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(54) Filter regenerating method and exhaust emission control device

(57) An additive agent is added to fuel, suction gas or exhaust gas, for lowering an ignition temperature of particulate matter contained in the exhaust gas. In a desired timing at which a pressure difference between the front and rear of a filter, arranged in an exhaust pipe, is increased due to the operation of an engine, an electric heater element of the filter is supplied with electric power of at least 2 kW for 10 to 80 seconds, to quickly burn the particulate matter having a lowered ignition temperature and captured by the filter. This regeneration method can be carried out in such a condition that the engine continuously operates and the exhaust gas containing the particulate matter constantly passes through the filter, without isolating the filter.

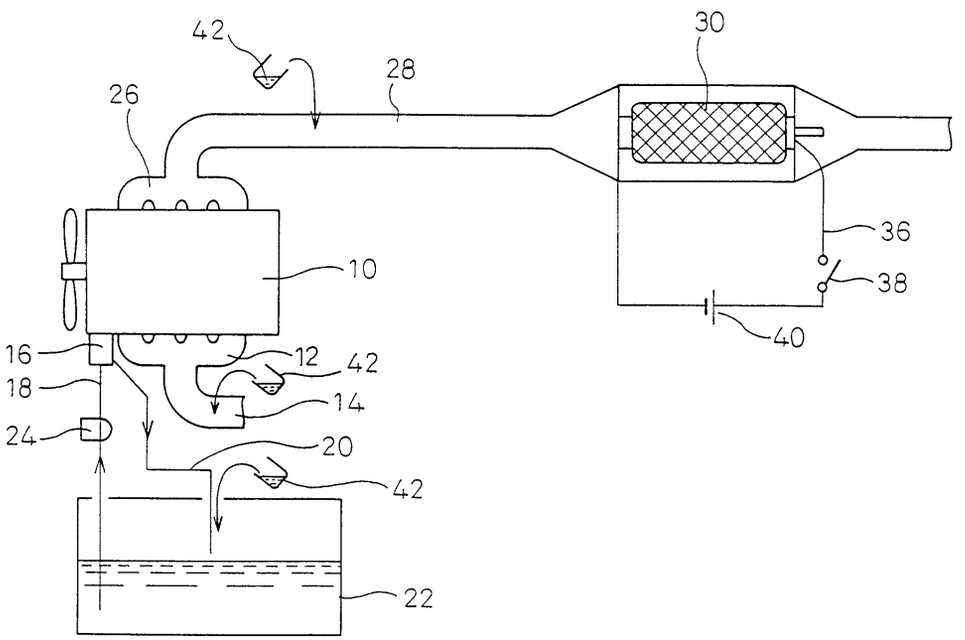

Fig. 1

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a method for electrically regenerating a filter used for capturing particulate matter contained in exhaust gas of an internal combustion engine such as a diesel engine. Also, the present invention relates to an exhaust emission control device capable of carrying out this filter regenerating method.

BACKGROUND ART

[0002] Particulate matter harmful to environment, such as soot, is contained in an exhaust gas from a diesel engine. To reduce the discharge of such particulate matter into air, filters for removing the particulate matter, capable of being provided in an exhaust system of a diesel engine have been developed.

[0003] In general, a pressure loss is generated in the exhaust system when the particulate matter has been captured in the filter. Particularly, the clogging of the filter causes a large pressure difference between the upstream and downstream sides of the filter to deteriorate a filter structure. Generally, it is possible to regenerate the filter function by timely burning particulate matter captured in the filter. Various filter regenerating methods have been proposed heretofore, and particularly, an electric heater system and a fuel-additive system have been well-known in these methods.

[0004] According to the filter-regeneration method with the electric heater system, the filter is regenerated by heating it to a predetermined temperature by an easily controllable electric heater so as to burn the particulate matter captured in the filter by heat of the heater. For example, Japanese Unexamined Patent Publication (Kokai) Nos. 2-256812 and 6-241023 disclose filters to which this method is applicable and in which an electric heater element is incorporated integrally with a filter member. This type of filter may confine the heat imparted by the electric heater element within the filter member, and thus may advantageously reduce electric energy required for burning the particulate matter.

[0005] The filter-regeneration method with the electric heater system is normally carried out in such a condition that the filter is thermally isolated by shutting off an exhaust pipe at the downstream and upstream of the filter for the purpose of the effective heating of the filter. Particularly, to ensure the thermal isolation of the filter during a period when the engine continuously operates to constantly output the exhaust gas into the exhaust system, a bypass pipe extending to bypass the filter is provided in the exhaust system. In this case, a switching mechanism is provided to change or direct the exhaust flow toward either one of the filter and the bypass pipe. Also, a device for introducing air into the filter may be provided to facilitate the burning of the particulate matter.

[0006] According to the filter-regeneration method with the fuel-additive system, an additive agent for lowering the ignition temperature of the particulate matter is added to fuel, suction gas or exhaust gas so as to burn the particulate matter at a relatively low temperature. According to this method, it is expected that the particulate matter is burned by heat of the exhaust gas during the operation of the engine. As a result, it is possible to construct a simple exhaust emission control device without the necessity of electric heater, bypass pipe or others required for the electric heater system.

[0007] Also, as disclosed in Japanese Unexamined Patent Publication (Kokai) No. 60-153413, another filter-regeneration method with both the electric heater system and the additive system has been known. This method may advantageously use an electric heater having a relatively small capacity since the ignition temperature of the particulate matter is lowered by the addition of the additive agent in the suction system, the exhaust system or the fuel system. Generally, this method is also carried out in the condition that the filter is thermally isolated. Accordingly, the bypass pipe, switching mechanism or others are provided in the exhaust system.

[0008] The filter-regeneration method with the electric heater system described above may complicate a structure of the exhaust emission control device because of the provision of electric heater, bypass pipe or others. On the contrary, it is possible to simplify the structure of the exhaust emission control device according to the filter-regeneration method with the additive system. However, it is only a time when a large load is applied to the engine that the temperature of exhaust gas reaches the ignition temperature of particulate matter lowered by the additive. In other words, when the load is relatively small, for example, in a case of the engine of an automobile running on a normal urban street, the temperature of exhaust gas hardly reaches the ignition temperature. The filter clogging or deterioration may be caused due to the accumulation of particulate matter exceeding an allowable amount, in such a condition that the exhaust gas temperature only incidentally or occasionally reaches the ignition temperature.

[0009] It may be expected that the problems in the above respective systems are eliminated by the above-mentioned method having both the electric heater and additive systems. However, this system still needs the isolation of the filter during the regeneration of the filter, and therefore a bypass pipe, a switching mechanism, an air-intake device or others must be provided in the exhaust system. Thus, the problem of the complicated structure of the exhaust emission control device has not yet been solved.

SUMMARY OF THE INVENTION

[0010] An object of the present invention is to provide a method for electrically regenerating a particulate filter, which enables the filter to be regenerated in a simple manner by burning particulate matter captured in the filter, without isolating the filter in an exhaust pipe.

[0011] Another object of the present invention is to provide an exhaust emission control device which has a simple structure and can carry out such a filter regenerating method.

[0012] In one aspect of the present invention, a method is provided for regenerating a filter used for capturing particulate matter contained in exhaust gas by heat of an electric heater element, comprising the steps of lowering an ignition temperature of the particulate matter by an additive agent; and supplying electric power of at least 2 kW for 10 to 80 seconds to the electric heater element to quickly burn the particulate matter having a lowered ignition temperature and captured in the filter, while continuously passing the exhaust gas through the filter. The electric heater element can be supplied with the electric power of 15 kW or less.

[0013] In another aspect of the present invention, an exhaust emission control device is provided that comprises a filter disposed in an exhaust pipe to capture particulate matter contained in exhaust gas, an electric heater element for heating the filter, and a mechanism for adding an additive agent into fuel, suction gas or exhaust gas to lower an ignition temperature of the particulate matter, characterized in that the electric heater element quickly burns the particulate matter having a lowered ignition temperature and captured in the filter, under an electric power supply of at least 2 kW for 10 to 80 seconds.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Fig. 1 is a schematic view of an exhaust emission control device according to one embodiment of the present invention.

[0015] Fig. 2 is a schematic sectional view of a filter used in the exhaust emission control device shown in Fig. 1.

[0016] Fig. 3 is an illustration showing the results of experiments for the filter regeneration method according to the present invention.

[0017] Fig. 4 is an illustration showing the results of experiments for the filter regeneration method according to the present invention.

[0018] Fig. 5 is an illustration showing the results of experiments for the filter regeneration method according to the present invention.

MODES FOR CARRYING OUT THE INVENTION

[0019] The present invention will be described in more detail below on the basis of the embodiments thereof with reference to the accompanying drawings.

[0020] Fig. 1 is a schematic illustration of a construction of an exhaust emission control device, according to one embodiment of the present invention, which is applied to a normal diesel engine. An air-intake system for the diesel engine includes an intake manifold 12 connected to an intake port of an engine body 10 and an intake pipe 14. A fuel system of the diesel engine includes an fuel injection pump 16 connected to the engine body 10 and a fuel tank 22 connected to the fuel injection pump 16 via a fuel supply pipe 18 and a fuel return pipe 20. Usually, a fuel filter 24 is provided in the fuel supply pipe 18.

[0021] An exhaust system of the diesel engine includes an exhaust manifold 26 connected to an exhaust port of the engine body 10 and an exhaust pipe 28 connected at one end to the exhaust manifold 26. A filter 30 integrally incorporating therein an electric heater element is mounted at the other end of the exhaust pipe 28. The filter 30 is one of components constituting the exhaust emission control device, and has a function for capturing particulate matter emitted from the engine body 10.

[0022] The filter 30 according to this embodiment may be constituted by a filter cartridge typically disclosed, for example, in Japanese Unexamined Patent Publication (Kokai) No. 6-241023. As shown in Fig. 2, the filter 30 includes a tubular support member 32 made of a resistor having an electric resistance in a range from 10 to 200 mΩ and a filter body 34 made of inorganic fibers, such as an aluminum borosilicate, an aluminum oxide, a silicon dioxide or a silicon carbide. The filter body 34 is supported on and directly wound around the support member 32. The support member 32 is connected to a direct current source 40 via an electric lead 36 and a switch 38 (Fig. 1) and acts as an electric heater element for generating heat under a power supply. Accordingly, it is possible to burn the particulate matter captured in the filter body 34 by supplying the electric power to the support member 32 to effectively heat the filter body 34 at a predetermined temperature.

[0023] Further, the exhaust emission control device is provided with a mechanism for adding an additive agent 42 for lowering an ignition temperature of the particulate matter into fuel, suction gas or exhaust gas. As such a mechanism,

a system for manually supplying the additive agent 42 to the fuel tank 22, or a device (not shown) for supplying the additive agent to the fuel system (the fuel supply pipe 18), the air-intake system (the intake pipe 14) or the exhaust system (the exhaust pipe 28) may be employed.

[0024] The additive agent 42 may be suitably selected in accordance with the natures of particulate matter contained in exhaust gas. The additive agent 42, which can be suitably used for the particulate matter contained in the exhaust gas of the diesel engine, is, e.g., a ferrocene (trade name: SATACENE) available from Chemische Betriebe Pluto GmbH in Herne, Germany; a copper compound in the form of liquid suspension (trade name: E-Z-Add) available from Lubrizol Co. in Ohio, USA; a cerium complex (trade name: EOLYS or DPX-9) available from Rhone Poulene in Paris, France; a ferrocene (trade name: Catane) available from Econalytic Systems Co. in Colorado, USA; and a platinum/cerium compound (trade name: PLATINUM PLUS) available from Clean Diesel Technologies in Connecticut, USA.

[0025] Conventionally, the regeneration of filter in the exhaust emission control device of this type has been carried out in a state wherein the filter is thermally isolated as described before. This is because that, in a state wherein the exhaust gas is constantly flowing through the filter due to the continuous operation of engine, there is a tendency in that the exhaust gas operates as a coolant for absorbing heat from the filter. This tendency is significant when the engine load is relatively small; for example, 50% or less of the rated value of the engine.

[0026] The inventor of the present application found that it is possible to effectively regenerate the filter 30 in the exhaust emission control device of the above-mentioned construction even while constantly passing exhaust gas containing particulate matter through the filter 30 under the continuous operation of the engine body 10, by carrying out a characteristic regeneration method described below.

[0027] In more detail, the filter regeneration method of the present invention is characterized in that, particularly referring to the above-mentioned embodiment, the additive agent 42 is added to fuel, suction gas or exhaust gas, and the electric heater element or support member 32 of the filter 30 is supplied with the electric power of at least 2 kW for 10 to 80 seconds, so as to quickly burn the particulate matter captured in the filter body 34, which has a lowered ignition temperature. The threshold of the electric power, i.e., 2 kW, is determined or calculated in consideration of a heat absorption by the exhaust gas passing through the filter 30 during the filter regeneration process. In this respect, to realize the electric energy consumption of the same level as in the conventional electric heater type filter regeneration method, the power supply to the support member 32 is preferably 15 kW or less.

[0028] Also, the filter regeneration method according to the present invention can be carried out at a desired instant when the pressure difference increases between the upstream and downstream sides of the filter 30 in the exhaust pipe 28. Alternatively, it is possible to select a timing of the regeneration process in accordance with the duration of engine driving, the running distance of vehicle and so on.

[0029] The method of the present invention wherein a relatively high electric power is supplied in a relatively short period enables particulate matter to effectively burn while minimizing a useless heat dissipation from the filter body 34. Also, since this method solely requires substantially the same electric energy of several hundreds kJ as in the conventional electric heater type filter regeneration method, it is possible to restrict the increase of the capacity of an electric power source. Also, since the particulate matter quickly burns by a high electric power, the adverse cooling effect of exhaust gas can be minimized even though the exhaust gas containing particulate matter is constantly passing through the filter 30 under the continuous operation of engine body 10. As a result, the regeneration process can be carried out without isolating the filter 30 in the exhaust pipe.

[0030] Therefore, according to the method of the present invention, a bypass pipe can be eliminated, as shown in Fig. 1, from the exhaust emission control device, and thereby the switching mechanism for the exhaust gas flow can be also omitted. Since oxygen sufficiently exists in the exhaust gas for quickly burning particulate matter in the filter body 34, no air introducing device for the exhaust system is also necessary. Accordingly, the exhaust emission control device is simplified in structure.

[0031] In the filter regeneration method according to the present invention, the optimum values of electric power supplied to the filter and of time required for a power supply are determined on the basis of the flow rate and temperature of an exhaust gas during the regeneration process, a property and amount of particulate matter captured in the filter body, a constitution of an additive agent, etc. Since the relationship between the filter regeneration effect and the supplied electric power as well as the power supply time includes a number of parameters, it is not easy to define a preferred range of the supplied electric power and of the power supply time, which may provide a desired effect. However, assuming that a filter regeneration process is carried out under general operating conditions of an automobile having a normal diesel engine and running on a normal urban street, the upper limit of electric energy supplied from a normal battery for the filter regeneration under such operating conditions is naturally set. With reference to such an upper limit of electric power, the above-identified ranges of the supplied electric power and of the power supply time are defined in mainly consideration of a quick burning of particulate matter in a shorter time.

[0032] The exhaust emission control device according to the present invention should not be limited to the above embodiment. For example, the filter is not limited to the above structure wherein the filter body is directly wound around the support member as an electric heater element, but may be any other structures having various sizes, shapes and

material compositions, provided that the electric heater element is thermally integral with the filter body to facilitate the heat transmission to the filter body.

Examples

[0033] Explanation will be made below on some experiments carried out under various conditions to clarify the operation and effect of the present invention. In this regard, in the following experiments, it can be deemed that the filter has been regenerated when the pressure difference between the upstream and downstream sides of the filter is reduced after the filter regeneration process in comparison with the pressure difference of the initial or former condition.

[0034] The exhaust emission control device shown in Fig. 1 was constructed in the following constitution. As the engine body 10, an IDI engine (trade name: 6A) having a displacement of 3.4 liter, produced by Cummins Co. of Indiana, USA, was employed. As the filter 30, a filter cartridge with a built-in heater (a total length: 265 mm, a diameter: 96 mm) produced by 3M Co. of Minnesota, USA, was employed. This cartridge included the support member 32 (trade mark: Inconel 600) produced by INCO Co. of West Virginia, USA, and the filter body 34 (trade mark: Nextel 312) produced by 3M of Minnesota, USA. The support member 32 had a resistance of 168 ± 18 mΩ and was composed of nickel of 76.0%, chromium of 15.5% and iron of 8.5% by weight. Also, the filter body 34 was composed of alumina (Al_2O_3) of 62%, silica (SiO_2) of 24% and boron oxide (B_2O_3) of 14% by weight. A ferrocene additive agent (trade name: SATACENE) produced by Chemische Betriebe Pluto was added to fuel at a ratio of 120 ppm as the additive agent 42.

Example 1

[0035] The engine body 10 was operated at a rotational speed of 1560 rpm under a load corresponding to 50% of the rated value, and exhaust gas containing particulate matter and having a temperature of 250°C to 300°C was continuously directed through the exhaust pipe 28, until the pressure difference between the upstream and downstream sides of the filter reaches 40 kPa due to the particulate matter accumulated in the filter 30. The switch 38 was turned ON in this state to supply electric power of 4.4 kW to the support member 32 for 1 minute so as to try the regeneration of filter 30. As a result, as shown in Fig. 3, although the pressure difference was once increased to a small extent due to the temperature rise of exhaust gas, the pressure difference was suddenly reduced within one minutes after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 2.4 kPa. Thus, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Example 2

[0036] The particulate matter was accumulated in the filter 30 under the same conditions as in Example 1. In this state, the support member 32 was supplied with electric power of 3.5 kW for one minute so as to try the regeneration of filter 30. As shown in Fig. 3, the pressure difference suddenly reduced in the same manner as in Example 1 within one minute after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 2.2 kPa. This, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Example 3

[0037] Exhaust gas was continuously directed through the exhaust pipe 28 in the same condition as in Example 1, until the pressure difference between the upstream and downstream sides of the filter reaches 20 kPa due to the particulate matter captured in the filter 30. In this state, the support member 32 was supplied with electric power of 4.5 kW for one minute so as to try the regeneration of filter 30. As shown in Fig. 4, the pressure difference suddenly reduced in the same manner as in Example 1 within one minute after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 2.7 kPa. Thus, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Example 4

[0038] The particulate matter was accumulated in the filter 30 under the same conditions as in Example 3. In this state, the support member 32 was supplied with electric power of 4.0 kW for one minute so as to try the regeneration of filter 30. As shown in Fig. 4, the pressure difference suddenly reduced in the same manner as in Example 3 within one minute after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-

out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 5.1 kPa. Thus, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Example 5

[0039] The particulate matter was accumulated in the filter 30 under the same conditions as in Example 3. In this state, the support member 32 was supplied with electric power of 3.5 kW for one minute so as to try the regeneration of filter 30. As shown in Fig. 4, the pressure difference suddenly reduced in the same manner as in Example 3 within one minute after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 16.9 kPa. Thus, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Example 6

[0040] Exhaust gas was continuously directed through the exhaust pipe 28 in the same condition as in Example 3, until the pressure difference between the upstream and downstream sides of the filter reaches 20 kPa due to the particulate matter captured in the filter 30, and then the engine was operated at a lowered rotational speed of 800 rpm under no load. In this state, the support member 32 was supplied with electric power of 4.4 kW for one minute so as to try the regeneration of filter 30. After the initiation of power supply for 78 seconds, the engine rotational speed was returned to 1560 rpm and the load was returned to 50 %. As shown in Fig. 5, the pressure difference reduced to a some extent by no load operation was further lowered in the same manner as in Example 3 within one minute after the initiation of power supply, which is a proof of the completion of regeneration due to the burning-out of particulate matter. As shown in Table 1, the pressure difference had finally reduced to 1.2 kPa. Thus, in this example, the filter 30 could be regenerated in a simple manner without thermally isolating the same.

Table 1

	Rotational speed	Load	Additive	Supplied power	Pressure difference (before)	Pressure difference (after)
Example 1	1560 rpm	50%	present	4.4 kW	40 kPa	2.4 kPa
Example 2	1560 rpm	50%	present	3.5 kW	40 kPa	2.2 kPa
Example 3	1560 rpm	50%	present	4.5 kW	20 kPa	2.7 kPa
Example 4	1560 rpm	50%	present	4.0 kW	20 kPa	5.1 kPa
Example 5	1560 rpm	50%	present	3.5 kW	20 kPa	16.9 kPa
Example 6	800 rpm	0%	present	4.4 kW	20 kPa	1.2 kPa

[0041] As apparent from the above description, according to a method of the present invention for electrically regenerating a filter for capturing particulate matter in exhaust gas, it is possible to easily regenerate the filter in a simple manner wherein the particulate matter captured in the filter is burnt without thermally isolating the filter in an exhaust pipe. Also, it is possible to quickly burn the particulate matter by an electric heater element in such a condition that the exhaust gas is continuously directed through the filter. In this case, it is possible to eliminate a bypass pipe and/or a switching mechanism in an exhaust system and, therefore, to simplify the structure of the exhaust emission control device.

Claims

1. A method for regenerating a filter used for capturing particulate matter contained in exhaust gas by heat of an electric heater element, comprising:

   lowering an ignition temperature of the particulate matter by an additive agent; and
   supplying electric power of at least 2 kW for 10 to 80 seconds to the electric heater element to quickly burn the particulate matter having a lowered ignition temperature and captured in the filter, while continuously passing the exhaust gas through the filter.

2. The method as set forth in claim 1, wherein the electric heater element is supplied with the electric power of 15 kW or less.

3. The method as set forth in claim 1, wherein said lowering step comprises adding the additive agent to fuel, intake gases or exhaust gases of a vehicle containing the filter body.

4. The method as set forth in claim 1, wherein the electric power is supplied to the heater element after the pressure difference between upstream and downstream sides of the filter body is high enough to cause deterioration of the filter structure.

5. The method as set forth in claim 1, wherein the electric power is supplied to the heater element after the pressure difference between upstream and downstream sides of the filter body reaches 40 kPa due to the particulate matter accumulated in the filter.

6. An exhaust emission control device comprising:

a filter disposed in an exhaust pipe to capture particulate matter contained in exhaust gas;
an electric heater element for heating the filter; and
a mechanism for adding an additive agent into fuel, suction gas or exhaust gas to lower an ignition temperature of the particulate matter,
wherein said electric heater element quickly burns said particulate matter having a lowered ignition temperature and captured in said filter, under an electric power supply of at least 2 kW for 10 to 80 seconds.

7. The device as set forth in claim 6, wherein said filter body is wound around said heater element.

8. The device as set forth in claim 6, wherein said heater element extends into said filter body.

9. The device as set forth in claim 6, wherein said heater element is supplied with about 15 kW or less of electric power.

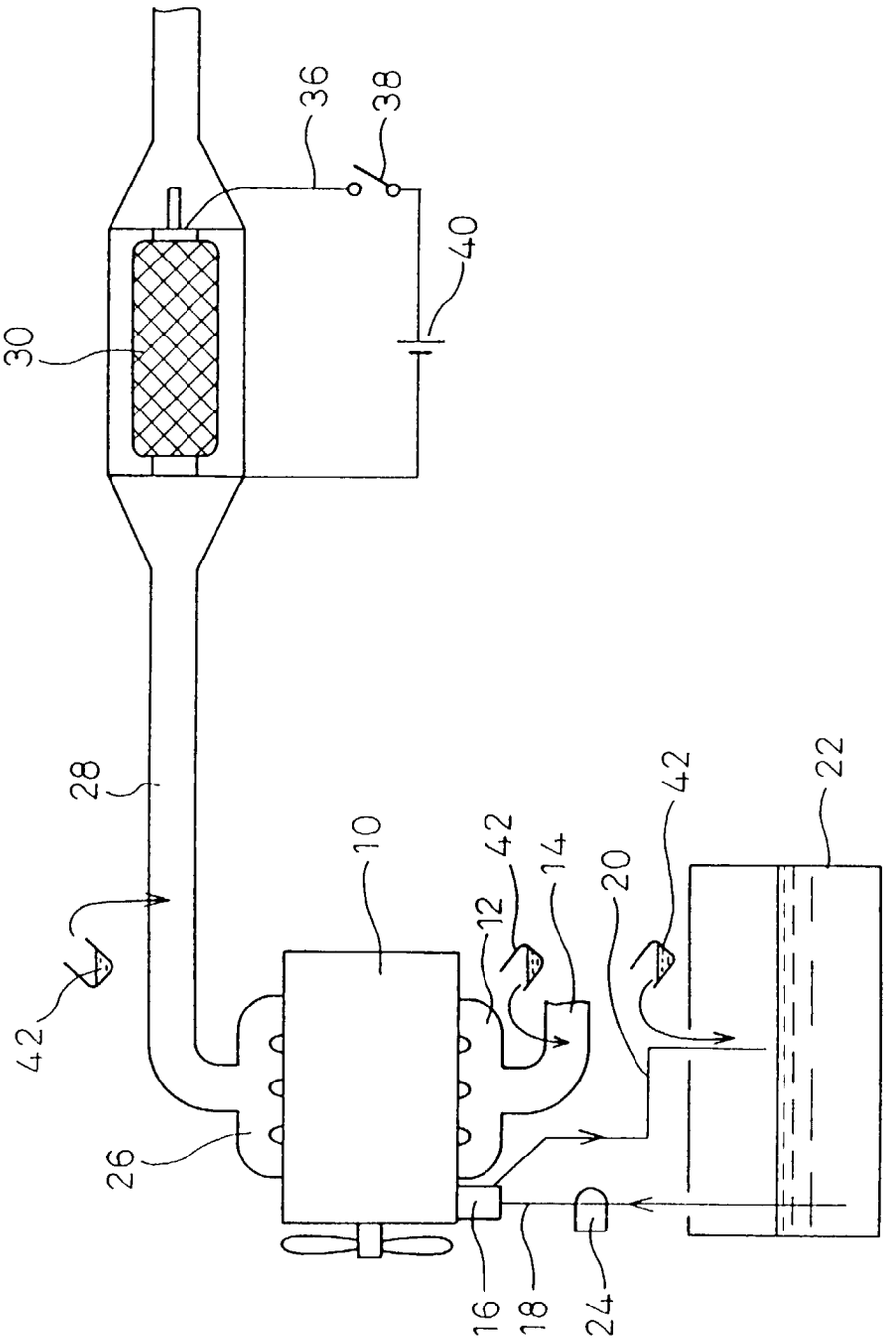


Fig. 1

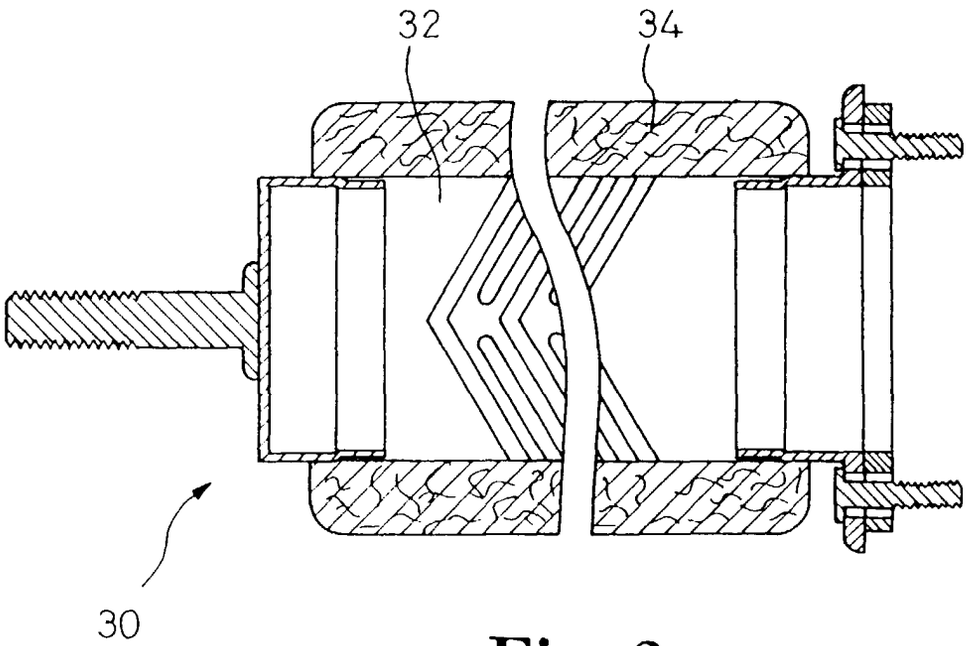
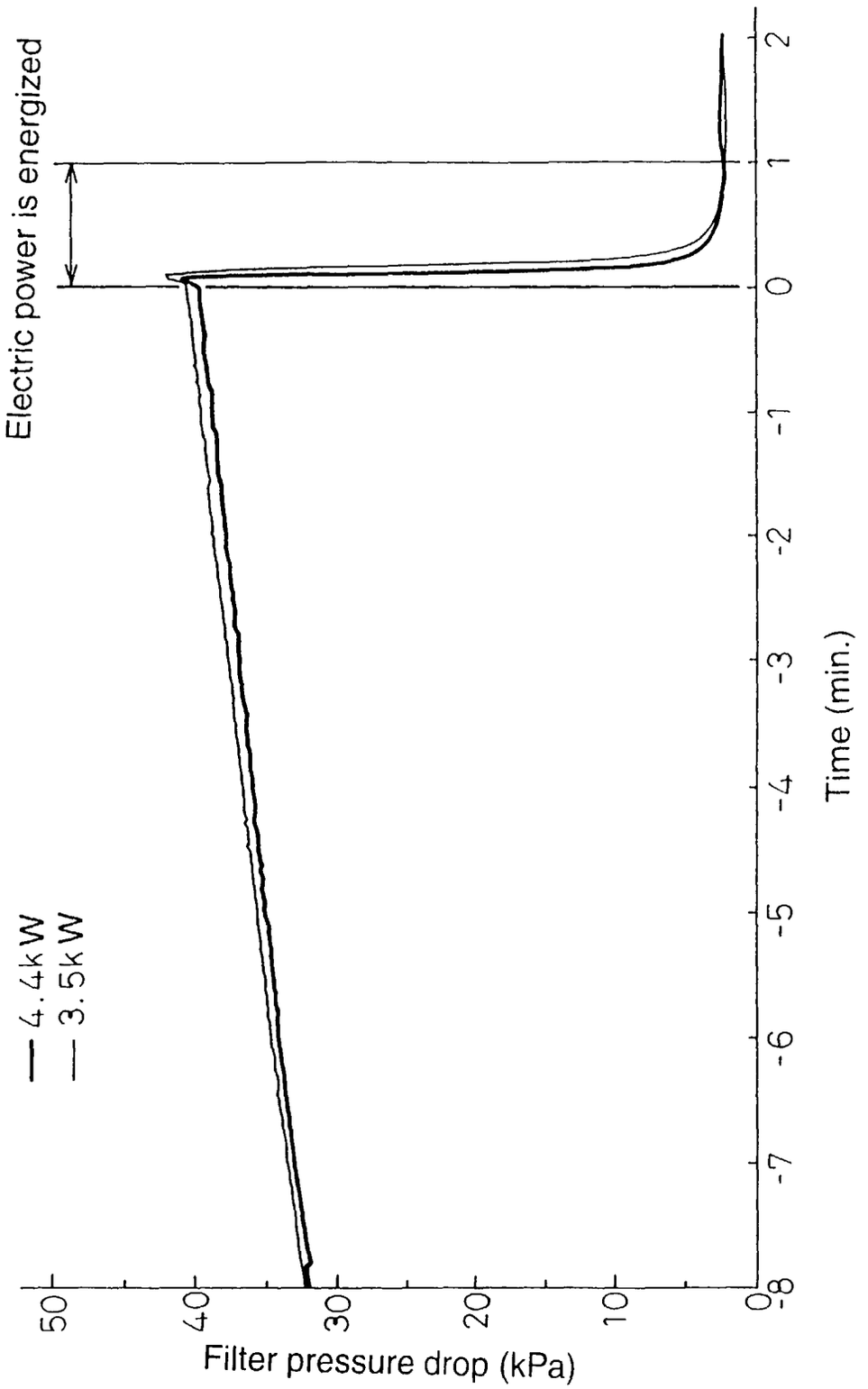


Fig. 2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4.4kW
3.5kW
Filter pressure drop (kPa)
Time (min.)
50
40
30
20
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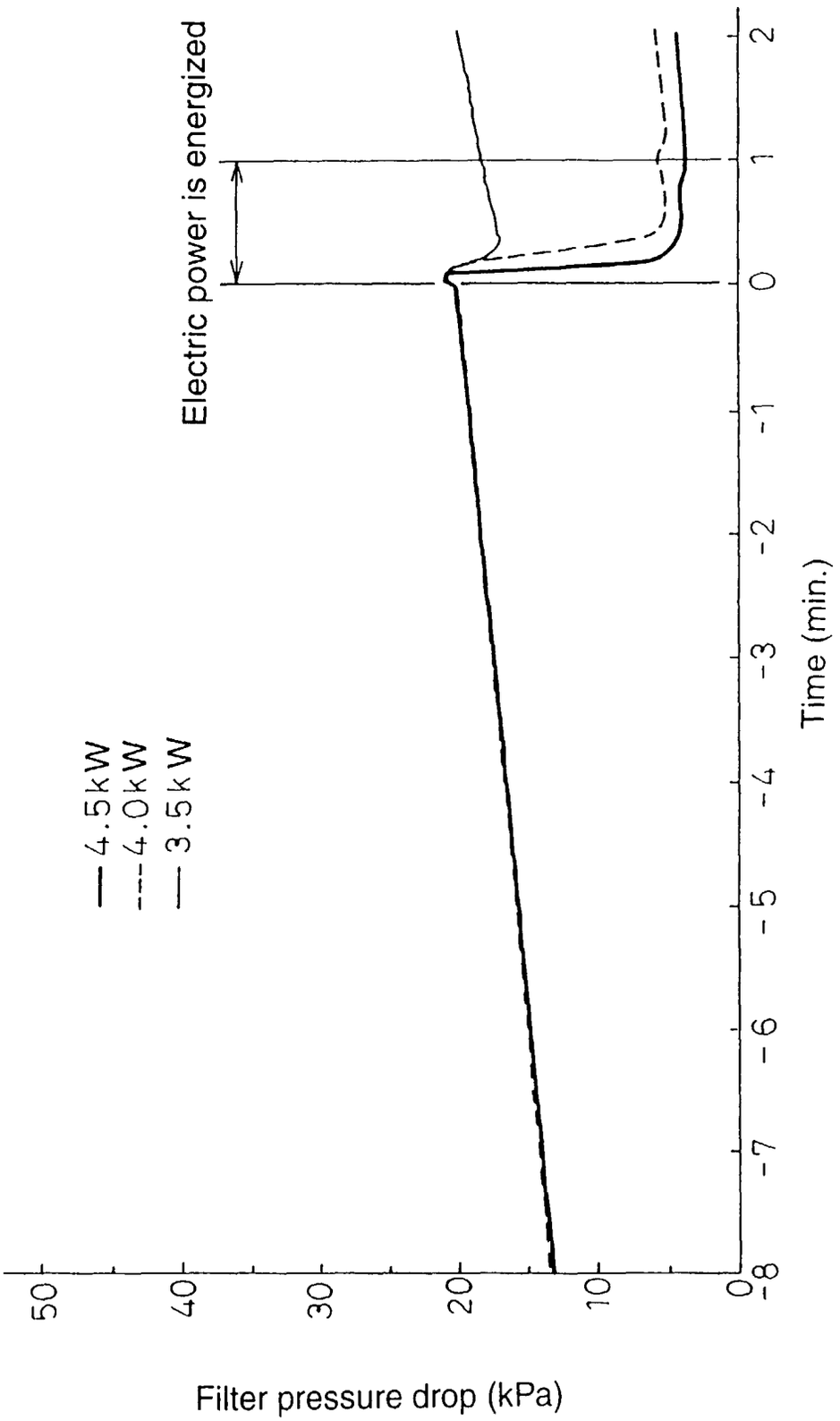
0
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8

Fig. 3


Electric power is energized
4.5kW
4.0kW
3.5kW
Time (min.)
Filter pressure drop (kPa)
50
40
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20
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-7
-6
-5
-4
-3
-2
-1
0
1
2

Fig. 4

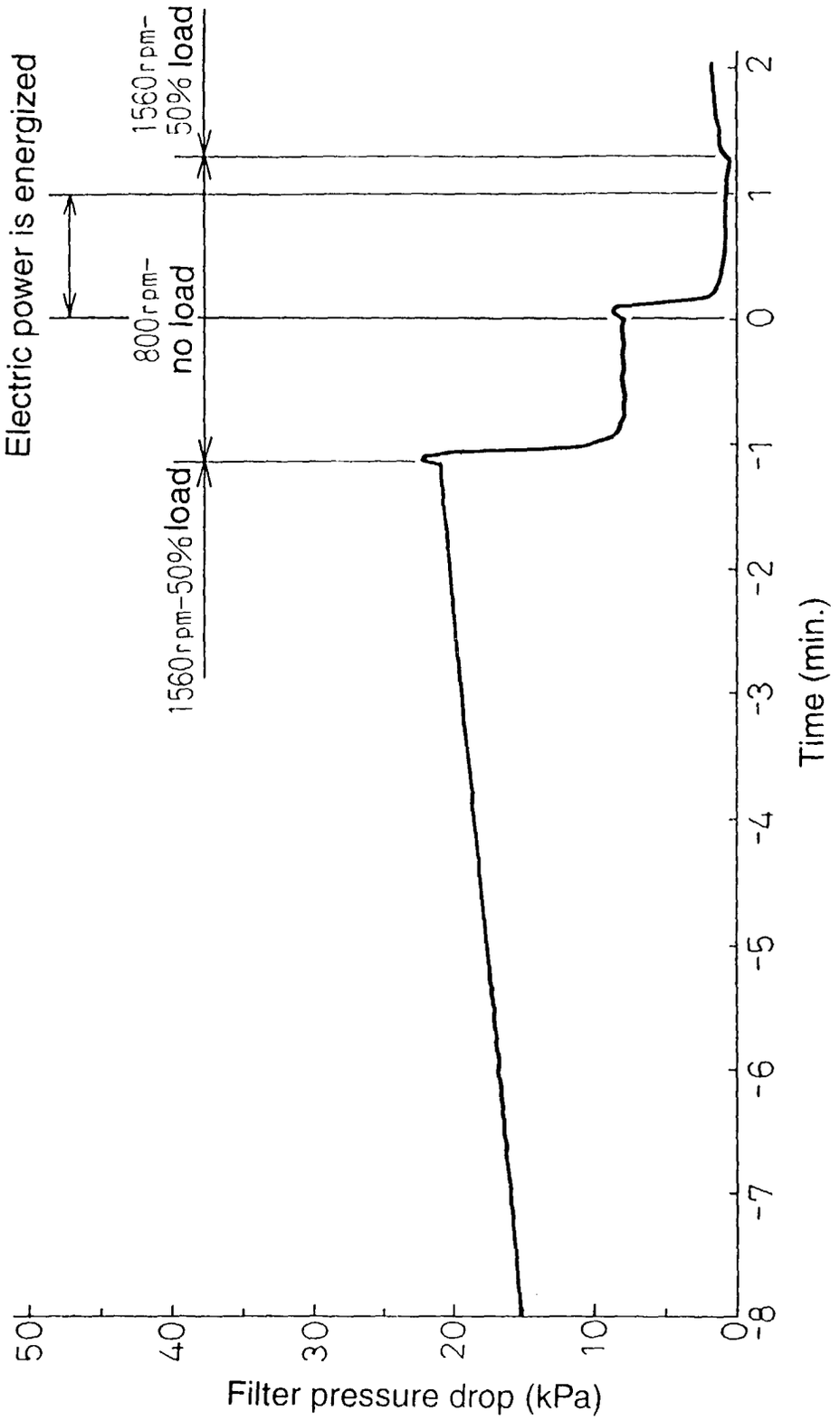
Electric power is energized
1560rpm-50% load
800rpm-no load
1560rpm-50%load
Filter pressure drop (kPa)
Time (min.)
50
40
30
20
10
0
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2

Fig. 5