

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a method for managing NOx storage catalyst disposed in an exhaust passage of a diesel engine to reduce NOx in exhaust gas, and more specifically, to a method for reproducing the function of the NOx storage catalyst.

[0002] Conventionally, a NOx storage catalyst is equipped in the exhaust passage of, for example, a diesel engine to efficiently store the nitrogen oxides (NOx) in the exhaust gas under a condition in which the engine is operated by burning a lean air-fuel mixture.

[0003] The NOx storage catalyst has a property for storing NOx when the exhaust gas is in an oxidizing atmosphere, and releasing NOx when the exhaust gas is in a reducing atmosphere. If a reductant such as hydrocarbon (HC) is present in the exhaust gas, the NOx released into the exhaust gas quickly reacts with a reductant and reduces to nitrogen (N₂).

[0004] In an internal combustion engine with such NOx storage catalyst equipped in the exhaust passage, the NOx in the exhaust gas is efficiently reduced (purified) by appropriately switching the exhaust gas, flowing into the NOx storage catalyst, between the oxidizing atmosphere and the reducing atmosphere.

[0005] In general, the fuel for the internal combustion engine contains sulfur components, and thus the exhaust gas contains, besides NOx, sulfur components originating from the sulfur components in the fuel. The sulfur components present in the exhaust gas bonds with the NOx storage catalyst more efficiently than NOx. Thus, the sulfur components cannot be easily released from the catalyst even under a condition sufficient for releasing the NOx stored in the catalyst (condition in which the concentration of the reductant in the exhaust gas exceeds a predetermined value). Thus, as the engine operation continues, the sulfur components in the exhaust gas are gradually stored in the NOx storage catalyst, or a phenomenon known as sulfur poisoning occurs. When sulfur poisoning advances, the limit value of the stored amount of NOx by the NOx storage catalyst decreases, and, as a result, the purifying/efficiency of the NOx decreases.

[0006] The sulfur components stored in the NOx storage catalyst are known to be released from the catalyst by satisfying the condition of further increasing the concentration of the reductant in the exhaust gas or raising the temperature of the NOx storage catalyst, rather than satisfying the condition achieved with the normal supply control of a reducing agent. Thus, in an engine provided with an NOx storage catalyst in an exhaust passage and having a property in which sulfur components gradually accumulate as the engine continues to operate, it is common to release the sulfur components accumulated in the NOx storage catalyst by executing a control (hereinafter referred to as sulfur process (S-process) control)

to increase the concentration of the reductant in the exhaust gas at the upstream side of the NOx storage catalyst, and to increase the temperature of the NOx storage catalyst to a high value (for example, 690°C).

[0007] Japanese Patent No. 3104692 describes a method in which sulfur is released by directly adding the reducing agent, in an atomized state, to the upstream side of the NOx storage catalyst installed in the exhaust passage while a pre-process is performed to lower the air-fuel ratio of the air-fuel mixture burned in the engine, within a range in which the combustion state of the engine (operating range) is not affected. In this way, by simultaneously performing the adjustment (pre-process) of the air-fuel ratio and the addition of the reducing agent, the S-process control suppresses the consumption of the reducing agent and is thus efficiently carried out.

[0008] In performing the pre-process that lowers (richens) the air-fuel ratio, the combustion state of the engine, and moreover, the exhaust gas property is likely to change. Thus, in the initial stage when executing the S-process control, it is difficult to control the air-fuel ratio of the exhaust gas to an optimum value for releasing the sulfur components accumulated in the NOx storage catalyst. As a result, there is a possibility of the exhaust gas property being temporarily deteriorated.

SUMMARY OF THE INVENTION

[0009] It is an object of the present invention to provide a method for efficiently processing the sulfur components accumulated in a NOx storage catalyst without deteriorating the exhaust property of the NOx storage catalyst disposed in the exhaust passage of a diesel engine.

[0010] To achieve the above object, the present invention provides a method for managing a NOx storage catalyst arranged in an exhaust passage of a diesel engine. The method includes releasing sulfur components accumulated in the NOx storage catalyst. The releasing includes a first process for decreasing the air-fuel ratio of an air-fuel mixture that is to be burned in the engine, and a second process for adding a reducing agent to an upstream side of the NOx storage catalyst in the exhaust passage. The second process is started when a predetermined starting condition is satisfied after the first process is started. The starting condition is that the air-fuel ratio of upstream side exhaust gas, which is the exhaust gas in the upstream side of the NOx storage catalyst in the exhaust passage, is stable.

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 embodiment together with the accompanying drawings in which:

Fig. 1 is a schematic configuration view showing a diesel engine according to a first embodiment of the present invention;

Fig. 2 is a time chart showing the transition of the air-fuel ratio of exhaust gas observed during an S-process control;

Fig. 3 is a flow chart showing specific procedures of the S-process control according to the first embodiment;

Fig. 4 is a schematic diagram showing a diesel engine according to a second embodiment of the present invention;

Fig. 5 is a flow chart showing specific procedures of the S-process control according to the second embodiment;

Figs. 6(a) to 6(g) are time charts respectively showing changes for a combustion mode, a delay counter, an opening angle of a throttle valve, an opening angle of an EGR valve, a graduation counter, a fuel injection amount, and a permission flag F during the performance of the S-process;

Figs. 7 is a flow chart showing procedures for performing a low-temperature combustion mode and procedures for setting the permission flag F; and

Fig. 8 is a flow chart showing procedures for performing a low-temperature combustion mode and procedures for setting the permission flag F.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] An exhaust purifying apparatus (exhaust emission control system) of a diesel engine according to a first embodiment of the present invention will now be described.

[Structure and function of the engine]

[0013] Referring to Fig. 1, an internal combustion engine 1 (hereinafter referred to as an "engine") is an in-line, four cylinder diesel engine of which the main parts include a fuel injection system 10, a combustion chamber 20, an intake passage 30, and an exhaust passage 40.

[0014] First, the fuel injection system 10 includes a supply pump 11, a common rail 12, fuel injection valves 13, a fuel adding valve 14, an engine fuel passage P1, and a fuel adding passage P2. The supply pump 11 raises the pressure of the fuel pumped from the fuel tank (not shown) to a high value and supplies the fuel to the common rail 12 through the engine fuel passage P1. The common rail 12 functions as an accumulation chamber for keeping the high-pressure fuel supplied from the supply pump 11 at a predetermined pressure (accumulation pressure), and then allocates such stored fuel to each of the fuel injection valves 13. Each fuel injection valve 13 is a solenoid valve incorporating an electromagnetic solenoid (not shown) and appropri-

ately opens to inject or supply the fuel into the combustion chamber 20. The supply pump 11 supplies some of the fuel pumped from the fuel tank to the fuel adding valve 14 through the fuel adding passage P2. The fuel adding valve 14 is a solenoid valve incorporating an electromagnetic solenoid (not shown), and adds an appropriate amount of fuel, which functions as a reducing agent, to the upstream side of a catalytic casing 41 of the exhaust passage 40 at an appropriate timing.

[0015] A throttle valve 31 provided in the intake passage 30 is an electronically controlled switching valve having an opening angle that can be adjusted in a stepless manner. The throttle valve 31 functions, under a predetermined condition, to change the flow area of the intake air and adjust the supply (flow) of the intake air.

[0016] Furthermore, the catalytic casing 41 is provided at the downstream side of the fuel adding valve 14 of the exhaust passage 40. A known wall-flow particulate filter made mainly of a porous material is accommodated inside the catalytic casing 41. A known storage-reduction type NOx storage catalyst (hereinafter referred to as NOx storage catalyst) is carried at the surface of the particulate filter. The NOx storage catalyst consists of a NOx storage catalyst and a precious metal catalyst.

[0017] Various types of sensors are installed to each part of the engine 1 to output a signal related to the environmental condition of the relevant part or the operating state of the engine 1. For example, an oxygen concentration sensor 60 provided at the upstream side of the catalytic casing 41 of the exhaust passage 40 outputs a detection signal that continuously changes in response to the oxygen concentration in the exhaust gas. The detection signal of the oxygen concentration sensor 60 reflects, besides the air-fuel ratio of the air-fuel mixture for the engine combustion, the amount of the reductant supplied to the exhaust gas through the fuel adding valve 14, and thus acts as an index directly representing the amounts of the oxidizing component (oxygen (O₂) and the like) and the reductant (hydrocarbon (HC) and the like) in the exhaust gas. The component ratio of the oxidizing component and the reductant in the exhaust gas derived from the detection signal of the oxygen concentration sensor 60 is referred to as the air-fuel ratio (A/FEHT) of the exhaust gas. If the reducing agent supplied through the fuel adding valve 14 increases, the air-fuel ratio of the exhaust gas becomes relatively low (richens) with respect to the air-fuel ratio A/F of the air-fuel mixture used for engine combustion. If the amount of the reducing agent supplied through the fuel adding valve 14 is "0", the air-fuel ratio of the exhaust gas is substantially equal to the air-fuel ratio of the air-fuel mixture for the engine combustion. The oxygen concentration sensor 60 is electrically connected to an electronic control unit (ECU) 50.

[0018] The ECU 50 has a logic operation circuit consisting of a central processing unit (CPU), a read-only memory (ROM), a random access memory (RAM) a

back-up RAM, a timer counter 95 and the like. The ECU 50 performs various types of control relating to the operating state of the engine 1. For example, under a predetermined condition, the ECU 50 executes a control (feed-back control) to operate the fuel injection valve 13 so that the air-fuel ratio A/FEHT of the exhaust gas derived from the detection signal of the oxygen concentration sensor 60 converges or approaches a target value. Furthermore, under a predetermined condition, the ECU 50, based on the operating state of the engine 1, executes a control (feed-forward control) to operate the fuel injection valve 13 with reference to a map (not shown) set in advance.

[Function of the NOx storage catalyst]

[0019] As stated above, the NOx storage catalyst consists of an NOx storage catalyst and a precious metal catalyst.

[0020] The NOx storage catalyst can store NOx if the oxygen concentration in the exhaust gas is high, and release the stored NOx if the oxygen concentration in the exhaust gas is low (concentration of the reductant is high). Furthermore, if HC or CO and the like are present in the exhaust gas when NOx is released into the exhaust gas, the precious metal catalyst oxidizes the HC and CO, and as a result, an oxidation-reduction reaction occurs between the NOx, or the oxidizing component, and the HC or CO, or the reductant. In other words, the HC or CO is oxidized to H₂O or CO₂, and the NOx is reduced to N₂.

[0021] If the NOx storage catalyst stores a predetermined limit amount of NOx even if the oxygen concentration in the exhaust gas is high, the NOx storage catalyst will not store the NOx more than the limit amount. In the engine 1, the reductant is intermittently supplied to the upstream side of the catalytic casing 41 of the exhaust passage 40 by adding fuel, and thus the concentration of the reductant in the exhaust gas increases. Before the amount of the NOx stored by the NOx storage catalyst reaches the limit amount, the reductant periodically releases or reduce-purifies the NOx stored in the NOx storage catalyst. This recovers the NOx storage ability of the catalyst.

[Outline of S-process control]

[0022] The sulfur components originating from the sulfur components contained in the fuel is accumulated in the NOx storage catalyst (or S poisoning occurs) as the engine operation continues. The ECU 50 executes the sulfur process (S-process) control to remove the sulfur components accumulated in the NOx storage catalyst. The S-process control satisfies a particular condition defined by the air-fuel ratio A/FEHT of the exhaust gas exposed to the NOx storage catalyst by, for example, drive controlling the fuel adding valve 14 or controlling the combustion state of the engine 1.

[0023] Fig. 2 is one example of a time chart showing the transition of the air-fuel ratio A/FEHT of the exhaust gas observed when the S-process control is executed.

[0024] When a request to execute the S-process control is made (time t1), the ECU 50 performs a pre-process (first process) to lower (richen) the air-fuel ratio A/FEHT of the exhaust gas to a predetermined target value (for example, about 25: hereinafter referred to as air-fuel ratio pre-process value) α so that the fuel, in an atomized state, supplied by fuel addition efficiently acts on the NOx storage catalyst. The pre-process may be performed by for example, narrowing the throttle valve 31, and reducing the amount of air drawn into the combustion chamber 20. The pre-process may be performed by controlling the timing and the amount of fuel injection through the fuel injection valves 13. For example, besides carrying out most of the fuel injection near the compression top dead center to obtain engine power, a sub-fuel injection may be carried out at a different timing to lower (richen) the air-fuel ratio A/FEHT of the exhaust gas.

[0025] After the air-fuel ratio A/FEHT of the exhaust gas reaches the air-fuel ratio pre-process value α with the pre-process, the actual process of releasing sulfur (S-discharging process, or second process) starts (time t2). With the start of the S-discharging process, the intermittent fuel addition is carried out through the fuel adding valve 14. Thus, the air-fuel ratio A/FEHT of the exhaust gas repeatedly fluctuates between rich (A/FEHT = β (for example, approximately 14) and lean (A/FEHT = α). Furthermore, due to the reaction heat generated when the additional fuel oxidizes in the catalytic casing 41, the bed temperature of the NOx storage catalyst increases to a predetermined value (for example, about 700°C), and is generally maintained at a constant value.

[0026] The easy release of sulfur components accumulated in the NOx storage catalyst is related to the air-fuel ratio A/FEHT of the exhaust gas. In general, as the air-fuel ratio A/FEHT of exhaust gas lowers (richens), the sulfur components are released more efficiently.

[Setting of stand-by time TS]

[0027] when the pre-process involving lowering (richening) of the air-fuel ratio is performed, the combustion state, moreover, the exhaust property of the engine is likely to change. This is because when the target value of the air-fuel ratio A/FEHT of the exhaust gas is greatly changed with the start of the pre-process, it becomes difficult for the air-fuel ratio A/FEHT of the exhaust gas to rapidly converge to the target value. As a result, when the S-discharging process starts at the same time as the start of the pre-process, or right after the start of the pre-process, the air-fuel ratio A/FEHT of the exhaust gas tends to easily deviate from the target value at the first step of the S-discharging process.

[0028] If the control to converge the air-fuel ratio A/FEHT of the exhaust gas to the target value is carried

out as a feed-back control based on the detection signal of the oxygen concentration sensor 60, the fluctuation of the air-fuel ratio A/FEHT due to significant change in the target value also becomes significant.

[0029] In the present embodiment, after the start of the pre-process, the time needed for the air-fuel ratio A/FEHT of the exhaust gas to stabilize around the air-fuel ratio pre-process value α is set in advance as a stand-by time TS. The S-discharging process starts after the stand-by time TS has elapsed. Thus, in the S-discharging process, controllability, especially in the initial stage (convergence of the air-fuel ratio A/FEHT of the exhaust gas to the target value), is enhanced.

[0030] If, on the other hand, a predetermined condition is met, the setting of the stand-by time TS is cancelled, and the S-discharging process starts at the same time as the start of the pre-process or right after the start of the pre-process.

[0031] For example, if the intake air amount of the engine 1 is rather low, the O₂ storage performance (ability) of the NOx storage catalyst is carried on for a long time. Thus, the NOx storage catalyst purifies the excessive reductant more efficiently. Therefore, in the present embodiment, if the amount of intake air GA is less than a predetermined value, or if the O₂ storage effect of the NOx storage catalyst is high, the setting of the stand-by time TS is cancelled.

[0032] Furthermore, in the NOx storage catalyst, the O₂ storage ability decreases as time elapses when it is being used. In other words, if the extent of degradation of the NOx storage catalyst is small, the NOx storage catalyst purifies the excessive reductant at a sufficiently high efficiency even if the excessive reductant flows into the NOx storage catalyst due to the air-fuel ratio A/FEHT of the exhaust gas. Thus, in the present embodiment, a numerical index (hereinafter referred to as a catalyst degradation index) CATDG that represents the extent of degradation of the NOx storage catalyst, such as duration of use of the NOx storage catalyst or the total flow of the exhaust gas that has passed the NOx storage catalyst, is derived. If the catalyst degradation index CATDG is less than a predetermined value, or if the O₂ storage effect of the NOx storage catalyst is high, the setting of the stand-by time TS is cancelled.

[0033] Furthermore, in the present embodiment, to perform the pre-process and the S-discharging process, the feed-back control based on the detection signal of the oxygen concentration sensor 60 is carried out so that the air-fuel ratio A/FEHT of the exhaust gas converges to the target value. When the pre-process or the S-discharging process is performed, the deviation between the actual measurement value (value based on the signal of the oxygen concentration sensor 60) A/FEHT, which correspond to the operating state of various components (fuel injection valve 13, fuel adding valve 14, throttle valve 31 and the like) of the engine 1, and the target value are monitored, and the deviation is stored as a learning value FAFG. In the subsequent perform-

ance of the pre-process and the S-discharging process, the learning value FAFG is used to correct the operation of the fuel injection valve 13, the fuel adding valve 14, the throttle valve 31 and the like. Thus, the speed and accuracy of converging the air-fuel ratio A/FEHT of the exhaust gas to the target value in the pre-process and the S-discharging process is improved. In the present embodiment, if the setting of the learning value FAFG is already completed (if the learning value FAFG is already stored), the setting of the stand-by time TS is cancelled. Here, the learning value FAFG is preferably set to be a numerical value that differs for every operating region (operating range determined by, for example, the load and the speed) of the engine 1.

[Specific procedures of the S-process]

[0034] Fig. 3 is a flow chart explaining specific procedures (routines) of the S-process according to the present embodiment. This routine is repeatedly executed at a predetermined time interval by means of the ECU 50 after the engine 1 is started.

[0035] In this routine, the ECU 50 first acquires, in step S101, various information (for example, fuel injection amount Q or engine speed NE) that reflects the operating state of the engine 1.

[0036] In step S102, the ECU 50 determines whether a request for the S-process is currently being made, that is, whether sulfur components exceeding the predetermined amount is accumulated in the NOx storage catalyst. If an affirmative decision (YES) is made in step S102, the processing by the ECU 50 proceeds to step S103. However, if a negative decision (NO) is made in step S102, the process of the ECU 50 branches off. A negative decision is made in step S102 not only in situations where the S-discharging process has not been carried out because there is no necessity for the S-discharging process, but also in situations where the S-discharging process has already been carried out and a sufficient amount of sulfur components have already released from the NOx storage catalyst. Furthermore, if the pre-process and the S-discharging process is being carried out when the negative decision is made in step S102, the ECU 50 interrupts (or terminates) the pre-process and the S-discharging process that are being performed in step S110.

[0037] In step S103, the ECU 50 starts the pre-process (or continues the performance of the pre-process). Here, the ECU 50 sets the stand-by time TS that corresponds to both the start of the pre-process and the operating state of the engine 1, and starts time measurement.

[0038] In the series of steps S104, S105, and S106, the ECU 50 determines whether the intake air amount GA is greater than or equal to a predetermined value γ (S104), whether the catalyst degradation index CATDG is greater than or equal to a predetermined value σ (S105), and whether the air-fuel ratio learning is incom-

plete (S106). If an affirmative decision (YES) is made in all of steps S104, S105, and S106, the process by the ECU 50 proceeds to S107. However, if any of the decisions made in step S104, S105, or S106 is a negative decision (NO), the process by the ECU 50 jumps to step S108. In step S108, the ECU 50 starts the S-discharging process (or continues to perform the S-discharging process).

[0039] Furthermore, in step S107, the ECU 50 determines whether the duration time t_x of the pre-process is greater than or equal to the stand-by time TS (set when starting the present pre-process), and if the decision is an affirmative decision (YES), the S-discharging process starts (or continues the performance of the S-discharging process) in step S108. On the other hand, if a negative decision (NO) is made in step S107, the process by the ECU 50 branches off.

[0040] In the method for managing the NOx storage catalyst to carry out the S-process control by following the above procedures, after the S-discharging process starts, the air-fuel ratio A/FEHT of the exhaust gas rapidly converges to the target value (value suited to release the sulfur components accumulated in the NOx storage catalyst). For example, the air-fuel ratio A/FEHT does not excessively decrease (richen) with the start of the S-discharging process. Thus, after the start of the S-discharging process, the generation of white fumes or a sulfurous smell during the initial stage is effectively suppressed.

[0041] Based on a simple control configuration in which the stand-by time TS is set based on the operating state of the engine 1, controllability of the air-fuel ratio of the exhaust gas by the second process is enhanced. For example, a complicated control configuration for confirming the stability of the air-fuel ratio A/FEHT of the exhaust gas is not necessary.

[0042] By canceling the stand-by time TS under specific conditions (" $GA < \gamma$ ", " $CATDG < \sigma$ " or "setting of learning value FAFG is complete"), the time required for the process of releasing the sulfur components accumulated in the NOx storage catalyst is shortened as a whole. Thus, the fuel necessary for such process or the consumption of the reducing agent is reduced.

[0043] The learning value FAFG reflects the change amount in the air-fuel ratio of the exhaust gas resulting from the pre-process. Thus, the amount of reducing agent that is added during the S-discharging process is optimally adjusted taking into consideration the change amount in the air-fuel ratio of the exhaust gas resulting from the pre-process. As a result, even if the stand-by time TS is cancelled, the exhaust gas characteristics do not deteriorate when the S-discharging process is started, and the sulfur components accumulated in the NOx storage catalysts is efficiently released.

[0044] In the present embodiment, the stand-by time TS is determined based on the operating state of the engine 1 at the time of the start of the pre-process. The effect of the present embodiment can still be obtained

even if a predetermined numerical value is used. Furthermore, in accordance with the change in the operating state of the engine 1 after the start (during performance) of the pre-process, the stand-by time TS may be shortened or extended.

[0045] In place of the control configuration for setting the stand-by time TS, after the start of the pre-process, for example, the fluctuation width of the output of the oxygen concentration sensor 60 may be monitored and when determined that the air-fuel ratio of exhaust gas is sufficiently stable (air-fuel ratio of the exhaust gas is sufficiently converged to target value), the S-discharging process may be started. In this case, the control configuration is more complicated but accuracy of control will be further improved.

[0046] Furthermore, the oxygen concentration sensor and the like may be installed at the downstream side of the NOx storage catalyst in the exhaust passage 40, and the catalyst degradation index CATDG may be calculated by referring to the history of transition of the detection signal of the oxygen concentration sensor 60 corresponding to the operating state of the engine 1.

[0047] Furthermore, in step S104 of the S-process control routine, a condition that "intake air amount is greater than or equal to the predetermined value" is adopted. In place of such a condition, other conditions indicating that "any parameter related to intake air amount is greater than or equal to a predetermined value", such as "depression amount of accelerator pedal is greater than or equal to a predetermined value" or "fuel injection amount through the fuel injection valve 13 is greater than or equal to a predetermined value" can be set. That is, the parameter used in step S104 does not have to be the intake air amount itself as long as the parameter is related to the intake air amount.

[0048] Furthermore, the learning value FAFG adopted for the condition setting of step S106 in the S-process control routine is a parameter set with the performance of the feed-back control based on the detection signal of the oxygen concentration sensor 60. However, the parameter is not limited to the learning value FAFG. As long as it is related to the amount of change of the air-fuel ratio of the exhaust gas resulting from the performance of the pre-process, other parameters having a similar meaning as the learning value FAFG can also be used as the parameter.

[0049] Furthermore, with regards to the NOx storage catalyst, by using various materials functioning to reduce the NOx in the exhaust gas, effects equivalent to or in accordance with the effects of the present embodiment may be obtained.

[0050] A second embodiment of the present invention will now be described with reference to Fig. 4 to Fig. 8.

[0051] Fig. 4 shows a schematic configuration of an engine 1 according to the second embodiment. The engine 1 is constructed by adding an EGR (exhaust gas recirculation) mechanism 71 to the engine 1 of the first embodiment. The other parts of the engine 1 are the

same as the engine 1 of the first embodiment. The EGR mechanism 71 includes an EGR passage 72 and an EGR valve 73. The EGR passage 72 connects the upstream side of the catalytic casing 41 in the exhaust passage 40 to the downstream side of the throttle valve 31 in the intake passage 30. The EGR valve 73 opens and closes to change the flow area of the EGR passage 72 to adjust the flow of the recirculation exhaust gas (hereafter referred to as EGR gas).

[0052] The ECU 50 executes an opening angle control of the throttle valve 31 and an opening angle control of the EGR valve 73 based on the operating state of the engine 1. For example, an intake air amount feed-back control is carried out, in which the opening angle of the EGR valve 73 is adjusted, so that the intake air amount is the target intake air amount (target value per one revolution of engine 1) set based on the engine load (or fuel injection amount) and the engine speed NE. Furthermore, an EGR control is executed to adjust the opening angle of the throttle valve 31 and the opening angle of the EGR valve 73 so that the EGR efficiency is the target EGR efficiency set based on the engine load (or fuel injection amount) and the engine speed NE.

[0053] With regards to the engine 1, the combustion mode involved in the EGR control may be switched between two types of combustion modes, a normal combustion mode and a low-temperature combustion mode. The low-temperature combustion mode is a combustion mode that slows the rise of the combustion temperature by introducing large amounts of EGR gas into the combustion chamber 20, and simultaneously reducing NOx and smoke. A combustion mode other than the low-temperature combustion mode is the normal combustion mode for performing normal EGR control (i.e., no performance of EGR). In the low-temperature combustion mode, with the introduction of large amounts of EGR gas into the combustion chamber 20, the amount of air drawn into the combustion chamber 20 decreases. This decrease the air-fuel ratio A/F of the mixture for combustion of the engine 1 and lowers the air-fuel ratio A/FEHT of the exhaust gas. In the present embodiment, the pre-process of lowering the air-fuel ratio A/FEHT of the exhaust gas to the air-fuel ratio pre-process value α is achieved by performing the low-temperature combustion mode.

[0054] Between the low-temperature combustion mode and the normal combustion mode, the optimum value of each of the parameters of the fuel injection system in the engine 1, such as the fuel injection time and the fuel injection amount differ. Thus, when switched between the two types of combustion modes, the parameters of the fuel injection system also need to be changed to the optimum value (target value) that complies with the switched combustion mode. For example, when switched from the normal combustion mode to the low-temperature combustion mode, the fuel injection time is changed toward the advancing side, the fuel injection pressure is changed toward the increasing side,

and the fuel injection amount is changed toward the increasing side. The fuel injection pressure is increased with the advancement of the fuel injection time because in the low-temperature combustion mode, a large amount of EGR gas is present in the combustion chamber 20 thus reducing ignitability. Accordingly, ignitability needs to be improved. Furthermore, the fuel injection amount is increased because in the low-temperature combustion mode, the output torque of the diesel engine 1 tends to lower with the introduction of a large amount of EGR gas into the combustion chamber 20. Thus, lowering of output torque needs to be suppressed.

[0055] Specific procedures (routine) of the S-process according to the present embodiment will now be explained with reference to the flow chart in Fig. 5. The present routine is executed for each fuel injection in the engine 1 by means of the ECU 50. In this routine, steps S203, S207, and S211 differ from the first embodiment, but the other steps S201, S203-S206, S208, and S210 correspond to steps S101, S103-S106, S108, and S110 in the flow chart of Fig. 3 according to the first embodiment.

[0056] With reference to Fig. 5, in step S201, various information that reflects the operating state of the engine 1 is acquired, and in step S202, a determination is made as to whether a request for the S-process is being made. If an affirmative decision (YES) is made, the low-temperature combustion mode starts (or performance of low-temperature combustion mode continues) to perform the S-process in step S203. With the performance of the low-temperature combustion mode, the pre-process is achieved and the air-fuel ratio A/FEHT of the exhaust gas begins to decrease toward the air-fuel ratio pre-process value α . Furthermore, in step S203, after the start of the low-temperature combustion mode (pre-process), a permission flag F for determining whether the S-discharging process should be performed is set to "1" (permitted) under a predetermined condition. If a negative decision (NO) is made in step S202, and when the low-temperature combustion mode (pre-process) or the S-discharging process is being performed, such processes are interrupted or terminated (step S210). Furthermore, the permission flag F is set to "0" (prohibited) (S211).

[0057] In the series of steps S204, S205, S206 following step S203, determinations are made as to whether the intake amount GA is greater than or equal to a predetermined value γ (S204), whether the catalyst degradation index CATDG is greater than or equal to a predetermined value σ (S205), and whether the air-fuel ratio learning is incomplete (S206). If an affirmative decision (YES) is made in all of steps S204, S205, and S206, the process proceeds to S207. In step S207, a determination is made as to whether the permission flag F for determining whether to perform the S-discharging process is "1" (permitted). If the permission flag F is "1" (permitted) under a predetermined condition after performing the low-temperature combustion mode, an affirma-

tive decision (YES) is made in step S207. If the decision made in step S207 is YES, the procedure proceeds to step S208 and the S-discharging process is performed (or the S-discharging process is continued), and intermittent fuel addition is carried out through the fuel adding valve 14.

[0058] When a negative decision (NO) is made in any of steps S204, S205, or S206, the process jumps to step S208 to perform the S-discharging process irrespective of whether or not the permission flag F is "1" (permitted).

[0059] The outline of the procedures for setting the permission flag F to "1" (permitted) will now be explained with reference to the time chart in Fig. 6.

[0060] The permission flag F is set to "1" (permitted) under a predetermined condition after the start of the low-temperature combustion mode for performing the S-process. In the low-temperature combustion mode, contrary to the performance of the normal combustion mode, the throttle valve 31 is controlled to the close side and the EGR valve 73 is controlled to the open side to introduce a large amount of EGR gas into the combustion chamber 20. Furthermore, the parameters of the fuel injection system, such as the fuel injection time, the fuel injection pressure, and the fuel injection amount, are controlled to values suited to the low-temperature combustion mode.

[0061] As shown in Fig. 6(a), when the low-temperature combustion mode to perform the S-process starts at timing t3, the target opening angle of the throttle valve 31 starts to change to the closing side (solid line in Fig. 6(c)) and the target opening angle of the EGR valve 73 starts to change to the opening side (solid line in Fig. 6(d)) at such timing. Subsequently, the actual opening angle of the throttle valve 31 gradually starts to close with a predetermined response delay with respect to the change in the target opening angle (broken line in Fig. 6(c)), and the actual opening angle of the EGR valve 73 also gradually starts to open with a predetermined response delay with respect to the change in the target opening angle (broken line in Fig. 6(d)). Furthermore, with respect to changes in the actual opening angle of the throttle valve 31 and the EGR valve 73, there is also a response delay in increasing the flow of the EGR gas.

[0062] There is a response delay in increasing the flow rate of the EGR gas involved in the start of the low-temperature combustion mode, but change of each parameter of the fuel injection system to values suited to the low-temperature combustion mode can be carried out with generally no response delay. Therefore, if the change of each of the above parameters are started simultaneously with the start (t3) of the low-temperature combustion mode, changes in each parameter will be completed before the change of the flow rate of the EGR gas is completed, and a problem will arise in that the value of each parameter will not correspond to the flow of the EGR gas until the change of the flow of the EGR gas is completed.

[0063] Thus, the change in each parameter is started

with a predetermined delay, in other words, with a delay corresponding to the response delay of the flow of the EGR gas, from the start (t3) of the low-temperature combustion mode. More specifically, a delay counter value C1 decremented for each fuel injection of the engine 1 is set to a initial value greater than "0" as shown in Fig. 6(b), and when such delay counter value C1 reaches "0" (timing t4), each parameter starts to change. By delaying the start of change of each parameter, the above mentioned problem would not occur.

[0064] Furthermore, a predetermined period after the start of change of each parameter is a graduating period in which the parameters are gradually changed. Such a graduating period is set to avoid sudden change of each parameter and to suppress, for example, shocks involved in such sudden change. A graduation counter value C2 in Fig. 6(e) is used to set the above mentioned graduating period. The graduation counter value C2 is set to an initial value, which is greater than "0", when the delay counter value C1 reaches "0" (timing t4), and is decremented for each fuel injection of the engine 1. The graduating period is the period when the graduation counter value C2 is greater than "0" (t4-t5), and the initial value of the graduation counter value C2 is set so that changes of each parameter will be completed during the graduating period. The transition of one of the parameters, the fuel injection amount, during the graduating period is shown in Fig. 6(f).

[0065] In the present embodiment, when the graduation counter value C2 decrements to a predetermined value, for example "0" (timing t5), the permission flag F is set to "1" (permitted) as shown in Fig. 6(g). With the setting of the permission flag F at "1", the S-discharging process in step S208 starts if an affirmative decision (YES) is made in step S207 in Fig. 5. In this case, the S-discharging process starts when the permission flag F becomes "1" after the start of the low-temperature combustion mode (pre-process). Therefore, after the low-temperature combustion mode is started, the S-discharging process will not be performed until the permission flag F is "1", in other words, as long as the graduation counter value C2 is greater than "0", and during such time, the air-fuel ratio A/FEHT of exhaust gas begins to stabilize. Thus, the S-discharging process starts after the air-fuel ratio A/FEHT of the exhaust gas is stabilized. This quickly converges the air-fuel ratio A/FEHT to the target value after the start of the S-process.

[0066] Graduation of the fuel injection amount to the , increasing side during the graduating period, or during the period in which the graduation counter value C2 is greater than "0", is carried out for each fuel injection. Such increase in the fuel injection amount for each fuel injection influences the air-fuel ratio A/FEHT of the exhaust gas during the performance of the low-temperature combustion mode (pre-process). The graduation counter value C2 is decremented for each fuel injection, and thus is a value related to the influence on the air-fuel ratio A/FEHT of the exhaust gas involved in the in-

crease of fuel injection amount for each fuel injection. In the present embodiment, the S-discharging process starts in response to the graduation counter value C2, or based on the fact that the graduation counter value C2 reached "0". Thus, in the engine 1 in which the fuel injection amount increases with the performance of the low-temperature combustion mode (pre-process), the S-discharging process is started at a suitable timing related to the air-fuel ratio A/FEHT of the exhaust gas.

[0067] Detailed description of procedures for setting the permission flag F to "1" (permitted) will now be explained based on the flow chart showing the low-temperature combustion performing routine of Fig. 7 and Fig. 8. The low-temperature combustion performing routine is executed each time the procedure by the ECU 50 proceeds to step S203 in the flow chart in Fig. 5.

[0068] In the low-temperature combustion performing routine, determination is first made as to whether or not the low-temperature combustion mode should start (S301 in Fig. 7). If an affirmative decision (YES) is made, the opening angle of the throttle valve 31 and the EGR valve 73 is instructed to change to increase the EGR efficiency (S302). This starts to draw a large amount of EGR gas into the combustion chamber 20 in the low-temperature combustion mode. Subsequently, to initialize the delay counter value C1, the delay counter value C1 is set to the initial value (S303). The delay counter value C1 set to the initial value in this way is decremented in the process of step S305 when it is determined that "C1=0" is not satisfied in step S304. Therefore, after being set to the initial value, the delay counter value C1 is decremented for each fuel injection to approach "0". In other words, the number of fuel injections from when the low-temperature combustion mode starts is counted, and the counter value approaches a first permission value whenever fuel is injected.

When the delay counter value C1 reaches "0" (S304:

[0069] YES), that is, when the number of fuel injections reaches the first permission value, a determination is made as to whether or not the delay counter value C1 has just reached "0" (S306). If an affirmative decision (YES) is made, instructions are given to change the parameters of the fuel injection system, such as the fuel injection time, the fuel injection pressure, and the fuel injection amount, to values that comply with the low-temperature combustion mode (S307). Then, the graduation counter value C2 is initialized to the initial value (S308). When the graduation counter value C2 is set to the initial value, a determination is made in step S309 of Fig. 8 as to whether "C2=0" is satisfied. If C2 is not equal to "0", the parameters are graduated to values that comply with the low-temperature combustion mode (S310), and the graduation counter value C2 is decremented (S311). Therefore, when one of the parameters, the fuel injection amount, gradually increases or graduates for each fuel injection toward a value that complies

with the low-temperature combustion mode, the graduation counter value C2 is also decremented to approach "0" for each fuel injection. In other words, after the number of fuel injections reaches the first permission value, the fuel injection amount is gradually increased to the predetermined target value, which is optimum for the low-temperature combustion mode, until or before the number of fuel injections further reaches the predetermined second permission value.

[0070] When the graduation counter value C2 reaches "0" (S309: YES), that is, when the number of fuel injections reaches the second permission value, a determination is made as to whether the graduation counter value C2 has just reached "0" (S312). If an affirmative decision (YES) is made, the permission flag F is set at "1" (permitted). With the setting of the permission flag F at "1" (S207), the S-discharging process in step S208 is performed if an affirmative decision is made at step S207 in Fig. 5.

[0071] In the second embodiment, the following advantages are obtained in addition to the advantages of the first embodiment.

[0072] After the start of the low-temperature combustion mode (pre-process) to perform the S-process, the fuel injection amount increases for each fuel injection toward a value that complies with the low-temperature combustion mode, but such increase in the fuel injection amount for each fuel injection influences the air-fuel ratio A/FEHT of the exhaust gas. Therefore, in the second embodiment, the S-discharging process is started based on the graduation counter value C2, which is decremented for each fuel injection in accordance with the increase in the fuel injection amount, that is, based on the fact that the graduation counter value C2 has decreased from the initial value to the permission value of "0". In other words, after the low-temperature combustion mode is started, the S-discharging process is started when the number of fuel injections reaches the predetermined permission value. As a result, the S-discharging process is started at a suitable timing even in the engine 1 in which the fuel injection amount increases with the performance of the low-temperature combustion mode.

[0073] If the start timing of the S-discharging process is not a suitable timing, for example, if the start timing is too early, the addition of the reducing agent (fuel) to the upstream side of the NOx storage catalyst through the fuel adding valve 14 by the S-discharging process is carried out when the decrease of the air-fuel ratio A/FEHT of the exhaust gas to the air-fuel ratio pre-process value α has not yet advanced in the low-temperature combustion mode (pre-process). Thus, a large amount of reducing agent would be needed to lower the air-fuel ratio A/FEHT of the exhaust gas to a value that can release the sulfur components accumulated in the NOx storage catalyst. This would lead to problems such as a rise in the catalyst bed temperature and degradation of the controllability of the air-fuel ratio A/FEHT of the exhaust gas.

However, the second embodiment prevents such problems from occurring.

[0074] 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 or scope of the invention. Therefore, the present invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

[0075] In a diesel engine, prior to a sulfur discharging process, a pre-process is performed to decrease the air-fuel ratio of the air-fuel mixture that is to be burned in the engine so that the air-fuel ratio A/FEHT of the exhaust gas reaches a predetermined pre-process value α . The time required for the air-fuel ratio A/FEHT of the exhaust gas to stabilize near the pre-process value α is set as a stand-by time TS. The sulfur discharging process starts after the stand-by time elapses. This enhances the convergence of the air-fuel ratio A/FEHT to the target value during the sulfur discharging process. If a predetermined condition is satisfied, the stand-by time is cancelled to start the sulfur discharging process when or just after the pre-process is started. This efficiently processes the sulfur components accumulated in a NOx storage catalyst, which is arranged in an exhaust passage of the engine, without deteriorating the exhaust gas property.

Claims

1. A method for managing a NOx storage catalyst arranged in an exhaust passage of a diesel engine to reduce NOx in exhaust gas, the method including releasing sulfur components accumulated in the NOx storage catalyst, said releasing including a first process for decreasing the air-fuel ratio of an air-fuel mixture that is to be burned in the engine, and a second process for adding a reducing agent to an upstream side of the NOx storage catalyst in the exhaust passage, the method being **characterized in that**:

the second process is started when a predetermined starting condition is satisfied after the first process is started, the starting condition being that the air-fuel ratio of upstream side exhaust gas, which is the exhaust gas in the upstream side of the NOx storage catalyst in the exhaust passage, is stable.

2. The method according to claim 1, **characterized in that** the starting condition is that a predetermined time required for stabilizing the air-fuel ratio of the upstream side exhaust gas elapses after the first process is started.

3. The method according to claim 1 or 2, **character-**

ized in that the starting condition is cancelled when a parameter related to intake air amount of the engine is less than a predetermined value.

4. The method according to any one of claims 1 to 3, **characterized in that** the starting condition is cancelled when a parameter related to a degradation level of the NOx storage catalyst is less than a predetermined value.

5. The method according to any one of claims 1 to 4, being further **characterized by**:

detecting a change amount of the air-fuel ratio of the upstream side exhaust gas that results from the first process and learning the change amount, the starting condition being cancelled after the learning is completed.

6. The method according to any one of claims 1 to 5, **characterized in that** the starting condition is that the number of times fuel is injected into a combustion chamber of the engine becomes greater than or equal to a predetermined value after the first process is started.

7. The method according to any one of claims 1 to 5, **characterized in that** the starting condition is that a counter value, decremented whenever fuel is injected into a combustion chamber of the engine, decreases to a predetermined value or less after the first process is started.

8. The method according to any one of claims 1 to 5, **characterized in that**:

the engine performs exhaust gas recirculation control, and switches combustion modes between a low-temperature combustion mode, for drawing a relatively large amount of recirculation exhaust gas into a combustion chamber of the engine, and a normal combustion mode; after the low-temperature combustion mode is started, the amount of fuel injected into the combustion chamber increases gradually to a predetermined target value that is suitable for the low-temperature combustion mode until or before the number of times fuel is injected into the combustion chamber reaches a predetermined permission value;

the first process is performed by performing the low-temperature combustion mode; and the starting condition is that the number of times fuel is injected into the combustion chamber becomes greater than or equal to the predetermined permission value after the low-temperature combustion mode is started.

9. The method according to any one of claims 1 to 5,
characterized in that:

mode is started.

the engine performs exhaust gas recirculation
control, and switches combustion modes be- 5
tween a low-temperature combustion mode, for
drawing a relatively large amount of recircula-
tion exhaust gas into a combustion chamber of
the engine, and a normal combustion mode;
after the low-temperature combustion mode is 10
started, an injection amount of fuel into the
combustion chamber increases gradually to a
predetermined target value that is suitable for
the low-temperature combustion mode until or
before a counter value, decremented whenever 15
fuel is injected into the combustion chamber,
decreases from a predetermined initial value to
a predetermined permission value;
the first process is performed by performing the
low-temperature combustion mode; and 20
the starting condition is that the counter value
becomes less than or equal to the predeter-
mined permission value after the low-tempera-
ture combustion mode is started.

25

10. The method according to any one of claims 1 to 5,
characterized in that:

the engine performs exhaust gas recirculation
control, and switches combustion modes be- 30
tween a low-temperature combustion mode, for
drawing a relatively large amount of recircula-
tion exhaust gas into a combustion chamber of
the engine, and a normal combustion mode;
an opening degree of an EGR valve that adjusts 35
the amount of recirculation exhaust gas drawn
into the combustion chamber is increased and
an opening degree of a throttle valve that ad-
justs the amount of intake air drawn into the
combustion chamber is decreased when the 40
low-temperature combustion mode is started;
after the number of times fuel is injected into
the combustion chamber reaches a predeter-
mined first permission value from when the low-
temperature combustion mode is started, the 45
amount of fuel injected into the combustion
chamber increases gradually to a predeter-
mined target value that is suitable for the low-
temperature combustion mode until or before
the number of times fuel is injected reaches a 50
predetermined second permission value from
the predetermined first permission value;
the first process is performed by performing the
low-temperature combustion mode; and
the starting condition is that the number of 55
times fuel is injected becomes greater than or
equal to the predetermined second permission
value after the low-temperature combustion

Fig.1

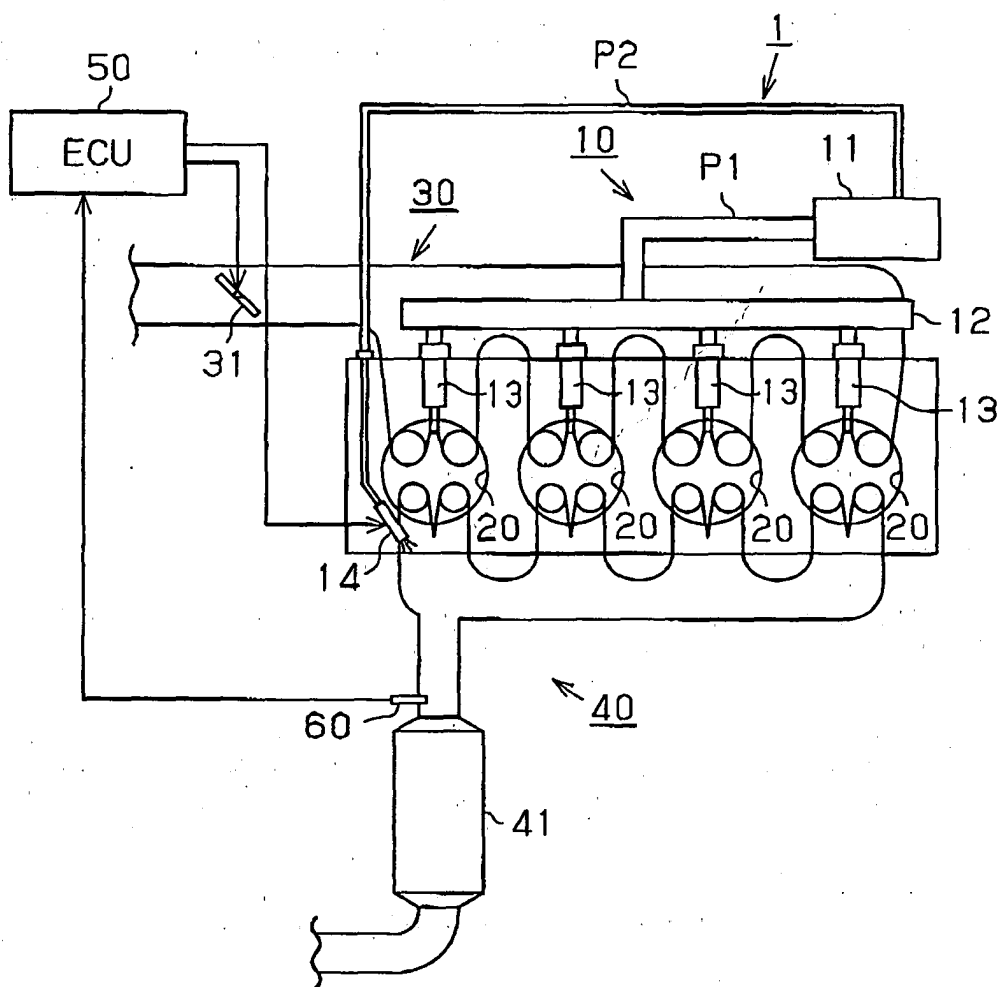


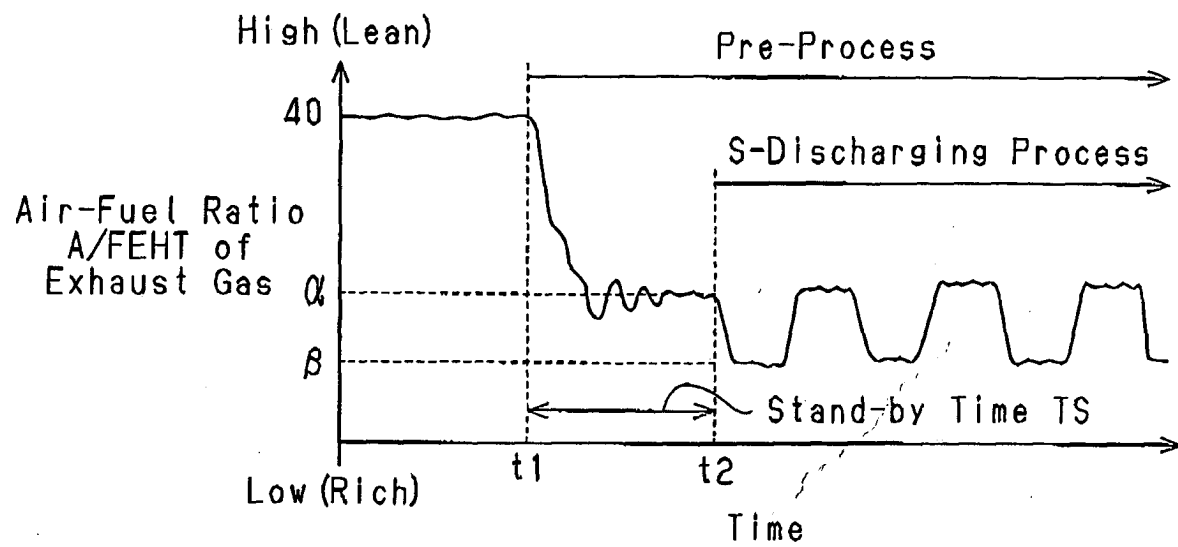
Fig.2

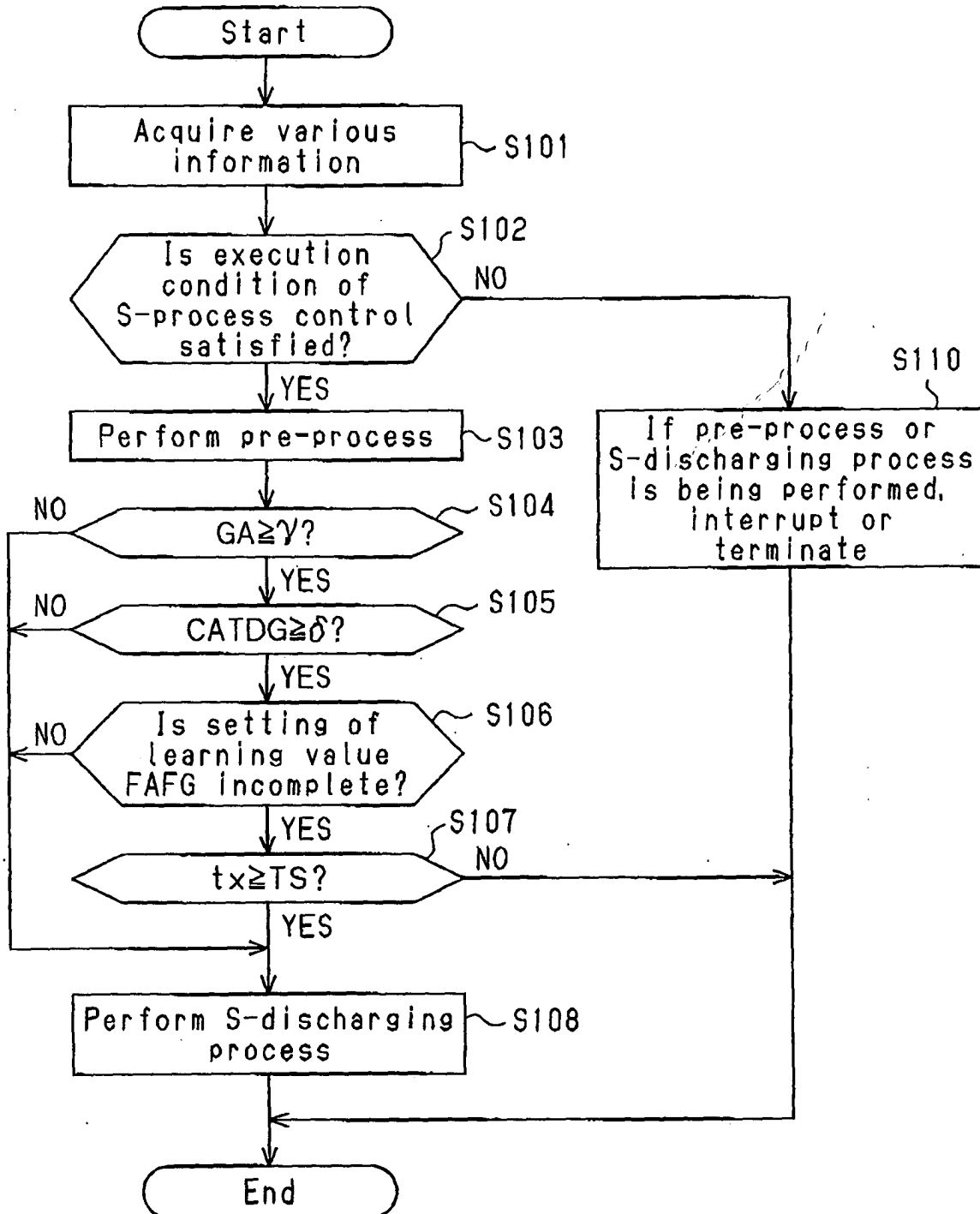
Fig.3

Fig.4

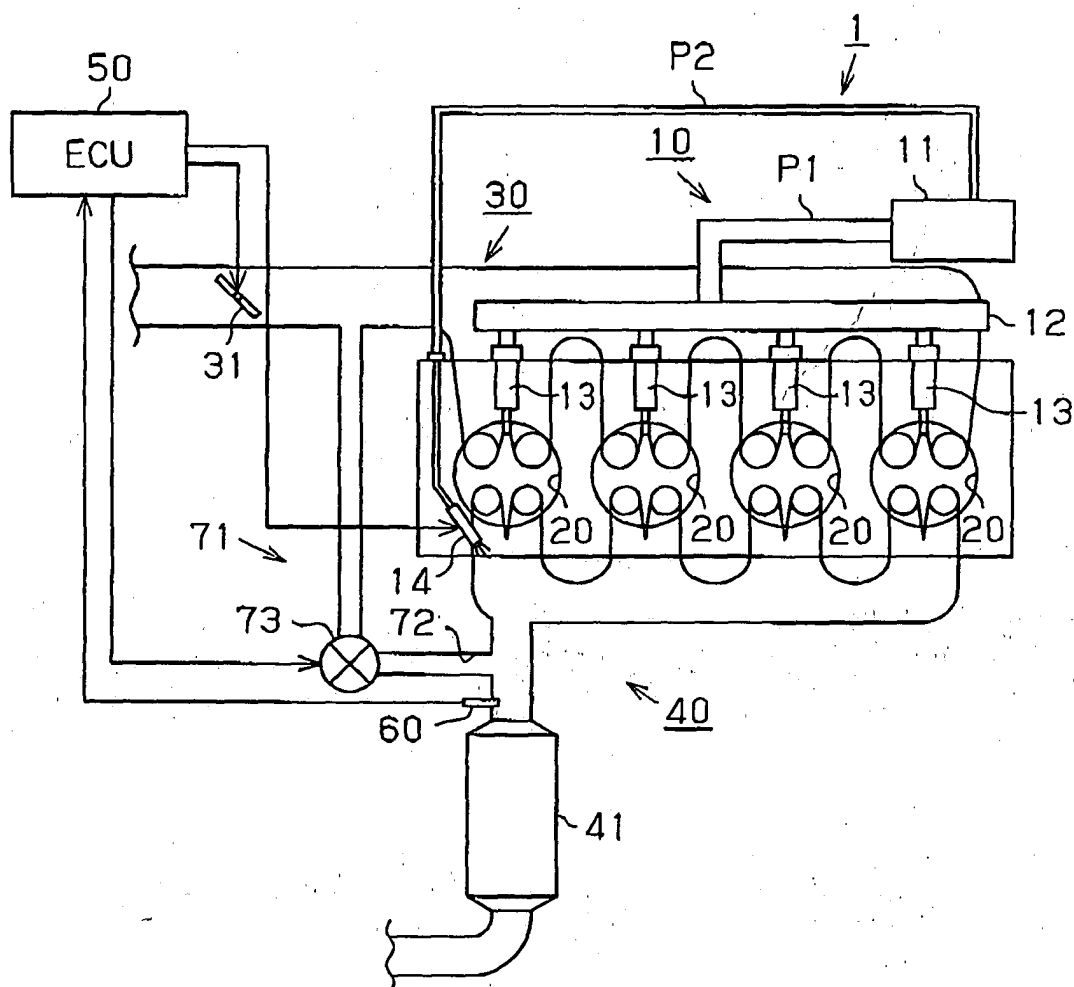


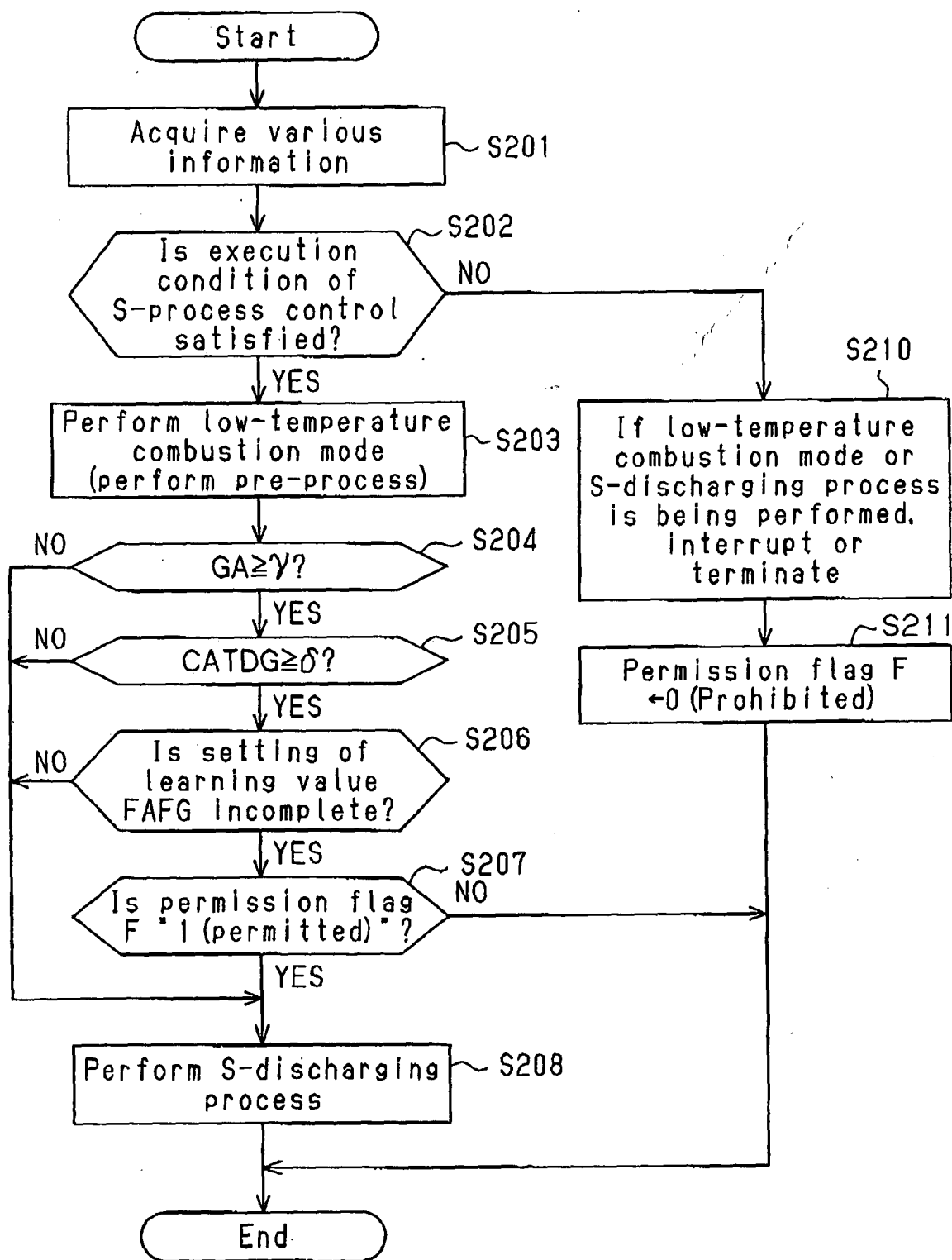
Fig.5

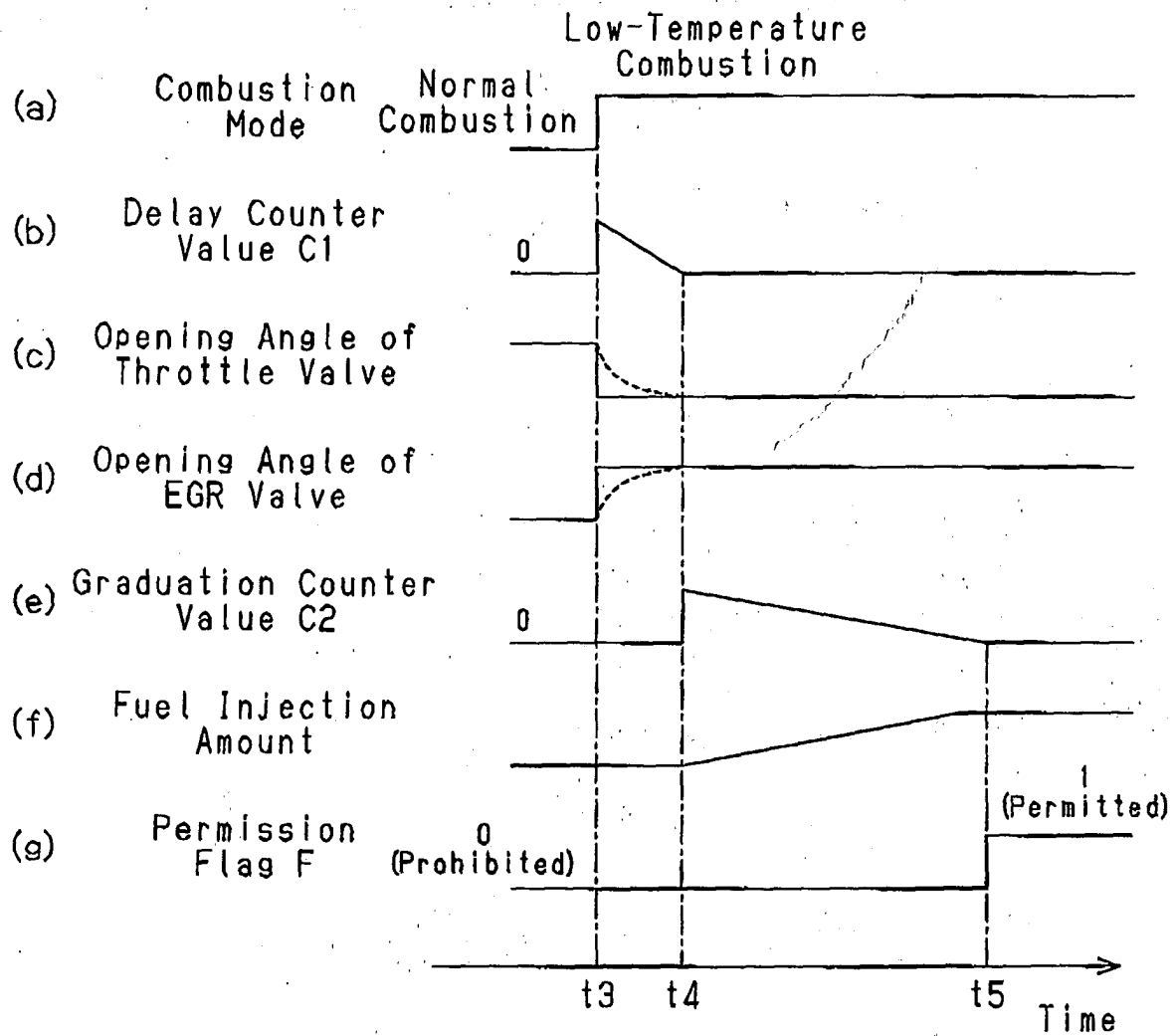
Fig.6

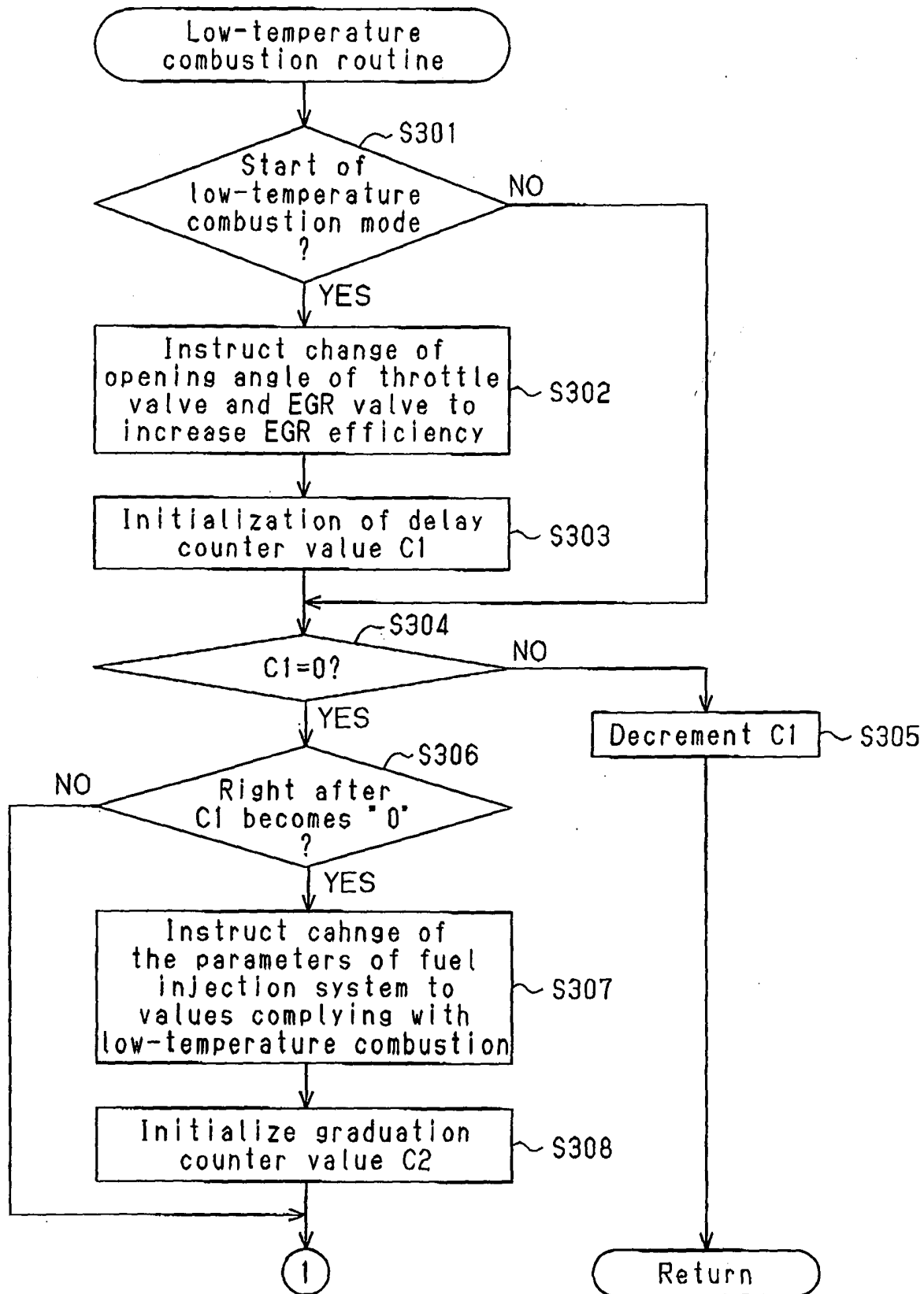
Fig.7

Fig.8