in the case where the covering is caused on the catalyst by HC components in the exhaust gas, as long as the regeneration of the NO_x-occluding and reducing catalyst is not completed, hydrogen is not detected by the H₂ sensor on the downstream side of the catalyst.

[0036] In the present invention, in the case where hydrogen components are detected by the H₂ sensor disposed on the downstream side of the NO_x-occluding and reducing catalyst in the process of the rich spike operation, it is judged that the regeneration of the NO_x-occluding and reducing catalyst has been completed, and the regenerating operation is terminated.

[0037] Due to the foregoing, in the present invention, even in the case where a relatively large amount of HC components are contained in the exhaust gas, it is possible to accurately judge that the regeneration of the NO_x-occluding and reducing catalyst has been completed, and the regenerating operation can be terminated. Therefore, it is possible to prevent the occurrence of a problem in which the exhaust gas purifying capacity is deteriorated when the regenerating operation is terminated before the regeneration of the NO_x-occluding and reducing catalyst completes. Further, it is possible to prevent the occurrence of a problem in which the regenerating opera-

tion is continued even after the completion of the regeneration and the fuel consumption is increased. Therefore, according to the present invention, the NO_x occluding and reducing catalyst can be appropriately regenerated.

[0038] According to the invention described in claim 3, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in at least an exhaust gas passage on the outlet side of the NO_x occluding and reducing catalyst, the regenerating operation includes operations for first supplying the exhaust gas of a rich air-fuel ratio to the NO_x occluding and reducing catalyst and then supplying the exhaust gas of a stoichiometric air-fuel ratio to the NO_x occluding and reducing catalyst and, the time at which the exhaust gas air-fuel ratio is switched from the rich air-fuel ratio to the stoichiometric air-fuel ratio is determined in accordance with the hydrogen component concentration detected by the outlet side H₂ sensor.

[0039] That is, in the invention described in claim 3, the regenerating operation is conducted by switching the air-fuel ratio into two steps of a rich air-fuel ratio and a stoichiometric air-fuel ratio. For example, in some cases, a high occlusion type NO_x occluding and reducing catalyst in which the NO_x occlusion capacity thereof is enhanced is used. The high occlusion type NO_x occluding and reducing catalyst is an NO_x occluding and reducing catalyst in which an amount of NO_x occluded per unit volume is greatly increased by using an occlusion material having a high affinity with NO_x. In the high occlusion type NO_x occluding and reducing catalyst, as the affinity of the occlusion material with NO_x is high, after a relatively large amount of NO_x has been desorbed at the initial stage of regeneration, a rate of desorption of NO_x is decreased. Therefore, in order to completely regenerate the NO_x occluding and reducing catalyst, it is necessary to conduct the regenerating operation over a long period of time.

[0040] Therefore, in the regenerating operation of the high occlusion type NO_x occluding and reducing catalyst, in order to suppress an increase in the fuel consumption, exhaust gas of a rich air-fuel ratio is supplied to the NO_x occluding and reducing catalyst at the initial stage of the regenerating operation so as to desorb a relatively large amount of NO_x and the catalyst is reduced and purified. After that, the air-fuel ratio of the exhaust gas is switched over to a stoichiometric air-fuel ratio and the NO_x occluding and reducing catalyst is completely regenerated over a relatively long period of time.

[0041] In this case, while a relatively large amount of NO_x is being desorbed from the NO_x occluding and reducing catalyst at the initial stage of the rich spike operation, all hydrogen components contained in the rich air-fuel ratio exhaust gas are consumed by reacting with NO_x; however, when the desorption of the initial stage is finished and a rate of desorption of NO_x is decreased, a portion of the hydrogen components contained in the exhaust gas flow out onto the downstream side of the NO_x occluding and reducing catalyst without reacting with NO_x.

[0042] In the present invention, when the hydrogen components are detected by the downstream side H₂ sensor, the air-fuel ratio of the exhaust gas is changed over from the rich air-fuel ratio to the stoichiometric air-fuel ratio. Therefore, even when the high occlusion type NO_x occluding and reducing catalyst is used, the NO_x occluding and reducing catalyst can be appropriately regenerated without continuing the rich air-fuel ratio operation for an unnecessary long period of time at the time of the regenerating operation.

[0043] In this connection, when the air-fuel ratio of the exhaust gas is changed to the stoichiometric air-fuel ratio, hydrogen is seldom generated. Therefore, hydrogen is not detected by the downstream side H₂ sensor.

[0044] According to the invention described in claim 4, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in an exhaust gas passage on the inlet side of the NO_x occluding and reducing catalyst, and at the time of executing the regenerating operation, an air-fuel ratio of the exhaust gas flowing into the NO_x occluding and reducing catalyst is controlled so that a hydrogen component concentration in the exhaust gas detected by the inlet side H₂ sensor can be a predetermined target value.

[0045] That is, in the invention described in claim 4, the H₂ sensor disposed on the inlet side (the upstream side) of the NO_x occluding and reducing catalyst detects a concentration of the hydrogen components flowing into the NO_x occluding and reducing catalyst, and the air-fuel ratio of the exhaust gas is controlled by feedback control in such a manner that the detected concentration of the hydrogen components becomes a target value.

[0046] Therefore, when the regenerating operation is conducted, an appropriate amount of hydrogen can be supplied to the NO_x occluding and reducing catalyst at all times, and the NO_x occluding and reducing catalyst can be appropriately regenerated.

[0047] According to the invention described in claim 5, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 4, wherein the target value of the hydrogen component concentration is high at the time of starting the regenerating operation, and then the target value of the hydrogen component concentration is gradually decreased with the lapse of time.

[0048] That is, in the invention described in claim 5, the concentration of the hydrogen components flowing into the NO_x occluding and reducing catalyst is set according to the NO_x desorbing rate at which NO_x is desorbed from the NO_x occluding and reducing catalyst at the time of the regenerating operation.

[0049] When the air-fuel ratio of the exhaust gas flowing into the NO_x occluding and reducing catalyst is changed from lean to rich at the time of the regenerating operation, an amount of NO_x, which is desorbed from the NO_x occluding and reducing catalyst, is large immediately after the air-fuel ratio is changed over to a rich air-fuel ratio. Then, the amount of NO_x is decreased with the lapse of time.

[0050] Accordingly, the hydrogen component concentration in the exhaust gas flowing into the NO_x occluding and reducing catalyst at the time of the regenerating operation is set high at the time of starting the regenerating operation and then is gradually decreased. Due to the foregoing, the hydrogen components can be supplied according to an amount of NO_x desorbed from the NO_x occluding and reducing catalyst, and the NO_x occluding and reducing catalyst can be appropriately regenerated.

[0051] According to the invention described in claim 6 there is provided an exhaust gas purifying device for an internal combustion engine according to claim 2, wherein according to the lapse of time from the start of the regenerating operation to the end of the regenerating operation which is judged according to the hydrogen component concentration

in the exhaust gas detected by the downstream side H_2 sensor, a degree of deterioration of the NO_x occluding and reducing catalyst is judged.

[0052] That is, in the invention described in claim 6, a completion of the regeneration of the NO_x occluding and reducing catalyst is judged based on the hydrogen component concentration detected by the downstream side H_2 sensor. At the same time, according to the lapse of time from the start of the regenerating operation to the completion of the regeneration of the NO_x occluding and reducing catalyst, a degree of deterioration of the NO_x occluding and reducing catalyst is judged.

[0053] The required time from the start to the completion of the regenerating operation corresponds to an amount of the occluded NO_x of the NO_x occluding and reducing catalyst. When the NO_x occluding and reducing catalyst is deteriorated and an amount of NO_x capable of being occluded is decreased accordingly, the required time for the completion of regeneration is shortened.

[0054] Therefore, in the case where the required time is decreased to a predetermined judgment value, it is possible to judge that the NO_x occluding and reducing catalyst has been deteriorated.

[0055] Due to the foregoing, according to the present invention, while the NO_x occluding and reducing catalyst is being appropriately regenerated, a degree of deterioration of the NO_x occluding and reducing catalyst can be accurately judged.

[0056] According to the invention described in claim 7, there is provided an exhaust gas purifying device for an internal combustion engine comprising an NO_x occluding and reducing catalyst disposed in an exhaust passage of an internal combustion engine, the NO_x occluding and reducing catalyst occluding NO_x contained in exhaust gas by one of the absorption and the adsorption or by both the absorption and the adsorption when an air-fuel ratio of the exhaust gas flowing into the catalyst is lean and reducing and purifying the occluded NO_x with a reducing component contained in the exhaust gas when an air-fuel ratio of the exhaust gas is a stoichiometric air-fuel ratio or a rich air-fuel ratio, the exhaust gas purifying device for an internal combustion engine further comprising: NO_x occluding and reducing catalysts arranged in series with each other on the upstream side and the downstream side of the exhaust gas passage of the internal combustion engine; and an H_2 sensor, which is arranged in series to each other in the exhaust gas passage between the upstream side NO_x occluding and reducing catalyst and the downstream side NO_x occluding and reducing catalyst, for detecting a hydrogen component concentration in the exhaust gas, wherein, when the NO_x occluding and reducing catalyst is to reduce and purify NO_x occluded during a lean air-fuel ratio operation of the engine, at the time of executing a regenerating operation in which the exhaust gas of a rich air-fuel ratio or a stoichiometric air-fuel ratio is supplied to the NO_x occluding and reducing catalyst for a predetermined period of time, according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor, an air-fuel ratio of the exhaust gas flowing into the upstream side NO_x occluding and reducing catalyst is controlled.

[0057] That is, in the invention described in claim 7, two NO_x occluding and reducing catalysts are arranged in series in the exhaust gas passage, and the H_2 sensor is disposed

between the upstream side NO_x occluding and reducing catalyst and the downstream side NO_x occluding and reducing catalyst.

[0058] In the so-called tandem type catalyst in which two NO_x occluding and reducing catalysts are arranged in series, an amount of the occluded NO_x in the lean air-fuel operation of the upstream side (the front stage) NO_x occluding and reducing catalyst and that of the downstream side (the rear stage) NO_x occluding and reducing catalyst are different from each other. Further, a state of the progress of the regeneration at the time of the regenerating operation of the upstream side (the front stage) NO_x occluding and reducing catalyst and that of the downstream side (the rear stage) NO_x occluding and reducing catalyst are different from each other. Therefore, when the H_2 sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst, if the regenerating operation is controlled based on the hydrogen component concentration detected by the thus arranged H_2 sensor, problems may occur.

[0059] In the present invention, as the H_2 sensor is arranged between the front stage NO_x occluding and reducing catalyst and the rear stage NO_x occluding and reducing catalyst, and as the regenerating operation is controlled based on the hydrogen component concentration contained in the exhaust gas detected by the thus arranged H_2 sensor, the NO_x occluding and reducing catalyst can be appropriately regenerated.

[0060] According to the invention described in claim 8, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 7, wherein an NO_x occlusion capacity of the upstream side NO_x occluding and reducing catalyst is larger than that of the downstream side NO_x occluding and reducing catalyst, an O_2 storage capacity of the upstream side NO_x occluding and reducing catalyst is smaller than that of the downstream side NO_x occluding and reducing catalyst, and an amount of platinum components carried on the upstream side NO_x occluding and reducing catalyst is larger than that carried on the downstream side NO_x occluding and reducing catalyst.

[0061] That is, according to the invention described in claim 8, an NO_x occlusion capacity of the upstream side NO_x occluding and reducing catalyst is larger than that of the downstream side NO_x occluding and reducing catalyst, while an O_2 storage capacity of the upstream side NO_x occluding and reducing catalyst is smaller than that of the downstream side NO_x occluding and reducing catalyst. Further, an amount of platinum components carried on the upstream side NO_x occluding and reducing catalyst is larger than that of the downstream side NO_x occluding and reducing catalyst.

[0062] Further, when an amount of supporting Pt of the upstream side NO_x occluding and reducing catalyst is increased, most of NO contained in the exhaust gas is oxidized on the catalyst and changed into NO_2 . Therefore, in addition to the setting in which an amount of the occluded NO_x per unit volume on the upstream side is set large, the upstream side NO_x occluding and reducing catalyst can effectively occlude and reduce and purify NO_x .

[0063] In the case where two NO_x occluding and reducing catalysts are arranged in series to each other, almost all of the occlusion and reducing purification is executed by the upstream side NO_x occluding and reducing catalyst. Therefore, by setting NO_x occlusion capacity (the maximum amount of NO_x can be occluded in the NO_x occluding and reducing catalyst) of the upstream side NO_x occluding and reducing catalyst at large value, an amount of NO_x capable of

being treated by the upstream side NO_x -occluding and reducing catalyst can be increased. Further, by decreasing a storage capacity of storing O_2 in the upstream side NO_x -occluding and reducing catalyst, hydrogen components and HC and CO components contained in the exhaust gas are not reacted with oxygen occluded in the catalyst in the upstream side NO_x -occluding and reducing catalyst during the regenerating operation, and most of HC and CO components in the exhaust gas are used for reducing NO_x .

[0064] According to the invention described in claim 9, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 7 or 8, wherein a time for terminating the regenerating operation is judged according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor at the time of executing the regenerating operation.

[0065] According to the invention described in claim 9, the timing at which the regenerating operation is to be terminated is judged according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor disposed between the front stage and the rear stage NO_x -occluding and reducing catalyst.

[0066] In the tandem type NO_x -occluding and reducing catalyst, at the time of operation of a lean air-fuel ratio, most of NO_x contained in the exhaust gas is occluded in the front stage NO_x -occluding and reducing catalyst. Therefore, the amount of NO_x occluded in the front stage NO_x -occluding and reducing catalyst is remarkably larger than the amount of NO_x occluded in the rear stage NO_x -occluding and reducing catalyst. For the above reasons, in the tandem type NO_x -occluding and reducing catalyst, it is important to sufficiently regenerate the front stage NO_x -occluding and reducing catalyst.

[0067] In the tandem type NO_x -occluding and reducing catalyst, it is usual that the rear stage NO_x -occluding and reducing catalyst is given a relatively large O_2 storage capacity so that the rear stage NO_x -occluding and reducing catalyst can be given a function of the three way catalyst. The O_2 storage capacity is a capacity that the NO_x -occluding and reducing catalyst occludes oxygen when the air-fuel ratio of the exhaust gas is lean and desorbs occluded oxygen when the air-fuel ratio of the exhaust gas becomes rich. Therefore, even if a relatively large amount of H_2 components flows into the rear stage NO_x -occluding and reducing catalyst after the regeneration of the front stage NO_x -occluding and reducing catalyst is completed, the hydrogen components are oxidized by oxygen desorbed from the rear stage NO_x -occluding and reducing catalyst. Thus, no hydrogen components are detected in the exhaust gas at the outlet of the rear stage NO_x -occluding and reducing catalyst.

[0068] Therefore, when the hydrogen sensor is arranged at the outlet of the rear stage NO_x -occluding and reducing catalyst, it is difficult to accurately judge the time at which the regenerating operation is to be terminated. That is, although the NO_x -occlusion capacity of the tandem type NO_x -occluding and reducing catalyst as a whole is regenerated when the regeneration of the front stage NO_x -occluding and reducing catalyst is completed, no hydrogen components are detected in the exhaust gas on the rear stage downstream side. Accordingly, the time at which the regenerating operation is to be terminated can not be accurately judged.

[0069] According to the present invention, as the H_2 sensor is arranged between the front stage catalyst and the rear stage catalyst of the tandem type NO_x -occluding and reducing

catalyst and the time at which the regenerating operation is to be terminated is judged based on the output of the H_2 sensor, the tandem type NO_x -occluding and reducing catalyst can be appropriately regenerated.

[0070] According to the invention described in claim 10, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 7 or 8, wherein the device further executes a poisoning regeneration treatment in order to desorb sulfur oxide occluded in the NO_x -occluding and reducing catalyst together with NO_x from the NO_x -occluding and reducing catalyst by making the air-fuel ratio of the exhaust gas flowing into the NO_x -occluding and reducing catalyst to be a rich air-fuel ratio and, at the same time, raising the temperature thereof and wherein an air-fuel ratio of the exhaust gas flowing into the upstream side NO_x -occluding and reducing catalyst is controlled according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor in the process of executing the poisoning regeneration treatment.

[0071] That is, according to the invention described in claim 10, the poisoning regeneration treatment control is executed according to an output of the H_2 sensor arranged between the front stage and the rear stage NO_x -occluding and reducing catalyst.

[0072] When the air-fuel ratio is lean, the NO_x -occluding and reducing catalyst occludes SO_x in the exhaust gas in the same manner as that of NO_x . However, as the affinity of SO_x with the occlusion material is strong, once SO_x is occluded in the NO_x -occluding and reducing catalyst, it is difficult for SO_x to be desorbed from the NO_x -occluding and reducing catalyst by a mere rich spike operation conducted for the regeneration of the NO_x -occluding and reducing catalyst. Therefore, once SO_x is occluded in the NO_x -occluding and reducing catalyst, SO_x is gradually accumulated in the catalyst.

[0073] Therefore, when an amount of SO_x occluded in the NO_x -occluding and reducing catalyst is increased, an amount of NO_x capable of being occluded in the NO_x -occluding and reducing catalyst is decreased, that is, the NO_x -occlusion capacity is decreased. That is, a so-called SO_x poisoning is caused.

[0074] In order to solve the problem of SO_x poisoning, it is necessary to conduct a poisoning regeneration treatment in which, while the air-fuel ratio of the exhaust gas flowing into the NO_x -occluding and reducing catalyst is being maintained at a rich air-fuel ratio, a temperature of the NO_x -occluding and reducing catalyst is raised. Even in the poisoning regeneration treatment, when hydrogen components are supplied to the NO_x -occluding and reducing catalyst, an SO_x desorbing rate, at which SO_x is desorbed from the NO_x -occluding and reducing catalyst, is increased, and the poisoning regeneration treatment can be completed in a short period of time.

[0075] In this case, in order to appropriately conduct the poisoning regeneration treatment, for example, it is necessary to appropriately judge the timing for terminating the poisoning regeneration treatment in the same manner as that of the regenerating operation of the NO_x -occluding and reducing catalyst. However, in the tandem type NO_x -occluding and reducing catalyst, there are some peculiar conditions in which, for example, an amount of SO_x occluded in the front stage NO_x -occluding and reducing catalyst is different from an amount of SO_x occluded in the rear stage NO_x -occluding and reducing catalyst. Therefore, if the poisoning regeneration treatment is conducted according to the output of the H_2

sensor disposed on the downstream side of the NO_x-occluding and reducing catalyst, it is difficult to appropriately conduct the poisoning regeneration treatment.

[0076] According to the present invention, the poisoning regeneration treatment control is executed according to an output of the H₂ sensor arranged between the front stage and the rear stage NO_x-occluding and reducing catalyst of the tandem type. Therefore, in addition to the regeneration of the NO_x-occluding and reducing catalyst, the poisoning regeneration treatment can be appropriately executed.

[0077] According to the invention described in claim 11 there is provided an exhaust gas purifying device for an internal combustion engine according to claim 10, wherein a time for terminating the poisoning regeneration treatment is judged according to the hydrogen component concentration in the exhaust gas detected by the H₂ sensor at the time of executing the poisoning regeneration treatment.

[0078] As hydrogen has a very strong reducing capability, when hydrogen components are contained in the exhaust gas flowing into the NO_x-occluding and reducing catalyst at the time of the poisoning regeneration treatment, the hydrogen components are immediately reacted with SO_x desorbed from the NO_x-occluding and reducing catalyst. Therefore, in the same manner as that of the rich spike operation, even at the time of the poisoning regeneration treatment, while SO_x is being desorbed, the hydrogen components contained in the exhaust gas are consumed for reducing SO_x. Therefore, no hydrogen flows out into the exhaust gas on the downstream side of the NO_x-occluding and reducing catalyst.

[0079] Accordingly, in the same manner as that of the judgment of the completion of the regeneration of the NO_x-occluding and reducing catalyst, even at the time of the poisoning regeneration treatment, the completion of the desorption of SO_x can be judged according to an output of the H₂ sensor disposed on the downstream side of the NO_x-occluding and reducing catalyst.

[0080] However, in this case, in the tandem type NO_x-occluding and reducing catalyst, most of SO_x contained in the exhaust gas is occluded in the front stage NO_x-occluding and reducing catalyst. Therefore, it is important that the front stage NO_x-occluding and reducing catalyst is sufficiently regenerated from the SO_x poisoning.

[0081] In the tandem type NO_x-occluding and reducing catalyst, the rear stage NO_x-occluding and reducing catalyst carries a relatively large amount of ceria (Ce) component in order to enhance the O₂ storage capacity thereof. Therefore, SO_x contained in the exhaust gas is bonded to ceria in the rear stage NO_x-occluding and reducing catalyst, and sulfate is formed. In this case, a bonding strength of ceria and SO_x is not so strong and SO_x can be relatively easily desorbed from the rear stage NO_x-occluding and reducing catalyst.

[0082] Therefore, in the poisoning regeneration treatment of the tandem type NO_x-occluding and reducing catalyst, at a point of time when the poisoning regeneration treatment of the front stage NO_x-occluding and reducing catalyst is terminated, all SO_x has already been desorbed from the rear stage NO_x-occluding and reducing catalyst. Accordingly, the poisoning regeneration treatment can be performed more effectively by judging the timing for terminating the poisoning regeneration treatment based on the state of desorption of SO_x from the front stage NO_x-occluding and reducing catalyst.

[0083] According to the present invention, at the time of the poisoning regeneration treatment, when hydrogen is detected

in the exhaust gas by the H₂ sensor arranged at a position between the front stage and the rear stage NO_x-occluding and reducing catalyst, the poisoning regeneration treatment is terminated. Therefore, not only the regeneration of the NO_x-occluding and reducing catalyst but also the regeneration from SO_x poisoning can be appropriately executed.

[0084] According to the invention described in claim 12, there is provided an exhaust gas purifying device for an internal combustion engine according to claim 8, wherein a degree of deterioration of the upstream side NO_x-occluding and reducing catalyst is judged according to a period of time from the start of the regenerating operation to the end of the regenerating operation which is judged according to the hydrogen component concentration in the exhaust gas detected by the H₂ sensor.

[0085] That is, according to the invention described in claim 12, a degree of deterioration of the front stage NO_x-occluding and reducing catalyst of the tandem type NO_x-occluding and reducing catalyst is judged by the output of the H₂ sensor arranged between the front stage and the rear stage.

[0086] In the tandem type NO_x-occluding and reducing catalyst, the NO_x-occlusion capacity of the front stage NO_x-occluding and reducing catalyst is more important than the NO_x-occlusion capacity of the rear stage NO_x-occluding and reducing catalyst. On the other hand, the deterioration of the tandem type NO_x-occluding and reducing catalyst advances from the front stage NO_x-occluding and reducing catalyst. Therefore, in order to accurately judge a degree of the deterioration of the tandem type NO_x-occluding and reducing catalyst, the hydrogen sensor must be arranged not on the downstream side of the rear stage NO_x-occluding and reducing catalyst but between the front and the rear stage NO_x-occluding and reducing catalyst. In the present invention, the H₂ sensor is arranged at a position between the front stage and the rear stage NO_x-occluding and reducing catalyst. Therefore, according to the present invention, the tandem type NO_x-occluding and reducing catalyst can be appropriately regenerated. At the same time, it is possible to accurately judge a degree of the deterioration of the front stage NO_x-occluding and reducing catalyst.

[0087] From the foregoing explanation, it will be understood that, according to the invention described in each claim, by controlling the regenerating operation of the NO_x-occluding and reducing catalyst based on a concentration of hydrogen components contained in exhaust gas detected by H₂ sensor, the NO_x-occluding and reducing catalyst can be appropriately regenerated.

BRIEF DESCRIPTION OF DRAWINGS

[0088] FIG. 1 is an arrangement view showing an outline of an embodiment in which the present invention is applied to an internal combustion engine for automobile use,

[0089] FIG. 2 is a view schematically showing a relation between a hydrogen component concentration in exhaust gas and an air-fuel ratio of exhaust gas,

[0090] FIG. 3 is a flowchart for explaining an operation of regenerating an NO_x-occluding and reducing catalyst in the first embodiment of the present invention,

[0091] FIG. 4 is a flowchart for explaining an operation of regenerating an NO_x-occluding and reducing catalyst in the second embodiment of the present invention,

[0092] FIG. 5 is a flowchart for explaining an operation of regenerating an NO_x-occluding and reducing catalyst in the third embodiment of the present invention,

[0093] FIG. 6 is a view for explaining a setting of a hydrogen concentration target value at the time of NO_x occluding and reducing catalyst regenerating operation in the fourth embodiment of the present invention.

[0094] FIG. 7 is a flowchart for explaining a deterioration judgment operation of an NO_x -occluding and reducing catalyst in the fifth embodiment of the present invention.

[0095] FIG. 8 is a view similar to FIG. 1, for explaining a structure of the sixth embodiment of the present invention and

[0096] FIG. 9 is a flowchart for explaining a poisoning regeneration treatment of an NO_x occluding and reducing catalyst in the seventh embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0097] By referring to the accompanying drawings, an embodiment of the present invention will be explained below.

[0098] FIG. 1 is an arrangement view showing an outline of an embodiment in which the present invention is applied to an internal combustion engine for automobile use.

[0099] In FIG. 1, reference numeral 1 is an internal combustion engine for an automobile. In this embodiment, the engine 1 is a 4-cylinder gasoline engine having 4 cylinders from #1 to #4. In the cylinders from #1 to #4, fuel injection valves 111 to 114 for injecting fuel are arranged in inlet ports of the respective cylinders. The engine 1 is a lean-burn engine which is capable of operating in a wide air-fuel ratio range from a rich air-fuel ratio to a lean air-fuel ratio and, in this embodiment, is operated at a lean air-fuel ratio in a greater part of the operation region.

[0100] In this embodiment, the cylinders #1 to #4 are divided into two cylinder groups. In this case, each cylinder group is composed of two cylinders, the ignition timings of which are not adjacent to each other. For example, in the embodiment shown in FIG. 1, the ignition order of igniting the cylinders is 1-3-4-2. Therefore, the cylinders #1 and #4 compose a cylinder group, and the cylinders #2 and #3 compose a cylinder group. An exhaust port of each cylinder is connected to an exhaust manifold of each cylinder. The exhaust manifold of each cylinder is connected to an exhaust passage of each cylinder group.

[0101] In FIG. 1, reference numeral 21a is an exhaust manifold for connecting exhaust ports of a group of cylinders composed of the cylinders #1 and #4 to an individual exhaust passage 2a, and reference numeral 21b is an exhaust manifold for connecting exhaust ports of a group of cylinders composed of the cylinders #2 and #3 to an individual exhaust passage 2b. In this embodiment, in the individual exhaust passages 2a, 2b, start catalysts 5a, 5b composed of three way catalysts are respectively arranged. The individual exhaust passages 2a, 2b join to a common exhaust passage 2 on the downstream side of the start catalysts.

[0102] In the common exhaust passage 2, a converter 70 is arranged in which the NO_x -occluding and reducing catalyst 7 described later is accommodated in a casing.

[0103] In FIG. 1, reference numerals 31, 33 are an upstream side H_2 sensor and a downstream side H_2 sensor which are respectively disposed on an inlet side and an outlet side of the converter 70 arranged in the exhaust passage 2. These H_2 sensors detect a concentration of hydrogen (H_2) components contained in the exhaust gas.

[0104] In FIG. 1, reference numeral 30 is an electronic control unit (ECU) of the engine 1. In this embodiment, ECU 30 is a known type microcomputer including RAM, ROM and

CPU. ECU 30 conducts basic control of the engine such as ignition timing control, fuel injection control and so forth.

[0105] In addition to the basic control stated above, ECU 30 in this embodiment conducts a regenerating operation in which every time an amount of NO_x occluded in the NO_x occluding and reducing catalyst 7 is increased to a predetermined amount, amounts of fuel injection of the injection valves 111 to 114 are increased so as to operate the engine for a short period of time at a rich air-fuel ratio or a stoichiometric air-fuel ratio. In this way, the NO_x occluding and reducing catalyst 7 desorbs the occluded NO_x so that the exhaust gas can be reduced and purified.

[0106] Further, in the present embodiment, ECU 30 controls an air-fuel ratio of the exhaust gas at the time of regenerating operation according to the concentration of hydrogen components in the exhaust gas at the inlet or the outlet of the NO_x occluding and reducing catalyst 7 detected by the H_2 sensors 31, 33 at the time of conducting the above regenerating operation.

[0107] In order to conduct control as described above, the following signals, which are parameters expressing a state of operation of the engine, are inputted into input ports of ECU 30. The signals to be inputted are: a signal corresponding to the inlet pressure of the engine sent from the inlet pressure sensor 41 provided in the engine inlet manifold not shown; a signal corresponding to the engine speed sent from the engine speed sensor 43 arranged close to the engine crank shaft not shown; and a signal expressing an amount of the depression of the brake pedal (a degree of opening of the acceleration pedal) sent from the acceleration opening degree sensor 45 arranged close to the acceleration pedal not shown of the engine 1. Further, concentrations of H_2 contained in the exhaust gas at the inlet and the outlet of the NO_x occluding and reducing catalyst 7 sent from the H_2 sensors 31, 33 are inputted.

[0108] Output ports of ECU 30 are connected to the fuel injection valves 111 to 114 of the cylinders via a fuel injection circuit not shown in order to control an amount of fuel injection into each cylinder and a fuel injection timing.

[0109] Next, the NO_x -occluding and reducing catalyst 7 of this embodiment will be explained below.

[0110] The NO_x occluding and reducing catalyst 7 of the present embodiment is composed as follows. For example, a catalyst substrate made of cordierite, which is formed into a honeycomb shape, is used. On a surface of this catalyst substrate, an aluminum coating is provided. On this aluminum layer, one component selected from a group of alkali metal such as potassium K, sodium Na, lithium Li and cesium Cs, alkali earth metal such as barium Ba and calcium Ca, and rare earth metal such as lanthanum La, cerium Ce and yttrium Y, and one component selected from precious metal such as platinum Pt are carried. In the case where an air-fuel ratio of the exhaust gas flowing into the NO_x -occluding and reducing catalyst is lean, the NO_x occluding and reducing catalyst absorbs NO_x (NO_2 , NO) in the exhaust gas in the form of nitric acid ions NO_3^- . When the oxygen concentration of the exhaust gas is lowered, the NO_x occluding and reducing catalyst discharges occluded NO_x , in other words, the NO_x occluding and reducing catalyst conducts occluding and desorbing action of NO_x in accordance with the air-fuel ratio of the exhaust gas.

[0111] That is, in the case where the engine 1 is operated at a lean air-fuel ratio and the exhaust gas flowing into the NO_x occluding and reducing catalyst is at a lean air-fuel ratio, NO_x

(NO) contained in the exhaust gas is oxidized, for example, on platinum Pt and changed into NO₂ and further oxidized to form nitric acid ions. In the case where, for example, BaO is used as the occlusion material, these nitric acid ions are absorbed in the occlusion material and bonded to barium oxide BaO and diffused in the occlusion material in the form of nitric acid ions NO₃⁻. Therefore, in the lean atmosphere, NO_x contained in the exhaust gas is occluded in the NO_x occluding and reducing catalyst in the form of nitrate.

[0112] In the case where the oxygen concentration in the exhaust gas flowing into the NO_x occluding and reducing catalyst is decreased, that is, in the case where the air-fuel ratio of the exhaust gas becomes a stoichiometric air-fuel ratio or a rich air-fuel ratio, an amount of generation of nitric ions on platinum Pt is decreased. Therefore, the reaction proceeds in a reverse direction, and the nitric acid ions NO₃⁻ in the occlusion material are desorbed from the occlusion material in the form of NO₂. In this case, when components functioning as a reducing agent such as CO or H₂ exist in the exhaust gas or in the case where HC components exist in the exhaust gas, NO₂ is reduced on platinum Pt by these components.

[0113] In the atmosphere of a lean air-fuel ratio, the NO_x occluding and reducing catalyst 7 occludes NO_x contained in the exhaust gas in the occlusion material (for example, BaO) in the form of nitric ions by the aforementioned mechanism. Therefore, as the nitric acid ion concentration in the occlusion material is increased, it becomes difficult for new nitric acid ions to be absorbed in the occlusion material, and a ratio of purifying NO_x in the exhaust gas is lowered. When an amount of NO_x occluded in the NO_x occluding and reducing catalyst reaches an upper limit, that is, the nitric acid ion concentration in the occlusion material is increased and reaches the saturated concentration, it becomes completely difficult for the NO_x occluding and reducing catalyst to occlude NO_x contained in the exhaust gas.

[0114] In the present embodiment, ECU 30 estimates an amount of NO_x generated from the engine 1 per unit time based on the parameters which represent the engine operating condition, such as an engine inlet pressure, an engine speed and an acceleration pedal opening degree, using relationships established by experiment in advance. A predetermined percentages of the amount of NO_x generated by the engine per unit time is considered to correspond the amount of NO_x occluded in the NO_x occluding and reducing catalyst per unit time. Therefore, the amount of NO_x occluded by the NO_x occluding and reducing catalyst 7 can be calculated by integrating the predetermined percentage of the amount of NO_x generated by the engine per unit time. Thus the integrated value, which is referred to as an NO_x counter, corresponds to an amount of NO_x which has been occluded in the NO_x occluding and reducing catalyst 7.

[0115] Further, ECU 30 regenerates the NO_x occluding and reducing catalyst 7 by carrying out a rich spike operation in which the exhaust gas of a rich air-fuel ratio is supplied to the NO_x occluding and reducing catalyst 7 by operating the engine 1 in a short period at a rich air-fuel ratio each time this NO_x counter reaches a predetermined value. Due to the foregoing, the NO_x occluding and reducing catalyst 7 always occludes NO_x under the condition that an amount of occluded NO_x is relatively low. Accordingly, it is possible to maintain the NO_x purifying ratio of the NO_x occluding and reducing catalyst to be high.

[0116] In this connection, instead of estimating the NO_x occlusion amount of the NO_x occluding and reducing catalyst 7 with the NO_x counter as described above, the timing for executing the rich-spike can be judged by disposing an NO_x sensor for detecting the NO_x concentration in the exhaust gas on the downstream side of the NO_x occluding and reducing catalyst 7.

[0117] When the NO_x occlusion amount of the NO_x occluding and reducing catalyst 7 is increased, the NO_x purifying capacity of the NO_x occluding and reducing catalyst 7 is lowered, and a part of NO_x in the exhaust gas passes through the NO_x occluding and reducing catalyst 7 without being occluded therein. Therefore, by disposing a NO_x sensor on the downstream side of the NO_x occluding and reducing catalyst 7, the rich-spike operation may be executed when the concentration of NO_x in the exhaust gas detected by the NO_x sensor increases and reaches a predetermined value (i.e., when the amount of NO_x occluded in the NO_x occluding and reducing catalyst 7 increased).

(1) FIRST EMBODIMENT

[0118] Referring to FIGS. 2 and 3, the first embodiment of the present invention will be explained below.

[0119] As described above, in the present embodiment, each time the NO_x occlusion amount of the NO_x occluding and reducing catalyst 7 reaches a predetermined amount, the rich spike operation is conducted so as to regenerate the NO_x occluding and reducing catalyst 7.

[0120] In order to appropriately regenerate the NO_x occluding and reducing catalyst, it is necessary that the rich spike operation is carried out until the regeneration of the NO_x occluding and reducing catalyst is completed and that the engine operation air-fuel ratio is returned to a lean air-fuel ratio after the regeneration has been completed.

[0121] Conventionally, the completion of the regeneration of the NO_x occluding and reducing catalyst was judged based on the output of an O₂ sensor disposed on the downstream side of the NO_x occluding and reducing catalyst as described in Japanese Patent Publication No. 2692380, and when the air-fuel ratio on the catalyst downstream side detected by the O₂ sensor is changed from a stoichiometric air-fuel ratio to a lean air-fuel ratio in the process of rich spike operation, it is judged that the regeneration of the NO_x occluding and reducing catalyst is completed. The air-fuel ratio of the exhaust gas is returned to the lean air-fuel ratio when the regeneration of the NO_x occluding and reducing catalyst is completed.

[0122] However, as described before, when an amount of HC components contained in the exhaust gas is large, HC components are attached onto a surface of the catalyst component of the NO_x occluding and reducing catalyst, and covering, which deteriorates the catalyst function, is caused. When covering is caused, a portion of the HC components contained in the exhaust gas flowing into the NO_x occluding and reducing catalyst pass through the catalyst without reacting with NO_x. Therefore, on the downstream side of the NO_x occluding and reducing catalyst, even when regeneration of the NO_x occluding and reducing catalyst has not been completed yet, the air-fuel ratio becomes rich.

[0123] Therefore, when the completion of regeneration of the NO_x occluding and reducing catalyst is judged according to an output of the O₂ sensor disposed on the downstream side of the NO_x occluding and reducing catalyst, even if the regeneration of the catalyst has not been completed yet, the rich

spike operation is terminated in some cases. Therefore, the regeneration of the NO_x occluding and reducing catalyst cannot be sufficiently executed.

[0124] Therefore, in the present embodiment, the above problems are solved by terminating the rich-spike operation when it is judged that the regeneration of the NO_x occluding and reducing catalyst is completed using the output of the H₂ sensor disposed on the downstream side of the NO_x occluding and reducing catalyst.

[0125] For example, the water gas shift reaction ($\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$) or steam reforming ($\text{HC} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$) is caused from HC, CO and H₂O which are generated at the time of combustion when the air-fuel ratio of the exhaust gas of the engine becomes rich, and hydrogen is generated. In the case of a usual internal combustion engine, H₂ is generated by the above reaction during a rich air-fuel ratio operation, however, these reactions are further facilitated by a three-way catalyst. Therefore, in the internal combustion engine having the three-way catalyst such as the start catalysts 5a, 5b in the exhaust gas passage on the upstream side of the NO_x occluding and reducing catalyst, a relatively large amount of hydrogen is contained in the exhaust gas during the rich-spike operation for regenerating the NO_x occluding and reducing catalyst.

[0126] Other than the three way catalyst, if a hydrogen generation catalyst which effectively generates the water gas shift reaction or the steam reforming is disposed in the exhaust gas passage, it is also possible to generate hydrogen during the operation of the engine at a rich air-fuel ratio.

[0127] FIG. 2 is a graph showing a relation between the air-fuel ratio of the exhaust gas and the amount of generation of H₂. FIG. 2 shows a relation between the amount of generation of H₂ in the start catalysts 5a, 5b and the air-fuel ratio of the exhaust gas. As shown in FIG. 2, when the air-fuel ratio is lean, the amount of generation of H₂ at the three way catalyst is zero. However, when the air-fuel ratio exceeds the stoichiometric air-fuel ratio and becomes rich, that is, when the air-fuel ratio is decreased, the amount of generation of H₂ at the three way catalyst is substantially linearly increased. Although the actual amounts of generated H₂ are different from each other, the amount of generation of H₂ in the engine combustion chamber and the amount of generation of H₂ in the case of using H₂ generation catalyst instead of the three way catalyst are substantially linearly increased when the air-fuel ratio is decreased.

[0128] The hydrogen component generated at the time of the rich spike operation as described above has a very strong reducing power. Therefore, the thus generated hydrogen component can directly react with NO_x-component without using a catalyst component such as Pt. Therefore, even when a relatively large amount of HC components are contained in the exhaust gas and covering is caused and the catalytic function is deteriorated, the hydrogen components in the exhaust gas excellently react with NO_x which has desorbed from the NO_x occluding and reducing catalyst.

[0129] Therefore, as long as NO_x is desorbed from the NO_x occluding and reducing catalyst, the hydrogen components contained in the exhaust gas are consumed by reacting with NO_x on the NO_x occluding and reducing catalyst. Therefore, the hydrogen components contained in the exhaust gas do not flow out onto the downstream side of the NO_x occluding and reducing catalyst.

[0130] Accordingly, in the case where the hydrogen components contained in the exhaust gas are detected by H₂

sensor 33 disposed on the downstream side of the NO_x occluding and reducing catalyst while the rich spike operation is being executed, it can be judged that the desorption (regeneration) of NO_x from the NO_x occluding and reducing catalyst has been completed.

[0131] In this connection, concerning the H₂ sensor 33 (31) of this embodiment, for example, it is possible to use a Pd/Ni alloy sensor which is especially responsive to hydrogen.

[0132] This type H₂ sensor is manufactured by KK Toyoda Micro Systems and put on the market under the trademark of "H2 scan". However, the sensor to be used in the present embodiment is not limited to the above specific sensor. As long as the sensor can continuously monitor the concentration of H₂ contained in the exhaust gas with a quick response, any sensor can be used in the present embodiment.

[0133] Next, the regenerating operation of the NO_x occluding and reducing catalyst of this embodiment will be explained below.

[0134] FIG. 3 is a flowchart for specifically explaining the regenerating operation of the NO_x occluding and reducing catalyst of this embodiment. This operation is conducted as a routine executed at regular intervals by ECU 30.

[0135] In the operation shown in FIG. 3, in step 301, it is judged whether or not the value of the regenerating operation execution flag X is set at 1. In the flag X, the value is set at 1 when the NO_x occlusion amount of the NO_x occluding and reducing catalyst 7 is increased to a predetermined value in the operation (not shown) separately executed by ECU 30. As described before, in this embodiment, by the NO_x occlusion amount estimating operation (not shown) separately executed, ECU 30 calculates the aforementioned NO_x counter value, which expresses the NO_x occlusion amount of the NO_x occluding and reducing catalyst, at regular intervals. When this NO_x-counter value reaches a predetermined value, the value of the regenerating operation executing flag x is set at 1.

[0136] In the case of X≠1 in step 301, an amount of NO_x occlusion of the NO_x occluding and reducing catalyst 7 has not reached a predetermined value. Therefore, it is unnecessary to regenerate the NO_x occluding and reducing catalyst 7. Accordingly, this operation is immediately terminated. In this case, the rich spike operation is not carried out and the engine 1 continues to conduct the lean air-fuel ratio operation.

[0137] In the case of X=1 in step 301, the program proceeds to step 303 and the rich spike operation (RS) is carried out. In the rich spike operation, the engine 1 operates at a predetermined rich air-fuel ratio. As a result, hydrogen is generated in the engine 1 and the start catalysts 5a, 5b. Therefore, the exhaust gas of a rich air-fuel ratio containing hydrogen components flows into the NO_x occluding and reducing catalyst 7.

[0138] Next, in step 305, the hydrogen component concentration HRR in the exhaust gas on the downstream side of the NO_x occluding and reducing catalyst is read in from the H₂ sensor on the downstream side of the NO_x occluding and reducing catalyst 7. In step 307, it is judged whether or not the hydrogen component concentration HRR is not less than the predetermined value α. In this case, α is a judgment value for preventing the occurrence of an erroneous judgment and set at a positive value close to zero.

[0139] As described before, while NO_x is being desorbed from the NO_x occluding and reducing catalyst 7 at the time of carrying out RS operation, the hydrogen components contained in the exhaust gas is reacted with NO_x and consumed. Therefore, the hydrogen component concentration HRR,

which is detected by the downstream side H_2 sensor 33, becomes zero. When the desorption of NO_x is completed, that is, when the regeneration of the NO_x -occluding and reducing catalyst is completed, hydrogen is detected by the downstream side H_2 sensor 33.

[0140] In this embodiment, when the hydrogen component concentration exceeds the judgment value α in step 307, it is judged that the regeneration of the NO_x -occluding and reducing catalyst 7 is completed, and the program proceeds to step 309 and the value of the regenerating operation executing flag is set at zero. When the value of the regenerating operation executing flag is set at zero, the value of the NO_x counter is returned to zero in the aforementioned NO_x counter calculation operation.

[0141] In the next execution of this operation, the operation is immediately terminated after step 301, and the rich spike operation is terminated and the air-fuel ratio of the exhaust gas is returned to the lean air-fuel ratio.

[0142] On the other hand, in the case of $HRR < \alpha$ in step 307, it is judged that hydrogen components do not flow out onto the downstream side of the NO_x -occluding and reducing catalyst 7 and the regeneration of the NO_x -occluding and reducing catalyst 7 is not completed. Therefore, the execution of this operation is terminated while the value of the flag X is being maintained at 1. Due to the foregoing, the rich spike operation of step 303 is continued even in the next execution of this operation.

[0143] In this embodiment, according to an output of the H_2 sensor 33 disposed on the downstream side of the NO_x -occluding and reducing catalyst 7, the completion of the regeneration of the NO_x -occluding and reducing catalyst 7 is accurately judged and the rich spike operation is terminated, that is, the air-fuel ratio of the exhaust gas is returned to the lean air-fuel ratio. Accordingly, the NO_x -occluding and reducing catalyst 7 can be appropriately regenerated.

[0144] In this connection, in the arrangement shown in FIG. 1, the H_2 sensors 31, 33 are respectively disposed on the upstream side and the downstream side of the NO_x -occluding and reducing catalyst 7. However, of course, the H_2 sensor 33 may be disposed only on the downstream side of the NO_x -occluding and reducing catalyst 7.

(2) SECOND EMBODIMENT

[0145] Next, the second embodiment of the present invention will be explained below.

[0146] In the first embodiment described above, when hydrogen components are detected in the exhaust gas by the H_2 sensor 33 disposed on the downstream side of the NO_x -occluding and reducing catalyst 7 in the process of executing the rich spike operation, the rich spike operation is terminated and the air-fuel ratio of the exhaust gas is immediately changed over to a lean air-fuel ratio. However, the present embodiment is different from the first embodiment at the following points. In the present embodiment, after the rich spike operation is terminated, the air-fuel ratio of the exhaust gas is maintained at the stoichiometric air-fuel ratio for a predetermined period of time, and then the air-ratio is returned to a lean air-fuel ratio.

[0147] As described before, a high-occlusion type NO_x -occluding and reducing catalyst, the NO_x -occlusion capacity of which is enhanced, has been recently used. In the high-occlusion type NO_x -occluding and reducing catalyst, the affinity of the occlusion material with NO_x is high. Therefore after a relatively large amount of NO_x has been desorbed at

the initial stage of the rich spike operation, a rate of desorption of NO_x is decreased. Accordingly, in order to completely regenerate the NO_x -occluding and reducing catalyst, it is necessary to continue the regenerating operation over a long period of time. However, when the engine is operated at a rich air-fuel ratio over a long period of time, a problem is caused that the fuel consumption of the engine is increased. When the rich air-fuel ratio operation is continued under the condition that the rate of desorption of NO_x is low, HC and CO contained in the exhaust gas do not react with NO_x but flow out to the downstream side of the NO_x -occluding and reducing catalyst. Therefore, the exhaust emission is deteriorated. Therefore, in the present embodiment, after a relatively large amount of NO_x has been desorbed from the NO_x -occluding and reducing catalyst in the initial stage, the rich spike operation is completed and the engine is operated at the stoichiometric air-fuel ratio and the NO_x -occluding and reducing catalyst is completely regenerated over a relatively long period of time.

[0148] In the present embodiment, the time at which the rich spike operation is terminated (the time at which the air-fuel ratio is changed over to the stoichiometric air-fuel ratio) is judged according to the output of the H_2 sensor 33 disposed on the downstream side of the NO_x -occluding and reducing catalyst 7.

[0149] That is, while the rich spike operation is being carried out, the exhaust gas of a rich air-fuel ratio containing hydrogen components flows into the NO_x -occluding and reducing catalyst. While NO_x is being desorbed from the NO_x -occluding and reducing catalyst 7, the hydrogen components contained in the exhaust gas is reacted with NO_x and consumed. Therefore, the H_2 sensor 33 disposed on the downstream side does not detect the hydrogen components.

[0150] However, in the case of a high occlusion type NO_x -occluding and reducing catalyst, when the initial desorption of NO_x is finished in the process of executing the spike rich operation and a rate of desorption of NO_x is sharply decreased, the amount of NO_x is low. Therefore, a portion of hydrogen components contained in the exhaust gas flows out onto the downstream side of the catalyst without reacting with NO_x .

[0151] Therefore, in the present embodiment, when NO_x is detected in the exhaust gas by the H_2 sensor 33 disposed on the downstream side at the time of executing the rich spike operation, it is judged that the initial desorption of NO_x from the NO_x -occluding and reducing catalyst 7 is completed, and the air-fuel ratio of the exhaust gas is changed over to the stoichiometric air-fuel ratio.

[0152] FIG. 4 is a flowchart for explaining the regenerating operation of the NO_x -occluding and reducing catalyst of the present embodiment described above. This operation is conducted by ECU 30 as a routine to be executed at regular intervals.

[0153] In this embodiment, the NO_x -occluding and reducing catalyst is regenerated by using the stoichiometric air-fuel ratio holding flag Y in addition to using the rich spike operation executing flag X. The value of the flag Y is set at 1 together with the value of the flag X when the value of the NO_x counter reaches a predetermined value in the NO_x -occlusion amount estimating operation described before.

[0154] In FIG. 4, when the operation is started, it is judged in step 401 whether or not the value of the stoichiometric air-fuel ratio holding flag Y is set at 1. As described later the value of the flag Y is set at 0 (step 419) after a predetermined

period of time has passed (steps 413 to 415) from when the value of the flag X is set at 0 (step 411) after the completion of the rich spike operation. Therefore, in the case of $Y \neq 1$ in step 401, the rich spike operation and the stoichiometric air-fuel ratio holding operation conducted after the rich spike operation are surely completed.

[0155] Therefore, in the case of $Y \neq 1$ in step 401, the operation of step 403 and after is not carried out and the operation of the present time is immediately terminated.

[0156] In the case of $Y=1$ in step 401, as the NO_x occluding and reducing catalyst is being regenerated, the program proceeds to step 403 and whether or not the rich spike operation in the initial stage of regenerating operation is completed is judged according to the value of the flag X. In the case of $X=1$ (not completed), the rich air-fuel ratio operation is continued until hydrogen components are detected in the exhaust gas by the H_2 sensor 33 provided on the downstream side of the NO_x occluding and reducing catalyst. The operation described in steps 403 to 411 is the same as that described in steps 301 to 309 shown in FIG. 3.

[0157] On the other hand, in the case of $X=1$ in step 403, this means that although the rich spike operation has already been completed, the stoichiometric air-fuel ratio holding operation is not terminated yet. Therefore, the program proceeds to step 413 and the value of the counter CT is increased by 1, and the program proceeds to step 415 and it is judged whether or not the value of the counter CT, which was increased, has reached a predetermined value β . In this case, β is a counter value corresponding to a period of time in which the NO_x occluding and reducing catalyst should be maintained at the stoichiometric air-fuel ratio after the completion of the rich spike operation. That is, β is a period of time necessary for completing the regeneration of the NO_x occluding and reducing catalyst at the stoichiometric air-fuel ratio after the desorption of NO_x in the initial stage. The value of β differs according to the capacity and the type of the NO_x occluding and reducing catalyst. Therefore, it is preferable that the value of β is determined by experiment in which an actual NO_x occluding and reducing catalyst is used.

[0158] In the case of $\text{CT} < \beta$ in step 415, the regeneration of the NO_x occluding and reducing catalyst has not been completed yet. Therefore, the program proceeds to step 417 and the engine is operated at the stoichiometric air-fuel ratio. Due to the foregoing, the exhaust gas of the stoichiometric air-fuel ratio flows into the NO_x occluding and reducing catalyst 7, and the regeneration of the NO_x occluding and reducing catalyst 7 is continued without greatly increasing the fuel consumption of the engine 1.

[0159] In the case of $\text{CT} \geq \beta$ in step 415, as the regeneration of the NO_x occluding and reducing catalyst 7 has already been completed, the program proceeds to step 419, and the values of the flag Y and the counter CT are reset to 0. Due to the foregoing, in the next operation, the operation is terminated immediately after the operation of step 401. Therefore, the regenerating operation of the NO_x occluding and reducing catalyst is not conducted and a usual lean air-fuel ratio operation is conducted.

[0160] According to the embodiment shown in FIG. 4, when hydrogen components contained in the exhaust gas are detected by the H_2 sensor 33 provided on the downstream side of the NO_x occluding and reducing catalyst 7 in the process of the regenerating operation, the rich spike operation is terminated and the exhaust gas is held at a predetermined stoichiometric air-fuel ratio after that. Due to the foregoing, even

when a high occlusion type NO_x occluding and reducing catalyst is used, it is possible to appropriately regenerate the NO_x occluding and reducing catalyst 7.

(3) THIRD EMBODIMENT

[0161] Next, the third embodiment will be explained below.

[0162] In the first and the second embodiment described above, the time for terminating the regenerating operation of the NO_x occluding and reducing catalyst and the time for terminating the rich spike operation are judged by the hydrogen concentration detected by the downstream side H_2 sensor 33 provided on the downstream side of the NO_x occluding and reducing catalyst 7.

[0163] On the other hand, in the present embodiment, the air-fuel ratio of the exhaust gas is controlled so that the hydrogen component concentration detected by the upstream side H_2 sensor 31 disposed on the upstream side of the NO_x occluding and reducing catalyst becomes a predetermined value during the regenerating operation of the NO_x occluding and reducing catalyst 7.

[0164] As explained in FIG. 2, the hydrogen component concentration in the exhaust gas changes according to the air-fuel ratio of the exhaust gas. Accordingly, if the air-fuel ratio of the exhaust gas at the time of a regenerating operation of the NO_x occluding and reducing catalyst is changed, the hydrogen component concentration in the exhaust gas is also changed and, in some cases, the amount of hydrogen supplied to the NO_x occluding and reducing catalyst becomes insufficient. This may cause an insufficient regeneration of the NO_x occluding and reducing catalyst.

[0165] In the present embodiment, the air-fuel ratio of the exhaust gas is feedback controlled based on the output of the upstream side H_2 sensor 31 so that the hydrogen component concentration in the exhaust gas flowing into the NO_x occluding and reducing catalyst becomes a predetermined value at the time of a regenerating operation of the NO_x occluding and reducing catalyst 7. Due to the above feedback control, an appropriate amount of hydrogen components can be always supplied to the NO_x occluding and reducing catalyst 7 in the process of regenerating the NO_x occluding and reducing catalyst 7.

[0166] FIG. 5 is a flowchart for explaining the regenerating operation of the NO_x occluding and reducing catalyst 7 of the present embodiment described above. This operation is conducted by ECU 30 as a routine to be executed at regular intervals.

[0167] Operation of FIG. 5 is carried out as follows. First, in step 501, it is judged whether or not the value of the regeneration execution flag X is set at 1. In the same manner as that of the first and the second embodiment, in the present embodiment, the value of the flag X is set at 1 by the operation not shown, which is separately executed by ECU 30, when the NO_x occlusion amount of the NO_x occluding and reducing catalyst 7 is increased to a predetermined value.

[0168] In this connection, the value of the regenerating operation execution flag X of this embodiment may be set in such a manner that, for example, after the value is set at $X=1$, the value is reset to 0 after a predetermined period of time has passed. Alternatively, the value of the flag X may be reset to 0 according to the operation shown in FIGS. 3 and 4.

[0169] In the case of $X=1$ (the execution of regenerating operation) in step 501, the rich spike operation is conducted in step 503, and an amount of fuel injection of the engine 1 is increased and the engine 1 is operated at a rich air-fuel ratio.

Due to the foregoing, the exhaust gas of a rich air-fuel ratio containing hydrogen components flows into the NO_x-occluding and reducing catalyst 7, and the NO_x-occluding and reducing catalyst 7 is regenerated.

[0170] Next, in step 505, the hydrogen component concentration HRF in the exhaust gas flowing into the NO_x-occluding and reducing catalyst 7 is read in from the H₂ sensor 31 disposed on the upstream side of the NO_x-occluding and reducing catalyst 7. In steps 507 to 509, an amount of fuel injection of the engine 1 during the rich spike operation, is decreased (step 509) or increased (step 511) so that the hydrogen component concentration value HRP, which is actually measured, can be a predetermined target value γ .

[0171] The target value γ of the hydrogen component concentration changes by the NO_x-occlusion amount at the time of starting the regenerating operation and by the type of the NO_x-occluding and reducing catalyst. Therefore, it is preferable that the target value γ of the hydrogen component concentration is determined based on experiment in which the actual NO_x-occluding and reducing catalyst is used.

[0172] Due to the foregoing, in the present embodiment, when the NO_x-occluding and reducing catalyst 7 is actually regenerated, an appropriate amount of hydrogen is always supplied to the NO_x-occluding and reducing catalyst 7. Therefore, the NO_x-occluding and reducing catalyst 7 can be appropriately regenerated.

[0173] In this connection, the regenerating operation of the NO_x-occluding and reducing catalyst of the present embodiment, in which the upstream side H₂ sensor 31 (shown in FIG. 1) is used, can be conducted independently. However, as described above, it is possible to conduct the regenerating operation in which the downstream side H₂ sensor 33 (shown in FIG. 1) of the first or the second embodiment is also used.

(4) FOURTH EMBODIMENT

[0174] Next, the fourth embodiment of the present invention will be explained below. In this embodiment, in the same manner as that of the third embodiment described above, the air-fuel ratio of the exhaust gas is feedback controlled so that the hydrogen component concentration in the exhaust gas detected by the upstream side H₂ sensor 31 becomes the target value γ .

[0175] The flowchart of the regenerating operation of this embodiment is the same as that (shown in FIG. 5) of the third embodiment.

[0176] In the third embodiment described above, the target value γ of the hydrogen component concentration HRF in the exhaust gas flowing into the NO_x-occluding and reducing catalyst 7, is set at a constant value. On the other hand, in the present embodiment, the target value γ is set so that it can be changed according to the lapse of time. Therefore, at the time of starting the regenerating operation (the rich spike operation), the target value γ is set to be high, and then the target value γ is set so that it can be lowered with the lapse of time. Only this point of this embodiment is different from the third embodiment.

[0177] FIG. 6 is a graph schematically showing a change in the hydrogen component target value γ with the time in the present embodiment. As shown in FIG. 6, the value of γ is high at the time of starting the regenerating operation of the NO_x-occluding and reducing catalyst 7. As time passes, the value of γ is gradually decreased.

[0178] When the regenerating operation of the NO_x-occluding and reducing catalyst is started and the exhaust gas

of a rich air-fuel ratio flows into the NO_x-occluding and reducing catalyst, first, the NO_x attached onto a surface of Pt and alumina on the NO_x-occluding and reducing catalyst and the NO_x, existing in the neighborhood of the occlusion material surface in the form of ions, are simultaneously desorbed and, after that, the NO_x-occluded in the occlusion material is moved from the inside of the occlusion material onto the surface and desorbed.

[0179] Therefore, at the beginning of the regenerating operation of the NO_x-occluding and reducing catalyst, a relatively large amount of NO_x is desorbed in a short period of time. After that, a rate of the desorption of NO_x is gradually decreased. Therefore, an amount of hydrogen components necessary for reducing the desorbed NO_x is large at the beginning of the regenerating operation. After that, the amount of hydrogen components necessary for reducing the thus desorbed NO_x is decreased.

[0180] In the present embodiment, as shown in FIG. 6, the hydrogen component concentration in the exhaust gas is set in accordance with the desorption rate of NO_x of desorbing from the NO_x-occluding and reducing catalyst during the regenerating operation. Therefore, the regeneration of the NO_x-occluding and reducing catalyst can be appropriately conducted.

(5) FIFTH EMBODIMENT

[0181] Next, the fifth embodiment of the present invention will be explained below.

[0182] In the present embodiment, a degree of the deterioration of the NO_x-occluding and reducing catalyst is judged in accordance with the time required for the regenerating operation. The time required for the regenerating operation, i.e., the timing for terminating the regenerating operation is determined in accordance with the output of the downstream side H₂ sensor 33 as explained in the first embodiment (shown in FIG. 3).

[0183] As described before, in the first embodiment (shown in FIG. 3), a point of time, at which the regeneration of the NO_x-occluding and reducing catalyst 7 is completed, is detected by the downstream side hydrogen sensor 33. In this connection, a necessary period of time from the start of the regeneration to the completion of the regeneration is increased and decreased according to an amount of NO_x occluded in the NO_x-occluding and reducing catalyst 7.

[0184] In each embodiment described above, according to the value of the NO_x counter and the output of NO_x sensor disposed on the downstream side of the NO_x-occluding and reducing catalyst, an amount of NO_x, which is occluded in the NO_x-occluding and reducing catalyst, is estimated, and each time this NO_x-occlusion amount reaches a predetermined value, the regenerating operation is executed. Therefore, it is considered that the NO_x-occlusion amount of the NO_x-occluding and reducing catalyst 7 at the time of starting the regenerating operation should be a constant value by nature, and the period of time from the start of the regenerating operation to the end should be a substantially constant.

[0185] However, as the NO_x-occluding and reducing catalyst 7 deteriorates, the NO_x-occlusion capacity is lowered. Therefore, for example, in the case where the NO_x-occlusion amount is estimated with the NO_x counter, even if the NO_x component concentration in the exhaust gas is constant, as the NO_x-occluding and reducing catalyst deteriorates, an amount of NO_x, which is occluded in the NO_x-occluding and reducing catalyst per unit time, is decreased and an actual amount of

NO_x, which is occluded in the NO_x occluding and reducing catalyst is decreased to be smaller than the value of the NO_x counter.

[0186] In the case where the NO_x sensor is disposed on the downstream side of the NO_x occluding and reducing catalyst and the NO_x occlusion amount is estimated, when the occlusion capacity of the NO_x occluding and reducing catalyst is deteriorated, a smaller amount of NO_x flows out on the downstream side of the occluded NO_x than an amount which flows out of the occluded NO_x of the catalyst which is not deteriorated.

[0187] Therefore, in the case where the catalyst is deteriorated, an amount of occluded NO_x of the NO_x occluding and reducing catalyst is decreased at the time of starting the regenerating operation in case where the regenerating operation is started according to the NO_x counter and in the case where the regenerating operation is started according to an output of the NO_x sensor.

[0188] The required time from the start of the regenerating operation to the end is increased and decreased according to an amount of the occluded NO_x of the NO_x occluding and reducing catalyst 7. Therefore, when the amount of the occluded NO_x of the NO_x occluding and reducing catalyst 7 is decreased at the time of starting the regenerating operation, the required time from the start of the regenerating operation to the end is shortened. That is, the required time necessary for the regenerating operation is shortened as the catalyst deteriorates.

[0189] In the present embodiment, the above fact is utilized. When the required time from the start of the regenerating operation to the end becomes shorter than a predetermined period of time, it is judged that the NO_x occluding and reducing catalyst 7 has been deteriorated.

[0190] FIG. 7 is a flowchart for explaining a deterioration judgment operation of the present embodiment. This operation is conducted by ECU 30 as a routine to be executed at regular intervals.

[0191] In this embodiment, a period of time, from a point of time at which the value of the regenerating operation executing flag X used in the first embodiment (shown in FIG. 3) is changed from 0 to 1 (the start of the regenerating operation) to a point of time at which the value of the regenerating operation executing flag X is changed from 1 to 0, is measured and, when this value becomes lower than a predetermined value, it is judged that the NO_x occluding and reducing catalyst 7 is deteriorated.

[0192] That is, in the operation shown in FIG. 7, first, in step 701, it is judged whether or not the value of the flag X is set at 1 at present. As described before, by the operation separately executed by ECU 30, the flag X is set at 1 when the regenerating operation is started.

[0193] In the case of X=1 in step 701, step 703 is executed next, and the value of the judgment execution flag XS is set at 1 and the value of the regeneration time counter CN is increased by Δt in step 705.

[0194] In this case, the judgment execution flag XS is a flag for executing the judgment operation of step 711 to step 715 only once after the completion of the regenerating operation.

[0195] The regeneration time counter CN is a counter to express the lapse of time from the start of the regenerating operation. In this case, a counter increment Δt in step 705 is an interval (time) of repetition of the operation shown in FIG. 7. In the case where the regenerating operation is not conducted, the value of the counter CN is always cleared in step 717.

Therefore, the value of the counter CN calculated in step 705 is equal to the lapse of time from the establishment of X=1 in step 701.

[0196] In the case where X $\neq$ 1 in step 701, that is, in the case where the regeneration of the NO_x occluding and reducing catalyst 7 is not being conducted, the program proceeds to step 707, and it is judged according to the value of the flag XS whether or not the execution of the operation of this time is the first execution from the completion of the regenerating operation (from the time of X $\neq$ 0).

[0197] In the case of X=1, the flag XS is always set at XS=1 in step 703. At the time of the first execution of the operation after X $\neq$ 1, the flag XS is set at XS=0 in step 709.

[0198] Therefore, in the case where XS=1 in step 707, it is the first execution of the operation from the completion of the regenerating operation. Accordingly, in this case, the value of the counter CN is equal to the required time from the start of the regeneration of the NO_x occluding and reducing catalyst 7 to the end.

[0199] Therefore, in the case of X=1 in step 707, it is judged in step 711 whether or not the required time CN of the regenerating operation is shorter than the predetermined judgment value δ .

[0200] In the case of CN< δ , it can be judged that the NO_x occlusion capacity is decreased due to the deterioration of the catalyst and the required time of the regenerating operation is shortened. Therefore, the value of the deterioration flag XF is set at 1 (deterioration) in step 713.

[0201] In the case where CN $\geq$ δ in step 711, the value of the flag XF is set at 0 (normal) in step 715.

[0202] In this case, δ is the required time for the regenerating operation in the case where the NO_x occlusion capacity is deteriorated by the deterioration of the catalyst so that problems may be caused in the practical use. Therefore, it is preferable that the value of δ is set by making an experiment in which the actual catalyst is used.

[0203] After the judgment has been carried out in steps 711 to 715, the value of the counter CN is cleared and the operation of this time is terminated. In this connection, as the value of XS is set at 0 in step 709, the judgment operation of steps 711 to 715 is conducted only once immediately after the completion of the regeneration of the NO_x occluding and reducing catalyst 7. After that, step 717 is directly carried out after step 707.

[0204] As described above, according to the present embodiment, while the regenerating operation of the NO_x occluding and reducing catalyst 7 is being appropriately carried out, it is possible to accurately judge whether or not the NO_x occluding and reducing catalyst 7 has deteriorated.

[0205] The deterioration judgment operation of this embodiment is carried out together with the regenerating operation of the first embodiment (shown in FIG. 3). Further, when the third embodiment (shown in FIG. 5) described before is simultaneously carried out and a hydrogen component concentration contained in the exhaust gas flowing into the NO_x occluding and reducing catalyst 7 in the process of the regenerating operation is controlled to be a predetermined value, the deterioration judgment accuracy can be further enhanced.

(6) SIXTH EMBODIMENT

[0206] Next, the sixth embodiment of the present invention will be explained below.

[0207] FIG. 8 is the same view as FIG. 1 showing an arrangement of the present embodiment.

[0208] The arrangement of FIG. 8 is different from that of FIG. 1 on the following points. In the arrangement of FIG. 8, a so-called tandem type NO_x occluding and reducing catalyst is used in which two NO_x occluding and reducing catalysts 71, 73 are arranged in series with each other in the exhaust gas passage instead of the NO_x occluding and reducing catalyst 7 of FIG. 1.

[0209] The tandem type NO_x occluding and reducing catalyst of this embodiment is composed in such a manner that the front stage NO_x occluding and reducing catalyst 71 and the rear stage NO_x occluding and reducing catalyst 73 are arranged in the casing 70 while leaving an appropriate interval between them. In the space formed between the front stage and the rear stage, H₂ sensor 35, which is the same as H₂ sensors 31, 33 shown in FIG. 2, is arranged.

[0210] In the tandem type NO_x occluding and reducing catalyst, when the characteristic of the NO_x occluding and reducing catalyst of the front stage is made to be different from that of the NO_x occluding and reducing catalyst of the rear stage, the exhaust gas purifying performance of the tandem type NO_x occluding and reducing catalyst is enhanced from that of a single stage NO_x occluding and reducing catalyst.

[0211] For example, in the tandem type NO_x occluding and reducing catalyst of the present embodiment, the NO_x occlusion capacity of the front stage NO_x occluding and reducing catalyst 71 is larger than that of the rear stage NO_x occluding and reducing catalyst 73, and the O₂ storage capacity of the front stage NO_x occluding and reducing catalyst 71 is smaller than that of the rear stage NO_x occluding and reducing catalyst 73. Further, the catalyst supporting amount of Pt of the front stage NO_x occluding and reducing catalyst 71 is larger than that of the rear stage NO_x occluding and reducing catalyst 73.

[0212] In the case where two NO_x occluding and reducing catalysts are arranged in series to each other, NO_x is first occluded in the front stage NO_x occluding and reducing catalyst. As an O₂ storage capacity of the front stage is set at a small value, even at the time of carrying out the regenerating operation, the hydrogen components and HC and CO components contained in the exhaust gas do not react with oxygen occluded in the catalyst and most of the hydrogen components and HC and CO components are used for reducing NO_x.

[0213] As the amount of Pt carried on the catalyst in the front stage is increased, most of NO contained in the exhaust gas is oxidized on the front stage catalyst and changed into NO₂. Therefore, an amount of occlusion of NO_x per unit volume at the front stage is increased. Therefore, in addition to the setting in which the occlusion capacity of the front stage NO_x occluding and reducing catalyst is increased, the occlusion and the reducing purification of NO_x can be effectively accomplished in the front stage NO_x occluding and reducing catalyst 71.

[0214] On the other hand, in the rear stage NO_x occluding and reducing catalyst 73, the O₂ storage capacity is set relatively high. Therefore, for example, even in the case where the air-fuel ratio of the exhaust gas passing through the front stage NO_x occluding and reducing catalyst at the time of carrying out the regenerating operation becomes rich, the rear stage NO_x occluding and reducing catalyst 73 can be maintained in an atmosphere close to the stoichiometric air-fuel ratio. As the NO_x occluding and reducing catalyst has a func-

tion of the three way catalyst in the neighborhood of the stoichiometric air-fuel ratio, in the tandem type NO_x occluding and reducing catalyst, at the time of the regeneration, the rear stage NO_x occluding and reducing catalyst 73 functions as a three way catalyst using oxygen discharged from the O₂ storage. Therefore, even when NO_x, which has been desorbed at the front stage, is not reduced for some reason and flows into the rear stage NO_x occluding and reducing catalyst 73, NO_x can be reduced and purified on the rear stage NO_x occluding and reducing catalyst 73.

[0215] As described above, in the tandem type NO_x occluding and reducing catalyst, the NO_x occluding and reducing catalysts, the characteristics of which are different from each other, are separately arranged at the front stage and the rear stage, so that the exhaust gas purifying efficiency can be enhanced. However, as a result of adopting the above structure, in the case where the same control as that of each embodiment described before is conducted, if H₂ sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst 73, problems may be caused.

[0216] For example, in the case where the time for terminating the regenerating operation is judged according to an output of H₂ sensor in the same manner as that of the first embodiment, if H₂ sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst 73, it is difficult to judge the time for terminating the regenerating operation.

[0217] The reason is described as follows. In the tandem type NO_x occluding and reducing catalyst described before, the rear stage NO_x occluding and reducing catalyst 73 has a relatively large O₂ storage capacity. Therefore, even when the front stage NO_x occluding and reducing catalyst 71 completes the regenerating operation at the time of executing the regenerating operation and the hydrogen components are contained in the exhaust gas at the outlet of the front stage NO_x occluding and reducing catalyst 71, these hydrogen components react with oxygen, which is discharged from the rear stage NO_x occluding and reducing catalyst 73, when these hydrogen components pass through the rear stage NO_x occluding and reducing catalyst 73. Accordingly, these hydrogen components do not flow out onto the downstream side of the rear stage NO_x occluding and reducing catalyst 73.

[0218] Accordingly, when an H₂ sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst 73 and the time for terminating the regenerating operation is judged based on the output of the H₂ sensor, it is difficult to judge the completion of the regenerating operation accurately unless all oxygen occluded in the rear stage NO_x occluding and reducing catalyst 73 is discharged.

[0219] However, actually, in the tandem NO_x occluding and reducing catalyst, almost all of the occlusion and the reducing purification of NO_x are conducted in the front stage NO_x occluding and reducing catalyst 71, and the rear stage NO_x occluding and reducing catalyst 73 only performs an auxiliary role. Therefore, an amount of occluded NO_x is much smaller than that of the front stage. Accordingly, after the completion of the regeneration of the front stage NO_x occluding and reducing catalyst 71, it is unnecessary to continue the regenerating operation. When the regenerating operation is continued until the hydrogen components are detected in the exhaust gas on the downstream side of the rear stage NO_x occluding and reducing catalyst, the fuel consumption of the engine is increased.

[0220] Therefore, in the present embodiment, according to an output of H₂ sensor 35 which is arranged in a space formed between the front stage NO_x occluding and reducing catalyst 71 and the rear stage NO_x occluding and reducing catalyst 73, the time of the completion of the regenerating operation of the front stage NO_x occluding and reducing catalyst 71 is judged so as to finish the regenerating operation.

[0221] As the regenerating operation of this embodiment is basically the same as that of the first embodiment (shown in FIG. 3), detailed explanations are omitted here.

[0222] In this connection, when the regenerating operation of the tandem type NO_x occluding and reducing catalyst is terminated when the regenerating operation of the front stage NO_x occluding and reducing catalyst 71 is completed as described in this embodiment, it appears that an amount of the NO_x occluded in the rear stage NO_x occluding and reducing catalyst 73 is increased while it is not being regenerated. However, as described before, the amount of the NO_x occluded in the rear stage NO_x occluding and reducing catalyst 73 is so small that it is unnecessary to frequently conduct the regenerating operation of the rear stage NO_x occluding and reducing catalyst 73. Practically, no problems are caused when the regenerating operation is conducted in such a manner that the engine 1 is continuously operated at the stoichiometric air-fuel ratio for a certain period of time and during which period the regenerating operation of the rear stage NO_x occluding and reducing catalyst 73 is naturally conducted.

(7) SEVENTH EMBODIMENT

[0223] As described before, in the NO_x occluding and reducing catalyst, when SO_x is contained in the exhaust gas flowing into the NO_x occluding and reducing catalyst, SO_x is occluded in the NO_x occluding and reducing catalyst simultaneously with NO_x under the condition of a lean air-fuel ratio.

[0224] In this case, NO_x occluded in the NO_x occluding and reducing catalyst can be relatively simply desorbed from the NO_x occluding and reducing catalyst 7 by carrying out the regenerating operation, however, as the affinity of SO_x with the occluded NO_x is strong and a stable chemical compound is generated, when SO_x is once occluded in the NO_x occluding and reducing catalyst, SO_x cannot be desorbed from the NO_x occluding and reducing catalyst by only a simple regenerating operation of the NO_x occluding and reducing catalyst. Therefore, SO_x is gradually accumulated in the catalyst and the NO_x occluding and reducing catalyst is affected by SO_x, that is, SO_x poisoning is caused.

[0225] Therefore, usually, when the NO_x occluding and reducing catalyst is used, each time an amount of SO_x occluded in the catalyst is increased to a certain value, the poisoning regeneration treatment is conducted so as to desorb SO_x from the NO_x occluding and reducing catalyst.

[0226] In the poisoning regeneration treatment, the engine is operated under the operating condition of a high exhaust gas temperature at a rich air-fuel ratio so as to maintain the NO_x occluding and reducing catalyst at a high temperature in a rich air-fuel ratio atmosphere. Even in this case, when hydrogen components are contained in the exhaust gas, the poisoning regeneration treatment time can be greatly shortened.

[0227] In the poisoning regeneration treatment, the generated sulfate is decomposed when the NO_x occluding and reducing catalyst temperature is raised, so as to desorb SO_x from the catalyst. When the NO_x occluding and reducing

catalyst is maintained at a rich air-fuel ratio, SO_x, which has been desorbed, is prevented from being occluded again in the NO_x occluding and reducing catalyst. However, actually, as the affinity of SO_x with the occluded NO_x is strong as described before, even if the air-fuel ratio is maintained to be rich, SO_x, which has been desorbed from the upstream portion of the NO_x occluding and reducing catalyst, is occluded again in the downstream portion. Therefore, while repeating desorption and occlusion, the SO_x desorbed from the upstream portion of the NO_x occluding and reducing catalyst gradually moves onto the downstream side. Accordingly, it takes a relatively long period of time for SO_x to be completely desorbed from the catalyst.

[0228] Therefore, the poisoning regeneration treatment requires a relatively long period of time and deteriorates the fuel consumption of the engine. Further, the NO_x occluding and reducing catalyst is exposed to a high temperature over a long period of time, which deteriorates the catalyst.

[0229] However, as the reducing power of hydrogen is very strong, it facilitates the desorption of SO_x from NO_x occluding and reducing catalyst, and further hydrogen reacts with SO_x, which has been once desorbed, and prevents SO_x, which has been once desorbed, from being occluded again into the NO_x occluding and reducing catalyst. Therefore, when H₂ is supplied to the NO_x occluding and reducing catalyst at the time of poisoning regeneration treatment, SO_x can be completely desorbed from the NO_x occluding and reducing catalyst in a short period of time.

[0230] In this case, in the same manner as that of the regenerating operation of the NO_x occluding and reducing catalyst, while SO_x is being desorbed from the NO_x occluding and reducing catalyst, the hydrogen components contained in the exhaust gas are consumed by reacting with SO_x. Therefore, the hydrogen components do not flow out onto the downstream side of the NO_x occluding and reducing catalyst. After all the SO_x has been desorbed, that is, after the poisoning regeneration treatment has been completed, the hydrogen components flow out onto the downstream side of the NO_x occluding and reducing catalyst for the first time.

[0231] Therefore, by the same method as that of judging the time for terminating the regenerating operation, the time for terminating the poisoning regeneration treatment can be accurately judged.

[0232] However, in the case where the tandem type NO_x occluding and reducing catalyst is used, when an H₂ sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst, the same problems as those caused in the judgment of the time for terminating the regenerating operation may occur. Therefore, it is difficult to accurately judge the time for terminating the poisoning regeneration treatment. Accordingly, such a problem may be caused that, although the poisoning regeneration treatment is not actually completed, the exhaust gas of a high temperature is supplied to the NO_x occluding and reducing catalyst at a rich air-fuel ratio over a long period of time. Therefore, when H₂ sensor is disposed on the downstream side of the rear stage NO_x occluding and reducing catalyst so as to judge the time for terminating the poisoning regeneration treatment of the tandem type NO_x occluding and reducing catalyst, the fuel consumption of the engine is increased due to the unnecessary rich air-fuel operation of the engine. Further, when the catalyst is exposed to a high temperature over a long period of time, the NO_x occluding and reducing catalyst is deteriorated.

[0233] In order to increase the O₂ storage capacity, the rear stage NO_x occluding and reducing catalyst carries a relatively large amount of ceria (Ce). Although ceria is easily bonded with SO_x and sulfate is easily formed, the bonding strength of ceria with SO_x is so weak that SO_x can be easily desorbed in a short period of time during the poisoning regeneration treatment.

[0234] Therefore, in this embodiment, the time for terminating the poisoning regeneration is judged by using H₂ sensor 35 (shown in FIG. 8) arranged in a space between the front stage and the rear stage.

[0235] FIG. 9 is a flowchart for explaining the poisoning regeneration treatment of this embodiment. The operation shown in FIG. 9 is basically the same as that of the flow chart of the regenerating operation of the first embodiment (shown in FIG. 3). The operation of FIG. 9 is different from operation of FIG. 3 only at the following three points. First, instead of the flag X, the poisoning regeneration treatment execution flag S is used. Secondly, in step 903, instead of the rich spike operation of step 303 of FIG. 3, the poisoning regenerating operation is executed in which the engine conducts a rich air-fuel ratio operation under the condition of a high exhaust gas temperature. Thirdly, in steps 905, 907, an output HRM of the H₂ sensor 35, which is arranged between the front stage and the rear stage, is used. Therefore, detailed explanations of FIG. 9 are omitted here.

[0236] As described above, the time for terminating the poisoning regeneration treatment is judged according to the hydrogen component concentration detected by the H₂ sensor arranged between the front stage NO_x occluding and reducing catalyst and the rear stage NO_x occluding and reducing catalyst. Due to the foregoing, it is possible to prevent an increase in the fuel consumption and a deterioration of the NO_x occluding and reducing catalyst.

(8) EIGHTH EMBODIMENT

[0237] Next, the eighth embodiment of the present invention will be explained below.

[0238] In the present embodiment, when the time for terminating the regenerating operation of the NO_x occluding and reducing catalyst is judged according to an output of the H₂ sensor 35 arranged between the front stage and the rear stage of the tandem type NO_x occluding and reducing catalyst shown in FIG. 8, a degree of deterioration of the front stage NO_x occluding and reducing catalyst 71 is judged according to the required time from the start of the regenerating operation to the end.

[0239] In this connection, the specific method of judging a degree of deterioration is substantially the same as that of the fifth embodiment shown in FIG. 7. Therefore, detailed explanations are omitted here.

[0240] As described before, in the tandem type NO_x occluding and reducing catalyst, the occlusion and the reducing purification of NO_x are mainly conducted by the front stage NO_x occluding and reducing catalyst 71. Therefore, it is necessary to accurately judge the degree of deterioration of the front stage NO_x occluding and reducing catalyst 71.

[0241] In the present embodiment, the degree of deterioration of the front stage NO_x occluding and reducing catalyst 71 is judged according to an output of the H₂ sensor 35 arranged between the front stage and the rear stage of the tandem type NO_x occluding and reducing catalyst. Due to the foregoing, while the tandem type NO_x occluding and reducing catalyst is

being appropriately regenerated, the degree of deterioration of the front stage NO_x occluding and reducing catalyst 71 can be judged.

1. An exhaust gas purifying device for an internal combustion engine comprising: an NO_x occluding and reducing catalyst disposed in an exhaust passage of an internal combustion engine, the NO_x occluding and reducing catalyst occluding NO_x contained in exhaust gas by one of the absorption and the adsorption or by both the absorption and the adsorption when an air-fuel ratio of the exhaust gas flowing into the catalyst is lean, and reducing and purifying the occluded NO_x with a reducing component contained in the exhaust gas when an air-fuel ratio of the exhaust gas is a stoichiometric air-fuel ratio or a rich air-fuel ratio; and

an H₂ sensor disposed in at least one of the exhaust gas passages on the inlet side and the outlet side of the NO_x occluding and reducing catalyst for detecting a hydrogen component concentration of the exhaust gas, wherein

the exhaust gas purifying device executes a regenerating operation in which the exhaust gas of a rich air-fuel ratio or a stoichiometric air-fuel ratio is supplied to the NO_x occluding and reducing catalyst for a predetermined period of time when the NO_x occluding and reducing catalyst is to reduce and purify the NO_x occluded in the NO_x occluding and reducing catalyst and, during the regenerating operation, the exhaust gas purifying device controls the air-fuel ratio of the exhaust gas flowing into the NO_x occluding and reducing catalyst based on the hydrogen component concentration, in the exhaust gas, detected by the H₂ sensor.

2. An exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in an exhaust gas passage on an outlet side of the NO_x occluding and reducing catalyst, and at the time of executing the regenerating operation, a time for terminating the regenerating operation is judged according to a hydrogen component concentration in the exhaust gas detected by the outlet side H₂ sensor.

3. An exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in at least an exhaust gas passage on the outlet side of the NO_x occluding and reducing catalyst, the regenerating operation includes operations for first supplying the exhaust gas of a rich air-fuel ratio to the NO_x occluding and reducing catalyst and then supplying the exhaust gas of a stoichiometric air-fuel ratio to the NO_x occluding and reducing catalyst and, the time at which the exhaust gas air-fuel ratio is switched from the rich air-fuel ratio to the stoichiometric air-fuel ratio is determined in accordance with the hydrogen component concentration detected by the outlet side H₂ sensor.

4. An exhaust gas purifying device for an internal combustion engine according to claim 1, wherein the H₂ sensor is arranged in an exhaust gas passage on the inlet side of the NO_x occluding and reducing catalyst, and at the time of executing the regenerating operation, an air-fuel ratio of the exhaust gas flowing into the NO_x occluding and reducing catalyst is controlled so that a hydrogen component concentration in the exhaust gas detected by the inlet side H₂ sensor can be a predetermined target value.

5. An exhaust gas purifying device for an internal combustion engine according to claim 4, wherein the target value of the hydrogen component concentration is high at the time of

starting the regenerating operation, and then the target value of the hydrogen component concentration is gradually decreased with the lapse of time.

6. An exhaust gas purifying device for an internal combustion engine according to claim 2, wherein according to the lapse of time from the start of the regenerating operation to the end of the regenerating operation which is judged according to the hydrogen component concentration in the exhaust gas detected by the downstream side H_2 sensor, a degree of deterioration of the NO_x occluding and reducing catalyst is judged.

7. An exhaust gas purifying device for an internal combustion engine comprising an NO_x occluding and reducing catalyst disposed in an exhaust passage of an internal combustion engine, the NO_x occluding and reducing catalyst occluding NO_x contained in exhaust gas by one of the absorption and the adsorption or by both the absorption and the adsorption when an air-fuel ratio of the exhaust gas flowing into the catalyst is lean and reducing and purifying the occluded NO_x with a reducing component contained in the exhaust gas when an air-fuel ratio of the exhaust gas is a stoichiometric air-fuel ratio or a rich air-fuel ratio,

the exhaust gas purifying device for an internal combustion engine further comprising:

NO_x occluding and reducing catalysts arranged in series to each other on the upstream side and the downstream side of the exhaust gas passage of the internal combustion engine; and an H_2 sensor, which is arranged in series to each other in the exhaust gas passage between the upstream side NO_x occluding and reducing catalyst and the downstream side NO_x occluding and reducing catalyst, for detecting a hydrogen component concentration in the exhaust gas, wherein

when the NO_x occluding and reducing catalyst is to reduce and purify NO_x occluded during a lean air-fuel ratio operation of the engine, at the time of executing a regenerating operation in which the exhaust gas of a rich air-fuel ratio or a stoichiometric air-fuel ratio is supplied to the NO_x occluding and reducing catalyst for a predetermined period of time, according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor, an air-fuel ratio of the exhaust gas flowing into the upstream side NO_x occluding and reducing catalyst is controlled.

8. An exhaust gas purifying device for an internal combustion engine according to claim 7, wherein an NO_x occlusion capacity of the upstream side NO_x occluding and reducing

catalyst is larger than that of the downstream side NO_x occluding and reducing catalyst, an O_2 storage capacity of the upstream side NO_x occluding and reducing catalyst is smaller than that of the downstream side NO_x occluding and reducing catalyst, and an amount of platinum components carried on the upstream side NO_x occluding and reducing catalyst is larger than that carried on the downstream side NO_x occluding and reducing catalyst.

9. An exhaust gas purifying device for an internal combustion engine according to claim 7 or 8, wherein a time for terminating the regenerating operation is judged according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor at the time of executing the regenerating operation.

10. An exhaust gas purifying device for an internal combustion engine according to claim 7 or 8, wherein the device further executes a poisoning regeneration treatment in order to desorb sulfur oxide occluded in the NO_x occluding and reducing catalyst together with NO_x from the NO_x occluding and reducing catalyst by making the air-fuel ratio of the exhaust gas flowing into the NO_x occluding and reducing catalyst to be a rich air-fuel ratio and, at the same time, raising the temperature thereof and,

wherein an air-fuel ratio of the exhaust gas flowing into the upstream side NO_x occluding and reducing catalyst is controlled according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor in the process of executing the poisoning regeneration treatment.

11. An exhaust gas purifying device for an internal combustion engine, according to claim 10, wherein a time for terminating the poisoning regeneration treatment is judged according to the hydrogen component concentration in the exhaust gas detected by the H_2 sensor at the time of executing the poisoning regeneration treatment.

12. An exhaust gas purifying device for an internal combustion engine according to claim 8, wherein a degree of deterioration of the upstream side NO_x occluding and reducing catalyst is judged according to a period of time from the start of the regenerating operation to the end of the regenerating operation which is judged according to the hydrogen component concentration, in the exhaust gas, detected by the H_2 sensor.

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