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(54) ELECTRIC DUST COLLECTOR

(57) An electrostatic precipitator includes a charging portion including two charging electrodes opposite to each other, the charging portion being configured to charge a particulate matter in a gas passing between the two charging electrodes by applying a first voltage between the two charging electrodes to generate a corona discharge; and a collection portion including two collection electrodes opposite to each other, the collection portion being configured to collect by a Coulomb force the particulate matter charged by the charging portion by applying a second voltage between the two collection electrodes. One collection electrode of the two collection electrodes surrounds a hollow space, and an opening to open the hollow space is formed in a part of the one collection electrode facing the other collection electrode.

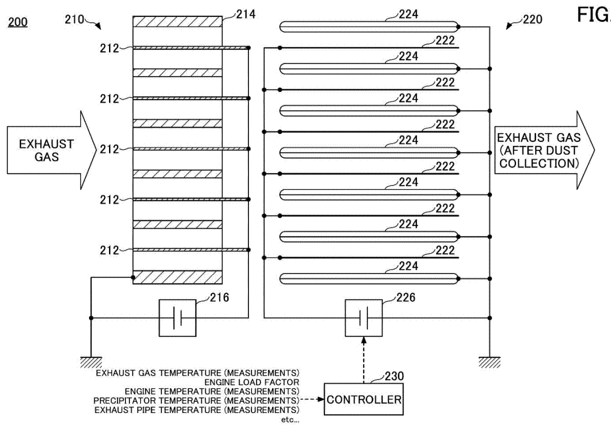

FIG.2

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to an electrostatic precipitator.

BACKGROUND ART

[0002] For example, an electrostatic precipitator having a charging portion for charging a particulate matter (PM) contained in a gas; and a precipitation portion (collection portion) disposed adjacent to a downstream side of the charging portion in which charged particulate matter is collected by a Coulomb force has been known (see Patent Document 1).

CITATION LIST

PATENT LITERATURE

[0003] Patent Document 1: Japanese Unexamined Patent Application Publication No. 2018-126714

SUMMARY OF INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0004] However, in Patent Document 1, an electrode of the collection portion for applying an electric field to the charged particulate matter has a flat shape. Therefore, depending on a speed of a flow of the gas, the particulate matter collected on a surface thereof may rescatter.

[0005] Therefore, the present disclosure aims at providing a technology capable of more efficiently collecting a particulate matter in view of the above-described problem.

MEANS FOR SOLVING PROBLEM

[0006] In order to accomplish the above-described purpose, according to an aspect of the present disclosure,

> an electrostatic precipitator including
> a charging portion including two charging electrodes opposite to each other, the charging portion being configured to charge a particulate matter in a gas passing between the two charging electrodes by applying a first voltage between the two charging electrodes to generate a corona discharge; and
> a collection portion including two collection electrodes opposite to each other, the collection portion being configured to collect by a Coulomb force the particulate matter charged by the charging portion by applying a second voltage between the two collection electrodes,
> one collection electrode of the two collection electrodes surrounding a hollow space, and an opening to open the hollow space being formed in a part of the one collection electrode facing the other collection electrode,
> is provided.

EFFECTS OF THE INVENTION

[0007] In accordance with the above-described embodiments, particulate matter can be collected more efficiently.

BRIEF DESCRIPTION OF DRAWINGS

[0008]

> [FIGURE 1] FIG. 1 is a diagram depicting an example of an exhaust gas purification system including an electrostatic precipitator.
> [FIGURE 2] FIG. 2 is a diagram depicting an example of the electrostatic precipitator.
> [FIGURE 3] FIG. 3 is a diagram depicting an example of a structure of a charging electrode.
> [FIGURE 4] FIG. 4 is a diagram depicting an example of a structure of a collection electrode.
> [FIGURE 5] FIG. 5 is a diagram depicting another example of the structure of the collection electrode.
> [FIGURE 6] FIG. 6 is a diagram illustrating a method of controlling a voltage applied to the collection portion.

MODE FOR CARRYING OUT THE INVENTION

[0009] Hereinafter, embodiments will be described with reference to the drawings.

[Summary of exhaust gas purification system]

[0010] First, an exhaust gas purification system 1 including an electrostatic precipitator 200 according to the present embodiment will be described with reference to FIG. 1.

[0011] FIG. 1 is a diagram illustrating an example of the exhaust gas purification system 1 including the electrostatic precipitator 200 according to the present embodiment.

[0012] The exhaust gas purification system 1 is loaded in a ship. Hereinafter, "ship" means, unless otherwise specified, a ship in which an electrostatic precipitator 200 is loaded.

[0013] As shown in FIG. 1, the exhaust gas purification system 1 includes a main engine 100, the electrostatic precipitator 200, a scrubber 300, and a pump 400. The exhaust gas purification system 1 purifies an exhaust gas emitted from the main engine 100 and discharges an exhaust gas from a chimney of the ship to the outside.

[0014] The main engine 100 (an example of an engine) rotates a propeller to propel the ship. The main engine is, for example, a diesel engine capable of using heavy oil C as a fuel.

[0015] The electrostatic precipitator 200 collects particulate matter (PM) contained in the exhaust gas (an example of gas) of the main engine 100. Exhaust gas collected by the electrostatic precipitator 200 (particulate matter is removed) is fed to the scrubber 300.

[0016] The scrubber 300 sprays seawater supplied through the pump 400 into the exhaust gas of the main engine 100 passing therethrough to absorb sulfur oxide (SOx) contained in the main engine 100 into the seawater. The seawater supplied to the scrubber 300 may be seawater that is constantly pumped out of the sea using an open loop system or seawater that is neutralized and circulated (reused) in a neutralization tank using a closed loop system. The exhaust gas from the scrubber 300 from which SOx components have been removed is released into the atmosphere outside the ship through the chimney of the ship. Seawater that absorbs the SOx components of the exhaust gas discharged from the scrubber 300 is discharged into the sea outside the ship using the open loop system or is returned to the neutralization tank using the closed loop system for reuse.

[0017] The pump 400 pumps seawater into the scrubber 300 from the sea or from the neutralization tank.

[0018] Thus, the exhaust gas purification system 1 can purify the exhaust gas of the main engine 100 using the electrostatic precipitator 200 and the scrubber 300.

[Example of an electrostatic precipitator]

[0019] Next, an example of the electrostatic precipitator 200 will be described with reference to FIGS. 2 to 6.

<Configuration of electrostatic precipitator>

[0020] FIG. 2 is a diagram illustrating an example of an electrostatic precipitator 200 in accordance with the present embodiment. FIG. 3 is a diagram showing an example of the structure of a charging portion 210 (charging electrodes 212 and 214). Specifically, FIG. 3 is a front view of the charging electrodes 212 and 214 viewed along the direction of a flow. FIGS. 4 and 5 show an example of the structure of a collection portion 220 (collection electrodes 222 and 224). Specifically, FIG. 4 is a longitudinal cross-sectional view of the collection electrodes 222 and 224 having the direction of a flow of the exhaust gas as a reference. FIG. 4 is a diagram depicting the collection electrode 224 viewed from the collection electrode 222 opposite to the collection electrode 224.

[0021] As shown in FIG. 2, the electrostatic precipitator 200 includes the charging portion 210, the collection portion 220, and a controller 230.

[0022] The charging portion 210 includes the charging electrodes 212 and 214 and a DC power supply 216.

[0023] The charging electrodes 212 and 214 are arranged opposite to each other, and generate a corona discharge therebetween according to a voltage applied by the DC power supply 216. This allows the particulate matter passing through the charging portion 210 to be electrified (charged). The charging electrodes 212 and 214 may be formed of an electrically conductive material such as stainless steel, tungsten, titanium, or carbon material. Hereinafter, the same may apply to the collection electrodes 222 and 224 described later.

[0024] The DC power supply 216 (an example of the first power supply) applies a voltage to generate a corona discharge between the charging electrodes 212 and 214. Specifically, the positive electrode of the DC power supply 216 is connected to the charging electrode 214 and grounded, and the negative electrode of the DC power supply 216 is connected to the charging electrode 212. Thus, a negative voltage is applied between the charging electrodes 212 and 214 such that the charging electrode 214 is set to the reference potential (ground potential) and the charging electrode 212 is set to a negative high potential. Then, a corona discharge is generated from the charging electrode 212, and thereby the particulate matter of the exhaust gas passing between the charging electrodes 212 and 214 is negatively charged.

[0025] The negative electrode of DC power supply 216 may be, on the other hand, connected to the charging electrode 214 and grounded, and the positive electrode of the DC power supply 216 may be connected to the charging electrode 212. In this case, a positive voltage is applied between the charging electrodes 212 and 214 such that the charging electrode 214 is set to the reference potential and the charging electrode 212 is set to a positive high potential. Then, a corona discharge is generated from the charging electrode 212, and thereby the particulate matter of the exhaust gas passing between the charging electrodes 212 and 214 is positively charged.

[0026] The charging electrodes 212 and 214 may be configured as a pair of a discharging electrode and a counter electrode of a cylindrical coaxial system (hereinafter, referred to as a "cylindrical coaxial electrode pair"), for example, as shown in FIGS. 2 and 3. Specifically, the charging electrode 214 as the counter electrode may have a substantially cylindrical inner peripheral surface extending along the direction of the flow of the exhaust gas, and the charging electrode 212 as the discharge electrode may have an elongated shape so as to extend along the central axis of the inner peripheral surface of the charging electrode 214. The term "substantially" is intended, for example, to allow manufacturing errors, and will be used hereinafter in the same sense. Thus, a distance (gap length) between the charging electrode 214 of the reference potential side and the charging electrode 212 of the high voltage side is substantially uniform at any position. Therefore, it is possible to avoid transition to a spark discharge and form a stable corona discharge. The charging electrode 212 and the charging electrode 214 (inner peripheral surface) are provided to extend in the direction of the flow of the exhaust gas, so that a pressure loss in the charging portion 210 can be reduced.

[0027] Also, as shown in FIG. 3, the charging electrode 214 has a plurality of substantially cylindrical inner peripheral surfaces arranged in parallel with respect to the direction of the flow of the exhaust gas, each having a corresponding charging electrode 212 interposed therein, so that a plurality of cylindrical coaxial electrode pairs are configured. Thus, the stable corona discharge is realized, and a flow area of the exhaust gas is secured while a dimension in the flow direction of the exhaust gas of the charging portion 210 is maintained, so that the pressure loss can be further reduced and the flow rate of the exhaust gas can be made relatively larger.

[0028] The collection portion 220 is disposed adjacent to the charging portion 210 on the downstream side of the flow of the exhaust gas. The collection portion 220 includes the collection electrodes 222 and 224, and a DC power supply 226.

[0029] The collection electrodes 222 and 224 are arranged opposite to each other, and a voltage is applied therebetween by the DC power supply 226 to exert a Coulomb force on the particulate matter in the exhaust gas charged by the charging portion 210 and collect the particulate matter onto the collection electrode 224.

[0030] The DC power supply 226 (an example of a second power supply) applies a voltage between the collection electrodes 222 and 224, to generate an electric field between the collection electrodes 222 and 224. The DC power supply 226 is provided separately from the DC power supply 216 which applies a voltage to the charging portion 210 (charging electrodes 212 and 214). Thus, the DC power supply 226 can vary the voltage applied to the collection portion 220 (collection electrodes 222 and 224) independently of the voltage applied to the charging portion 210. Specifically, the positive electrode of the DC power supply 226 is connected to the collection electrode 224 and grounded, and the negative electrode of the DC power supply 226 is connected to the collection electrode 222. Thus, a negative voltage is applied between the collection electrodes 222 and 224 such that the collection electrode 224 is set to the reference potential (ground potential) and the collection electrode 222 is set to a negative high potential. Therefore, when the particulate matter negatively charged in the charging portion 210 enters between the collection electrodes 222 and 224, a Coulomb force drawn into the collection electrode 224 having the reference potential acts on the particulate matter, and the particulate matter is collected into the collection electrode 224.

[0031] The positive electrode of the DC power supply 226 may be connected to the collection electrode 224, and the negative electrode thereof may be connected to the collection electrode 222 and grounded. Thus, a positive voltage is applied between the collection electrodes 222 and 224 such that the collection electrode 222 is set to the reference potential (ground potential) and the collection electrode 224 is set to a positive high potential. Therefore, when the particulate matter negatively charged in the charging portion 210 enters between the collection electrodes 222 and 224, a Coulomb force drawn into the collection electrode 224 having the positive high potential acts on the particulate matter, and the particulate matter is collected into the collection electrode 224. That is, when the particulate matter is negatively charged by the charging portion 210, the DC power supply 226 may apply a voltage between the collection electrodes 222 and 224 such that an electric field from the collection electrode 224 to the collection electrode 222 is applied. As described above, if the particulate matter is positively charged by the charging portion 210, the DC power supply 226 may apply a voltage between the collection electrodes 222 and 224 such that an electric field from the collection electrode 222 to the collection electrode 224 is applied. Thus, when the particulate matter positively charged in the charging portion 210 enters between the collection electrodes 222 and 224, a Coulomb force acts on the particulate matter in the direction of the electric field, and the particulate matter is collected into the collection electrode 224. Specifically, if the particulate matter is positively charged by the charging portion 210, the positive electrode of the DC power supply 226 may be connected to the collection electrode 222, the negative electrode of the DC power supply 226 may be connected to the collection electrode 224, and either of them may be grounded.

[0032] The collection electrode 222 may have a shape of a flat plate extending along the direction of the flow of the exhaust gas, for example, as shown in FIGS. 2 and 4.

[0033] The collection electrode 224 is configured to enclose a hollow space (in other words, have a shape of a hollow box) as shown in FIGS. 2, 4, and 5, for example, and a through-hole 224B for opening the hollow space is provided in a part facing the collection electrode 222. Specifically, the collection electrode 224 includes a main body portion 224A, the through-hole 224B, and a partition plate 224C. Further, both end portions of the collection electrode 224 in the depth direction of FIG. 4 are closed by a flat plate or the like.

[0034] The main body portion 224A includes two flat plate portions 224A1 opposite to the two collection electrodes 222, respectively, and curved surface portions 224A2 at the both end portions connecting the two flat plate portions 224A1. Thus, the hollow space surrounded by the two flat plate portions 224A1 and the curved surface portions 224A2 at the both ends thereof is formed.

[0035] The through-hole 224B (an example of an opening) is provided in the flat plate portion 224A1 in a manner of penetrating the flat plate portion 224A1. Specifically, as illustrated in FIGS. 4 and 5, a lot of through-holes 224B are provided in a manner of occupying a very small area with respect to the area of the flat plate portion 224A1. Thus, the through-holes 224B open the hollow space inside the main body portion 224A to communicate the space between the collection electrodes 222 and 224 with the space inside the collection electrode 224 (main body portion 224A). Therefore, the particulate matter in the exhaust gas that is drawn into the collection electrode 224 by a Coulomb force can be housed in the hollow space inside the collection electrode 224 (main body portion 224A). Therefore, it is possible to suppress re-scattering of the particulate matter collected by the collection electrode 224. In particular, since the exhaust gas discharged from the main engine 100 of a ship has a relatively high flow rate, for example, the probability of re-scattering is relatively high in the case where the collection electrode has a shape of flat plate. On the other hand, the collection electrode 224 can suppress the re-scattering of the collected particulate matter even when the flow rate is relatively high, as is the case for the exhaust gas of the main engine 100 of the ship.

[0036] The partition plate 224C is configured to partition the hollow space inside the main body portion 224A into a space on one side of the flat plate portion 224A1 and a space on the other side of the flat plate portion 224A1. Thus, the particulate matter flowing into the hollow space inside the main body portion 224A from the through-hole 224B of both flat plate portions 224A1 can be collected in a manner of adhering to both surfaces of the partition plate 224C. Therefore, in the hollow space where the flow speed is relatively lower than that of the main stream of exhaust gas, the particulate matter can be stably collected by fixing the particulate matter.

[0037] Thus, in the example of the present disclosure, a functional portion (charging portion 210) for charging the particulate matter of the exhaust gas and a functional portion for collecting the particulate matter are separated in the direction of the flow of the exhaust gas, and a pair of electrodes (charging electrodes 212 and 214 and collection electrodes 222 and 224) are provided for each functional portion.

[0038] For example, the function of the charging portion 210 and the function of the collection portion 220 may be integrated by arranging a discharging electrode, which generates a corona discharge, and the collection electrode, which collects the particulate matter charged by the corona discharge, opposite to each other, and applying a voltage between the discharging electrode and the collection electrode. However, in this case, the particulate matter charged by the discharge is likely to be concentrated on the downstream side of the flow of the exhaust gas at the collection electrode, which is actually collected, because the particulate matter moves in the flow of the exhaust gas. Therefore, the upstream portion of the flow of the exhaust gas in the collection electrode may not perform the function of collecting the particulate matter and the discharge electrode may become unnecessarily long up to the downstream side of the flow of the exhaust gas due to the necessity of matching the length of the collection electrode. In particular, since the flow speed of the exhaust gas of the main engine 100 of the ship is relatively high (large), the length (size) of the collection electrode and the discharge electrode may be excessive. Therefore, the size of the electrostatic precipitator 200 may become larger.

[0039] In contrast, in the example of the present disclosure, the function of charging the particulate matter of the exhaust gas and the function of collecting the charged particulate matter are separated in the direction of the flow of the exhaust gas, and the sizes can be optimized for their function, respectively. Therefore, it is possible to reduce the size of the electrostatic precipitator 200. In particular, it is suitable for the case where there is a limited space for the arrangement of the electrostatic precipitator 200, such as a ship.

[0040] The controller 230 controls the DC power supply 226. The controller 230 is implemented as a function of any hardware or any combination of hardware and software. For example, the controller 230 is configured mainly by a computer including a memory device such as a CPU (Central Processing Unit), a RAM (Random Access Memory), a non-volatile auxiliary storage device such as a ROM (Read Only Memory), an input/output (I/O) interface device, and the like.

[0041] Various signals used for controlling the DC power supply 226 are input to the controller 230. For example, a signal corresponding to a measured value of a temperature (exhaust gas temperature) of the exhaust gas flowing into the electrostatic precipitator 200 from a temperature sensor located near the inlet of the exhaust gas of the electrostatic precipitator 200 may be input to the controller 230. For example, a signal relating to a load factor (engine load factor) of the main engine 100 may be input to the controller 230 from another controller which controls the main engine 100. For example, the controller 230 may be input with a signal corresponding to a measured value of a temperature (engine temperature) of a predetermined portion of the main engine 100 from a temperature sensor installed in the predetermined portion of the main engine 100 (e.g., an exhaust manifold). For example, the controller 230 may be input with a signal corresponding to a measured value of a temperature (precipitator temperature) of a predetermined portion of the electrostatic precipitator 200 from a temperature sensor installed in the predetermined portion of the electrostatic precipitator 200 (e.g., a housing of the electrostatic precipitator 200A). For example, the controller 230 may be input with a signal corresponding to a measured value of a temperature of an exhaust pipe (exhaust pipe temperature) from a temperature sensor installed in the exhaust pipe between the main engine 100 and the electrostatic precipitator 200.

<Control method of electrostatic precipitator>

[0042] FIG. 6 is a diagram illustrating a method of controlling the voltage applied to the collection portion 220 (collection electrodes 222 and 224). Specifically, FIG. 6 includes a graph 610 showing a relationship between the temperature of the gas (in the present embodiment, the exhaust gas) to be precipitated and the resistivity of the particulate matter (PM), and a graph 620 showing a relationship between the temperature of the gas (exhaust gas) to be precipitated and the voltage applied to the collection portion 220.

[0043] As shown in the graph 610, the resistivity (i.e., conductivity) of the particulate matter varies according to the temperature state of the exhaust gas.

[0044] The particulate matter acts as a dielectric when the resistivity increases and the insulation becomes relatively high, and dielectric polarization can occur in the particulate matter collected and deposited on the collection electrode 224. Thus, a particulate matter with a relatively high resistivity may have a potential difference of a polarity opposite to the potential difference of the collection portion 220 due to the dielectric polarization. Particularly, when the deposited layer of particulate matter is relatively thick, the potential difference is also relatively large, and as a result, a back discharge occurs and the particulate matter may scatter.

[0045] Specifically, it has been found that when the resistivity of the particulate matter increases to about 10^{11} [Ωcm], a back discharge is likely to occur. Therefore, as shown in the graph 610, when the temperature of the particulate matter, i.e., the temperature of the exhaust gas, is in the range from about 100°C to about 200°C, and the resistivity of the particulate matter is greater than or equal to 10^{11} [Ωcm], the back discharge is likely to occur.

[0046] In contrast, in the example of the present disclosure, the controller 230 controls the DC power supply 226 to make the voltage applied to the collection portion 220 relatively large (high) when the resistivity of the particulate matter is relatively low (i.e., a relatively high conductivity) and the possibility of the occurrence of the back discharge is relatively low. On the other hand, the controller 230 makes the voltage applied to the collection portion 220 relatively small (low) when the resistivity of the particulate matter is relatively high (i.e., a relatively low conductivity) and the possibility of the occurrence of the back discharge is relatively high. Thus, the controller 230 can suppress the re-scattering of the particulate matter due to the back discharge under the assumption that a relatively high electric field is applied to collect the particulate matter.

[0047] For example, as shown in the graph 620, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to the temperature states of the exhaust gas flowing into the electrostatic precipitator 200. Specifically, the controller 230 may control the DC power supply 226 by setting the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_H which is relatively high, when the temperature of the exhaust gas flowing into the electrostatic precipitator 200 is lower than 100°C or higher than 200°C. On the other hand, the controller 230 may control the DC power supply 226 by setting the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_L which is relatively low, when the temperature of the exhaust gas flowing into the electrostatic precipitator 200 is in a range of from 100°C to 200°C inclusive. Thus, the controller 230 makes relatively lower the voltage applied between the collection electrodes 222 and 224 in the temperature range of the exhaust gas in which the back discharge is likely to occur, thereby suppressing the re-scattering of the collected particulate matter.

[0048] The temperature state of the exhaust gas flowing into the electrostatic precipitator 200 is measured by the temperature sensor positioned near the inlet of the electrostatic precipitator 200, for example, as described above, and a signal corresponding to the measured value may be input to the controller 230. The controller 230 may also estimate the temperature of the exhaust gas flowing into the electrostatic precipitator 200 based on, for example, the temperature (measurement) of the exhaust gas measured by a temperature sensor installed further upstream from the inlet of the electrostatic precipitator 200. The controller 230 may also estimate the temperature of the exhaust gas flowing into the electrostatic precipitator 200 from other information as described below.

[0049] For example, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to the state of the main engine 100 (an example of a supply source of gas) associated with the temperature of the exhaust gas.

[0050] The controller 230 may, for example, switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to the load state (e.g., engine load factor) of the main engine 100. This is because, as shown in FIG. 6, when the load of the main engine 100 is relatively small, the temperature of the exhaust gas decreases, and when the load of the main engine 100 is relatively high, the temperature of the exhaust gas becomes relatively high.

[0051] Specifically, when the load factor of the main engine 100 is lower than a predetermined value LF1 or higher than a predetermined value LF2 (>LF1), the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_H. Meanwhile, when the load factor of the main engine 100 is in a range of from the predetermined value LF1 to the predetermined value LF2 inclusive, the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_L. The predetermined values LF1 and LF2 correspond to the load factors of the main engine 100 when the temperature of the exhaust gas flowing into the electrostatic precipitator 200 is 100°C and 200°C, respectively.

[0052] The load factor information of the main engine 100 may be obtained from the other controller controlling the main engine 100 as described above. Further, data on an operation status of the main engine 100 may be acquired from the other controller by the controller 230, and the controller 230 may calculate the load factor of the main engine 100 from the data on the acquired operation status.

[0053] The controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to, for example, the temperature state of the predetermined portion of the main engine 100. This is because when the temperature of the exhaust gas of the main engine 100 is relatively low, the temperature of the main engine 100 itself is relatively low, and when the temperature of the exhaust gas of the main engine 100 is relatively high, the temperature of the main engine 100 itself is relatively high.

[0054] Specifically, when the temperature of the predetermined portion of the main engine 100 is lower than a predetermined value ET1 or higher than a predetermined value ET2 (>ET1), the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_H. Meanwhile, the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_L when the temperature of the predetermined portion of the main engine 100 is in a range of from the predetermined value ET1 to the predetermined value ET2 inclusive. The predetermined values ET1 and ET2 correspond to the temperatures at the predetermined portion of the main engine 100 when the temperature of the exhaust gas flowing into the electrostatic precipitator 200 is 100°C and 200°C, respectively.

[0055] The temperature of the predetermined portion of the main engine 100 is measured by the temperature sensor installed in the main engine 100 as described above, and a signal corresponding to the measured value may be input to the controller 230.

[0056] The controller 230 may estimate the temperature of the exhaust gas flowing into the electrostatic precipitator 200 based on the load factor of the main engine 100, the temperature state of the predetermined portion, or the like. The controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 in the same manner as described above according to the estimated value of the temperature of the exhaust gas flowing into the electrostatic precipitator 200.

[0057] For example, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to the temperature (exhaust pipe temperature) of a predetermined portion of the exhaust pipe (an example of a gas supply path) between the main engine 100 and the electrostatic precipitator 200. The controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 according to the temperature (precipitator temperature) of a predetermined portion of the electrostatic precipitator 200. This is because when the temperature of the exhaust gas of the main engine 100 is relatively low, the temperature of the exhaust pipe and the electrostatic precipitator 200 is relatively low, and when the temperature of the exhaust gas of the main engine 100 is relatively high, the temperature of the exhaust pipe and the electrostatic precipitator 200 is relatively high.

[0058] Specifically, when the exhaust pipe temperature is lower than a predetermined value XT1 or higher than a predetermined value XT2 (>XT1), the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_H. Meanwhile, the controller 230 may set the voltage applied between the collection electrodes 222 and 224 to a predetermined value Va_L when the exhaust pipe temperature is within a range of from the predetermined value XT1 to a predetermined value XT2 inclusive. The predetermined values XT1 and XT2 correspond to the exhaust pipe temperatures when the temperature of the exhaust gas flowing into the electrostatic precipitator 200 is 100°C and 200°C, respectively. The same method may be employed when controlled according to the precipitator temperature.

[0059] The controller 230 may estimate the temperature of the exhaust gas flowing into the electrostatic precipitator 200 based on the temperature of the exhaust pipe, the precipitator temperature, or the like. The controller 230 may switch the voltage applied between the collection electrodes 222 and 224 of the collection portion 220 in the same manner as described above according to the estimated value of the temperature of the exhaust gas flowing into the electrostatic precipitator 200.

[Other example of electrostatic precipitator]

[0060] Next, another example of the electrostatic precipitator will be described.

[0061] The above-described example of the electrostatic precipitator 200 may be changed or modified as appropriate.

[0062] For example, in the above-described example of the electrostatic precipitator 200, a single through-hole 224B of the collection electrode 224 may be provided in the flat plate portion 224A1 facing the collection electrode 222.

[0063] Also, for example, in the above-described example of the electrostatic precipitator 200, the lower limit of the temperature range of the exhaust gas which makes the voltage applied between the collection electrodes 222 and 224 relatively low may be set within a predetermined range before and after 100°C instead of at 100°C. This predetermined range may, for example, exceed or be less than 100°C by 10°C, i.e., in the range of from 90°C to 110°C. Similarly, in the above-described example of the electrostatic precipitator 200, the upper limit of the temperature range of the exhaust gas which makes the voltage applied between the collection electrodes 222 and 224 relatively low may be set within a predetermined range before and after 200°C instead of at 200°C. This predetermined range may, for example, exceed or less than 200°C by 10°C, i.e., the range of from 190°C to 210°C.

[0064] For example, in the above-described example of the electrostatic precipitator 200, the boundary value of the temperature of the exhaust gas for switching the voltage applied between the collection electrodes 222 and 224 from the relatively high state to the relatively low state may be different from the boundary value for switching from the relatively low state to the relatively high state. For example, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 from the relatively high state to the relatively low state when the temperature of the exhaust gas becomes 100°C or higher from a state of lower than 100°C. Meanwhile, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 from the relatively low state to the high state when the temperature of the exhaust gas becomes lower than a predetermined temperature, which is lower than 100°C (for example, 95°C), from a state of the predetermined temperature or higher. Similarly, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 from a relatively high state to a relatively low state when the temperature of the exhaust gas becomes 200°C or lower from a state of higher than 200°C. Meanwhile, the controller 230 may switch the voltage applied between the collection electrodes 222 and 224 from a relatively low state to a relatively high state when the temperature of the exhaust gas becomes higher than a predetermined temperature, which is higher than 200°C (for example, 205°C), from a state of the predetermined temperature or lower. Thus, it is possible to suppress an occurrence of a state in which the voltage applied between the collection electrodes 222 and 224 is switched at a relatively high frequency.

[0065] Also, for example, the above-described example of the electrostatic precipitator 200 may collect particulate matter from an exhaust gas emitted from an engine located at a different location from the ship.

[0066] Also, for example, the above-described example of the electrostatic precipitator 200 may collect particulate matter contained in a gas different from the engine exhaust gas.

[Operation]

[0067] Next, an operation of the electrostatic precipitator 200 according to the present embodiment will be summarized.

[0068] In the present embodiment, the electrostatic precipitator 200 includes a charging portion 210 and a collection portion 220. Specifically, the charging portion 210 includes charging electrodes 212 and 214, opposite to each other, a voltage being applied between the charging electrodes 212 and 214, and charges particulate matter in a gas (e.g., exhaust gas) passing between the charging electrodes by generating a corona discharge. The collection portion 220 includes collection electrodes 222 and 224, opposite to each other, a voltage being applied between the collection electrodes 222 and 224, and collects by a Coulomb force the particulate matter charged by the charging portion 210. Then, one collection electrode 224 of the collection electrodes 222 and 224 is configured to surround a hollow space, and a through-hole 224B for opening the hollow space is provided at a part of the collection electrode 224 facing the other collection electrode 222.

[0069] Thus, in the electrostatic precipitator 200, the function of charging particulate matter in the passing gas can be separated from the function of collecting charged particulate matter in the direction of the flow of the gas. Therefore, the size of the electrostatic precipitator 200 can be optimized for each function, thereby reducing the size of the electrostatic precipitator 200.

[0070] In addition, by causing the collection electrode 224 to attract the particulate matter charged by a Coulomb force, the particulate matter is collected in the hollow space inside the through-hole 224B of the collection electrode 224. Therefore, even when the flow speed of the gas is relatively high, it is not affected by the flow speed and re-scattering can be suppressed. Thus, particulate matter in the gas can be collected more efficiently.

[0071] In the present embodiment, a voltage may be applied between the collection electrodes 222 and 224 such that the one collection electrode 224 has the reference potential and the other collection electrode 222 has the polarity that is the same as the charging electrode 212 with the higher potential of the charging electrodes 212 and 214. A voltage may also be applied between the collection electrodes 222 and 224 so that the other collection electrode 222 has the reference potential and the polarity of the one collection electrode 224 is opposite to the charging electrode 212 with the higher potential.

[0072] Thus, the electrostatic precipitator 200 can apply an electric field between the collection electrodes 222 and 224 such that the particulate matter charged by the charging portion 210 is collected by the collection electrode 224.

[0073] In the present embodiment, the other collection electrode 222 has a flat plate shape, the one collection electrode 224 has a flat plate portion 224A1 facing the other collection electrode 222, and the flat plate portion 224A1 may be provided with a plurality of through-holes 224B for opening the hollow space.

[0074] Thus, the electrostatic precipitator 200 can collect the particulate matter charged by the charging portion 210 in the hollow space inside the collection electrode 224 through the plurality of through-holes 224B.

[0075] In the present embodiment, the charging portion 210 may also include the DC power supply 216 that applies a voltage to the charging electrodes 212 and 214. The collection portion 220 may then include the DC power supply 226, which applies a voltage to the collection electrodes 222 and 224, that is different from the DC power supply 216.

[0076] Thus, the electrostatic precipitator 200 can vary the voltage applied to the collection portion 220 independently of the voltage applied to the charging portion 210.

[0077] In the present embodiment, the electrostatic precipitator 200 (controller 230) may vary the magnitude of the voltage applied between the collection electrodes 222 and 224 according to a temperature state of a passing gas.

[0078] For example, the conductivity (resistivity) of a particulate matter varies with the temperature state of the passing gas. Then, when the conductivity decreases (i.e., the resistivity increases), the collected and deposited particulate matter may have a high inverse potential to the potential of the collection electrode 224 due to a dielectric polarization, and as a result, a back discharge may occur and the particulate matter may re-scatter.

[0079] On the other hand, the electrostatic precipitator 200 can vary the magnitude of the voltage applied to the collection portion 220 according to the temperature state of the gas that affects the conductivity of the particulate matter. Thus, for example, the electrostatic precipitator 200 can make the applied voltage relatively small to lower an electric field required for charge-up under a state where the conductivity of the particulate matter is reduced and a back discharge is highly likely to occur. Therefore, the electrostatic precipitator 200 can suppress the re-scattering of the particulate matter due to the back discharge.

[0080] In the present embodiment, the electrostatic precipitator 200 (controller 230) may vary the magnitude of the voltage applied between the collection electrodes 222 and 224 according to the state of the gas supply source associated with the temperature state of the passing gas. For example, the electrostatic precipitator 200 (controller 230) may vary the magnitude of the voltage applied between the collection electrodes 222 and 224 according to the load state of the main engine 100 or the temperature state of a predetermined portion of the main engine 100.

[0081] Thus, the electrostatic precipitator 200 can adjust the applied voltage based on the relationship between the state of the gas supply and the temperature state of the passing gas, in consideration of the conductivity of the particulate matter. Therefore, the electrostatic precipitator 200 can specifically suppress the re-scattering of the particulate matter due to the back discharge.

[0082] Also, in the present embodiment, the electrostatic precipitator 200 (controller 230) may vary the magnitude of the voltage applied between the collection electrodes 222 and 224 according to at least one of the temperature state of the supply path (e.g., exhaust pipe) of the passing gas and the temperature state of a predetermined portion of the electrostatic precipitator 200.

[0083] Accordingly, the electrostatic precipitator 200 can adjust the applied voltage, based on the relationship between the temperature state of the supply path of the gas or the predetermined portion of the electrostatic precipitator 200 and the temperature state of the passing gas, in consideration of the conductivity of the particulate matter. Therefore, the electrostatic precipitator 200 can specifically suppress the re-scattering of the particulate matter due to the back discharge.

[0084] In the present embodiment, when the temperature of the passing gas is within the predetermined temperature range, the electrostatic precipitator 200 (controller 230) makes a magnitude of voltage applied between the two collection electrodes smaller than the case where the temperature is outside the predetermined temperature range. The predetermined temperature range is, for example, a range between a lower limit specified in a predetermined range before and after 100°C and an upper limit specified in a predetermined range before and after 200°C.

[0085] Accordingly, the electrostatic precipitator 200 can specifically reduce (lower) the electric field applied between the collection electrodes 222 and 224 in the area where the back discharge is likely to occur.

[0086] Also, in the present embodiment, the charging electrode 214 having a reference potential of the two charging electrodes 212 and 214 may have a substantially cylindrical inner peripheral surface extending in the direction of the flow of the gas. The charging electrode 212 with the higher potential of the charging electrodes 212 and 214 may be disposed to extend in the direction of the flow of the gas substantially coaxially with the inner peripheral surface of the charging electrode 214.

[0087] Thus, the pressure loss of the gas passing through the charging portion 210 can be suppressed. In addition, since the distances (gap lengths) to the charging electrode 214 on the reference potential side are substantially uniform at any position of the charging electrode 214 on the high voltage side, it is possible to avoid the transition to the spark discharge and form a stable corona discharge.

[0088] As described above, the embodiments have been described in detail, disclosure of the present invention is not limited to the above-described specific embodiments, and various modifications and variations are possible within the scope of the appended claims.

[0089] Finally, the present application claims priority under Japanese Patent Application No. 2020-139592, filed August 20, 2020, the entire contents of which are incorporated herein by reference.

REFERENCE SIGNS LIST

[0090]

1	Exhaust gas purification system
100	Main engine (Engine, Gas supply source)
200	Electrostatic precipitator
210	Charging portion
212,214	Charging electrode
216	DC power supply (First power supply)
220	Collection portion
222, 224	Collection electrode
224A	Main body portion
224A1	Flat plate portion
224A2	Curved surface portion

224B	Through-hole (Opening)
224C	Partition plate
226	DC power supply (Second power supply)
230	Controller
300	Scrubber
400	Pump

Claims

1. An electrostatic precipitator comprising:

   a charging portion including two charging electrodes opposite to each other, the charging portion being configured to charge a particulate matter in a gas passing between the two charging electrodes by applying a first voltage between the two charging electrodes to generate a corona discharge; and
   a collection portion including two collection electrodes opposite to each other, the collection portion being configured to collect by a Coulomb force the particulate matter charged by the charging portion by applying a second voltage between the two collection electrodes,
   wherein one collection electrode of the two collection electrodes surrounds a hollow space, and an opening to open the hollow space is formed in a part of the one collection electrode facing the other collection electrode.

2. The electrostatic precipitator according to claim 1, wherein
   the second voltage is applied between the two collection electrodes so that the one collection electrode has a reference potential and the other collection electrode has a polarity that is same as the charging electrode with a higher potential of the two charging electrodes, or the other collection electrode has the reference potential and the one collection electrode has a polarity opposite to the charging electrode with the higher potential.

3. The electrostatic precipitator according to claim 1 or 2, wherein

   the other collection electrode has a flat shape,
   the one collection electrode has a flat plate portion facing the other collection electrode, and
   a plurality of openings to open the hollow space are formed in the flat plate portion.

4. The electrostatic precipitator according to any one of claims 1 to 3, wherein

   the charging portion includes a first power source configured to apply the first voltage between the two charging electrodes, and
   the collection portion includes a second power source different from the first power source and configured to apply the second voltage between the two collection electrodes.

5. The electrostatic precipitator according to any one of claims 1 to 4, wherein
   a magnitude of the second voltage applied between the two collection electrodes is changed according to a temperature state of the gas.

6. The electrostatic precipitator according to claim 5, wherein
   the magnitude of the second voltage applied between the two collection electrodes is changed according to a state of a supply source of the gas associated with the temperature state of the gas.

7. The electrostatic precipitator according to claim 6, wherein

   the supply source of the gas is an engine,
   the gas of the engine is exhaust gas, and
   the magnitude of the second voltage applied between the two collection electrodes is changed according to a load state of the engine or according to a temperature state of a predetermined portion of the engine.

8. The electrostatic precipitator according to claim 5, wherein
   the magnitude of the second voltage applied between the two collection electrodes is changed according to a temperature state of a supply path of the gas, a predetermined portion of the electrostatic precipitator, or both.

9. The electrostatic precipitator according to any one of claims 5 to 8, wherein
   when a temperature of the passing gas is within a predetermined temperature range, the magnitude of the second voltage applied between the two collection electrodes is made smaller than the magnitude in the case where the temperature of the passing gas is outside the predetermined temperature range.

10. The electrostatic precipitator according to claim 9, wherein
    the predetermined temperature range is a range between a lower limit which exceeds or is less than 100°C by a predetermined range and an upper limit which exceeds or is less than 200°C by a predetermined range.

11. The electrostatic precipitator according to any one of claims 1 to 10, wherein

    the charging electrode having a reference potential of the two charging electrodes has a substantially cylindrical inner peripheral surface extending along a direction of a flow of the gas, and the charging electrode having a higher potential of the two charging electrodes is disposed to extend in the direction of the flow of the gas substantially coaxially with the inner peripheral surface.

FIG.1

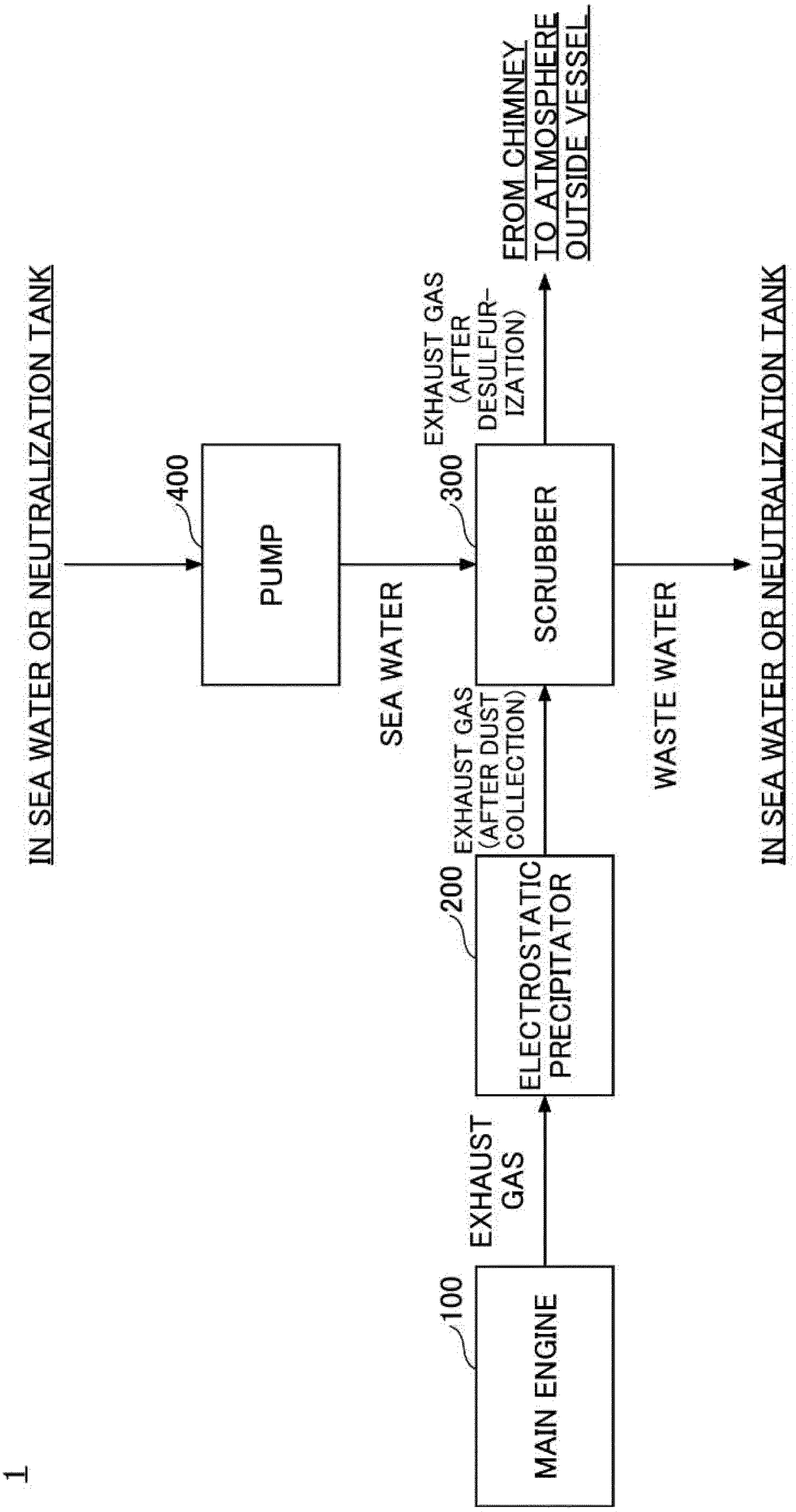
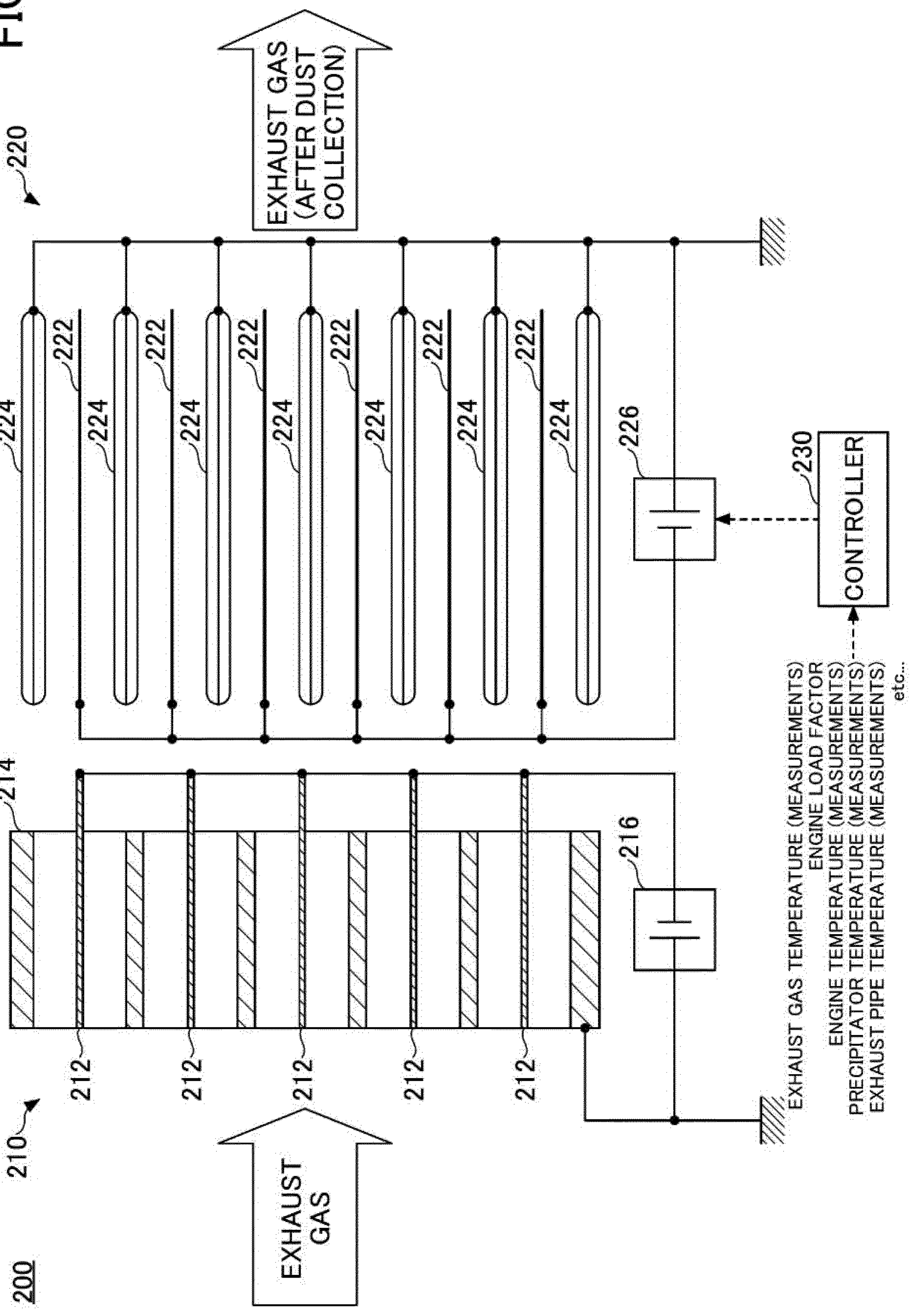

1
MAIN ENGINE
100
EXHAUST GAS
ELECTROSTATIC PRECIPITATOR
200
EXHAUST GAS (AFTER DUST COLLECTION)
SCRUBBER
300
EXHAUST GAS (AFTER DESULFUR-IZATION)
FROM CHIMNEY TO ATMOSPHERE OUTSIDE VESSEL
IN SEA WATER OR NEUTRALIZATION TANK
PUMP
400
SEA WATER
WASTE WATER
IN SEA WATER OR NEUTRALIZATION TANK

FIG.2


200
210
220
EXHAUST GAS
EXHAUST GAS (AFTER DUST COLLECTION)
212
214
216
222
224
226
230
CONTROLLER
EXHAUST GAS TEMPERATURE (MEASUREMENTS)
ENGINE LOAD FACTOR
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PRECIPITATOR TEMPERATURE (MEASUREMENTS)
EXHAUST PIPE TEMPERATURE (MEASUREMENTS)
etc...

FIG.3

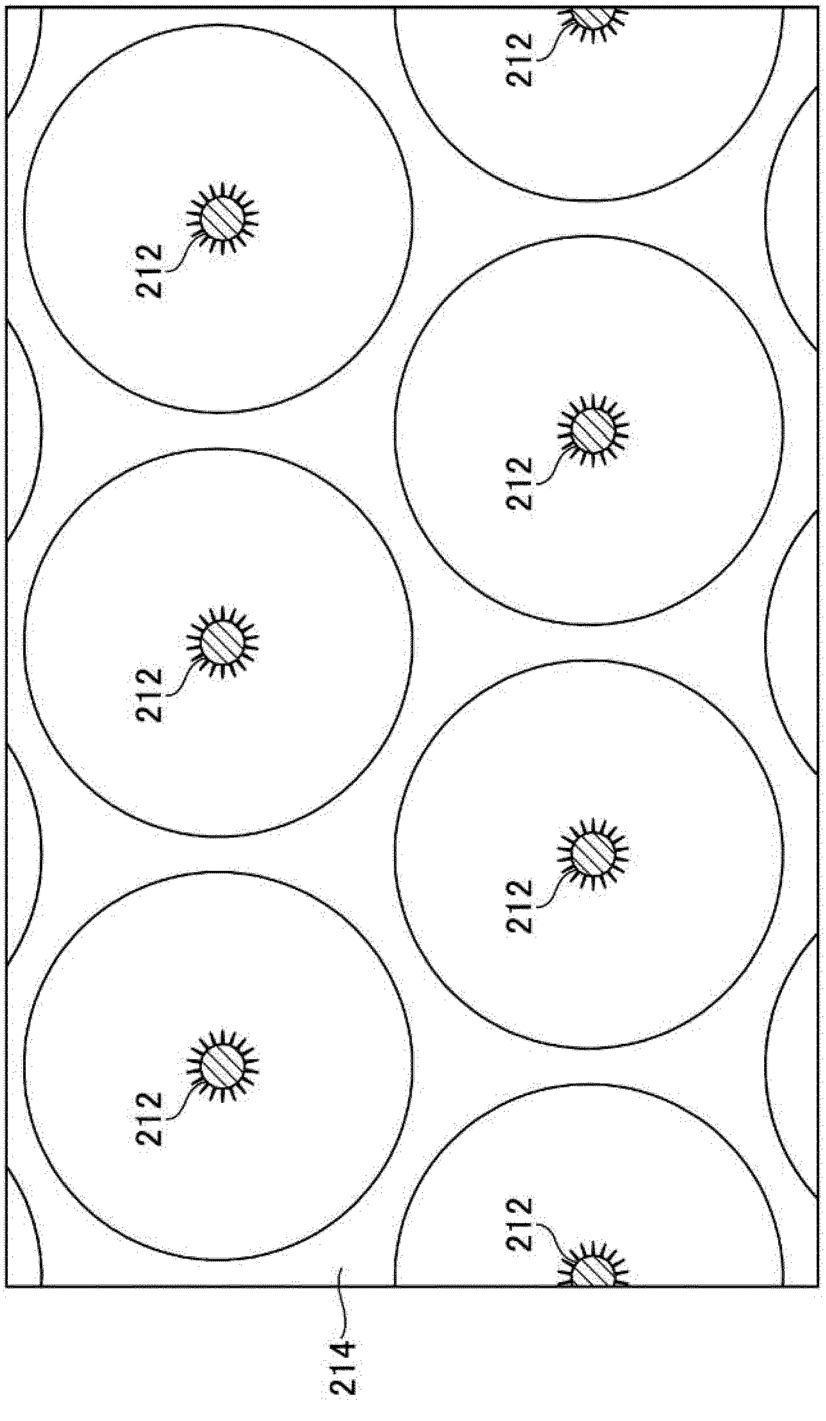
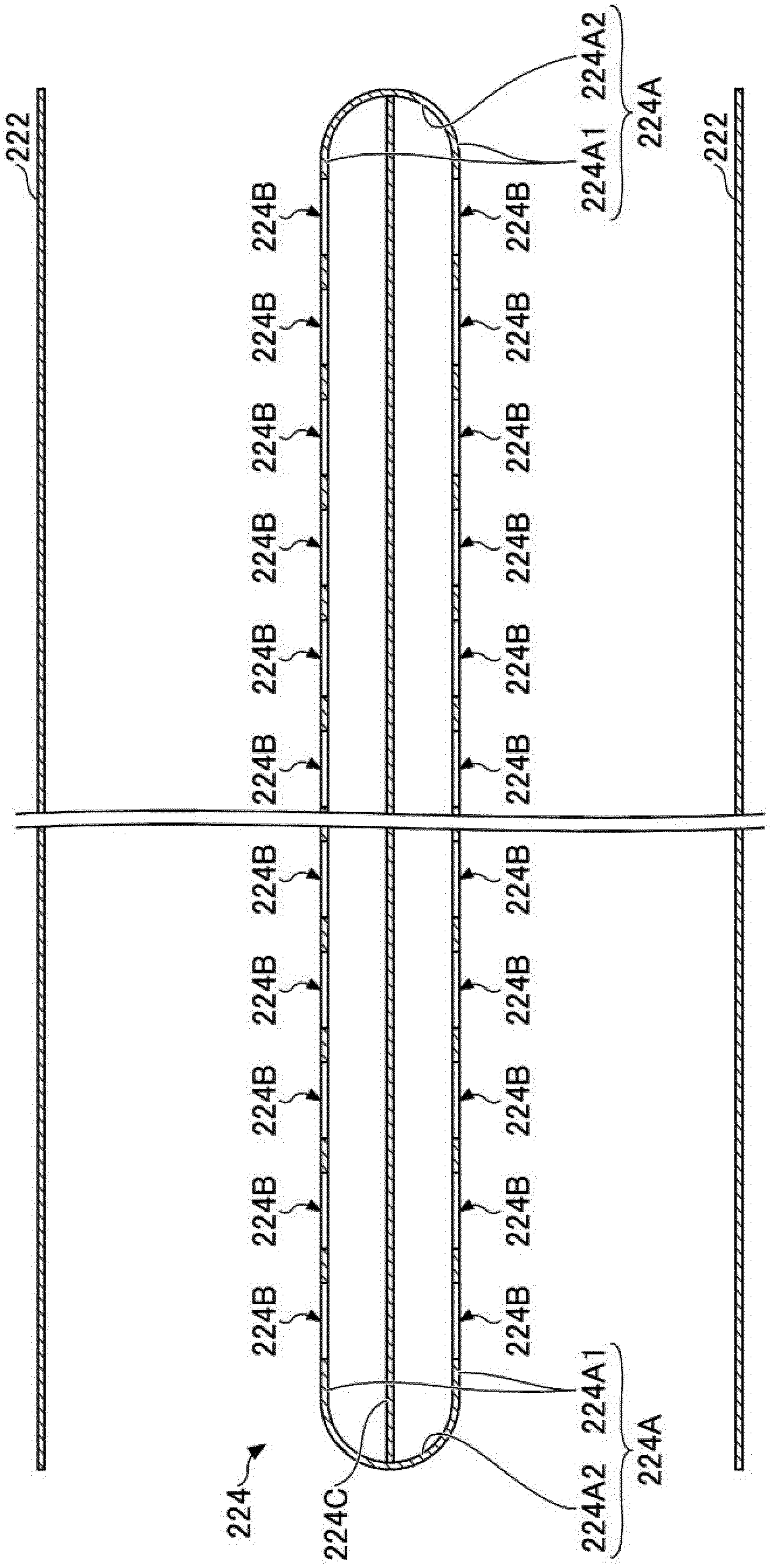


FIG.4



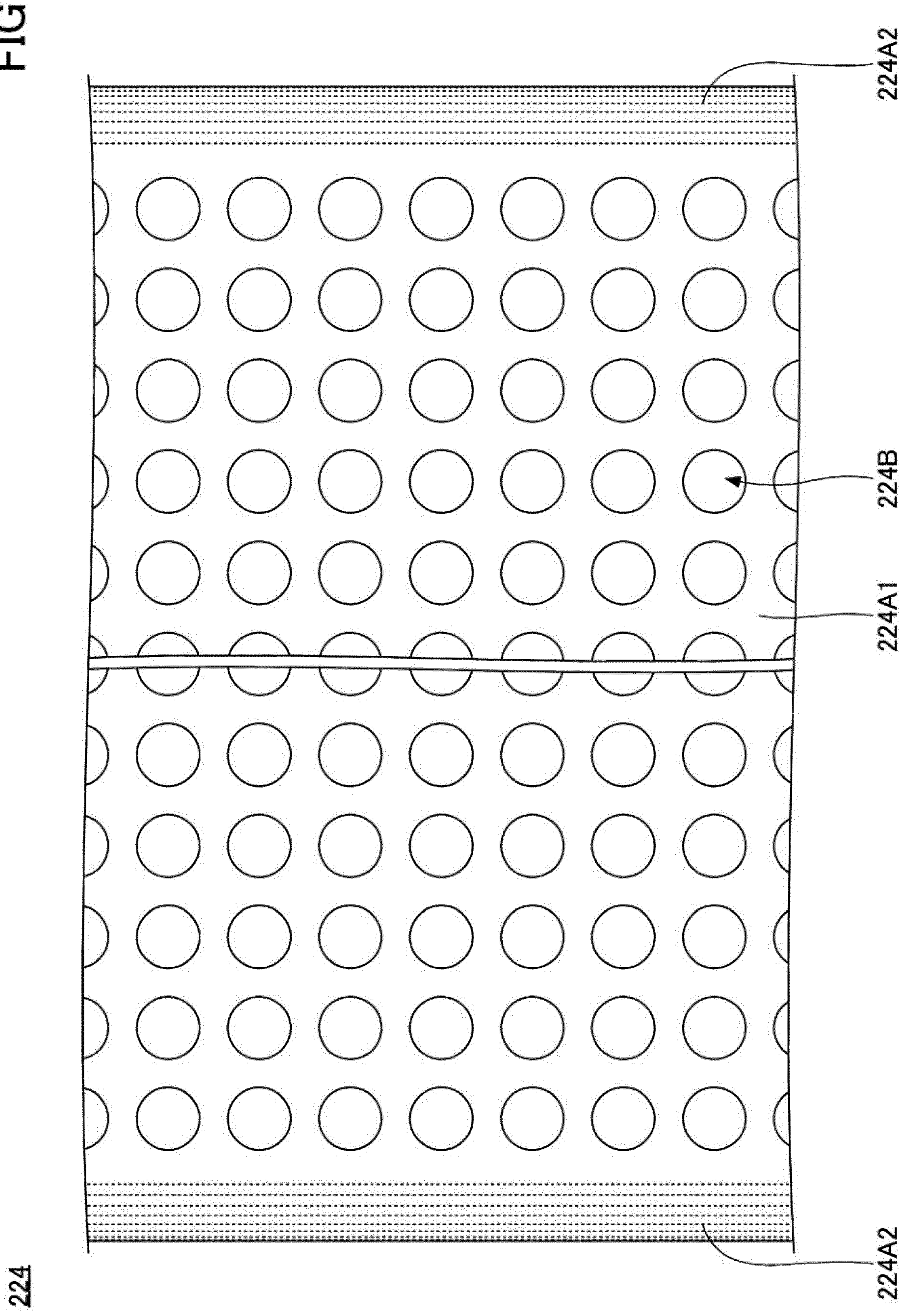
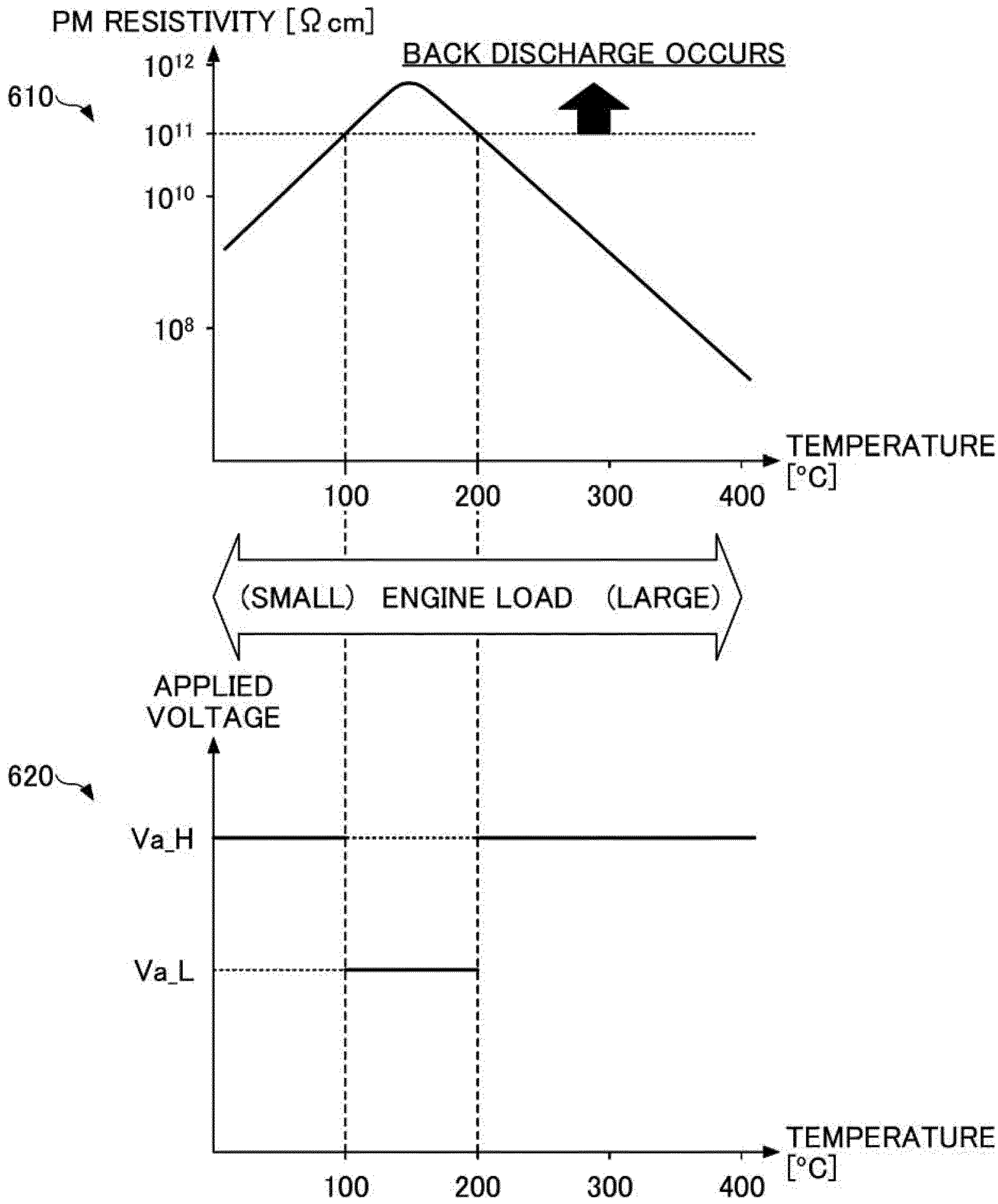


FIG.5

FIG.6


PM RESISTIVITY [Ω cm]
BACK DISCHARGE OCCURS
610
10^{12}
10^{11}
10^{10}
10^{8}
TEMPERATURE [°C]
100
200
300
400
(SMALL) ENGINE LOAD (LARGE)
APPLIED VOLTAGE
620
Va_H
Va_L
TEMPERATURE [°C]
100
200
300
400

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2021/024036

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. B03C3/40(2006.01)i, B03C3/41(2006.01)i, B03C3/51(2006.01)i, B03C3/68(2006.01)i, F01N3/01(2006.01)i
FI: B03C3/40A, B03C3/41A, B03C3/51, B03C3/68Z, F01N3/01
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. B03C3/40, B03C3/41, B03C3/51, B03C3/68, F01N3/01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2013-188708 A (FUJI ELECTRIC CO., LTD.) 26 September 2013 (2013-09-26), claims 1, 3-4, paragraphs [0028], [0029], [0038], [0040], fig. 2, 3, 5	1-4 5-11
Y	JP 2-174952 A (DAIKIN INDUSTRIES, LTD.) 06 July 1990 (1990-07-06), claim 1	5-11
Y	JP 11-249382 A (SHARP CORPORATION) 17 September 1999 (1999-09-17), claim 1, fig. 9	11
A	JP 2011-245429 A (FUJI ELECTRIC CO., LTD.) 08 December 2011 (2011-12-08), entire text	1-11
A	JP 2018-109375 A (FUJI ELECTRIC CO., LTD.) 12 July 2018 (2018-07-12), entire text	1-11

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 August 2021	31 August 2021

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/024036

JP 2013-188708 A	26 September 2013	(Family: none)
JP 2-174952 A	06 July 1990	(Family: none)
JP 11-249382 A	17 September 1999	(Family: none)
JP 2011-245429 A	08 December 2011	(Family: none)
JP 2018-109375 A	12 July 2018	(Family: none)

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2018126714 A **[0003]**
- JP 2020139592 A **[0089]**