

Description

BACKGROUND OF THE INVENTION

5 **[0001]** The present invention relates to an apparatus for controlling an exhaust purification apparatus provided in the exhaust system of an internal combustion engine and to an apparatus for determining deterioration of such a catalyst.

10 **[0002]** A typical exhaust purification catalyst, particularly, a NO_x storage reduction catalyst, is poisoned with sulfur components contained in fuel. When the degree of sulfur poisoning is increased, the NO_x storage reduction performance of the catalyst is degraded. Therefore, when a certain amount of sulfur components is accumulated in the NO_x storage reduction catalyst, a temperature increase process is executed to heat the catalyst. Also, the air-fuel ratio of exhaust gas is richened to perform a sulfur release control is executed in which sulfur components are discharged from the NO_x storage reduction catalyst.

15 **[0003]** However, if the air-fuel ratio is continuously richened during the sulfur release control, sulfur components are intermittently discharged from the catalyst. Accordingly, the concentration of sulfur components in exhaust gas is increased. This produces stench. Therefore, Japanese Laid-Open Patent Publication No. 2000-274232 (pages 4 to 5, Fig. 2) discloses a technology for preventing the concentration of sulfur components in exhaust gas from being excessive by intermittently richening air-fuel ratio of exhaust gas. Specifically, an execution period, in which the air-fuel ratio is richened, and an intermission period, in which the air-fuel ratio is not richened, are alternately repeated.

20 **[0004]** During the execution period, fuel in the exhaust purification catalyst is oxidized and heated, which increases the catalyst bed temperature. On the other hand, during the intermission period, heating of the catalyst is stopped and the catalyst is cooled by exhaust gas, which lowers the catalyst bed temperature. That is, the air-fuel ratio is intermittently richened so that the catalyst bed temperature is periodically increased and lowered. Therefore, in some cases, even if the average catalyst bed temperature is adjusted to be a target temperature, the catalyst bed temperature can be increased beyond the target temperature during the execution period. Even if the catalyst bed temperature is excessively high only temporarily, the exhaust purification catalyst is degraded with heat.

25 **[0005]** Typically, to prevent the catalyst bed temperature from being excessively increased during the execution period, the length of the execution period is set such that the maximum value of the catalyst bed temperature due to richening of the air-fuel is less than the temperature at which the exhaust purification catalyst starts deteriorating due to heat.

30 **[0006]** However, the temperature of a brand new exhaust purification catalyst and the temperature of an old exhaust purification catalyst are increased in different manners even if the air-fuel ratio is richened under the same conditions. Compared to an old exhaust purification catalyst, the maximum value of the catalyst bed temperature of a brand new exhaust purification catalyst when the air-fuel ratio is richened is higher. Therefore, if the conditions of the execution period are designed for old catalysts, the catalyst bed temperature will be excessively increased by richening the air-fuel ratio when the exhaust purification catalyst is still brand new, which can cause the catalyst to prematurely deteriorate. On the other hand, if the conditions of the execution period are designed for a brand new catalyst and the catalyst is gradually worn out, the execution period can end even if the catalyst bed temperature has not been sufficiently increased. This hinders effective emission of sulfur components and degrades the accuracy of the sulfur release control.

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40 As a result, the emission deteriorates and the period of the sulfur poisoning is extended, which degrades the fuel economy.

SUMMARY OF THE INVENTION

45 **[0007]** Accordingly, it is an objective of the present invention to provide a catalyst control apparatus for an internal combustion engine, which apparatus readily suppresses an excessive increase in a catalyst bed temperature and degradation of accuracy of sulfur release control. The present invention also pertains to a catalyst deterioration determination apparatus used in the catalyst control apparatus to determine the degree of deterioration of an exhaust purification catalyst.

50 **[0008]** To achieve the foregoing and other objectives and in accordance with the purpose of the present invention, an apparatus for controlling an exhaust purification catalyst is provided. The catalyst is located in an exhaust system of an internal combustion engine. During sulfur release control for permitting the catalyst to recover from sulfur poisoning, the apparatus repeats a richening period and a non-richening period. In the richening period, the apparatus intermittently supplies fuel to exhaust gas at a section upstream of the catalyst, thereby lowering the air-fuel ratio of exhaust gas that contacts the catalyst to a value equal to or less than the stoichiometric air-fuel ratio. In the non-richening period, the apparatus does not supply fuel to exhaust gas. The apparatus includes deterioration degree detecting means and changing means. The deterioration degree detecting means detects the degree of deterioration of the exhaust purification catalyst. The changing means changes the ratio of the duration of the richening period to

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the duration of the non-richening period according to the deterioration degree of the exhaust purification catalyst detected by the deterioration degree detecting means.

[0009] The present invention also provides an apparatus for detecting a degree of deterioration of an exhaust purification catalyst located in an exhaust system of an internal combustion engine. The apparatus includes fuel supply means, catalyst bed temperature detecting means, and deterioration degree determination means. The fuel supply means intermittently supplies fuel to exhaust gas at a section upstream of the exhaust purification catalyst. The catalyst bed temperature detecting means detects a physical quantity that represents an actual catalyst bed temperature of the exhaust purification catalyst. The deterioration degree determination means that the smaller a range of fluctuation of the physical quantity, which fluctuation being caused by supply of fuel to exhaust gas and detected by the catalyst bed temperature detecting means, the greater the deterioration degree of the exhaust purification catalyst.

[0010] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a block diagram illustrating a general configuration of a vehicle diesel engine and a control system according to a first embodiment, in which the control system functions as a catalyst control apparatus and a catalyst deterioration determination apparatus;

Fig. 2 is a flowchart showing a sulfur release process according to the first embodiment;

Fig. 3 is a flowchart showing a deterioration degree determination process according to the first embodiment;

Fig. 4 is a flowchart showing a sulfur emitting process according to the first embodiment;

Fig. 5 is a diagram showing a map f used for computing the duration of a richening period R_t based on an amplitude value A_{mpin} ;

Fig. 6 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the first embodiment, when a NOx storage reduction catalyst is brand new;

Fig. 7 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the first embodiment, when a NOx storage reduction catalyst has deteriorated to some extent;

Fig. 8 is a flowchart showing a deterioration degree determination process according to a second embodiment;

Fig. 9 is a flowchart showing a sulfur emitting process according to a second embodiment;

Fig. 10 is diagram showing a map h used for computing a detection interval t_{dt} based on an intake flow rate GA ;

Fig. 11 is a diagram showing a fuel purification rate map used for obtaining a fuel purification rate;

Fig. 12 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the second embodiment, when a NOx storage reduction catalyst is brand new;

Fig. 13 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the first embodiment, when a NOx storage reduction catalyst has deteriorated to some extent;

Fig. 14 is a flowchart showing a sulfur emitting process according to a third embodiment;

Fig. 15 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the third embodiment, when a NOx storage reduction catalyst has deteriorated to some extent;

Fig. 16 is a flowchart showing a sulfur emitting process according to a fourth embodiment;

Fig. 17 is a diagram showing a map p used for computing the duration of a richening period R_t based on a temperature difference ΔT_{in} ; and

Fig. 18 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the fourth embodiment, when a NOx storage reduction catalyst has deteriorated to some extent.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Fig. 1 is a block diagram illustrating a general configuration of a vehicle diesel engine and a control system according to a first embodiment. The control system functions as a catalyst control apparatus and a catalyst deterioration determination apparatus.

[0013] As shown in Fig. 1, the diesel engine 2 has cylinders. In this embodiment, the number of the cylinders is four, and the cylinders are denoted as #1, #2, #3, and #4. A combustion chamber 4 of each of the cylinders #1 to #4 includes an intake port 8. The combustion chambers 4 are connected to a surge tank 12 via the intake ports 8 and an intake manifold 10. Each intake port 8 is opened and closed by an intake valve 6. The surge tank 12 is connected to outlets of an intercooler 14 and supercharger through an intake passage 13. In this embodiment, an compressor 16a of an exhaust turbocharger 16 functions as a supercharger. An inlet of the compressor 16a is connected to an air cleaner

18. An exhaust gas recirculation (hereinafter, referred to as EGR) passage 20 is connected to the surge tank 12. An EGR gas supply port 20a of the EGR passage 20 opens to the surge tank 12, so that the surge tank 12 and the EGR passage 20 communicate with each other. A throttle valve 22 is located in a section of the intake passage 13 between the surge tank 12 and the intercooler 14. An intake flow rate sensor 24 and an intake temperature sensor 26 are located

5 between the compressor 16a and the air cleaner 18.
[0014] The combustion chamber 4 of each of the cylinders #1 to #4 includes an exhaust port 30. The combustion chambers 4 are connected to an inlet of an exhaust turbine 16b via the exhaust ports 30 and an exhaust manifold 32. Each exhaust port 30 is opened and closed by an exhaust valve 28. An outlet of the exhaust turbine 16b is connected to an exhaust passage 34. Exhaust gas is drawn into the exhaust turbine 16b at a section of the exhaust manifold 32 that is close to the fourth cylinder #4.

10 [0015] Three catalytic converters 36, 38, 40 are located in the exhaust passage 34. The first catalytic converter 36 supports an NOx storage reduction catalyst 36a, which functions as an exhaust purification catalyst. When exhaust gas is regarded as an oxidizing atmosphere (lean) during a normal operation of the diesel engine 2, the NOx storage reduction catalyst 36a occludes nitrogen oxides (NOx) in exhaust. When the exhaust gas is regarded as a reducing atmosphere (stoichiometric or lower air-fuel ratio), the NOx storage reduction catalyst 36a emits occluded NOx in the form of nitrogen monoxide. The emitted nitrogen monoxide is reduced by hydrocarbon and carbon monoxide. In this manner, the first catalytic converter 36 removes NOx from exhaust gas, thereby purifying the exhaust gas.

15 [0016] The second catalytic converter 38, which is located downstream of the first catalytic converter 36, accommodates a filter 38a. The filter 38a has a monolithic wall. The wall has pores through which exhaust gas passes. The areas of the wall defining the pores are coated with a layer containing a NOx storage reduction catalyst, which functions as an exhaust purification catalyst. That is, the NOx occlusion reduction catalyst is supported by the filter 38a. Therefore, when exhaust gas passes through the pores, NOx in the exhaust gas is removed as described above. Also, when exhaust gas passes through the pores, particulate matter in the exhaust gas is trapped by the wall of the filter 38a. The trapped particulate matter starts being oxidized by active oxygen generated when NOx is occluded under a high temperature oxidizing atmosphere. The particulate matter is entirely oxidized by ambient excessive oxygen. In this manner, the second catalytic converter 38 removes NOx and particulate matter in exhaust gas, thereby purifying the exhaust gas. In the first embodiment, the second catalytic converter 38 is integrated with the first catalytic converter 36.

20 [0017] The third catalytic converter 40, which is located downstream of the first and second catalytic converters 36, 38, supports an oxidation catalyst 40a. The oxidation catalyst 40a oxidizes hydrocarbon and carbon monoxide in exhaust gas to purify the exhaust gas.

25 [0018] A first exhaust temperature sensor 44 is located between the NOx storage reduction catalyst 36a and the filter 38a. A second exhaust temperature sensor 46 and an air-fuel ratio sensor 48 are located between the filter 38a and the oxidation catalyst 40a. The second exhaust temperature sensor 46 is closer to the filter 38a, and the air-fuel ratio sensor 48 is located closer to the oxidation catalyst 40a.

30 [0019] The air-fuel ratio sensor 48 detects the air-fuel ratio of exhaust gas based on components of the exhaust gas, and outputs electric signal in linear proportion to the detected air-fuel ratio. The first exhaust temperature sensor 44 detects an exhaust temperature T_{exin} at the corresponding position. Likewise, the second exhaust temperature sensor 46 detects an exhaust temperature T_{exout} at the corresponding position.

35 [0020] Pipes of a differential pressure sensor 50 are connected to a section upstream of the filter 38a and a section downstream of the filter 38a. The differential pressure sensor 50 detects the pressure difference ΔP between the sections upstream and downstream of the filter 38a, thereby detecting the degree of clogging in the filter 38a, or the degree of accumulation of particular matter.

40 [0021] An EGR gas intake port 20b of the EGR passage 20 is provided in the exhaust manifold 32, which connects the exhaust manifold 32 to the EGR passage 20. The EGR gas intake port 20b is located at a section of the exhaust manifold 32 that is close to the first cylinder #1, which section is opposite to a section of the exhaust manifold 32 at which the exhaust turbine 16b introduces exhaust gas.

45 [0022] An iron based EGR catalyst 52, an EGR cooler 54, and an EGR valve 56 are located in the EGR passage 20 in this order from the EGR gas intake port 20b to the EGR gas supply port 20a. The iron based EGR catalyst 52 functions to reform EGR gas and to prevent clogging of the EGR cooler 54. The EGR cooler 54 cools reformed EGR gas. By controlling the opening degree of the EGR valve 56, the flow rate of EGR gas supplied to the intake system through the EGR gas supply port 20a is adjusted.

50 [0023] A fuel injection valve 58 is provided at each of the cylinders #1 to #4 to directly inject fuel into the corresponding combustion chamber 4. The fuel injection valves 58 are connected to a common rail 60 with fuel supply pipes 58a. The common rail 60 is supplied with fuel by a variable displacement fuel pump 62, which is electrically controlled. High pressure fuel supplied from the fuel pump 62 to the common rail 60 is distributed to the fuel injection valves 58 through the fuel supply pipes 58a. A fuel pressure sensor 64 for detecting the pressure of fuel is attached to the common rail 60.

55 [0024] The fuel pump 62 supplies low-pressure fuel to a fuel adding valve 68 through a fuel supply pipe 66. The fuel adding valve 68 is provided in the exhaust port 30 of the fourth cylinder #4 and injects fuel to the exhaust turbine 16b.

In this manner, fuel adding valve 68 adds fuel to exhaust gas. Addition of fuel to exhaust gas by the fuel adding valve 68 is performed in a catalyst control procedure, which is described below.

5 [0025] An electronic control unit (ECU) 70 is mainly composed of a digital computer having a CPU, a ROM, and a RAM, and drive circuits for driving other devices. The ECU 70 reads signals from the intake flow rate sensor 24, the intake temperature sensor 26, the first exhaust temperature sensor 44, the second exhaust temperature sensor 46, the air-fuel ratio sensor 48, the differential pressure sensor 50, an EGR opening degree sensor in the EGR valve 56, the fuel pressure sensor 64, and a throttle opening degree sensor 22a. Further, the ECU 70 reads signals from an acceleration pedal sensor 74 that detects the depression degree of an acceleration pedal 72, or an acceleration pedal depression degree ACCP, a coolant temperature sensor 76 that detects the temperature of coolant THW of the diesel engine 2, an engine speed sensor 80 that detects the number of revolutions NE of a crankshaft 78, and a cylinder distinguishing sensor 82 that distinguishes cylinders by detecting the rotation phase of the crankshaft 78 or the rotation phase of the intake cams.

10 [0026] Based on received signals, the ECU 70 obtains the operating condition of the engine 2. Based on the obtained engine condition, the ECU 70 controls the amount and the timing of fuel injection by the fuel injection valves 58. Further, the ECU 70 controls the opening degree of the EGR valve 56, the throttle opening degree with the motor 22b, and the displacement of the fuel pump 62. Also, the ECU 70 executes filter regeneration control and sulfur release control, which will be described below.

20 [0027] According to the operating condition, the ECU 70 executes either of a normal combustion mode and a low temperature combustion mode. In the low temperature combustion mode, a large amount of exhaust gas is recirculated so that the combustion temperature is slowly increased. This simultaneously reduces NOx and smoke. In the low temperature combustion mode, an EGR valve opening map for the low temperature combustion mode is used. In this embodiment, the low temperature combustion mode is executed in a low load, middle-to-high rotation speed region. At this time, feedback control is executed by adjusting a throttle opening degree TA based on an air-fuel ratio AF detected by the air-fuel ratio sensor 48. In the normal combustion mode, normal EGR control (including a case where no exhaust gas is recirculated) is performed. In the normal combustion mode, an EGR valve opening map for the normal combustion mode is used.

25 [0028] The ECU 70 also executes four catalyst control procedures, which include a filter regeneration mode, a sulfur release control mode, a NOx reduction mode, and a normal mode.

30 [0029] In the filter regeneration mode, particulate matter deposited on the filter 38a of the second catalytic converter 38 is heated, so that the particulate matter is combusted and split into carbon dioxide and water. In this mode, addition of fuel from the fuel adding valve 68 is repeated in an air-fuel ratio higher than the stoichiometric air-fuel ratio so that the catalyst bed temperature is increased to a high temperature which is, for example, in a range from 600°C to 700°C. In the filter regeneration mode, after injection may be performed in which fuel is injected from the fuel injection valve 58 into the combustion chambers 4 during the expansion stroke or the exhaust stroke.

35 [0030] In the sulfur release control mode, sulfur components are emitted from the NOx storage reduction catalysts of the first and second catalytic converters 36, 38 so that the NOx occlusion capacity of the converters 36, 38, which has been lowered due to poisoning of sulfur, is restored. In this mode, a temperature increase process is executed, in which addition of fuel from the fuel adding valve 68 is repeated so that the catalyst bed temperature is increased to a high temperature which is, for example, 650°C. Also, an air-fuel ratio lowering process is executed in which intermittent addition of fuel from the fuel adding valve 68 is performed so that the air-fuel ratio is changed to the stoichiometric air-fuel' ratio or a value slightly lower than the stoichiometric air-fuel ratio. In the sulfur release control mode, after injection may be performed by the fuel injection valve 58.

40 [0031] In the NOx reduction mode, NOx occluded by the NOx storage reduction catalysts of the first and second catalytic converters 36, 38 is reduced to nitrogen. As a by-product, carbon dioxide and water are formed when NOx is reduced to nitrogen. In the NOx reduction mode, a process is executed, in which addition of fuel from the fuel adding valve 68 is repeated at a relatively long interval so that the catalyst bed temperature is increased to a not so high temperature which is, for example, in a range from 250°C to 500°C. Also, another process is executed, in which the air-fuel ratio is changed to the stoichiometric air-fuel ratio or a value lower than the stoichiometric air-fuel ratio.

45 [0032] In the normal mode, addition of fuel from the fuel adding valve 68 and after injection by the fuel injection valves 58 are not performed.

50 [0033] Next, the sulfur release control executed by the ECU 70 will be described.

[0034] Fig. 2 is a flowchart of this control. The control is repeatedly executed by the ECU 70 at a predetermined interval. That is, the sulfur release control is a periodical interruption process routine.

55 [0035] When the sulfur release control is started, the ECU 70 determines whether requirements for executing the sulfur release control are satisfied at step S102. The execution requirements of the sulfur release control include that the amount of sulfur poisoning is no less than a predetermined amount, that the filter regeneration mode is not currently selected, and that the temperatures of the NOx storage reduction catalysts of the first and second catalytic converters 36, 38, which are estimated from the exhaust temperatures T_{exin} , T_{exout} are not significantly high or low, and are in an

appropriate temperature range. When determining that the execution requirements of the sulfur release control are not satisfied, the ECU 70 ends this control.

[0036] When determining that the execution requirements of the sulfur release control are satisfied, the ECU 70 proceeds to step S104 and determines whether requirements for starting a sulfur emitting process are satisfied. The starting requirement of the sulfur emitting process is that the catalyst bed temperatures of the NOx storage reduction catalysts of the first and second catalytic converters 36, 38 have reached to values near a target temperature (for example, 650°C), specifically, that an estimated catalyst bed temperature of the NOx storage reduction catalyst is no less than 600°C. The estimated catalyst bed temperatures of the NOx storage reduction catalysts of the first and second catalytic converters 36, 38 may be computed based on the operating condition of the engine 2 (for example, the number of revolutions NE of the engine 2) and the amount of added fuel. Alternatively, the estimated catalyst bed temperatures may be estimated from the exhaust temperature T_{exin} .

[0037] When determining that the starting requirements of the sulfur emitting process are not satisfied, the ECU 70 proceeds to step S106 and executes temperature increase control. During the temperature increase control, the NOx storage reduction catalyst 36a is assumed to be brand new, and a predetermined amount fuel is intermittently added to exhaust from the fuel adding valve 68 such that the NOx storage reduction catalyst 36a is not excessively heated and the estimated catalyst bed temperature of the NOx storage reduction catalyst 36a is not less than 600°C. At this time, although the catalyst bed temperature of the NOx storage reduction catalyst of the second catalytic converter 38 is close to the catalyst bed temperature of the NOx storage reduction catalyst 36a of the first catalytic converter 36, the catalyst bed temperature of the NOx storage reduction catalyst of the second catalytic converter 38 fluctuates less than the catalyst bed temperature of the NOx storage reduction catalyst 36a. Therefore, the NOx storage reduction catalyst 36a of the first catalytic converter 36 is more likely to be excessively heated than the NOx storage reduction catalyst of the second catalytic converter 38 during the sulfur emitting process. Thus, the following description will focus on the NOx storage reduction catalyst 36a.

[0038] Even if the starting requirements of the sulfur emitting process are determined to be unsatisfied, the temperature increase control is executed at step S106, and the starting requirement of the sulfur emitting process will eventually be satisfied. Then, the ECU 70 proceeds to step S108 instead of step S106, after step S104. Then, as show in Fig. 3, the ECU 70 executes deterioration degree determination process. Subsequently, at step S110, the ECU 70 executes the sulfur emitting process.

[0039] When the deterioration degree determination process is started, the ECU 70 first determines whether requirements for executing the deterioration degree determination process are satisfied at step S122 as shown in Fig 3. The execution requirements of the deterioration degree determination process include a condition where the value of the exhaust temperature T_{exin} detected by the first exhaust temperature sensor 44 is periodically changed in a stable manner, that is, a condition where the operating condition of the engine 2 (for example, and the load and the number of revolution E of the engine 2) are stable.

[0040] When determining that the execution requirements of the deterioration degree determination process are not satisfied, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 4.

[0041] On the other hand, when determining that the execution requirements of the deterioration degree determination process are satisfied, the ECU 70 proceeds to step S123 and determines whether an amplitude value A_{mpin} has been obtained in the current sulfur release routine. When determining that the amplitude value A_{mpin} has been obtained, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 4. When determining that the amplitude value A_{mpin} has not been obtained, the ECU 70 proceeds to step S124. At step S124, the ECU 70 executes a process for obtaining the maximum value T_{inmax} of the exhaust temperature T_{exin} detected by the first exhaust temperature sensor 44. Further, at step S126, the ECU 70 executes a process for obtaining the minimum value T_{inmin} of the exhaust temperature T_{exin} .

[0042] When executing the sulfur emitting process of Fig. 4, which will be discussed below, a richening period R_t , during which the air-fuel ratio of exhaust is richened, and a non-richening period L_t , during which the air-fuel ratio is not richened, are repeated as shown in the graph of upper portion of Fig. 6. Accordingly, the actual catalyst bed temperature of the NOx storage reduction catalyst 36a is repeatedly increased during the richening period R_t and decreased during the non-richening period L_t . The exhaust temperature T_{exin} detected by the first exhaust temperature sensor 44 represents the actual catalyst bed temperature of the NOx storage reduction catalyst 36a. Therefore, the maximum value T_{inmax} of the exhaust temperature T_{exin} represents the maximum value of the catalyst bed temperature during the richening period R_t , and the minimum value T_{inmin} of the exhaust temperature T_{exin} represents the minimum value of the catalyst bed temperature during the non-richening period L_t . At step S124, the ECU 70 obtains the maximum value T_{inmax} , if there is any, from the values of the exhaust temperature T_{exin} detected by the first exhaust temperature sensor 44 during the sulfur emitting process. At step S126, the ECU 70 obtains the minimum value T_{inmin} , if there is any, from the values of the exhaust temperature T_{exin} detected by the first exhaust temperature sensor during the sulfur emitting process.

[0043] At subsequent step S128, the ECU 70 determines whether the maximum value T_{inmax} and the minimum value T_{inmin} both have been obtained. When determining that the one or both of the maximum value T_{inmax} and the minimum value T_{inmin} have not been obtained, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 4.

[0044] In an example shown by the graph in the lower portion of Fig. 6, the maximum value T_{inmax} appears at time t_0 when the air-fuel ratio of exhaust gas is richened during the richening period R_t . Subsequently, the minimum value T_{inmin} appears at time t_1 by stopping the richening of the air-fuel ratio of exhaust gas during the non-richening period L_t . In such a case, the ECU 70 obtains the maximum value T_{inmax} and the minimum value T_{inmin} at steps S124 and S126, respectively. At step S128, the ECU 70 determines that both of the maximum value T_{inmax} and the minimum value T_{inmin} have been obtained. Thereafter, the ECU 70 proceeds to step S130 and computes the amplitude value A_{mpin} according to a formula 1:

$$A_{mpin} \leftarrow T_{inmax} - T_{inmin}$$

Then, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 4. The computed amplitude value A_{mpin} is stored in nonvolatile memory in the ECU 70, and is maintained when the ECU 70 is turned off.

[0045] When the sulfur emitting process is started, the ECU 70 first determines whether the amplitude value A_{mpin} has been obtained in the current sulfur release control at step S152 as shown in Fig 4. When determining that the amplitude value A_{mpin} has not been obtained, the ECU 70 proceeds to step S154, and sets the duration of the richening period R_t to an initial value R_{tint} . The initial value R_{tint} is a value obtained through experiments. The initial value R_{tint} is determined such that a brand new NOx storage reduction catalyst 36a does not deteriorate due to heat even if richening with fuel added by the fuel adding valve 68 is continued for the duration of the initial value R_{tint} . A brand new NOx storage reduction catalyst 36a will deteriorate due to heat if the catalyst bed temperature exceeds a predetermined temperature (for example, the upper limit temperature shown in Fig. 6).

[0046] In subsequent step S158, the ECU 70 computes the duration of the non-richening period L_t , which should be determined for setting the catalyst bed temperature of the NOx storage reduction catalyst 36a to a target bed temperature T_{cat} . The computation is executed using a map g, based on the initial value R_{tint} , a heat value H_{ex} obtained by adding fuel of a predetermined amount Q_{add} to exhaust gas from the fuel adding valve 68, the exhaust temperature T_{ex} that contacts the NOx storage reduction catalyst 36a, an exhaust amount V_{ex} , a heat capacity C_{ex} of the exhaust system, and the target bed temperature T_{cat} .

[0047] The predetermined value Q_{add} is an amount of fuel that is added to exhaust from the fuel adding valve 68 when the duration of the richening period R_t is set to the initial value R_{tint} . The heat value H_{ex} is an amount of heat generated by oxidation of fuel of the predetermined value Q_{add} when a brand new NOx storage reduction catalyst 36a is used. The exhaust temperature T_{ex} is estimated based on the engine operating condition (the load and the number of revolution NE of the engine 2). The exhaust amount V_{ex} represents the amount of exhaust that is exhaust during a period including the richening period R_t and the non-richening period L_t , and is computed based on an intake flow rate GA detected by the intake flow rate sensor 24 and the total time of the richening period R_t and the non-richening period L_t . The heat capacity C_{ex} is a value that has been obtained through experiments in advance, and a fixed value determined by the type of engine.

[0048] At subsequent step S160, based on a first counter that shows elapsed time since the richening has been started, the ECU 70 determines whether the elapsed time since the richening has been started is equal to or more than a richening period R_t . When determining that the richening period R_t has not been elapsed, the ECU 70 proceeds to step S162, and causes the fuel adding valve 68 to add fuel to exhaust. That is, at step S162, the ECU 70 starts or continues richening of exhaust gas. At subsequent step S164, the ECU 70 increments the value of the first counter. Then, the ECU 70 ends the sulfur emitting process.

[0049] Thereafter, addition of fuel by the fuel adding valve 68 is repeated every time the sulfur emitting process is executed as long as the time after the richening was started is less than the richening period R_t . Accordingly, the value of the first counter continues being incremented. When the time after the richening was started reaches the richening period R_t , the ECU 70 does not proceed to step S162 after step S160, instead proceeds to step S166. At step S166, the ECU 70 does not cause the fuel adding valve 68 to add fuel to exhaust gas. That is, the richening is stopped at step S166. At subsequent step S168, based on a second counter that shows elapsed time since the richening has been stopped, the ECU 70 determines whether the elapsed time since the richening has been stopped is equal to or more than a non-richening period L_t . When determining that the non-richening period L_t has not been elapsed, the ECU 70 proceeds to step S170. At step S170, the ECU 70 increments the second counter, and ends the sulfur emitting process.

[0050] Thereafter, the value of the second counter continues being incremented as long as the time after the richening

was stopped is less than the non-richening period L_t . When the time after the richening was stopped reaches the non-richening period L_t , the ECU 70 does not proceed to step S170 after step S168, instead proceeds to step S172. At step S172, the ECU 70 clears the value of the first counter value. At subsequent step S174, the ECU 70 clears the value of the second counter. Then, the ECU 70 ends the sulfur emitting process.

5 **[0051]** If the amplitude value A_{mpin} is not obtained in a subsequent execution of the sulfur emitting process during the sulfur emitting process, the ECU 70 sets the duration of the richening period R_t to the initial value R_{tint} at step S154. Further, at step S158, the ECU 70 computes the duration of the non-richening period L_t using the map g, and proceeds to step 160. In this case, since the richening has not even been started, the time elapsed after the richening period R_t was started has not reached the richening period R_t . Therefore, the ECU 70 proceeds to step S162 and causes the fuel adding valve 68 to add fuel to exhaust gas. In this manner, richening of exhaust gas is started again.

10 **[0052]** If the maximum value T_{inmax} and the minimum value T_{inmin} are obtained and the amplitude value A_{mpin} is computed in the deterioration degree determination process shown in Fig. 3, the ECU 70 does not proceed to step S154 after step S152, but to step 156 in the sulfur emitting process. At step S156, the ECU 70 computes the duration of the richening period R_t to be set. The computation is executed using a map f shown in Fig. 5, based on the size of an amplitude value A_{mpin} , which represents the degree of deterioration of the NOx storage reduction catalyst 36a. The greater the value of the amplitude value A_{mpin} is, the lower the degree of deterioration of the NOx storage reduction catalyst 36a becomes and the higher the oxidation efficiency for fuel at the NOx storage reduction catalyst 36a (the same as the fuel purification rate) becomes. In this case, the richening period R_t is set to a short value to correspond to the catalyst bed temperature, which rapidly increases after the richening is started. On the other hand, the smaller the value of the amplitude value A_{mpin} is, the greater the degree of deterioration of the NOx storage reduction catalyst 36a becomes and the lower the oxidation efficiency of the NOx storage reduction catalyst 36a becomes. In this case, the richening period R_t is set to a long value to correspond to the catalyst bed temperature, which slowly increases after the richening is started.

15 **[0053]** As described above, the duration of the non-richening period L_t to be set is computed at subsequent step S158 based on the map g using the initial value R_{tint} , the heat value H_{ex} , the exhaust temperature T_{ex} , the heat capacity C_{ex} , and the target bed temperature T_{cat} . At subsequent step S160, when determining that the period of time from starting the richening has not reached the richening period R_t , the ECU 70 performs addition of fuel at step S162. Then at step S164, the ECU 70 increments the value of the first counter.

20 **[0054]** Next time the deterioration degree determination process is executed, since the amplitude value A_{mpin} will have already been obtained, the ECU 70 therefore will end the deterioration degree determination process without proceeding to steps S124 to S130 after step S123. Therefore, in subsequent executions of the sulfur emitting process, the ECU 70 does not proceed to step S154 after step S152, but proceeds to step S156. At step S156, the ECU 70 sets the duration of the richening period R_t based on the amplitude value A_{mpin} .

25 **[0055]** When the NOx storage reduction catalyst 36a recovers from sulfur poisoned state, the ECU 70 determines that the requirements for executing the sulfur release control are not satisfied at step S102, while executing the sulfur release control shown in Fig. 2. The ECU 70 then ends the sulfur release control. Thereafter, if the execution requirements are satisfied, for example, when the sulfur poisoning amount reaches the predetermined amount, the deterioration degree determination process and the sulfur emitting process are executed. That is, the duration of the richening period R_t is set to the initial value R_{tint} at step S154, and the amplitude value A_{mpin} is computed at steps S124 to S130. Then, based on the computed amplitude value A_{mpin} , the duration of the richening period R_t is set at step S156.

30 **[0056]** Fig. 6 shows changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature in a case where the NOx storage reduction catalysts of the first and second catalytic converters 36, 38 are brand new. In this case, the duration of the richening period R_t computed based on the amplitude value A_{mpin} is the same as the initial value R_{tint} .

35 **[0057]** On the other hand, Fig. 7 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature in a case where the NOx storage reduction catalyst 36a has deteriorated to some extent. In this case, the duration of the richening period R_t computed based on the amplitude value A_{mpin} is longer than the initial value R_{tint} . Therefore, like the case where the NOx storage reduction catalyst 36a is brand new, which is shown in Fig. 6, the catalyst bed temperature of the NOx storage reduction catalyst 36a is increased to a value equal to or higher than the target temperature such that the maximum value T_{inmax} does not exceed the upper limit temperature.

40 **[0058]** The first exhaust temperature sensor 44 corresponds to catalyst bed temperature detecting means that detects a physical quantity representing the actual catalyst bed temperature of the exhaust purification catalyst. The ECU 70 functions as deterioration degree detecting means that detects the deterioration degree of the exhaust purification catalyst, and changing means that changes the ratio of the duration of the richening period to the duration of the non-richening period according to the deterioration degree of the exhaust purification catalyst detected by the deterioration degree detecting means. The ECU 70 also functions as fuel supply means that intermittently supplies fuel to exhaust gas at a section upstream of the exhaust purification catalyst, and as deterioration degree determination means. The narrower the range of fluctuation of the physical quantity detected by the catalyst bed temperature as the fuel supply means supplies fuel to exhaust gas, the higher the deterioration degree of the exhaust purification catalyst that is

determined by the deterioration degree determination means.

[0059] In this embodiment, the deterioration degree determination process shown in Fig. 3 and steps S152, S154 of the sulfur emitting process shown in Fig. 4 correspond to a process executed by the deterioration degree detecting means. Step S156 of the sulfur emitting process corresponds to a process executed by the changing means. The sulfur emitting process corresponds to a process executed by the fuel supply means. The deterioration degree determination process and step S156 of the sulfur emitting process correspond to a process executed by the deterioration degree determination means.

[0060] The first embodiment has the following advantages.

[0061] (1) During the execution of the sulfur release control, the richening period R_t , in which the air-fuel ratio of exhaust gas is richened, and the non-richening period L_t , in which the air-fuel ratio is not richened, are alternately repeated. Every time the richening period R_t or the non-richening period L_t is executed, the catalyst bed temperature of the NOx storage reduction catalyst 36a is repeatedly increased and decreased. The amplitude value A_{mpin} reflects fluctuation (amplitude) of the catalyst bed temperature. The more deteriorated the NOx storage reduction catalyst 36a, the smaller the magnitude of the amplitude value A_{mpin} , or the magnitude of fluctuation of the catalyst bed temperature. Therefore, the amplitude value A_{mpin} indicates the degree of deterioration of the NOx storage reduction catalyst 36a.

[0062] In the first embodiment, when the amplitude value A_{mpin} is great as shown in the map f of Fig. 5, that is, in a case where the deterioration of the NOx storage reduction catalyst 36a has not significantly developed, the duration of the richening period R_t is set relatively short. When the amplitude value A_{mpin} is small as shown in the map f of Fig. 5, that is, in a case where the deterioration of the NOx storage reduction catalyst 36a has considerably developed, the duration of the richening period R_t is set relatively long. Therefore, with changes of the degree of deterioration of the NOx storage reduction catalyst 36a, an increase in the catalyst bed temperature of the NOx storage reduction catalyst 36a is prevented from being excessive or too little. Thus, the deterioration of the NOx storage reduction catalyst 36a due to an excessive increase in the catalyst bed temperature and a decrease in the sulfur emitting efficiency due to insufficient increase in the catalyst bed temperature are prevented. The sulfur emitting efficiency is prevented from being lowered in this manner. As a result, deterioration of emission due to the lowered accuracy of the sulfur release control and a decrease of the fuel economy due to an extended period of the sulfur release control are suppressed.

[0063] (2) The amplitude value A_{mpin} is computed in a state where the duration of the richening period R_t is set to the initial value R_{tint} . Based on the amplitude value A_{mpin} thus computed, the degree of deterioration of the NOx storage reduction catalyst 36a is determined. In this manner, since the duration of the richening period R_t has a constant value (the initial value R_{tint}) when the amplitude value A_{mpin} is computed, the computed amplitude value A_{mpin} accurately corresponds to the degree of deterioration of the NOx storage reduction catalyst 36a. When the duration of the richening period R_t is set to the initial value R_{tint} , the amount of fuel added by the fuel adding valve 68 during the richening period R_t is the minimum value. Therefore, when determining the degree of deterioration of the NOx storage reduction catalyst 36a by computing the amplitude value A_{mpin} , the NOx storage reduction catalyst 36a is unlikely to be excessively heated.

[0064] A second embodiment of the present invention will now be described with reference to the drawings.

[0065] In the second embodiment, the degree of deterioration of the exhaust purification catalyst is not determined based on the amplitude value A_{mpin} , but is determined based on the rate of increase of the exhaust temperature T_{exin} . Also, in the second embodiment, not the duration of the richening period R_t , but the duration of the non-richening period L_t is changed according to the degree of deterioration of the exhaust purification catalyst.

[0066] In the second embodiment, a deterioration degree determination process of Fig. 8 is executed instead of the deterioration degree determination process of Fig. 4, and a sulfur emitting process of Fig. 9 is executed instead of the sulfur emitting process of Fig. 4. Other processes and the hardware configuration are the same as those of the first embodiment.

[0067] When the deterioration degree determination process of Fig. 8 is started, the ECU 70 first determines whether requirements for executing the deterioration degree determination process are satisfied at step S202. The requirements for executing the deterioration degree determination process are the same as those of the deterioration degree determination process of Fig. 3.

[0068] When determining that the execution requirements of the deterioration degree determination process are not satisfied, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 9. On the other hand, when determining that the execution requirements of the deterioration degree determination process are satisfied, the ECU 70 proceeds to step S204 and computes a detection interval t_{dt} of the exhaust temperature T_{exin} . The computation is performed using a map h shown in Fig. 10 based on the intake flow rate GA. The ECU 70 detects the exhaust temperature T_{exin} at a point in time where the detection interval t_{dt} has elapsed from when the fuel adding valve 68 added fuel to exhaust gas in the sulfur emitting process shown in Fig. 9, which will be discussed below. When the fuel adding valve 68 adds fuel to exhaust gas, the catalyst bed temperature of the NOx storage reduction catalyst 36a is increased, and the exhaust temperature T_{exin} is increased, accordingly. The rate of increase of the exhaust temperature T_{exin} changes according to the degree of deterioration of the NOx

storage reduction catalyst 36a and the intake flow rate GA. Specifically, the higher the deterioration degree of the NOx storage reduction catalyst 36a, the lower the rate of increase of the exhaust temperature T_{exin} . The greater the intake flow rate GA, the higher the rate of increase of the exhaust temperature T_{exin} . The detection interval t_{dt} is computed and set using the map h shown in Fig. 10 such that the rate of increase of the exhaust temperature T_{exin} is always constant regardless of the value of the intake flow rate GA as long as the degree of deterioration of the NOx storage reduction catalyst 36a is the same.

[0069] At subsequent step S206, the ECU 70 determines whether time elapsed from when the fuel adding valve 68 started adding fuel to exhaust gas is being currently counted. The counting is started at step S212, which will be discussed below. When determining that the counting is being currently performed, the ECU 70 proceeds to step S208 and determines whether now is the time to start addition of fuel by the fuel adding valve 68. The ECU 70 determines that now is the time to start addition of fuel if the ECU 70 determined that the period from when the richening had been started did not reach the richening period R_t at step S240 of the sulfur emitting process shown in Fig. 9 in the previous execution of the sulfur release control. Otherwise, the ECU 70 determines that now is not the time to start addition of fuel.

[0070] When determining that now is not the time to start addition of fuel, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 9. On the other hand, when determining that now is the time to start addition of fuel, the ECU 70 sets the exhaust temperature T_{exin} detected at the moment to the initial exhaust temperature T_a . Then, at subsequent step S212, the ECU 70 starts counting time elapsed from when addition of fuel from the fuel adding valve 68 was started. Thereafter, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 9.

[0071] In the case where counting of the time elapsed from when addition of fuel from the fuel adding valve 68 was started was started during the previous execution of the deterioration degree determination process, the ECU 70, in the subsequent execution of the deterioration degree determination process, does not proceed to step S208 after step S206, but proceeds to step S214. Then, at step S214, the ECU 70 determines whether time elapsed from when addition of fuel was started has reached the detection interval t_{dt} . When determining that the time elapsed since addition of fuel was started has not reached the detection interval t_{dt} , the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 9.

[0072] On the other hand, when determining that the time elapsed since addition of fuel was started has reached the detection interval t_{dt} , the ECU 70 at step S216 computes a temperature difference ΔT_{in} between the exhaust temperature T_{exin} detected at the moment and the initial exhaust temperature T_a according to a formula 2:

$$\Delta T_{\text{in}} \leftarrow T_{\text{exin}} - T_a$$

The temperature difference ΔT_{in} corresponds to the rate of increase of the exhaust temperature T_{exin} in a referential exhaust flow rate state when the detection interval t_{dt} is used as a unit. At subsequent step S218, the ECU 70 stops counting time elapsed from when addition of fuel was started. Thereafter, the ECU 70 ends the deterioration degree determination process, and proceeds to the sulfur emitting process shown in Fig. 9.

[0073] Before the difference of the temperature difference ΔT_{in} is computed at step S216, the temperature difference T_{in} is set to an initial value ΔT_{inint} that corresponds to a brand new NOx storage reduction catalyst 36a is used.

[0074] The sulfur emitting process will now be described with reference to Fig. 9. When the sulfur emitting process is started, the ECU 70 first execute a computation process $k(\Delta T_{\text{in}}, \Delta T_{\text{inint}}, \Delta T_{\text{ine}}, T_{\text{ex}})$ based on the temperature difference ΔT_{in} , the initial value ΔT_{inint} , a temperature difference ΔT_{ine} , and the exhaust temperature T_{ex} , thereby computing a fuel purification rate K_{ex} . The temperature difference ΔT_{ine} will be discussed below. In the computation process $k(\Delta T_{\text{in}}, \Delta T_{\text{inint}}, \Delta T_{\text{ine}}, T_{\text{ex}})$, a fuel purification rate K_{exs} for a case where a non-deteriorated catalyst is used and a fuel purification rate K_{exe} for a case where a deteriorated catalyst is used are obtained using a fuel purification map shown in Fig. 11, which is related to the fuel purification rate K_{exs} and the fuel purification rate K_{exe} . Then, the computed fuel purification rates K_{exs} , K_{exe} are prorated by the temperature differences ΔT_{in} , ΔT_{ine} and the initial value ΔT_{inint} . As a result, the fuel purification rate K_{ex} is obtained. More specifically, the fuel purification rate K_{ex} is computed according to a formula 3:

$$K_{\text{ex}} \leftarrow K_{\text{exs}} - \{(K_{\text{exs}} - K_{\text{exe}}) \times (\Delta T_{\text{inint}} - \Delta T_{\text{in}}) / (\Delta T_{\text{inint}} - \Delta T_{\text{ine}})\}$$

[0075] The fuel purification rate K_{exs} is obtained through experiments in which the temperature T_{ex} of exhaust gas that contacts the NOx storage reduction catalyst 36a is used as a parameter. Also, the fuel purification rate K_{exs} is a fuel purification rate by a brand new NOx storage reduction catalyst 36a, that is, a non-deteriorated NOx storage reduction catalyst 36a. The fuel purification rate K_{exe} is also obtained through experiments in which the exhaust temperature T_{ex} as a parameter. The fuel purification rate K_{exe} is a fuel purification rate by an old NOx storage reduction

catalyst 36a, that is, a somewhat deteriorated NOx storage reduction catalyst 36a. The temperature difference ΔT_{ine} is a value obtained through experiments and corresponds to the temperature difference ΔT_{in} that is computed when a somewhat deteriorated NOx storage reduction catalyst 36a is used.

[0076] At subsequent step S234, the ECU 70 sets the duration of the richening period R_t to the initial value R_{tinit} . This process is the same as the process of step S154 in the sulfur emitting process shown in Fig. 4. At subsequent step S236, the ECU 70 computes the heat value H_{ex} of a single addition of fuel according to a formula 4:

$$H_{ex} \leftarrow (K_{ex}/K_{exs}) \times H_{exint}$$

A constant H_{exint} in the formula 4 is a heat value of a single addition of fuel when a brand new NOx storage reduction catalyst 36a is used.

[0077] Thereafter, the ECU 70 computes the non-richening period L_t using the map g at step S238. The map g is the same map g that is used at step S158 of the sulfur emitting process shown in Fig. 4. Steps 240, S242, S244, S246, S248, S250, S252, and S254 in Fig. 9, which are executed by the ECU 70 after step S238 are each the same as steps S160, S162, S164, S166, S168, S170, S172, and S174 of the sulfur emitting process shown in Fig. 4.

[0078] As described above, the deterioration degree of the NOx storage reduction catalyst 36a is reflected on the temperature difference ΔT_{in} . The smaller the temperature difference ΔT_{in} , the more deteriorated the deterioration of the NOx storage reduction catalyst 36a is determined to be. The temperature difference ΔT_{in} , which reflects the deterioration degree of the NOx storage reduction catalyst 36a, is reflected on the duration of the non-richening period L_t through the fuel purification rate K_{ex} and the heat value H_{ex} . Therefore, the more deteriorated the NOx storage reduction catalyst 36a, the shorter the duration of the non-richening period L_t is set so that the catalyst bed temperature reaches the target bed temperature.

[0079] Fig. 12 is a graph showing changes in the air-fuel ratio of exhaust gas in the second embodiment when the NOx storage reduction catalyst 36a is brand new. Fig. 13 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature in the second embodiment when the NOx storage reduction catalyst 36a has deteriorated to some extent. As shown in Fig. 12, when the NOx storage reduction catalyst 36a is brand new, the temperature difference ΔT_{in} between the catalyst bed temperature at points in time t_{20} , t_{22} , where the fuel adding valve 68 starts adding fuel to exhaust gas, and the catalyst bed temperature at points in time t_{21} , t_{23} , where the detection period t_{dt} has elapsed from points in time t_{20} , t_{22} is relatively great. Thus, the duration of the non-richening period L_t is set relatively long so that the catalyst bed temperature reaches the target bed temperature. On the other hand, as shown in Fig. 13, when the NOx storage reduction catalyst 36a has deteriorated to some extent, the temperature difference ΔT_{in} between the catalyst bed temperature at points in time t_{30} , t_{32} , where the fuel adding valve 68 starts adding fuel to exhaust gas, and the catalyst bed temperature at points in time t_{31} , t_{33} , where the detection period t_{dt} has elapsed from points in time t_{30} , t_{32} is relatively small. Thus, the duration of the non-richening period L_t is set relatively short so that the catalyst bed temperature reaches the target bed temperature.

[0080] In this embodiment, the deterioration degree determination process shown in Fig. 8 corresponds to a process executed by the deterioration degree detecting means. Steps S232, S236, S238 of the sulfur emitting process shown in Fig. 9 correspond to a process executed by the changing means. The sulfur emitting process corresponds to a process executed by the fuel supply means. The deterioration degree determination process and step S232 of the sulfur emitting process correspond to a process executed by the deterioration degree determination means.

[0081] The second embodiment has the following advantage.

[0082] (1) As in the first embodiment, during the execution of the sulfur release control, the richening period R_t and the non-richening period L_t are alternately repeated. Every time the richening period R_t or the non-richening period L_t is executed, the catalyst bed temperature of the NOx storage reduction catalyst 36a is repeatedly increased and decreased. The more deteriorated the NOx storage reduction catalyst 36a, the smaller the temperature difference ΔT_{in} , which corresponds to the rate of increase of the catalyst bed temperature due to the start of the richening period R_t , becomes. That is, the deterioration degree of the NOx storage reduction catalyst 36a is reflected on the temperature difference ΔT_{in} . Therefore, the deterioration degree of the NOx storage reduction catalyst 36a is easily determined based on the temperature difference ΔT_{in} .

[0083] When the ECU 70 determines that the NOx storage reduction catalyst 36a has scarcely deteriorated since the temperature difference ΔT_{in} is sufficiently great, a high value of the fuel purification rate K_{ex} is set based on the fuel purification map of Fig. 11 to maintain the catalyst bed temperature at the target bed temperature. As a result, the duration of the non-richening period L_t is set relatively long. Accordingly, an excessive increase of the catalyst bed temperature due to richening of the air-fuel ratio of the exhaust gas is prevented. Thereafter, when the ECU 70 determines that the NOx storage reduction catalyst 36a has deteriorated to some extent since the temperature difference ΔT_{in} is small, a low value of the fuel purification rate K_{ex} is set based on the fuel purification map of Fig. 11 to maintain the catalyst bed temperature at the target bed temperature. As a result, the duration of the non-richening period L_t is

set relatively short. Accordingly, a decrease of the fuel emitting efficiency due to an insufficient increase of the catalyst bed temperature is suppressed. In this manner, even if the deterioration degree of the NOx storage reduction catalyst 36a is changed, the catalyst bed temperature is not excessively increased, and the sulfur release control is executed accurately.

5 **[0084]** A third embodiment of the present invention will now be described with reference to the drawings.

[0085] In the third embodiment, the duration of the non-richening period L_t is changed based on the amplitude value A_{mpin} , which is computed through the deterioration degree determination process shown in Fig. 3. In the third embodiment, a sulfur emitting process shown in Fig. 14 is executed instead of the sulfur emitting process shown in Fig. 4. Other processes and the hardware configuration are the same as those of the first embodiment.

10 **[0086]** When the sulfur emitting process shown in Fig. 14 is started, the ECU 70 first sets the duration of the richening period R_t to the initial value R_{tint} at step S302. The process of step S302 is the same as the process of step S154 in the sulfur emitting process shown in Fig. 4.

[0087] Thereafter, the ECU 70 determines whether the amplitude value A_{mpin} has already been obtained in the current execution of the sulfur release process at step S304. When determining that the amplitude value A_{mpin} has not been obtained, the ECU 70 proceeds to step S306, and sets the duration of the non-richening period L_t to the initial value L_{tint} . The initial value L_{tint} is set such that the average catalyst bed temperature of the NOx storage reduction catalyst 36a when the fuel adding valve 68 is adding fuel to exhaust in a case where the initial value R_{tint} is set as the duration of the richening period R_t , and the NOx storage reduction catalyst 36a is brand new becomes the target bed temperature.

20 **[0088]** Steps 314, S316, S318, S320, S322, S324, S326, and S328 in Fig. 14, which are executed by the ECU 70 after step S306 are each the same as steps S160, S162, S164, S166, S168, S170, S172, and S174 of the sulfur emitting process shown in Fig. 4. In this manner, the initial values R_{tint} and L_{tint} are set as the duration of the richening period R_t and the duration of the non-richening period L_t , respectively, and through the deterioration degree determination process shown in Fig. 3, the maximum value T_{inmax} and the minimum value T_{inmin} are obtained and the amplitude value A_{mpin} is computed.

[0089] When the amplitude value A_{mpin} is computed in this manner, the ECU 70, in the subsequent sulfur emitting process, proceeds to step S308, instead of step S306, after step S304. At step S308, the ECU 70 performs a computation process $m(A_{mpin}, A_{mpinint}, A_{mpe}, T_{ex})$ based on the amplitude value A_{mpin} , an initial value $A_{mpinint}$, and an amplitude value A_{mpe} to compute the fuel purification rate K_{ex} .

30 **[0090]** In the computation process $m(A_{mpin}, A_{mpinint}, A_{mpe}, T_{ex})$, a fuel purification rate K_{exs} for a case where a non-deteriorated catalyst is used and a fuel purification rate K_{exe} for a case where a deteriorated catalyst is used are obtained using a fuel purification map shown in Fig. 11 based on the exhaust temperature T_{ex} . Then, the computed fuel purification rates K_{exs} , K_{exe} are prorated by the amplitude values A_{mpin} , A_{mpe} and the initial value $A_{mpinint}$. As a result, the fuel purification rate K_{ex} is obtained. More specifically, the fuel purification rate K_{ex} is computed according to a formula 5:

$$K_{ex} \leftarrow K_{exs} - \{ (K_{exs} - K_{exe}) \times (A_{mpinint} - A_{mpin}) / (A_{mpinint} - A_{mpe}) \}$$

40 **[0091]** The initial value $A_{mpinint}$ corresponds to the amplitude value A_{mpin} obtained when a non-deteriorated NOx storage reduction catalyst 36a is used. The amplitude value A_{mpe} corresponds to the amplitude value A_{mpin} obtained when a deteriorated NOx storage reduction catalyst 36a is used.

[0092] At subsequent step S310, the ECU 70 computes the heat value H_{ex} of a single addition of fuel according to the formula 4. Further, at subsequent step S312, the ECU 70 computes the non-richening period L_t using the map g. The process of step S312 is the same as the process of step S158 in the sulfur emitting process shown in Fig. 4. Thereafter, the ECU 70 ends the sulfur emitting process after executing the above described steps S314 to S328.

45 **[0093]** As described above, the deterioration degree of the NOx storage reduction catalyst 36a is reflected on the amplitude value A_{mpin} . The smaller the amplitude value A_{mpin} , the more deteriorated the NOx storage reduction catalyst 36a is determined to be. The amplitude value A_{mpin} , which reflects the deterioration degree of the NOx storage reduction catalyst 36a, is reflected on the duration of the non-richening period L_t through the fuel purification rate K_{ex} and the heat value H_{ex} . Therefore, the more deteriorated the NOx storage reduction catalyst 36a, the shorter the duration of the non-richening period L_t is set so that the catalyst bed temperature reaches the target bed temperature.

50 **[0094]** Fig. 15 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the third embodiment, when the NOx storage reduction catalyst 36a has deteriorated to some extent. In the third embodiment, changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature when the NOx storage reduction catalyst 36a is brand new are the same as those of the first embodiment shown in Fig. 6. As shown in Fig. 15, when the NOx storage reduction catalyst 36a has deteriorated to some extent, the duration of the non-richening period L_t is set shorter than the initial value L_{tint} so that the catalyst bed temperature reaches the target bed

temperature.

[0095] In this embodiment, the deterioration degree determination process shown in Fig. 3 and steps S304, S306 of the sulfur emitting process shown in Fig. 14 correspond to a process executed by the deterioration degree detecting means. Steps S308 to S312 of the sulfur emitting process correspond to a process executed by the changing means. The sulfur emitting process corresponds to a process executed by the fuel supply means. The deterioration degree determination process and step S308 of the sulfur emitting process correspond to a process executed by the deterioration degree determination means.

[0096] The third embodiment has the following advantage.

[0097] (1) As in the first and second embodiments, during the execution of the sulfur release control, the richening period R_t and the non-richening period L_t are alternately repeated. Every time the richening period R_t or the non-richening period L_t is executed, the catalyst bed temperature of the NOx storage reduction catalyst 36a is repeatedly increased and decreased. The amplitude value A_{mpin} , which represents the amplitude of the exhaust temperature T_{exin} detected by the first exhaust temperature sensor 44, reflects fluctuation (amplitude) of the catalyst bed temperature. The more deteriorated the NOx storage reduction catalyst 36a, the smaller the magnitude of the amplitude value A_{mpin} becomes, that is, the magnitude of fluctuation of the catalyst bed temperature becomes. Therefore, the amplitude value A_{mpin} indicates the degree of deterioration of the NOx storage reduction catalyst 36a.

[0098] In the third embodiment, when the amplitude value A_{mpin} is great, that is, in a case where the deterioration of the NOx storage reduction catalyst 36a has not significantly developed, the duration of the non-richening period L_t is set relatively long through the processes of steps S308, S310, and S312. When the amplitude value A_{mpin} is small, that is, in a case where the deterioration of the NOx storage reduction catalyst 36a has considerably developed, the duration of the non-richening period L_t is set relatively long. In this manner, in the third embodiment, the duration of the non-richening period L_t , not the duration of the richening period R_t , is changed. Accordingly, an increase in the catalyst bed temperature of the NOx storage reduction catalyst 36a is prevented from being excessive or too little with changes of the degree of deterioration of the NOx storage reduction catalyst 36a. Thus, the deterioration of the NOx storage reduction catalyst 36a due to an excessive increase in the catalyst bed temperature and a decrease in the sulfur emitting efficiency due to insufficient increase in the catalyst bed temperature are prevented.

[0099] (2) The amplitude value A_{mpin} is computed in a state where the duration of the non-richening period L_t is set to the initial value L_{tint} . Based on the amplitude value A_{mpin} thus computed, the degree of deterioration of the NOx storage reduction catalyst 36a is determined. In this manner, since the duration of the non-richening period L_t has a constant value (the initial value L_{tint}) when the amplitude value A_{mpin} is computed, the computed amplitude value A_{mpin} accurately corresponds to the degree of deterioration of the NOx storage reduction catalyst 36a.

[0100] A fourth embodiment of the present invention will now be described with reference to the drawings.

[0101] In the fourth embodiment, the duration of the richening period R_t is changed based on the temperature difference ΔT_{pin} , which is computed through the deterioration degree determination process shown in Fig. 8. In the fourth embodiment, a sulfur emitting process shown in Fig. 16 is executed instead of the sulfur emitting process shown in Fig. 9. Other processes are the same as those of the second embodiment, and the hardware configuration is the same as that of the first embodiment.

[0102] When the sulfur emitting process shown in Fig. 16 is started, the ECU 70 first computes the duration of the richening period R_t to be set at step S402. The computation is executed using a map p shown in Fig. 17 based on the temperature difference ΔT_{in} , which reflects the degree of deterioration of the NOx storage reduction catalyst 36a. The greater the temperature difference ΔT_{in} , the less deteriorated the NOx storage reduction catalyst 36a and the higher the oxidation efficiency for fuel at the NOx storage reduction catalyst 36a (the same as the fuel purification rate). In this case, the richening period R_t is set to a short value to correspond to the catalyst bed temperature, which rapidly increases after the richening is started. On the other hand, the smaller the temperature difference ΔT_{in} , the more deteriorated the NOx storage reduction catalyst 36a and the lower the oxidation efficiency of the NOx storage reduction catalyst 36a. In this case, the richening period R_t is set to a long value to correspond to the catalyst bed temperature, which slowly increases after the richening is started.

[0103] At subsequent step S404, the ECU 70 computes the non-richening period L_t using the map g. The process of step S404 is the same as the process of step S158 in the sulfur emitting process shown in Fig. 4. Steps S406, S410, S412, S414, S416, S418, and S420 in Fig. 16, which are executed by the ECU 70 after step S404 are each the same as steps S160, S162, S164, S166, S168, S170, S172, and S174 of the sulfur emitting process shown in Fig. 4.

[0104] As described above, the deterioration degree of the NOx storage reduction catalyst 36a is reflected on the temperature difference ΔT_{in} , and the temperature difference ΔT_{in} is reflected on the duration of the richening period R_t by means of the map p. Therefore, the more deteriorated the NOx storage reduction catalyst 36a, the longer the duration of the richening period R_t is set.

[0105] Fig. 18 is a graph showing changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature according to the fourth embodiment, when the NOx storage reduction catalyst 36a has deteriorated to some extent. In the fourth embodiment, changes in the air-fuel ratio of exhaust gas and the catalyst bed temperature when the NOx

storage reduction catalyst 36a is brand new are the same as those of the second embodiment shown in Fig. 12. As shown in Fig. 18, when the NOx storage reduction catalyst 36a has deteriorated to some extent, the duration of the richening period R_t is set shorter than the initial value L_{tint} as the temperature difference ΔT_{in} is decreased, so that the catalyst bed temperature reaches the target bed temperature and that the NOx storage reduction catalyst 36a is not excessively heated. In this embodiment, the deterioration degree determination process shown in Fig. 8 corresponds to a process executed by the deterioration degree detecting means. Steps S402, S404 of the sulfur emitting process shown in Fig. 16 correspond to a process executed by the changing means. The sulfur emitting process corresponds to a process executed by the fuel supply means. The deterioration degree determination process and step S402 of the sulfur emitting process correspond to a process executed by the deterioration degree determination means.

[0106] The fourth embodiment has the following advantage.

[0107] (1) As in the first to third embodiments, during the execution of the sulfur release control, the richening period R_t and the non-richening period L_t are alternately repeated. Every time the richening period R_t or the non-richening period L_t is executed, the catalyst bed temperature of the NOx storage reduction catalyst 36a is repeatedly increased and decreased. The more deteriorated the NOx storage reduction catalyst 36a, the smaller the temperature difference ΔT_{in} , which corresponds to the rate of increase of the exhaust temperature T_{exin} due to the start of the richening period R_t , becomes. That is, the deterioration degree of the NOx storage reduction catalyst 36a is reflected on the temperature difference ΔT_{in} . Therefore, the deterioration degree of the NOx storage reduction catalyst 36a is easily determined based on the temperature difference ΔT_{in} .

[0108] When the ECU 70 determines that the NOx storage reduction catalyst 36a has scarcely deteriorated since the temperature difference ΔT_{in} is sufficiently great, the duration of the richening period R_t is set relatively short based on the map p of Fig 17. Accordingly, an excessive increase of the catalyst bed temperature of the NOx storage reduction catalyst 36a due to richening of the air-fuel ratio of the exhaust gas is prevented. Thereafter, when the ECU 70 determines that the NOx storage reduction catalyst 36a has deteriorated to some extent since the temperature difference ΔT_{in} has been decreased, the duration of the richening period R_t is set relatively long based on the map p of Fig 17. Accordingly, a decrease of the fuel emitting efficiency due to an insufficient increase of the catalyst bed temperature is suppressed. In this manner, even if the deterioration degree of the NOx storage reduction catalyst 36a is changed, the catalyst bed temperature is not excessively increased, and the sulfur release control is executed accurately.

[0109] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit of scope of the invention. Particularly, it should be understood that the invention may be embodied in the following forms.

[0110] (a) In the second and fourth embodiments, the durations of the non-richening period L_t and the richening period R_t are not set to the initial values when computing the temperature difference ΔT_{in} , but set to values that correspond to the state at the time. However, as in the first and third embodiment, the duration of the non-richening period L_t and the richening period R_t may be set to the initial values when the sulfur release control is started, and the sulfur emitting process may be executed after the durations are set to values that correspond to the temperature difference ΔT_{in} after the temperature difference ΔT_{in} is computed.

[0111] Also, in the second and fourth embodiment, the initial exhaust temperature T_a is detected immediately after richening of the air-fuel ratio of exhaust gas is started in the richening period R_t . However, in consideration of the fact that the exhaust temperature T_{exin} is increased after a little delay, the initial exhaust temperature T_a may be detected when a standby period, which corresponds to the intake flow rate GA, has elapsed after the richening period R_t is started.

[0112] (b) In the illustrated embodiments, the air-fuel ratio of exhaust gas is richened by causing the fuel adding valve 68 to add fuel to exhaust. However, the air-fuel ratio of exhaust gas may be richened by other means. The air-fuel ratio of exhaust gas may be richened, for example, by after injection, in which fuel is injected into the combustion chambers from the fuel injection valve 58 during an expansion stroke or exhaust stroke.

[0113] (c) In the illustrated embodiment, the duration of one of the non-richening period L_t and the richening period R_t is changed according to the degree of deterioration of the exhaust purification catalyst. However, the durations of both may be changed.

[0114] (d) The present invention is not limited to diesel engines, but may be applied to lean combustion gasoline engines.

[0115] The present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

Claims

1. An apparatus for controlling an exhaust purification catalyst, the catalyst being located in an exhaust system of an internal combustion engine (2), wherein, during sulfur release control for permitting the catalyst to recover from

sulfur poisoning, the apparatus repeats a richening period and a non-richening period, wherein, in the richening period, the apparatus intermittently supplies fuel to exhaust gas at a section upstream of the catalyst, thereby lowering the air-fuel ratio of exhaust gas that contacts the catalyst to a value equal to or less than the stoichiometric air-fuel ratio, and wherein, in the non-richening period, the apparatus does not supply fuel to exhaust gas, the apparatus being **characterized by**:

deterioration degree detecting means that detects the degree of deterioration of the exhaust purification catalyst; and

changing means that changes the ratio of the duration of the richening period to the duration of the non-richening period according to the deterioration degree of the exhaust purification catalyst detected by the deterioration degree detecting means.

2. The apparatus according to claim 1, **characterized in that** the changing means changes the ratio of the duration of the richening period to the duration of the non-richening period such that the greater the deterioration degree of the exhaust purification catalyst detected by the deterioration degree detecting means, the greater the rate becomes.

3. The apparatus according to claim 1 or 2, **characterized in that** a catalyst bed temperature of the exhaust purification catalyst is estimated based on a temperature of exhaust gas that contacts the exhaust purification catalyst and a heat value obtained from the amount of fuel supplied to exhaust gas and a fuel purification rate at the exhaust purification catalyst, wherein the rate of the duration of the richening period to the duration of the non-richening period is changed to control the estimated catalyst bed temperature, and

wherein the changing means corrects the fuel purification rate according to the deterioration degree of the exhaust purification catalyst detected by the deterioration degree detecting means, thereby changing the ratio of the duration of the richening period to the duration of the non-richening period according.

4. The apparatus according to any one of claims 1 to 3, **characterized by** comprising catalyst bed temperature detecting means for detecting a physical quantity that represents an actual catalyst bed temperature of the exhaust purification catalyst, and

wherein the deterioration degree detecting means determines that the smaller a range of fluctuation of the physical quantity caused by supply of fuel to exhaust gas, the greater the deterioration degree of the exhaust purification catalyst.

5. The apparatus according to any one of claims 1 to 3, **characterized by** comprising catalyst bed temperature detecting means for detecting a physical quantity that represents an actual catalyst bed temperature of the exhaust purification catalyst, and

wherein the deterioration degree detecting means determines that the smaller a rate of increase in the physical quantity caused by supply of fuel to exhaust gas, the greater the deterioration degree of the exhaust purification catalyst.

6. The apparatus according to claim 4 or 5, **characterized in that** the deterioration degree detecting means detects the deterioration degree based on a physical quantity that is detected by the catalyst bed temperature detecting means when supply of fuel to exhaust gas is performed in a state where the rate of the duration of the richening period to the duration of the non-richening period is set to correspond to a case where an exhaust purification catalyst that has not deteriorated is used.

7. The apparatus according to any one of claims 4 to 6, **characterized in that** the catalyst bed temperature detecting means is an exhaust temperature sensor (44) located downstream of the exhaust purification catalyst, wherein the physical quantity detected by the catalyst bed temperature detecting means is an exhaust temperature detected by the exhaust temperature sensor.

8. The apparatus according to any one of claims 1 to 7, **characterized in that** the exhaust purification catalyst is a NOx storage reduction catalyst.

9. The apparatus according to any one of claims 1 to 8, **characterized in that** the internal combustion engine is a diesel engine.

10. The apparatus according to any one of claims 1 to 9, **characterized in that** supply of fuel to exhaust gas is per-

formed either by adding fuel to exhaust gas from a fuel adding valve provided in the internal combustion engine or by injecting fuel into a combustion chamber provided in the internal combustion engine during an expansion stroke or an exhaust stroke.

5 11. An apparatus for detecting a degree of deterioration of an exhaust purification catalyst located in an exhaust system of an internal combustion engine, the apparatus being **characterized by**:

fuel supply means for intermittently supplying fuel to exhaust gas at a section upstream of the exhaust purification catalyst;

10 catalyst bed temperature detecting means for detecting a physical quantity that represents an actual catalyst bed temperature of the exhaust purification catalyst; and

deterioration degree determination means, wherein the deterioration degree detecting means determines that the smaller a range of fluctuation of the physical quantity, which fluctuation being caused by supply of fuel to exhaust gas and detected by the catalyst bed temperature detecting means, the greater the deterioration degree of the exhaust purification catalyst.

12. The apparatus according to claim 11, **characterized in that** the catalyst bed temperature detecting means is an exhaust temperature sensor (44) located downstream of the exhaust purification catalyst, wherein the physical quantity detected by the catalyst bed temperature detecting means is an exhaust temperature detected by the exhaust temperature sensor.

13. The apparatus according to claim 11 or 12, **characterized in that** the exhaust purification catalyst is a NOx storage reduction catalyst.

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Fig.2

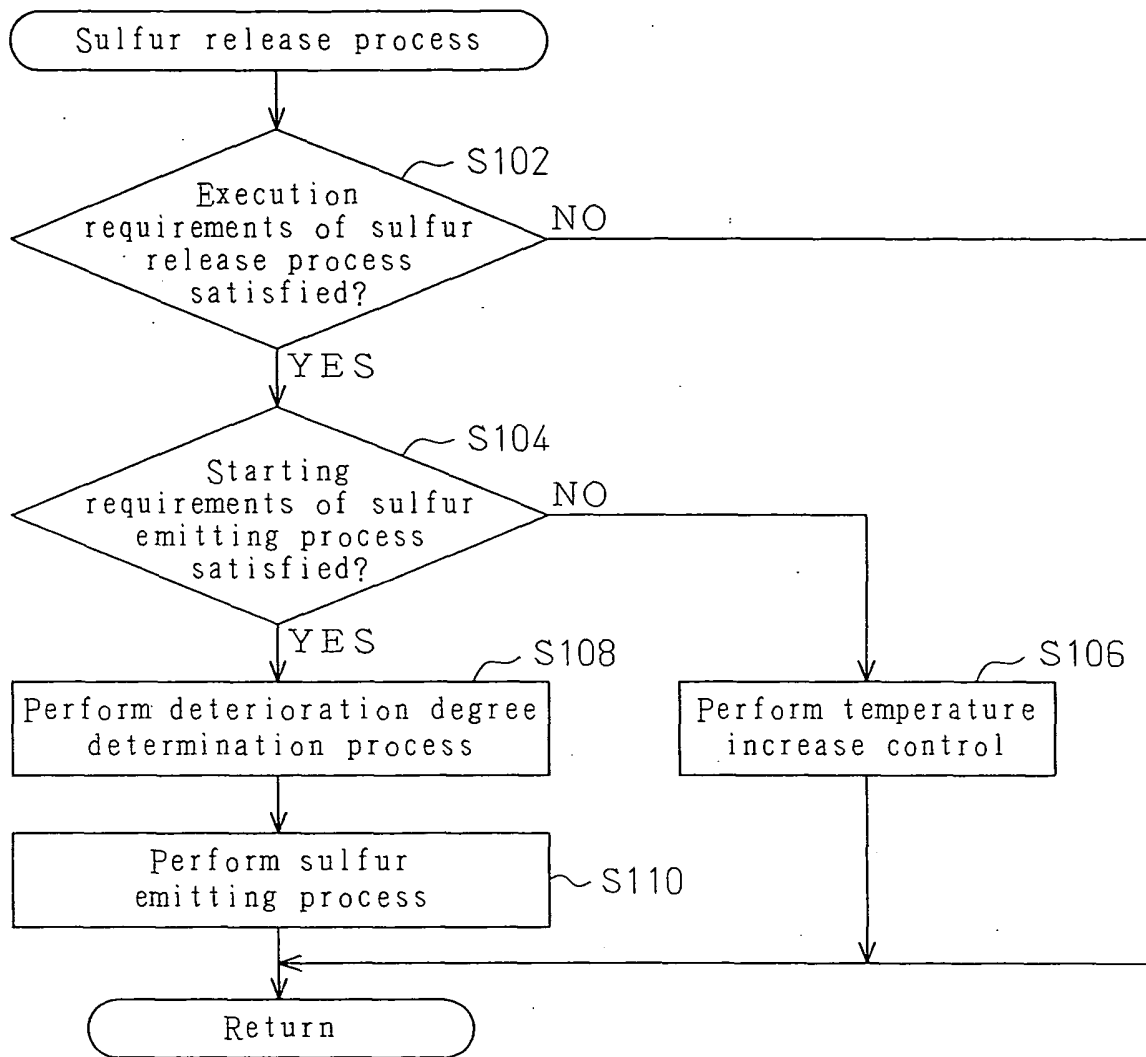


Fig.3

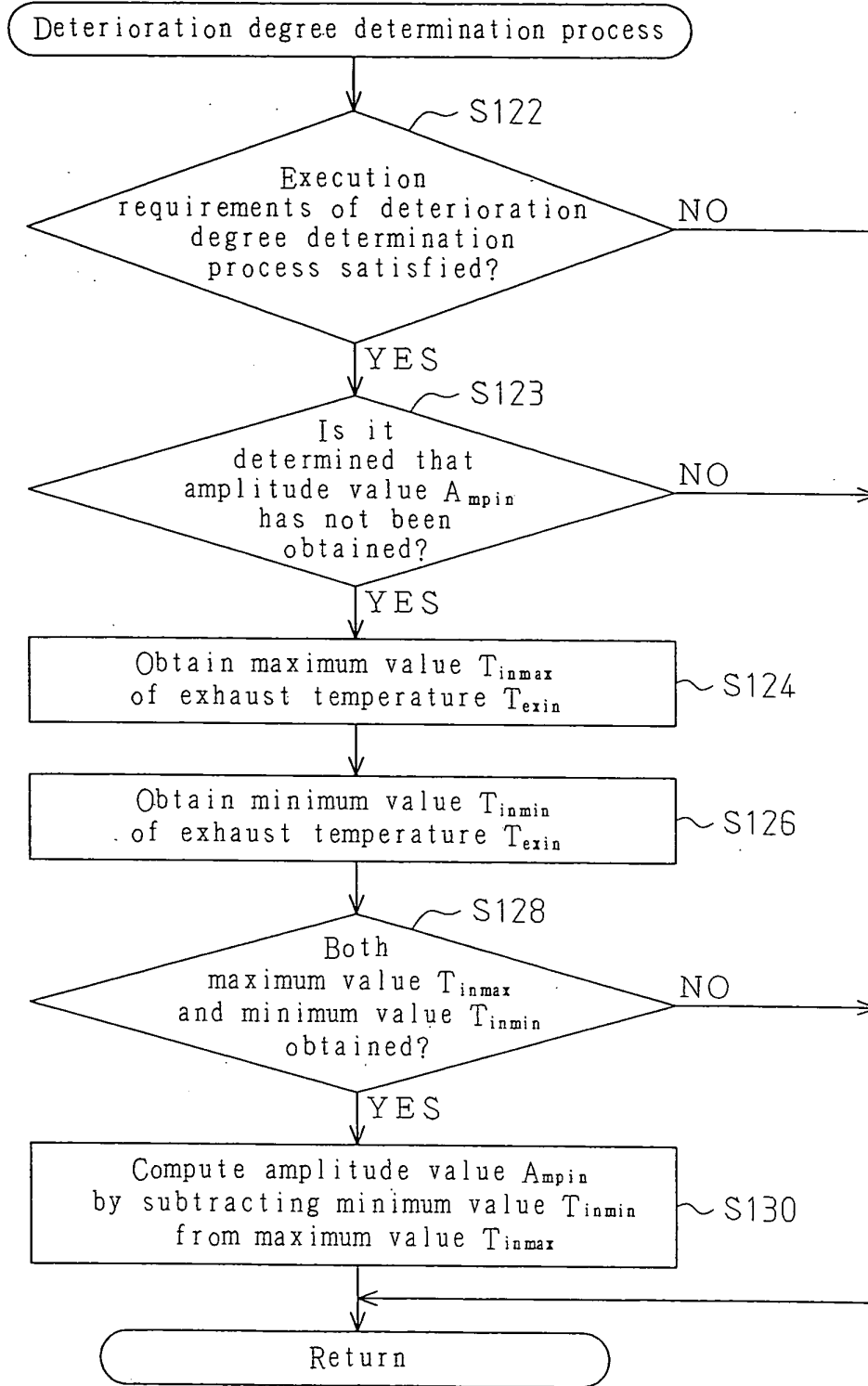


Fig.4

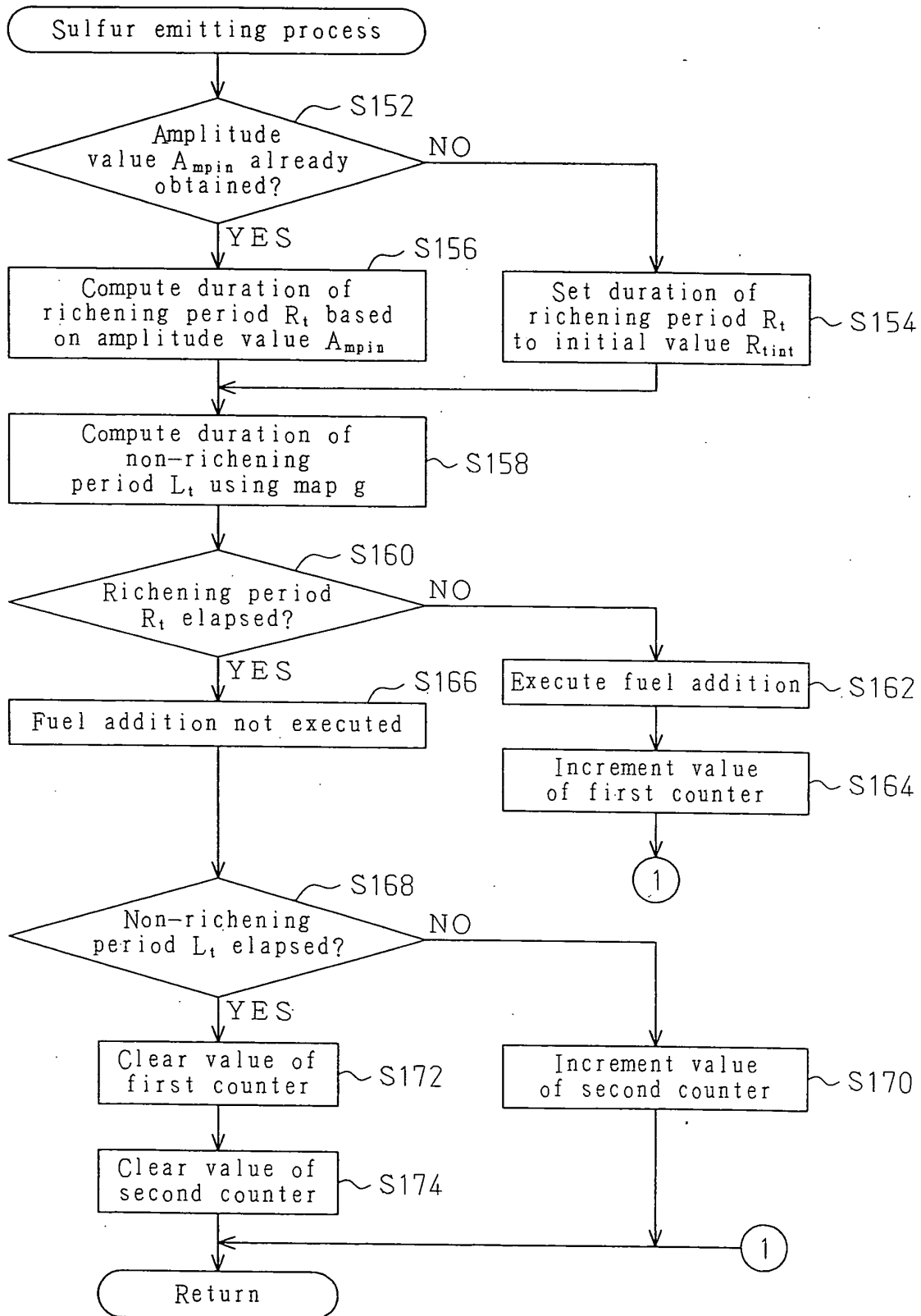


Fig.5

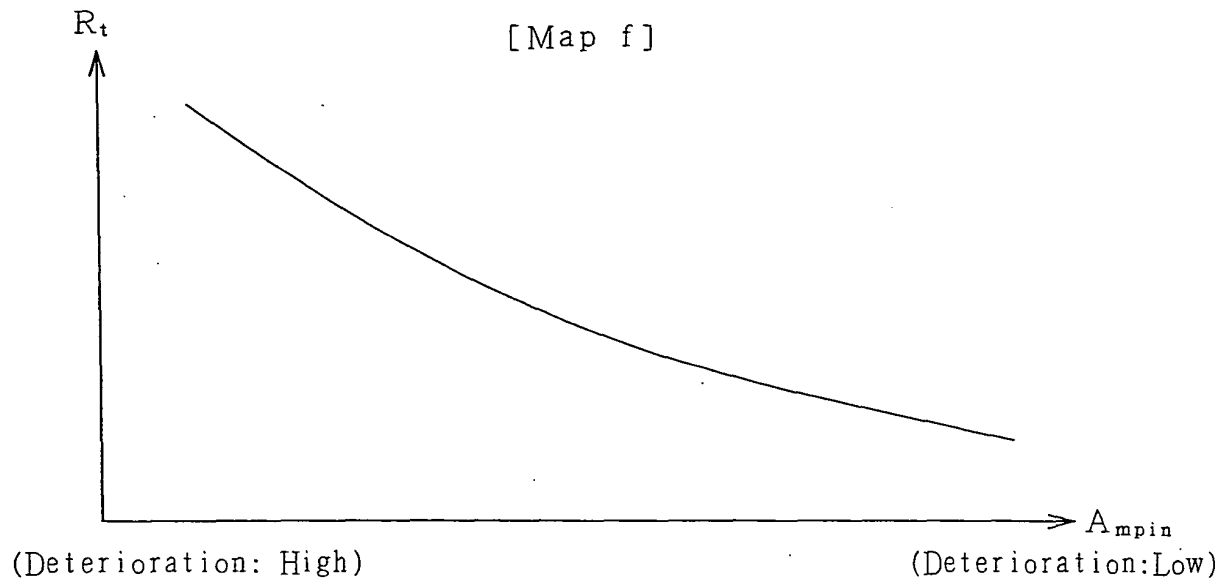


Fig.6

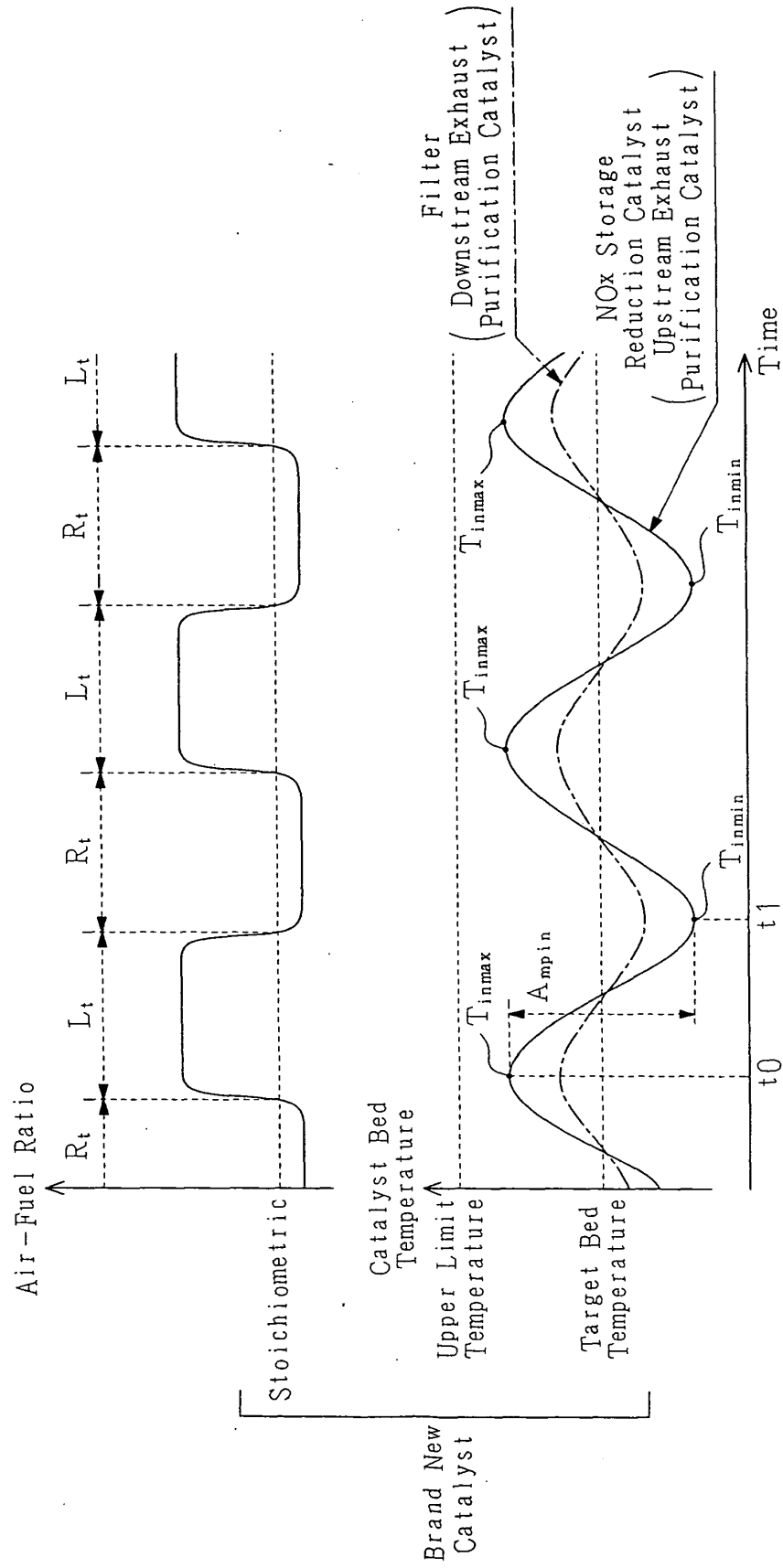


Fig.7

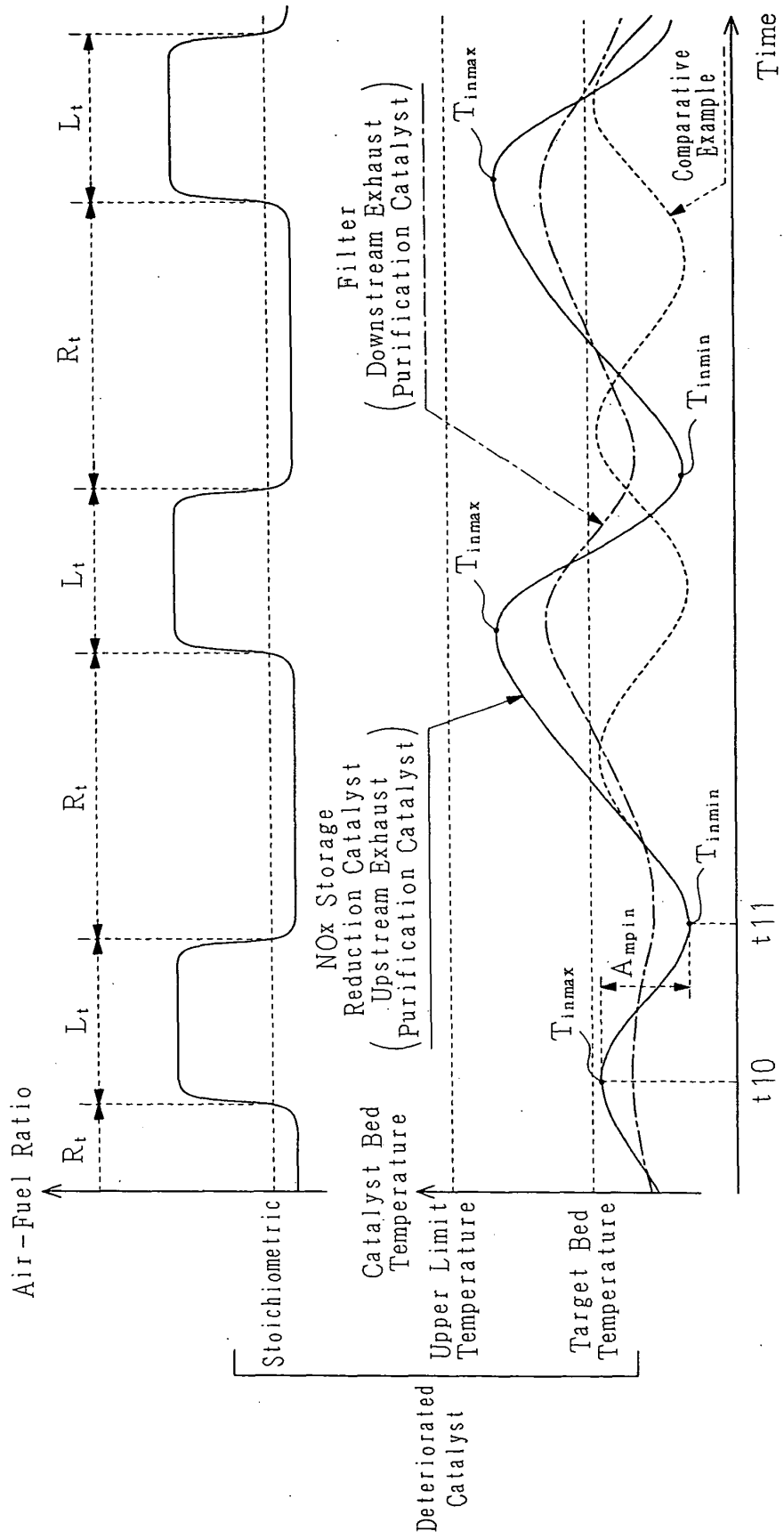


Fig.8

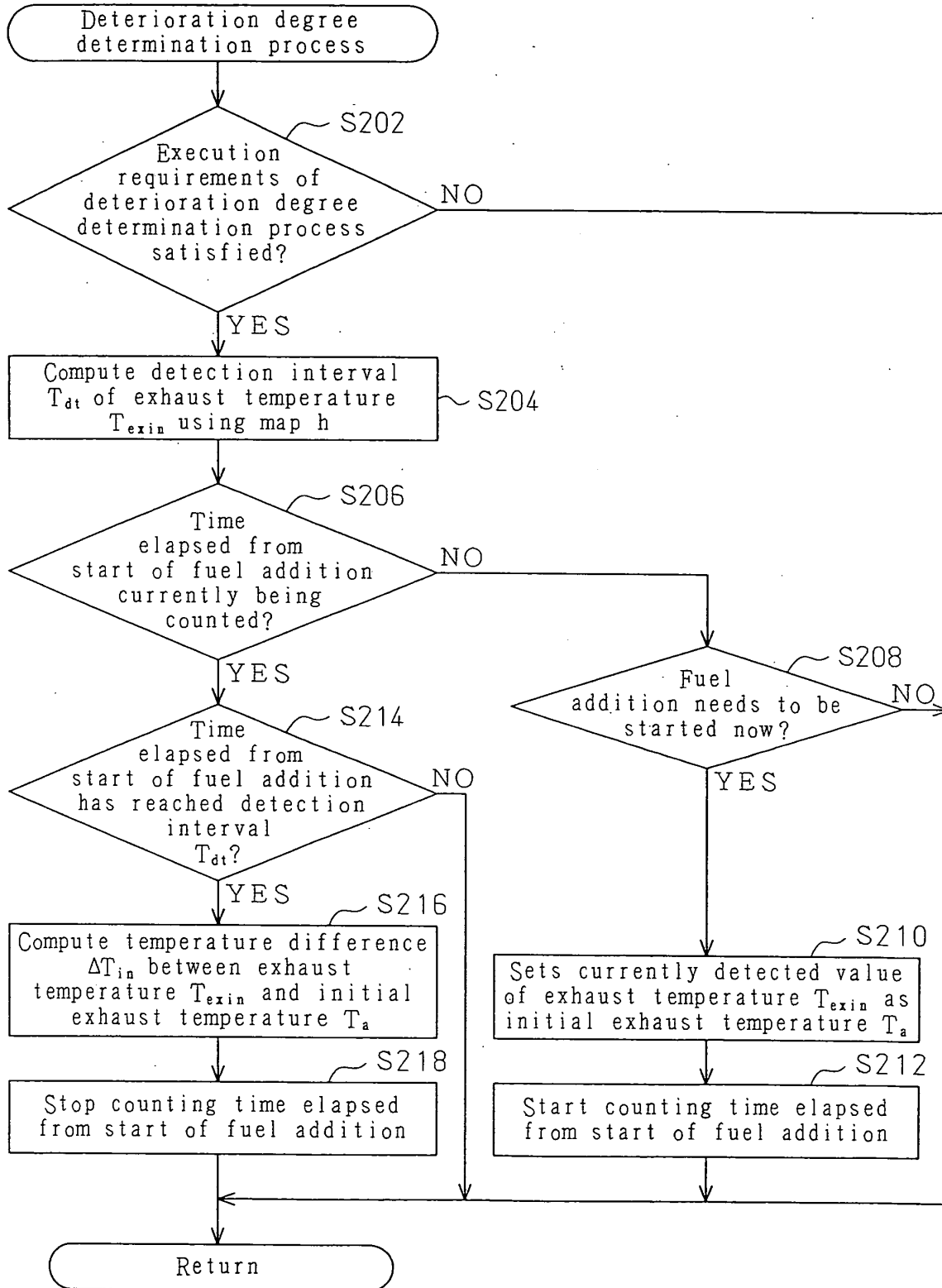


Fig.9

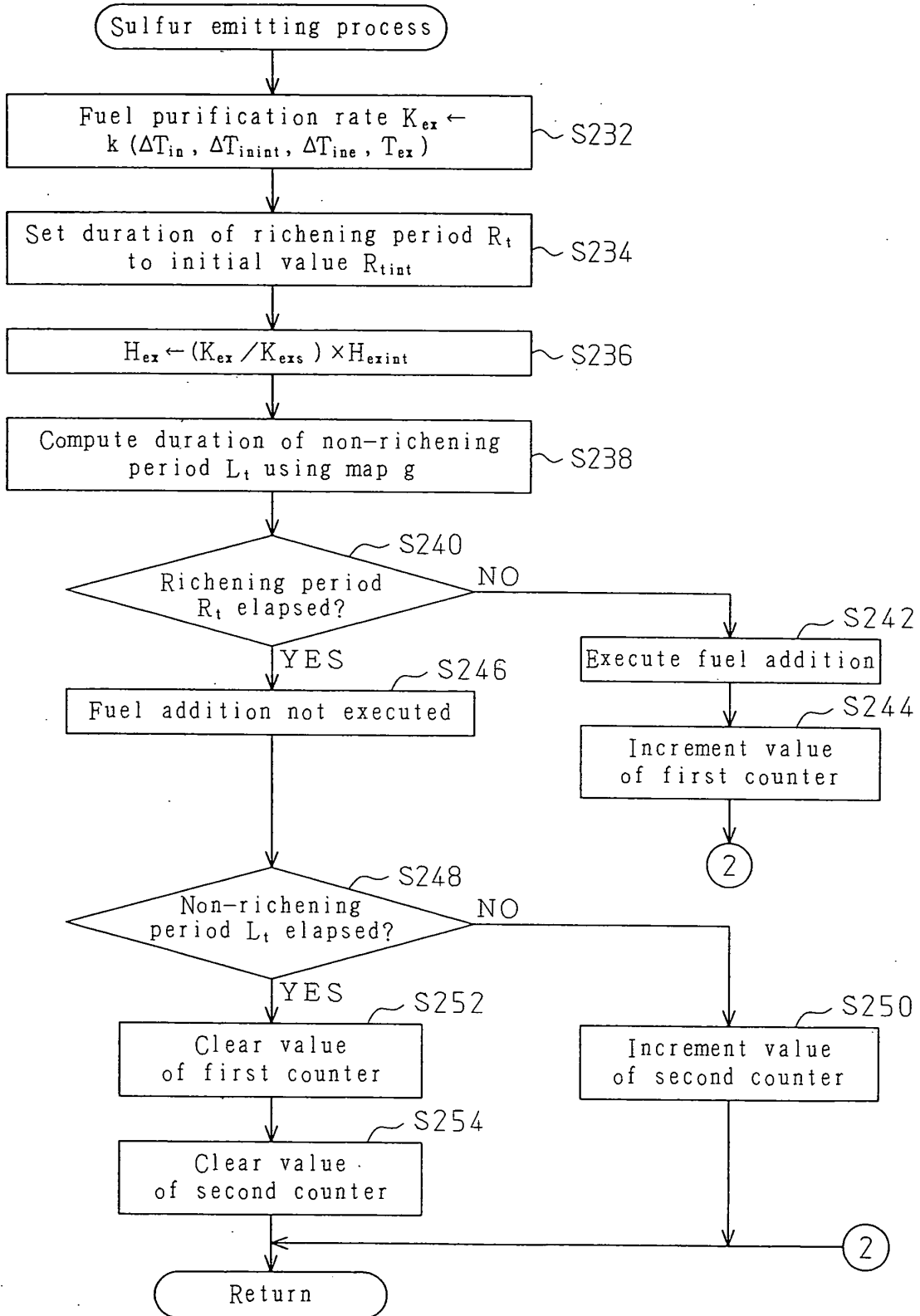


Fig.10

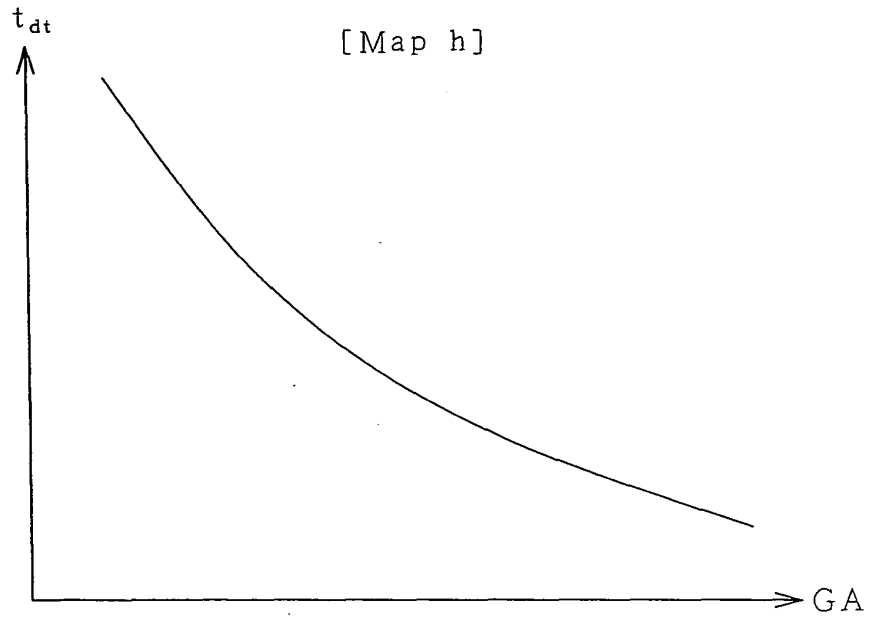


Fig.11

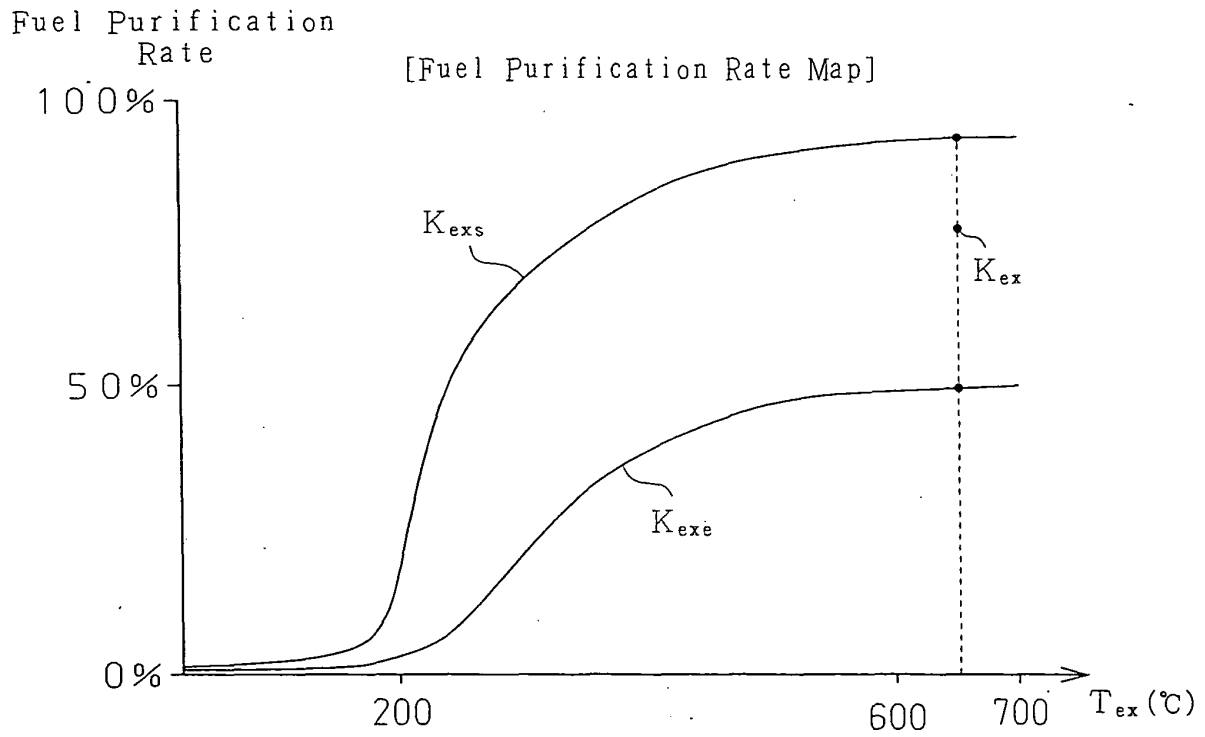


Fig.12

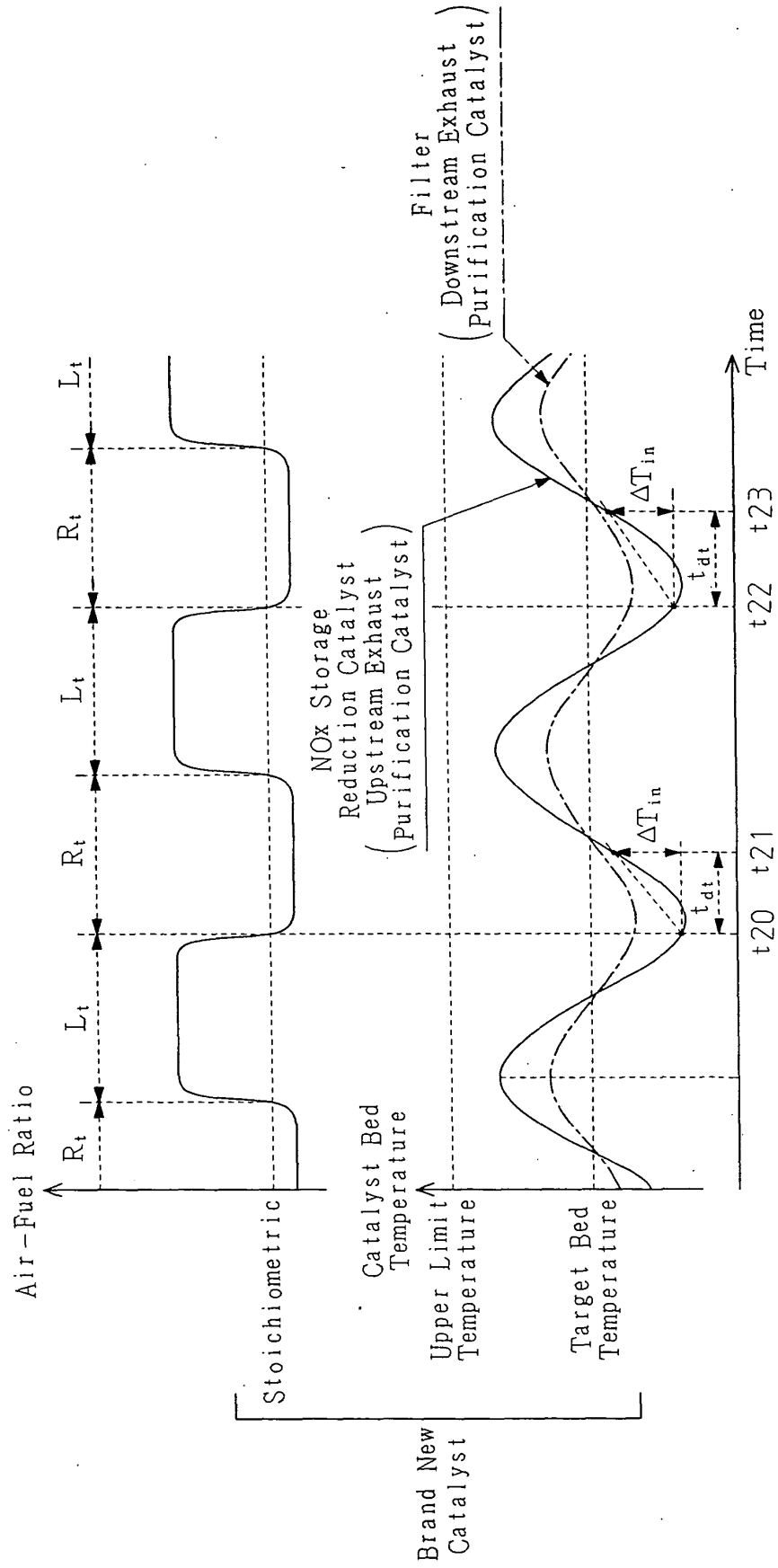


Fig.13

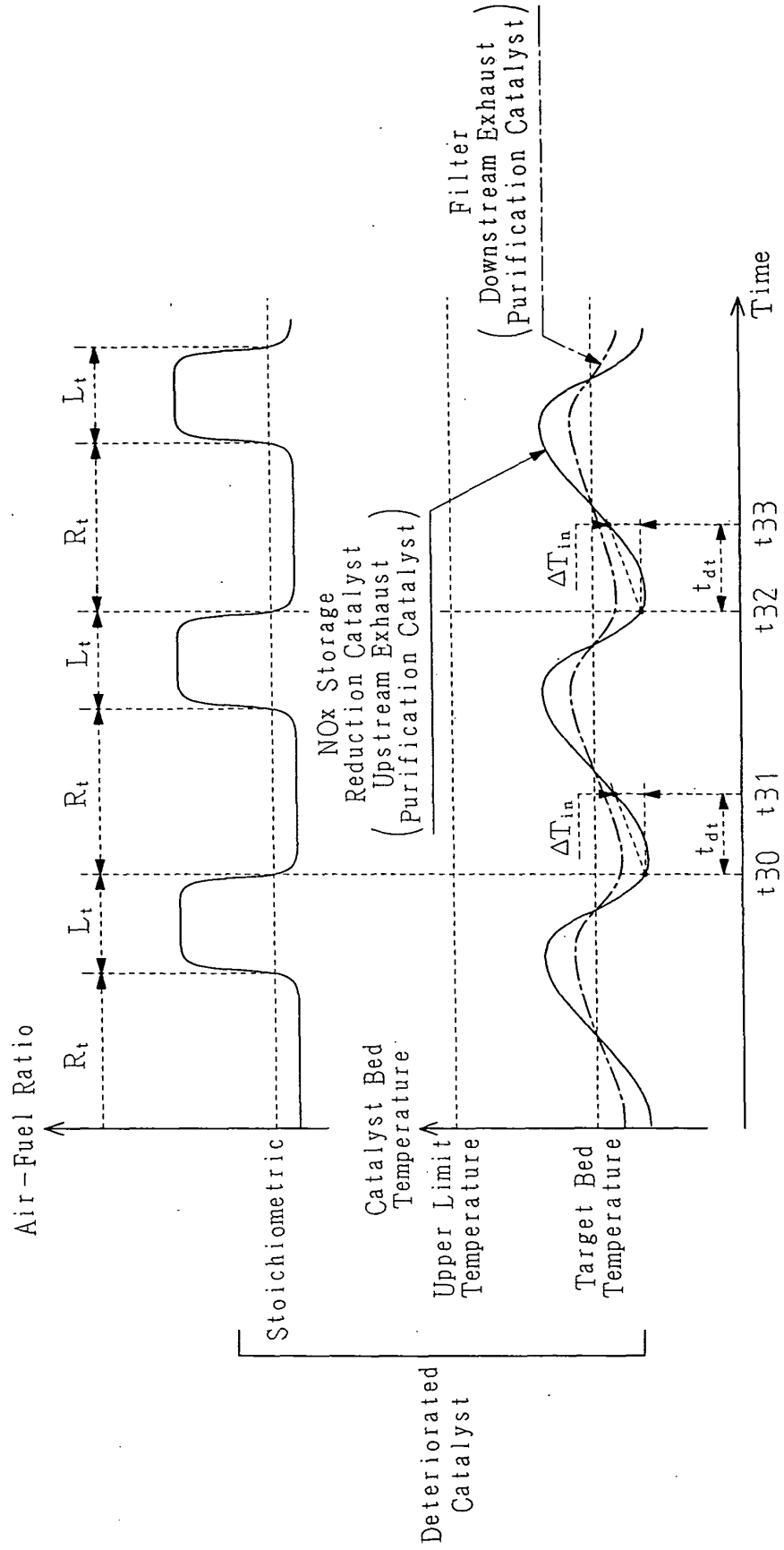


Fig.14

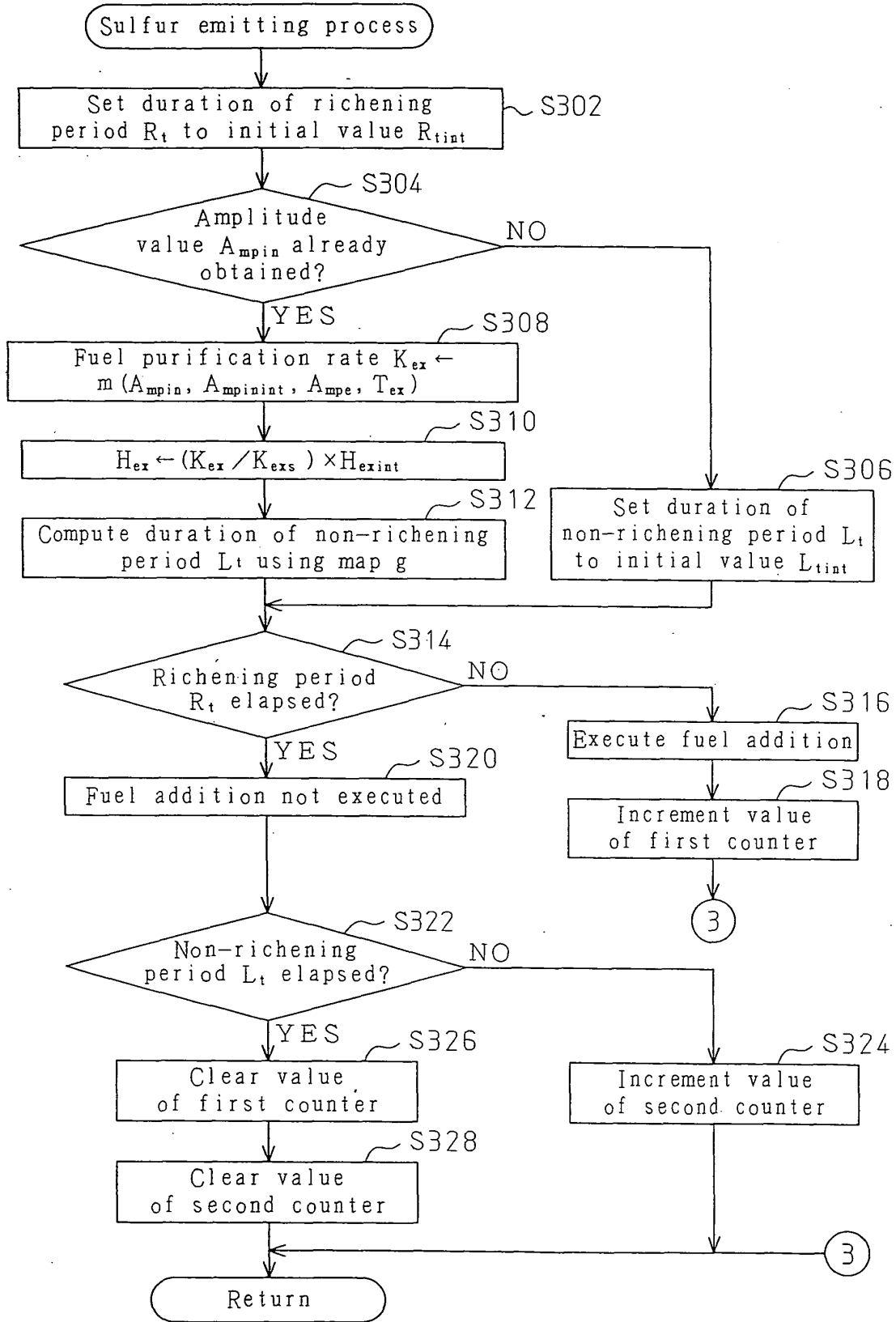


Fig.15

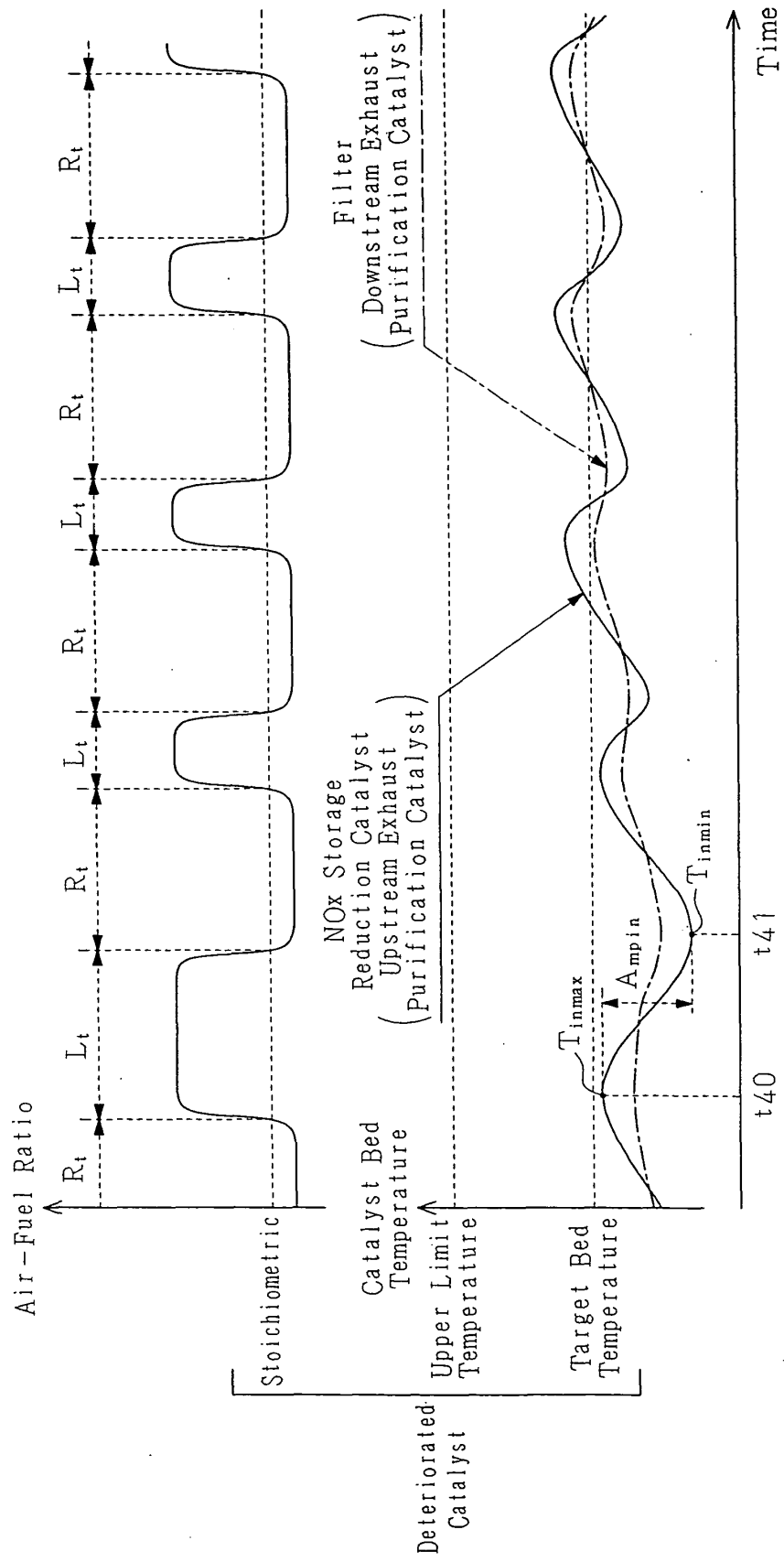


Fig.16

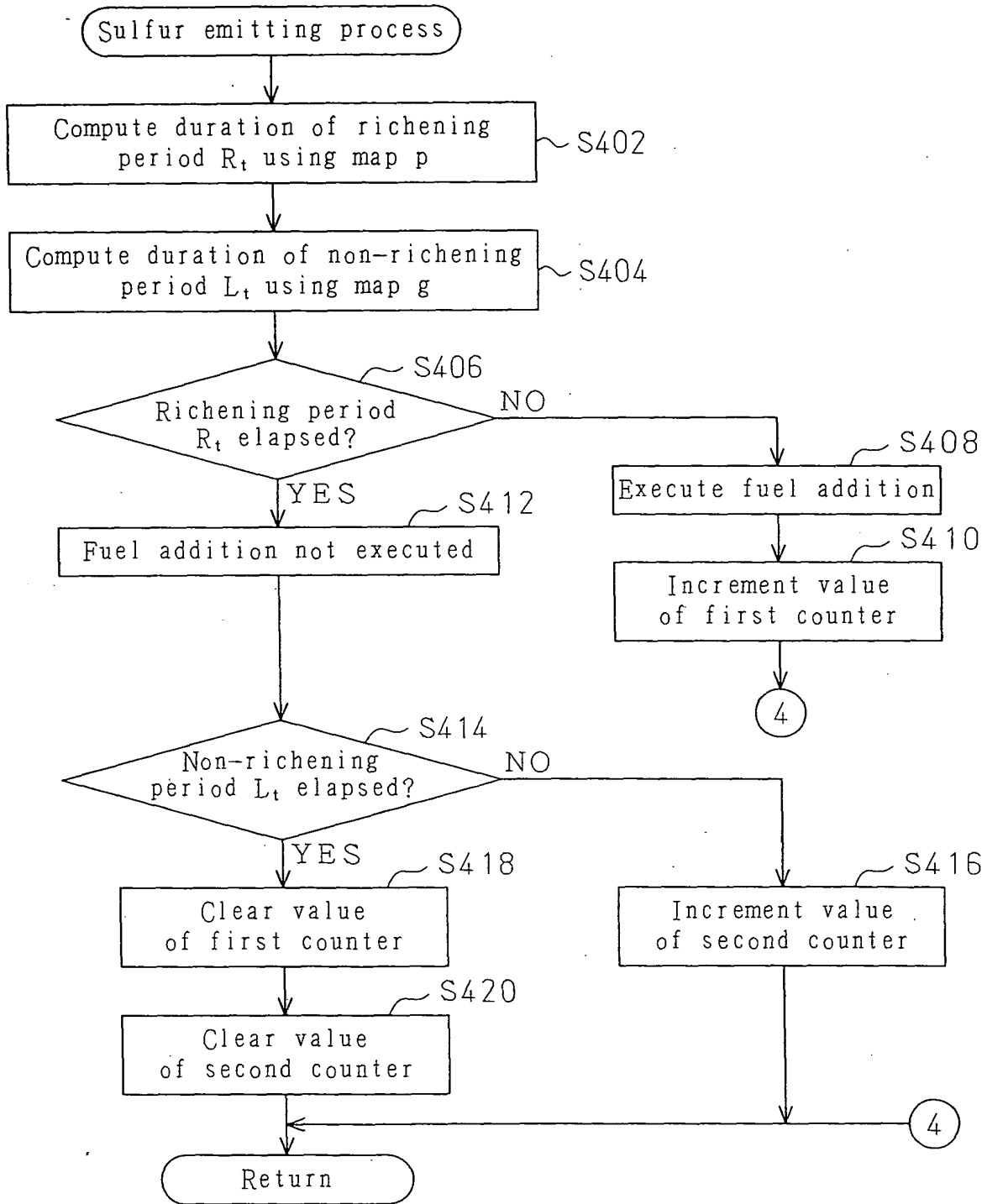


Fig.17

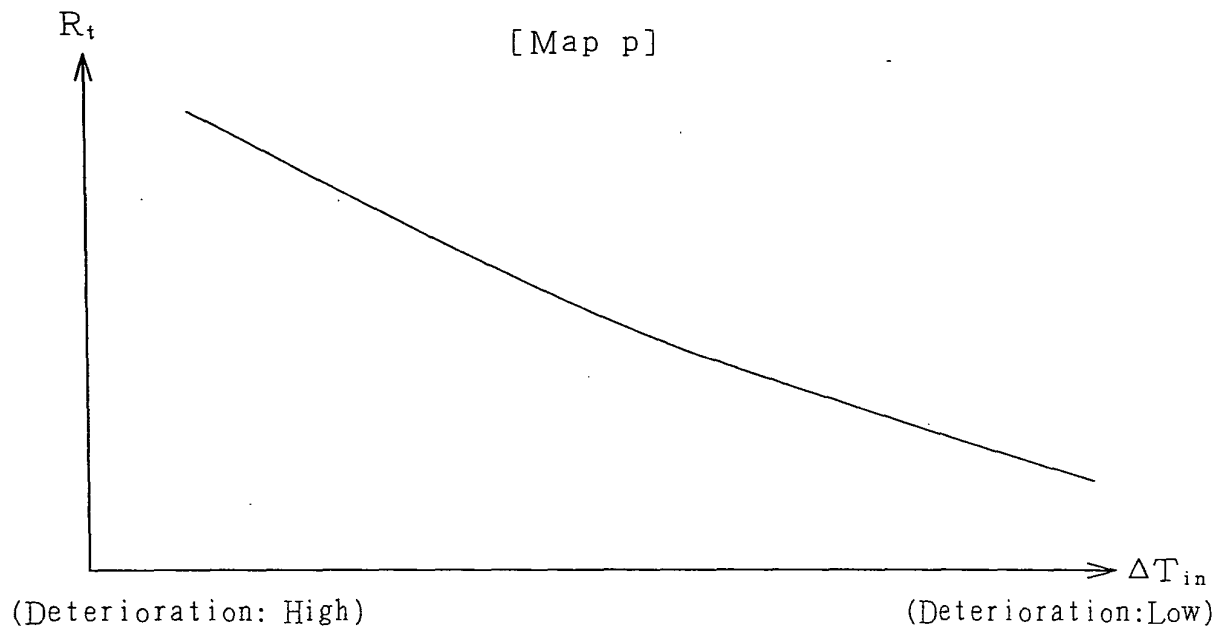


Fig.18

