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(54) **Exhaust gas treatment apparatus**

(57) There is provided an exhaust gas treatment apparatus (1a) including: a tubular body (10) and a discharge electrode (12) disposed inside the tubular body (10). The tubular body (10) has a shape where an inner diameter of the tubular body (10) is gradually reduced in a predetermined range from a face (25) which contains a central point (24x) of generation of corona discharge (24) generated by the discharge electrode (12) and which is perpendicular to the flow passage toward the downstream side (44) of the flow passage.

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Description

Background of the Invention and Related Art Statement

[0001] The present invention relates to an exhaust gas treatment apparatus. More specifically, the present invention relates to exhaust gas treatment apparatus capable of decreasing the number of the particulates present in exhaust gas by agglomerating the particulate matter contained in the exhaust gas.

[0002] There is increased need to remove particulate matter and harmful substances in exhaust gas discharged from internal combustion engines such as automobile engines, construction machine engines; industrial machine stationary engines and other combustion burning appliances; and the like in consideration of influence on the environment. In particular, in recent years, the regulations regarding the removal of the particulate matter (hereinbelow sometimes referred to as "PM") contained in exhaust gas have had a tendency to be strengthened on a global basis.

[0003] As an exhaust gas treatment apparatus for treating exhaust gas containing PM as described above, there is disclosed, for example, an apparatus where PM is electrically collected by adsorbing PM onto a positively electrified body with negatively electrifying the PM by the electrified body after the PM is agglomerated by allowing the PM to collide against a collision guide member provided inside the flow passage where exhaust gas passes (see, e.g., JP-A-2001-41024). The PM passed through the positively electrified body is collected in the filter downstream and incinerated and removed by applying current to the positively electrified body to allow it to function as a heater.

[0004] Such an exhaust gas treatment apparatus has a defect of increase in pressure loss because of complex flow passage constitution, and manufacturing of the apparatus is not easy. In addition, since sufficient agglomeration effect cannot be obtained, the particulate matter passes through the apparatus and is released without being agglomerated.

[0005] From such problems, there is disclosed an exhaust gas treatment apparatus provided with an agglomerator which electrifies particulate matter in exhaust gas by charge by corona discharge and agglomerates the particulate matter in an electrode collecting the charge by disposing two kinds of electrodes of charge emission and charge collection communicating the charge by corona discharge due to the application of a high voltage between them as an agglomerator for agglomerating particulate matter (PM) in exhaust gas in an exhaust gas passage which is formed by an exhaust pipe of an internal combustion engine and where exhaust gas circulates in the axial direction of the exhaust pipe in such a manner that a charge communication portion of the first electrode is located in almost the central portion in the diametral direction of the exhaust gas passage (see, e.g., JP-A-2005-320955).

[0006] In addition, as an agglomerator for exhaust gas treatment apparatus used for an exhaust gas treatment apparatus as described above and agglomerating the exhaust gas PM charged by corona discharge by an agglomeration portion, there is disclosed an agglomerator for an exhaust gas treatment apparatus provided with the first conductive body disposed on the downstream side of the exhaust gas stream of the electrified portion in the agglomeration portion with applying a voltage to the first conductive body to have a positive electric potential (see, e.g., JP-A-2005-324094).

[0007] Further, there is disclosed an exhaust gas purification apparatus provided with a PM agglomeration means generating particulate matter (agglomerated PM) having a large particle diameter by agglomerating the particulate matter contained in exhaust gas of an engine and PM trapping means disposed downstream of the exhaust gas flow direction of the PM agglomeration means and trapping the agglomerated PM agglomerated by the PM agglomeration means (see, e.g., JP-A-2006-29267).

[0008] However, the aforementioned JP-A-2005-320955 discloses an exhaust gas treatment apparatus where an electrode for collecting charge is disposed on the downstream side of the flow passage. In the case that the electrode is disposed in such a manner, particulate matter charged by corona discharge is accelerated by the electric field and passes through without being trapped by the other electrode. Therefore, in the aforementioned constitution, there is a problem that the effect in agglomerating the particulate matter is small to be almost impossible to agglomerate the particulate matter practically.

[0009] In addition, in the exhaust gas treatment apparatus described in the JP-A-2005-320955, there is a description of utilizing the electrode for collecting charge as an inner wall face of the flow passage. In such a case, the particulate matter always moving toward the downstream side on stream of exhaust gas easily passes through the range of the electric field. Therefore, even in such a case, there is a problem that the effect in agglomerating the particulate matter is small to be almost impossible to agglomerate the particulate matter practically. In particular, in a case that the exhaust gas flow rate is high or that the number of the particulates contained in exhaust gas is small, it is very difficult to trap the particulate matter on the inner wall face of the flow passage.

[0010] In addition, in the agglomerator for an exhaust gas treatment apparatus described in the JP-A-2005-324094, a high voltage is applied to the first conductive body constituting the agglomeration portion to draw the electrified particulate matter. It can shorten the moving distance of the electrified particulate matter and has high agglomeration effect in comparison with the exhaust gas treatment apparatus disposed in the JP-A-2005-320955. However, there is a problem that constitution of the electrode (the electrified portion and the agglomeration portion) is extremely complex to make it difficult to use it for an automobile or the like where large vibrations and the like are applied.

[0011] In addition, a PM agglomeration means used for the exhaust gas purification apparatus described in the JP-A-2006-29267 accelerates the particulate matter in the exhaust gas flow direction like the exhaust gas treatment apparatus described in the JP-A-2005-320955. Therefore, there is a problem that the effect in agglomerating the particulate matter is small to be almost impossible to agglomerate the particulate matter practically.

[0012] Further, the exhaust gas treatment apparatuses described in the aforementioned JP-A-2005-320955, JP-A-2005-324094, and JP-A-2006-29267 have been developed in order to treat exhaust gas containing a relatively large amount of particulate matter of a diesel engine or the like. In the case of using them for a gasoline engine or the like having a small number of the particulates in exhaust gas in comparison with a diesel engine or the like, the number of the particulates to be agglomerated is small, and the particle diameters of the particulates are small. Therefore, the effect in agglomerating the particulate matter is further reduced.

[0013] In particular, a new standard by EURO 6 is supposed to be applied as an exhaust gas regulation from 2012, and there is desired the development of an exhaust gas treatment apparatus capable of corresponding with a vehicle provided with a gasoline engine as a driving mechanism. In particular, since a gasoline engine has a low torque, if a filter increasing pressure loss of exhaust gas is disposed in an exhaust system, knocking is easily caused to cause an engine trouble or the like. Therefore, there is desired the development of an exhaust gas treatment apparatus provided with a mechanism which hardly charge a burden on an engine or the like.

[0014] In addition, when a filter is disposed in an exhaust system of a gasoline engine to run over a long distance, deposition of ash derived from components contained in a gasoline of a fuel becomes a serious problem. Since ash does not disappear even when high-temperature regeneration (burning) is performed in a filter unlike the PM, clogging is caused in the filter as a result to cause the increase in pressure loss.

Summary of the Invention

[0015] The present invention has been made in order to solve the aforementioned problems of prior art and aims to provide an exhaust gas treatment apparatus capable of decreasing the number of the particulates contained in exhaust gas by agglomerating the particulate matter contained in the exhaust gas.

[0016] As a result of earnest studies by the present inventors in order to solve the aforementioned problems of prior art, they found out that the problems can be solved by allowing the tubular body to have an inner diameter gradually reduced in a predetermined range from the central point generating corona discharge toward the down stream side of the flow passage in an exhaust gas treatment apparatus where a discharge electrode for causing corona discharge is disposed in a tubular body functioning as a flow passage where exhaust gas passes, particulate matter is charged by the corona discharge caused by the electrode, the charged particulate matter is trapped and agglomerated on the inner wall face of the tubular body to be bloated, and then the bloated particulate matter is scattered again; which led to the completion of the present invention. More specifically, according to the present invention, the following exhaust gas treatment apparatuses are provided.

[0017] [1] An exhaust gas treatment apparatus comprising: a tubular body functioning as a flow passage where exhaust gas passes, and a discharge electrode disposed in an central portion in a cross section perpendicular to a flow direction of the flow passage inside the tubular body and causing corona discharge in the vicinity thereof by applying a voltage; wherein the tubular body has a shape where an inner diameter of the tubular body is gradually reduced in a predetermined range from a face which contains a central point of generation of corona discharge generated by the discharge electrode and which is perpendicular to the flow passage toward the downstream side of the flow passage, and the number of particulates suspended in the exhaust gas is decreased by charging the particulate matter contained in the exhaust gas passing through the tubular body by corona discharge caused by the discharge electrode, collecting the charged particulate matter on an inner wall face of the tubular body by the electric field generated from the discharge electrode toward the inner wall face of the tubular body to agglomerate plural particulates, and allowing the agglomerated particulates to scatter again.

[0018] [2] The exhaust gas treatment apparatus according to [1], wherein the discharge electrode has a disc-like electrode support disposed perpendicularly to the flow direction of the flow passage and a needle-like discharger disposed perpendicularly to the electrode support and wherein the central point of generation of corona discharge is the central point of a face which contains the central point of generation of corona discharge of the tubular body and which is perpendicular to the flow passage.

[0019] [3] The exhaust gas treatment apparatus according to [2], wherein the tubular body has a shape where the inner diameter of the tubular body is reduced so that the distance from the central point of generation of corona discharge to the inner wall face of the tubular body in the predetermined range toward the downstream side of the flow passage is in the range of $\pm$10% of a length from the central point of generation of corona discharge to the inner wall face of the tubular body in the face which contains the central point of generation of corona discharge of the tubular body and which is perpendicular to the flow passage.

[0020] [4] The exhaust gas treatment apparatus according to [3], wherein the tubular body has a shape where a moving velocity of the charged particulate matter proceeding in an exhaust gas flow direction and a drift velocity when the particulate matter is drawn to the inner wall face are taken into consideration.

[0021] [5] The exhaust gas treatment apparatus according to any one of [1] to [4], wherein the length in the predetermined range where the inner diameter of the tubular body is gradually reduced is 0.2 to 0. 9 times the distance from the central point of generation of corona discharge of the tubular body to the inner wall face of the tubular body in the face perpendicular to the flow passage.

[0022] [6] The exhaust gas treatment apparatus according to any one of [1] to [5], wherein the discharge electrode is supported in the central portion of the flow passage by a porcelain bushing passing through the wall face of the tubular body and extended up to the central portion in a cross section perpendicular to the flow direction of the flow passage.

[0023] [7] The exhaust gas treatment apparatus according to [6], wherein the porcelain bushing has groove-shaped unevenness formed on the surface thereof.

[0024] [8] The exhaust gas treatment apparatus according to any one of [1] to [7], which is disposed in an exhaust system of a vehicle provided with a gasoline engine as a drive mechanism.

[0025] The exhaust gas treatment apparatus of the present invention can decrease the number of the particulates present in exhaust gas by agglomerating the particulate matter contained in exhaust gas. In particular, since an exhaust gas treatment apparatus of the present invention can decrease the number of the particulates even without disposing a filter or the like causing increase in pressure loss of the exhaust system, it can suitably be used as an exhaust gas treatment apparatus for treating exhaust gas discharged from a gasoline engine or the like where a harmful influence is caused by disposing a filter or the like causing increase in pressure loss.

Brief Description of the Drawings

[0026] [Fig. 1] Fig. 1 is a side view schematically showing an embodiment of an exhaust gas treatment apparatus of the present invention.

[0027] [Fig. 2] Fig. 2 is a plan view from the upstream side of the exhaust gas treatment apparatus shown in Fig. 1.

[0028] [Fig. 3] Fig. 3 is a cross-sectional view showing the A-A' cross section of the exhaust gas treatment apparatus shown in Fig. 2.

[0029] [Fig. 4] Fig. 4 is an explanatory view schematically explaining the process of treating exhaust gas by one embodiment of an exhaust gas treatment apparatus of the present invention.

[0030] [Fig. 5] Fig. 5 is a cross-sectional view schematically showing another embodiment of an exhaust gas treatment apparatus of the present invention.

[0031] [Fig. 6] Fig. 6 is an explanatory view schematically explaining the process of treating exhaust gas by another embodiment of an exhaust gas treatment apparatus of the present invention.

[0032] [Fig. 7] Fig. 7 is a front view schematically showing an example of a discharge electrode used for an exhaust gas treatment apparatus of the present invention.

[0033] [Fig. 8] Fig. 8 is a side view of the discharge electrode shown in Fig. 7.

[0034] [Fig. 9] Fig. 9 is a side view schematically showing an example of a porcelain bushing used for an exhaust gas treatment apparatus of the present invention.

[0035] [Fig. 10] Fig. 10 is a top view of the porcelain bushing shown in Fig. 9.

[0036] [Fig. 11] Fig. 11 is a side view schematically showing another example of a porcelain bushing used for an exhaust gas treatment apparatus of the present invention.

[0037] [Fig. 12] Fig. 12 is a top view of the porcelain bushing shown in Fig. 11.

Reference Numerals

[0038] 1a, 1b: exhaust gas treatment apparatus, 10: tubular body, 10a: inner wall face, 12: discharge electrode, 12a: electrode support, 12b: discharger (needle-like discharger), 16: porcelain bushing, 18, 19: voltage introduction portion, 20: exhaust gas, 22: particulate matter, 22a: particulate matter (charged particulate matter), 22b: particulate matter (agglomerated particulate matter), 24: corona discharge, 24x: central point of generation (central point of generation of corona discharge), 25: face perpendicular to the flow passage (face which contains central point of generation of corona discharge and is perpendicular to the flow passage) 26: electric field, 32: second discharge electrode, 34: unevenness, 42: upstream side of the flow passage, 43: downstream side of flow passage, D1: inner diameter before inner diameter of tubular body is gradually reduced, D2: inner diameter after inner diameter of tubular body is gradually reduced, L1: length of predetermined range where inner diameter of tubular body is gradually reduced (length of predetermined range), R1: distance from central point of generation of corona discharge to inner wall face of tubular body in face perpendicular to the flow passage (radius in cross section of tubular body)

Detailed Description of the Invention

[0039] Embodiments for carrying out the present invention will be described with referring to drawings. However, the present invention is by no means limited to these embodiments, and, needless to say, various changes, modifications, and improvement may be made on the basis of knowledge of a person of ordinary skill in the art as long as they do not deviate from the scope of the present invention.

[1] Exhaust gas treatment apparatus:

[0040]

Fig. 1 is a side view schematically showing an embodiment of an exhaust gas treatment apparatus of the present invention, Fig. 2 is a plan view from the upstream side of the exhaust gas treatment apparatus shown in Fig. 1, Fig. 3 is a cross-sectional view showing the A-A' cross section of the exhaust gas treatment apparatus shown in Fig. 2, and Fig. 4 is an explanatory view schematically explaining the process of treating exhaust gas by one embodiment of an exhaust gas treatment apparatus of the present invention. Incidentally, Fig. 4 is a cross-sectional view showing an enlarged portion of a cross-sectional view shown in Fig. 3.

[0041] As shown in Figs. 1 to 4, the exhaust gas treatment apparatus 1a of the present embodiment is provided with a tubular body 10 functioning as a flow passage where exhaust gas 20 passes and a discharge electrode 12 disposed in an central portion in a cross section perpendicular to a flow direction of the flow passage inside the tubular body 10.

[0042] The exhaust gas treatment apparatus 1a of the present embodiment charges the particulate matter 22 contained in exhaust gas 20 passing through the tubular body 10 by corona discharge 24 caused by the aforementioned discharge electrode 12, collects the charged particulate matter 22a on the inner wall face 10a of the tubular body 10 by the electric field 26 generated from the discharge electrode 12 toward the inner wall face 10a of the tubular body 10 to agglomerate plural particulates 22a, and allows the agglomerated particulates 22b to scatter again, thereby decreasing the number of the particulates 22 suspended in the exhaust gas 20.

[0043] In the exhaust gas treatment apparatus 1a of the present embodiment, the aforementioned tubular body 10 has a shape where an inner diameter of the tubular body 10 is gradually reduced in a predetermined range from the face 25 which contains the central point 24x of generation of corona discharge 24 generated by the discharge electrode 12 and which is perpendicular to the flow passage toward the downstream side 43 of the flow passage. Incidentally, in Fig. 4, the numeral 42 shows the upstream side of the flow passage.

[0044] In the exhaust gas treatment apparatus 1a of the present embodiment, the particulate matter 22a drawn to the inner wall face 10a of the tubular body 10 by the electric field 26 communicates charge by being brought into contact with the tubular body 10 and trapped (i.e., dust collection) on the inner wall face 10a of the tubular body 10. In such a manner, the charged particulate matter 22a is drawn to the inner wall face 10a of the tubular body 10 in sequence. The trapped plural particulates are agglomerated by the Coulomb's force to form an aggregate of the plural particulates 22b. Then, the particulates 22b bloated by agglomeration up to a certain size has increased mass and is unable to stay (i.e. to keep being trapped) on the inner wall face 10a of the tubular body 10 to be discharged toward the downstream side on stream of the exhaust gas 20. Thus, the apparent number of the particulates 22 present in the exhaust gas 20 is decreased.

[0045] Thus, the exhaust gas treatment apparatus of the present embodiment traps the particulate matter contained in the exhaust gas on the inner wall face of the tubular body by charging the particulate matter to agglomerate plural particulates to be bloated, followed by allowing the particulate matter to scatter again, thereby decreasing the number (apparent number) of the particulate matter in the exhaust gas. In particular, the exhaust gas treatment apparatus of the present embodiment can decrease the number of the particulates even without disposing a filter or the like causing rise in pressure loss of the exhaust system and can agglomerate the particulate matter in a good condition even in the case that the number of the particulates of the exhaust gas is small. For example, not only as the apparatus for treating exhaust gas containing particulate matter in a relatively large amount such as a diesel engine, but also as the apparatus for treating exhaust gas discharged from a gasoline engine, it can suitably be used.

[0046] Incidentally, conventionally, there has been proposed an exhaust gas treatment apparatus (see, e.g., the aforementioned JP-A-2005-320955) where plural particulates are agglomerated. In such an exhaust gas treatment apparatus, in the case that the electrode for collecting charge is disposed on the downstream side of the flow passage, particulate matter charged by corona discharge is accelerated by the electric field and passes through without being trapped by the electrode for collecting charge. Therefore, in the aforementioned constitution, the effect in agglomerating the particulate matter is small, and it is almost impossible to agglomerate the particulate matter practically.

[0047] In addition, in the exhaust gas treatment apparatus disclosed in JP-A-2005-320955, there has been described the usage of the electrode for collecting charge as the inner wall face of the flow passage. However, in such a case, the particulate matter always moving toward the downstream side on stream of exhaust gas easily passes through the range of the electric field before it reaches the inner wall face of the flow passage. Therefore, also in such a case, the effect in agglomerating the particulate matter is small, and it is almost impossible to agglomerate the particulate matter practically. In particular, in a case that the exhaust gas flow rate is high or that the number of particulates contained in exhaust gas is small, it is very difficult to trap the particulate matter on the inner wall face of the flow passage.

[0048] That is, an electric field generated from the discharge electrode toward the inner wall face of the tubular body spreads from the central point (e. g. , in the case of a needle-shaped discharge electrode, the tip thereof) of generation of corona discharge in a spherical surface shape (equipotential face), and the electric field becomes weaker as the distance from the aforementioned central point of generation increases. Therefore, the electric field tends to be weaker toward outside of the tubular body as it goes toward downstream side from the aforementioned central point of generation, and the efficiency to trap the particulate matter always moving on stream of exhaust gas becomes extremely low.

[0049] In the exhaust gas treatment apparatus of the present embodiment, since the tubular body has a shape where the inner diameter is gradually reduced in a predetermined range from the central point of generation of corona discharge toward the downstream side of the flow passage, charged particulate matter can be trapped in a good condition on the inner wall face of the portion of the tubular body. In particular, by constituting the inner wall face of the tubular body to have a shape close to that of the electric field which spreads in an almost spherical surface shape (equipotential face) with the central point of generation of corona discharge as the base point, the charged particulate matter can be trapped in a better condition.

[0050] Incidentally, in the discharge electrode of the exhaust gas treatment apparatus of the present embodiment, it is preferable that the central point of the generation of corona discharge generated by discharge electrode is disposed in a position of the central point of a face perpendicular to the flow passage of the tubular body. This makes specifying of the central point of generation of corona discharge easy. That is, the central point of a face perpendicular to the flow passage of the tubular body is the central point of generation of corona discharge (or electric field). Incidentally, when the shape of the discharge electrode is a symmetrical shape such as a rotational symmetric shape, by disposing the central point of the discharge electrode to be located in the central point of the face perpendicular to the flow passage of the tubular body, the central point of generation of corona discharge can coincide with the central point of the face perpendicular to the flow passage of the tubular body.

[0051] Incidentally, by gradually reducing the inner diameter of the tubular body, the efficiency of trapping particulate matter on the inner wall face of the tubular body. However, on the other hand, since the inner diameter of the flow passage is reduced, the pressure loss of the exhaust system tends to be increased. Therefore, as shown in Fig. 4, the "length L1 of the predetermined range" where the inner diameter of the tubular body 10 is gradually reduced is preferably 0.2 to 0.9 times, more preferably 0.4 to 0.7 times, particularly preferably 0.5 to 0.6 times the distance R1 from the central point 24x of generation of corona discharge 24 of the tubular body 10 to the inner wall face of the tubular body in the face perpendicular to the flow passage. Such a constitution enables to improve the efficiency to trap the particulate matter in a good condition with suppressing the increase in pressure loss to the minimum.

[0052] Incidentally, the reduction rate of the inner diameter D2 after the inner diameter of the tubular body 10 is gradually reduced (hereinbelow referred to as the "reduction rate of the inner diameter of the tubular body") with respect to the inner diameter D1 before the inner diameter of the tubular body 10 is gradually reduced (i.e., inner diameter of the tubular body 10 on the upstream side of the central point 24x of generation of corona discharge 24) is preferably 0.6 to 48%, more preferably 5 to 23%, particularly preferably 9 to 15%. Incidentally, the reduction rate of the inner diameter of the tubular body can be obtained by the following formula (1).

$$\text{Reduction rate of inner diameter of tubular body} = (D1-D2)/D1\times 100 \cdots (1)$$

(wherein D1 is the inner diameter before the inner diameter of the tubular body is gradually reduced, while D2 is the inner diameter after the inner diameter of the tubular body is gradually reduced)

[0053] In addition, a tubular body used for the exhaust gas treatment apparatus of the present embodiment is preferably formed so that the inner diameter is reduced to form in an almost spherical surface shape where, in a predetermined range toward the downstream side of the flow passage, the distance from the central point of generation of corona discharge to the inner wall face of the tubular body is within the range of ±10% of the length in a face containing the aforementioned central point of generation of corona discharge, and perpendicular to the flow passage (i. e. , radius R1 in a cross section of the tubular body (see Fig. 4)). For example, when the distance is outside the range of -10%, since the inner diameter of the tubular body becomes narrow drastically, the pressure loss of the exhaust system may increase by disposing an exhaust gas treatment apparatus. On the other hand, when the distance is outside the range of +10%, the rate of reduction the tubular body (in other wards, rate of narrowing of the flow passage) is too small, and the particulate matter moving on stream of exhaust gas may easily exceed the effective electric field range.

[0054] The charged particulate matter moving in the electric field is moving at a speed balanced with the viscosity resistance of the exhaust gas in a direction of the inner wall face of the tubular body. Incidentally, the speed of the moving of the particulate matter in the inner wall face direction of the tubular body is sometimes referred to as a "drift velocity (w)".

[0055] The tubular body used for the exhaust gas treatment apparatus of the present embodiment is preferably constituted to have a shape in consideration of a moving velocity (v) of the charged particulate matter in the exhaust gas flow direction and a drift velocity (w) drawn to the inner wall face of the tubular body in a predetermined range toward the downstream side of the flow passage. That is, an inner face shape of the tubular body is not a spherical shape in consideration of equipotential face simply, but a shape in consideration of also a drift velocity (w) where the particulate matter is drawn to the inner wall face of the tubular body, thereby trapping the charged particulate matter in a good condition.

[0056] Hereinbelow, a calculation method of the aforementioned drift velocity (w) and a method for determining a shape of the tubular body in consideration of the moving velocity (v) and the drift velocity (w) of the particulate matter proceeding in the exhaust gas flow direction will be described in more detail.

[0057] The drift velocity (w) can be obtained by the following formula (2) with a charged amount (q) of the particulate matter, charged electric field strength (E), gas (exhaust gas) viscosity (μ), radius (a) of particulate matter, and Cunningham correction coefficient (Cm).

[0058]

[Formula 1]

$$w = 3qE \times Cm/6\pi\mu a \cdots (2)$$

[0059] However, in an actual exhaust gas treatment apparatus, a corona wind is present in a space where the charged particulate matter (charged particulates) is trapped, and it is difficult to obtain a field in consideration of space charge of the charged particulates. Therefore, it is preferable that the "apparent drift velocity (w_d)" is calculated from the experimental value (measurement value) of a dust collection efficiency (η) for trapping (collecting) the particulate matter to determine an ideal shape for the tubular body by employing the "apparent drift velocity (W_d) as the actual drift velocity. Incidentally, the experimental value (measurement value) of the dust collection efficiency (η) can be measured by a particle counter, for example, the electrical low pressure impactor produced by Dekati Ltd.

[0060] Incidentally, the aforementioned dust collection efficiency (η) is shown by the following formula (3) with the concentration (Wi) of particulate matter on the inlet side and the concentration (Wo) of particulate matter on the outlet side of the exhaust gas treatment apparatus.

[0061]

$$\eta = 1 - Wo/Wi \cdots (3)$$

$$\eta = 1 - \exp\ (-w_d A/Q) \cdots (4)$$

(In the formula (4), A denotes an area of a dust collection electrode (i.e., area of the inner wall face of the tubular body), and Q denotes a gas flow rate per unit time.)

[0062] An "apparent drift velocity (w_d)" can be calculated by the aforementioned formula (4) and the formula (5) with the aforementioned actual experimental value (measurement value of dust collection efficiency (μ)). Incidentally, for example, in an area (A) of a dust collection electrode, the inner portion of the tubular body has a circular columnar shape, the area is an area of the inner wall face in a range from the tip of the discharge electrode to 200 mm, and the gas flow rate (Q) per unit time is 15916 cm^3/sec (0.955 m^3/min.).

[0063] In addition, the moving velocity (v) of the charged particulate matter in the exhaust gas flow direction can be calculated from the aforementioned gas flow rate (Q) per unit time.

[0064] As a method for determining the shape of the tubular body in consideration of the moving velocity (v) in the exhaust gas flow direction and the drift velocity (apparent drift velocity (w_d)), a tubular body shape in an about elliptic shape can be determined by adding a drift moving distance in each position in the exhaust gas flow direction with respect to the equipotential face from the central point of generation of corona discharge. For example, When the distance from the central point of generation of corona discharge to the equipotential face is determined as R, polar coordinates (x, y) of the point R' constituting the tubular shape in consideration of the drift velocity can be shown by the following formulae (5) and (6), and the tubular shape in consideration of the drift velocity can be determined by suitably determining the length of the predetermined range where the inner diameter of the tubular body is gradually reduced with using the aforementioned polar coordinates (x, y) of the point R' constituting the tubular shape in consideration of the drift velocity.

$$x = R\cos\theta \cdots (5)$$

$$y = R\sin\theta + R\cos\theta \cdot w_d / v \cdots (6)$$

[0065] Incidentally, the tubular shape in consideration of the drift velocity can be determined by stipulating the almost elliptic shape where the moving distance (drift moving distance) of the particulate matter due of the electric field is considered by calculating the drift moving distance for every 0.05 mm in the pipe direction.

[0066] In the case of determining the shape of the tubular body in such a manner, it is preferable to use assumptions as described below for simplifying the calculation.

(1) The inner wall area of the tubular body at 200 mm on the downstream side from the tip of the discharge electrode is determined as the electrode area (Incidentally, the tubular body is assumed to be a straight pipe (having a fixed inner diameter of the pipe)).
(2) The gas flow rate (Q) per unit time and apparent drift velocity (w_d) are fixed regardless of the positions of the particulates in the tubular body.
(3) Even in the case that plural tips of the discharge electrode are present, the apparent central point of the electric field (central point of generation of corona discharge) is a central point of a face perpendicular to the flow passage.
(4) Though electric field is generated also on the upstream side of the discharge electrode, since the particulate matter is trapped on the downstream side of the discharge electrode, the tubular body is narrowed only on the downstream side of the flow passage. Incidentally, the drift of the particulate matter due to the electric field generated on the upstream side of the discharge electrode is ignored.

[0067] As described above, the shape of the tubular body can be made suitable for trapping the charged particulate matter, agglomerating the trapped particulate matter, and scattering the bloated particulate matter due to the agglomeration again. Further, by the use of the aforementioned assumptions, the shape of the tubular body can be determined more easily.

[0068] Incidentally, as a method for confirming the decrease in the number of the particulates in exhaust gas by the exhaust gas treatment apparatus of the present embodiment, a particle counter is disposed on the downstream side of the exhaust gas treatment apparatus to measure the number of the particulates in the exhaust gas. An example of the aforementioned particle counter is the Electrical Low Pressure Impactor (hereinbelow sometimes referred to as "ELPI") produced by Dekati Ltd. According to such ELPI, measurement (sampling) of the number of particulates having a particle diameter of 0.007 to 10 μm in the particulate matter is possible. Incidentally, upon measurement, the particulates are classified by the following particle diameters: 0.007 to 0.014, 0.014 to 0.0396, 0.0396 to 0.0718, 0.0718 to 0.119, 0.119 to 0.200, 0.200 to 0.315, 0.315 to 0.482, 0.482 to 0.760, 0.760 to 1.23, 1.23 to 1.95, 1.95 to 3.08, 3.08 to 6.27 (unit of μm).

[0069] As a more specific measurement method, in the first place, a particle counter is disposed on the downstream side of the exhaust gas treatment apparatus, and the number of the particulates in the exhaust gas is measured (sampled) in each of the case of applying a voltage in each of the electrodes (upon applying a voltage) and the case of applying no voltage (upon applying no voltage). Next, from the sum of the measurement data by each particle diameter range, the total number (total discharge number) of the particulates discharged from the downstream side is calculated out. Next, from the data of the total discharge number at each of the time of applying a voltage and the time of applying no voltage, the ratio of the number of the particulates reduced by the exhaust gas treatment apparatus of the present embodiment can be obtained.

[0070] In the case of treating exhaust gas by the use of an exhaust gas treatment apparatus of the present embodiment, there is no particular limitation on the flow rate of the exhaust gas to be treated, and the number of the particulates can be decreased in a good condition with an exhaust gas flow rate of, for example, 200 m/second or less. Incidentally, since the exhaust gas flow rate upon running of a general vehicle provided with a gasoline engine as a drive mechanism is 150 m/second (in the case of 2L engine, 6000 revolutions, and exhaust gas temperature of about 600°C), even in such a vehicle, the treatment of exhaust gas can be performed in a good condition by the use of the exhaust gas treatment apparatus of the present embodiment.

[0071] Hereinbelow, the exhaust gas treatment apparatus of the present embodiment will be described in more detail by each of the constituents.

[1-1] Tubular body:

[0072] The tubular body is connected to an exhaust system where exhaust gas being discharged from an internal combustion engine or the like and containing particulate matter passes to function as a flow passage where exhaust gas passes. As described above, the tubular body is constituted to have a shape where the inner diameter is gradually reduced in a predetermined range from the face containing the central point of generation of corona discharge and perpendicular to the flow passage toward the downstream side of the flow passage. Such a tubular body may be connected independently to the exhaust pipe for discharging exhaust gas from the internal engine, or a part of the exhaust pipe provided on the internal combustion engine may be used as the tubular body in the exhaust gas treatment apparatus of the present embodiment.

[0073] In the exhaust gas treatment apparatus of the present embodiment, a discharge electrode and a dust collection electrode are disposed inside the tubular body, and inside of the tubular body is conducted a treatment where (1) the particulate matter is charged by corona discharge, (2) the charged particulate matter is trapped on the inner wall face of the tubular body by an electric field, (3) plural trapped particulates are agglomerated, and (4) the agglomerated particulates are scattered again.

[0074] Such a tubular body is used as not only a flow passage where exhaust gas passes, but also the opposed electrode to generate an electric field between the tubular body and the dust collection electrode. Therefore, the tubular body is preferably constituted of a conductive material. When the tubular body is used as the opposed electrode of the dust collection electrode or the like, the tubular body is preferably grounded.

[0075] As the tubular body, there can suitably be used a body made of a conductive material such as stainless and iron used for an exhaust pipe of an automobile.

[0076] There is no particular limitation on the length of the tubular body as long as the tubular body has a length where the discharge electrode is disposed inside thereof, the range having the gradually reducing inner diameter of the tubular body is provided as described above, and the exhaust gas treatment from the charge of the particulate matter to the re-scattering of the aforementioned particulate matter can be performed in the tubular body.

[0077] In addition, the tubular body preferably has a circular cylindrical shape having a straight central axis and is preferably constituted so that the inner diameter is reduced in the aforementioned range. Such a constitution can trap the charged particulate matter in a good condition and inhibit excessive rise in pressure loss.

[1-2] Discharge electrode:

[0078] The discharge electrode is an electrode for generating corona discharge which charges the particulate matter in exhaust gas and disposed in the central portion in a cross section perpendicular to the flow direction of the flow passage inside the tubular body. In addition, the discharge electrode is used also as an electrode for generating an electric field for trapping the charged particulate matter with the inner wall face of the tubular body functioning as a flow passage of a fluid as an opposed electrode. This enabled the charged particulate matter to be trapped on the inner wall face of a tubular body.

[0079] The discharge electrode is preferably constituted to be able to generate corona discharge in a region up to the inner wall face of the flow passage formed by the tubular body including the vicinity of the discharge electrode in such a manner that more particulate matter, preferably all the particular matter in the exhaust gas passing through the tubular body passes through the space where the corona discharge is generated.

[0080] In the exhaust gas treatment apparatus 1a shown in Figs. 1 to 4, the discharge electrode 12 is supported in the central portion of the flow passage by the porcelain bushing 16 passing through the wall face of the tubular body 10 and extended to the central portion in a cross section perpendicular to the flow direction of the flow passage. Inside the porcelain bushing 16 is disposed a voltage introduction portion 18 including a wire for applying a voltage (high voltage) to the discharge electrode 12, and the voltage introduction portion 18 and the discharge electrode 12 are electrically connected with each other in a state that electrical insulation between the voltage introduction portion 18 and the tubular body 10 is secured.

[0081] Incidentally, Figs. 1 and 4 show an example of a case where a porcelain bushing 16 is disposed on the upstream side of the central point 24x of generation of corona discharge 24 so as to pass through the wall face of the tubular body 10. However, the porcelain bushing 16 may be disposed so as to pass through the wall face of the tubular body 10 on the downstream side of the central point 24x of generation of corona discharge 24 as in the exhaust gas purification apparatus 1b shown in Figs. 5 and 6. In such a case, the porcelain bushing 16 is disposed so as to pass through the portion constituted to have a shape where the inner diameter of the tubular body 10 is gradually reduced. Incidentally, the case where the porcelain bushing 16 is disposed on the upstream side of the central point 24x of generation of corona discharge 24 as shown in Figs. 1 to 4 has an advantage of easy installation of the porcelain bushing 15 and the discharge electrode 12. Here, Fig. 5 is a cross-sectional view schematically showing another embodiment of an exhaust gas treatment apparatus of the present invention. Fig. 6 is an explanatory view schematically explaining the process of treating exhaust gas by another embodiment of an exhaust gas treatment apparatus of the present invention. Incidentally, Fig. 5 shows the same cross section as that shown in Fig. 3.

[0082] There is no particular limitation on the shape of the discharge electrode as long as the discharge electrode has the tip portion formed at a sharp angle and corona discharge generated therein (more specifically, in the tip portion formed at a sharp angle) by application of the high voltage between the discharge electrode and the inner wall face of the tubular body. In the exhaust gas treatment apparatus 1a shown in Figs. 1 to 4, Figs. 7 and 8 show an example of the case where the discharge electrode 12 has a disk-like electrode support 12a disposed perpendicularly to the flow direction of the flow passage and a needle-like discharger 12b disposed perpendicularly to the electrode support 12a (i.e., in parallel with the flow direction). By such a constitution, an electric field concentrates in the tip portion of the needle-like discharger 12b to cause corona discharge in a good condition. In addition, by the needle-like discharger 12b, even if the tip portion is worn away in some degree, corona discharge can be caused by concentrating the electric field. Incidentally, "needle-like discharger" means a discharger having a thin stick shape as the entire shape besides a discharger having a sharp pointed tip portion. Incidentally, in a discharge electrode 12 having such a shape, the central portion of the electrode support 12a functions as a portion where a voltage from the voltage introduction portion 18 (see Fig. 1) is introduced.

[0083] Here, Fig. 7 is a front view schematically showing an example of the discharge electrode used for an exhaust gas treatment apparatus of the present invention. Fig. 8 is a side view of the discharge electrode shown in Fig. 7.

[0084] Incidentally, in Figs. 7 and 8, 12 dischargers 12b are disposed at regular intervals on the outside on each of the faces of the electrode support 12a, and four dischargers 12b are further disposed inside the positions of the 12 dischargers 12b. In addition, the four discharger 12b disposed inside are longer than the 12 discharger 12b disposed outside. Such a constitution can cause corona discharge over a wider range inside the tubular body to be able to charge the particulate matter in exhaust gas in a good condition. In addition, assemblage and manufacturing of the members are easy, and, since most of the particulate matter in exhaust gas can be passed through in the vicinity of the discharge portion, much particulate matter can be charged in a good condition.

[0085] Incidentally, in the case that plural tips of the discharge electrode are present, for example, as shown in Figs. 7 and 8, even in the case that the discharge electrode 12 has a disc-shaped electrode support 12a disposed perpendicularly to the flow direction of the flow passage and two or more needle-shaped dischargers 12b disposed perpendicularly to the electrode support 12a, the central point of generation of corona discharge (in other words, central point of generation of the electric field) can be the central point of a face perpendicular to the flow passage.

[0086] Incidentally, the shape of the discharge electrode is not limited to the aforementioned shape where needle-like dischargers are disposed on the electrode support, and, for example, a plurality of plate-like bodies each having at least one sharp blade edge-like side may be disposed on the electrode support. In the case of such a discharge electrode, the electric field concentrates on the blade edge of each plate-like body to cause corona discharge.

[0087] Regarding the material constituting the discharge electrode, there can suitably be used the same material as that constituting an electrode having conventionally been used for an exhaust gas treatment apparatus performing agglomeration by charging the particulate matter in exhaust gas. Examples of the material include stainless steel, iron, nickel, kovar, platinum, copper, gold, molybdenum, and tungsten.

[0088] In addition, the discharge electrode used for the exhaust gas treatment apparatus of the present embodiment preferably has a shape where more sharp portions are formed in a discharger portion so that the electric field may concentrate. In addition, it is preferable that dischargers are radially disposed from the center of the cross section of the tubular body and that it has a shape causing no decrease in pressure loss. In addition, as the discharger 12b shown in Figs. 7 and 8, it is preferably constituted so that many practical discharge positions are present.

[1-3] Porcelain bushing:

[0089] As described above, in the exhaust gas treatment apparatus of the present embodiment, it is preferable that the discharge electrode disposed inside the tubular body is supported in the central portion of the flow passage by a porcelain bushing passing through the wall face of the tubular body, being extended up to the central portion in a cross section perpendicular to the flow direction of the flow passage, and having electrical insulation. Such a constitution can cause corona discharge in a good condition by the discharge electrode and can generate an electric field for trapping the particulate matter in a good condition.

[0090] Examples of the material for the porcelain bushing include alumina, cordierite, mullite, and glass, and alumina or the like excellent in insulation, thermal resistance, thermal shock resistance, corrosion resistance, mechanical strength, and the like, can be used more suitably.

[0091] Such a porcelain bushing preferably has a constitution where a creeping discharge is not caused on the surface of the porcelain bushing upon applying a voltage on each of the electrodes. For example, as shown in Figs. 9 and 10, as a porcelain bushing 16 used for the exhaust gas treatment apparatus of the present embodiment, one having a groove-like unevenness 34 formed on the surface thereof can suitably be used. Here, Fig. 9 is a side view schematically showing an example of a porcelain bushing used for an exhaust gas treatment apparatus of the present invention, and Fig. 10 is a top view of the porcelain bushing shown in Fig. 9.

[0092] In addition, when particulate matter such as soot adheres to the porcelain bushing, insulation breakdown may be caused between the tubular body and the discharge electrode by the particulate matter adhering to the porcelain bushing to hinder the generation of the electric field for corona discharge or the dust collection. Therefore, for example, it may have a constitution having a heater disposed inside the porcelain bushing so that particulate matter adheres to the surface of the porcelain bushing can be combusted and removed by heating the heater.

[0093] In addition, it may have a constitution where a catalyst is applied on the surface of the porcelain bushing exposed inside the tubular body to be able to combust and remove adhering particulate matter by the heat of exhaust gas from an engine or the like when particulate matter adheres to the surface of the porcelain bushing. For example, as such a catalyst, an oxidation catalyst used for purification of exhaust gas discharged from an internal combustion engine or the like can suitably be used. Suitable examples of the oxidation catalyst include a conventionally known oxidation catalyst containing platinum (Pt), rhodium (Rh), palladium (Pd), or the like.

[0094] In addition, as shown in Figs. 11 and 12, it may have a shape where the side portion exposed inside the tubular body of the porcelain bushing 16 protrudes toward the upstream side of the flow passage. A porcelain bushing 16 thus constituted hardly hinders the flow of exhaust gas to reduce resistance of exhaust gas against the porcelain bushing 16, and the particulate matter hardly adheres to the surface of the porcelain bushing 16. Here, Fig. 11 is a side view schematically showing another example of a porcelain bushing used for an exhaust gas treatment apparatus of the present invention, and Fig. 12 is a top view of the porcelain bushing shown in Fig. 11.

[1-4] Voltage introduction portion:

[0095] The voltage introduction portion is a member including a wire or the like for applying a voltage to the discharge electrode and connected to a power source (not illustrated) for causing corona discharge and generating an electric field for trapping the charged particulate matter. Incidentally, in the exhaust gas treatment apparatus 1a of the present embodiment shown in Figs. 1 to 4, it passes through the porcelain bushing 16 passing through the wall face of the tubular body 10 from the outside of the tubular body 10 and extended up to the central portion in a cross section perpendicular to the flow direction of the flow passage to be electrically connected to the discharge electrode 12 disposed inside the tubular body 10.

[1-5] Power source:

[0096] The powder source is for applying a voltage to the discharge electrode, and, for example, a direct current power source (DC power source), a pulse power source, or the like may suitably be used. In particular, in the exhaust gas treatment apparatus of the present embodiment, a direct current power source (DC power source) is preferable.

[0097] Specific values of the voltage applied on the discharge electrode and the electric power can suitably be determined so that suitable discharge and electric field can be generated depending on the size of the tubular body functioning as the flow passage; the flow amount and flow rate of the exhaust gas passing through the flow passage; the amount, size, number of the particulates contained in the exhaust gas; and the like.

[0098] For example, though the voltage is not particularly limited, in the case that the discharge electrode is electrically connected with each other and that the exhaust gas treatment apparatus of the present embodiment is used for treating exhaust gas discharged from a gasoline engine, the voltage is preferably 6 to 10 kV, more preferably 8 to 9kV. In addition, the electric power is preferably 2 to 30W, more preferably 4 to 15W. Such a constitution enables to perform the treatment of exhaust gas discharged from a gasoline engine in a good condition.

Example

[0099] Hereinbelow, the present invention will be described more specifically by Examples. However, the present invention is by no means limited to these Examples.

(Example 1)

[0100] There was manufactured an exhaust gas treatment apparatus 1a as shown in Figs. 1 to 3. The tubular body 10 had a circular cylindrical shape having a length of 300mm in the exhaust gas flow direction, an outer diameter of 60.5

mm, and an inner diameter of 53.5 mm, and the material of the tubular body was stainless steel.

[0101] An alumina porcelain bushing 16 was disposed in the position of 30 mm from the end face on the upstream side of the flow direction of the tubular body 10 so that it passed through the tubular body 10, and a voltage introduction portion 18 was disposed inside the porcelain bushing 16. A discharge electrode 12 was connected to the voltage introduction portion 18 to fix the discharge electrode 12 inside the tubular body 10.

[0102] As shown in Figs. 7 and 8, the discharge electrode 12 was constituted by the disc-like electrode support 12a and the 16 dischargers 12b (12 dischargers at an angle of 30° outside, and 4 dischargers at an angle of 90° inside) disposed on the disc-like electric support 12a.

[0103] The disc-like electrode support had a shape where 1/4 circles having a radius of 7 mm was gouged out of the ring-shaped support having the outer periphery of 20 mm so that a cross-shaped support having a width of 3 mm remains in the central portion. In addition, through-holes each having a diameter of 1.5 mm were formed in portions where the dischargers were to be disposed, and the dischargers were disposed in the through-holes. Incidentally, the electrode support was formed of stainless steel.

[0104] Each of the dischargers had a diameter of 1.5 mm with a sharp needle-like tip end and was formed of stainless steel. Each of the 12 dischargers disposed on the outside had a length of protruding by 10 mm from the surface of the electrode support, and each of the 4 dischargers disposed on the inside had a length of protruding by 20 mm from the surface of the electrode support.

[0105] In addition, the tubular body was formed to have a shape where the inner diameter is gradually reduced in the range of 15 mm from the face containing the central point of generation of corona discharge toward the downstream side of the flow passage. Incidentally, the shape of the tubular body was determined by a method for determining the shape of the tubular body in consideration of the aforementioned moving velocity in the exhaust gas flow direction and apparent drift velocity.

[0106] As the measurement of the dust collection efficiency (η), exhaust gas discharged from an automobile engine was sent in the exhaust gas treatment apparatus constituted in the same manner as in the aforementioned exhaust gas treatment apparatus of Example 1, and a constant voltage of 8 kV (electric current of 0.5 mA) was applied to the discharge electrode to measure the number of the particulates on both the inlet and outlet sides of the exhaust gas treatment apparatus. Incidentally, the dust collection efficiency (η) was 0.735.

[0107] The conditions for exhaust gas in the measurement of the dust collection efficiency (η) were as follows:

Engine rotational frequency: 2430 rpm,
Torque: 30 Nm,
Exhaust gas temperature: 339°C,
Temperature conversion air amount: 0.955m^3/min.

[0108] In addition, as the conditions for determining the shape of the tubular body, the area (A) of an electrode for collecting dust was the area (335.98cm^2) of the inner wall face in the range from the tip of the discharge electrode to the position of 200 mm, and the gas flow rate (Q) per unit time was 15916 cm^3/sec (0.955 m^3/min).

[0109] The "apparent drift velocity (W_d)" calculated from the aforementioned formulae (4) and (5) was 63 cm/sec. In addition, the "moving velocity (v) of the charged particulate matter proceeding in the exhaust gas flow direction" calculated from the gas flow rate (Q) per unit time is 708 cm/sec. From the above results, there was determined the shape of the tubular body in consideration of the moving velocity (v) in the exhaust gas flow direction and the apparent drift velocity (w_d) .

[0110] The thus constituted exhaust gas treatment apparatus of Example 1 was attached to a soot generator generating particulate matter by a burner with light oil being used as the fuel, and test exhaust gas (hereinbelow referred to as "exhaust gas" simply) at about 195°C was introduced at a flow rate of 1.5 m^3/min. In such a state, as shown in Table 1, a direct current voltage of 8 kV with an electric power of 5W was applied on the discharge electrode of the exhaust gas treatment apparatus of Example 1 to treat the exhaust gas. The mass (g/hour) of the particulate matter on the inlet side of the exhaust gas treatment apparatus during treating the exhaust gas, the number ($\times 10^7$ particulates/sec.), the mass (g/hour), and the average particle diameter (μm) of the particulates on the outlet side were measured. The measurement results are shown in Table 2.

(Measurement of the number of particulates)

[0111] A particle counter (Electrical Low Pressure Impactor (ELPI) produced by Dekati Ltd.) was equipped on the downstream side of the discharge electrode to measure the number of the discharged particulates by each particle diameter range on the downstream side of each electrode in the case that a voltage was applied on the discharge electrode (upon applying a voltage) and in the case that no voltage was applied (upon applying no voltage) . Then, from the sum of the measurement data for each particle diameter range, the total number (total discharge number) of the particulate matter discharged from the downstream side was calculated out. Incidentally, in the measurement, particles having the diameter of 0.007 to 10 μm were measured and classified into the particulate diameter regions of 0.007 to 0.014, 0.014 to 0.0396, 0.0396 to 0.0718, 0. 0718 to 0. 119, 0. 119 to 0.200, 0.200 to 0.315, 0.315 to 0.482, 0.0482 to 0.760, 0.760 to 1.23, 1.23 to 1.95, 1.95 to 3.08, 3.08 to 6.27 (unit of μm). Incidentally, for example, in the case of the particle diameter of "0.07 to 0.014", particles having a particle diameter of 0.007 μm or more and below 0.014 μm are included.

(Measurement of ratio of reduced particulate matter)

[0112] From the data of the total discharge number ($\times 10^7$ particulates/sec.) upon each of the application of a voltage and the application of no voltage obtained by the aforementioned measurement of the number of particulates, the ratio of the reduced number of the discharged particle by the use of the exhaust gas treatment apparatus was calculated by the following formula (6).

(Total number upon applying no voltage - total number upon applying a voltage) / total number upon applying no voltage × 100 ... (6)

(Measurement of mass of particulate matter)

[0113] A bypass line from the exhaust gas flow passage was provided on each of the upstream side and the downstream side of the position where the exhaust gas treatment apparatus was disposed, and a paper filter for sampling the particulate matter in the exhaust gas passing through the bypass lines was disposed in each of the bypass lines. The sampling time of the particulate matter by the paper filter was three minutes, and the change in the paper filter mass by the sampling was calculated from the paper filter mass before sampling weighed in advance. By the mass change in the mass of each of the paper filters disposed on the upstream side and the downstream side, the mass (g/hour) of the particulate matter on each of the inlet side and the outlet side of the exhaust gas treatment apparatus was calculated.

(Average particle diameter of particulate matter)

[0114] From the measurement data by particle diameter obtained by the aforementioned measurement of the number of particulates, the average particle diameter of the particulates contained in exhaust gas was calculated by the following formula (7).

Average particle diameter = [Σ{(average particle diameter in each sampling range) × (number of particulates sampled in each sampling range)]/total discharge number ... (7)

(Pressure loss ΔP)

[0115] A socket was disposed as a slot for taking out exhaust gas pressure on each of the upstream side and the downstream side on the exhaust gas treatment apparatus mounted in the exhaust gas pipe and connected with a meter (digital manometer produced by Cosmo Instruments, Co., Ltd.) by means of a SUS tube and a teflon tube. The pressure P1 on the upstream side of the exhaust gas treatment apparatus and the pressure P2 on the downstream side of the exhaust gas treatment apparatus were measured, and the pressure loss (ΔP(kPa)=P1-P2) was calculated.

[0116]

Table 1

	Inner diameter of tubular body of (mm)	Distance where inner diameter is gradually reduced (mm)	Inner diameter after inner diameter of tubular body is (mm)	Addition of drift velocity	Discharge electrode	
					Voltage (kV)	Electric power (W)
Example 1	53.5	15	47	Added	8	16
Example 2	53.5	20	39	Added	8	16
Example 3	53.5	25	23.4	Added	8	16
Example 4	53.5	15	44.3	Not added	8	16
Example 5	53.5	20	35.5	Not added	8	16
Comp. Ex. 1	53.5	Zero	53.5	None	8	16

[0117]

Table 2

	Condition of exhaust gas		Particulate matter on inlet side	Particulate matter on outlet side			Ratio of reduced number of particulates (%)	Pressure loss ΔP (kPa)
	Flow rate (m/sec.)	Temperature (°C)	Mass (g/hour)	Mass (g/hour)	Number ($\times 10^7$ /sec.)	Average particle diameter (μm)		
Example 1	12	195	1.05	0.37	5.13	0.038	66	0.16
Example 2	12	195	1.07	0.37	4.82	0.038	68	0.4
Example 3	12	195	1.06	0.35	3.22	0.038	79	2.65
Example 4	12	195	1.06	0.37	5.03	0.038	67	0.21
Example 5	12	195	1.07	0.37	4.72	0.038	69	0.6
Comp. Ex. 1	12	195	1.08	0.39	6.03	0.038	60	0.03

(Example 2)

[0118] There was manufactured an exhaust gas treatment apparatus constituted in the same manner as in Example 1 except that the inner diameter of the tubular body was formed to be generally reduced in the range from the face containing the central point of generation of corona discharge to the position of 20 mm toward the downstream side of the flow passage, and exhaust gas was treated in the same manner as in Example 1. The measurement results of the mass (g/hour) of particulate matter on the inlet side of the exhaust gas treatment apparatus and the number ($\times 10^7$ particulates/sec.), mass (g/hour), and average particle diameter (μm) of particulates on the outlet side during the exhaust gas treatment are shown in Table 2.

(Example 3)

[0119] There was manufactured an exhaust gas treatment apparatus constituted in the same manner as in Example 1 except that the inner diameter of the tubular body was formed to be generally reduced in the range from the face containing the central point of generation of corona discharge to the position of 25 mm toward the downstream side of the flow passage, and exhaust gas was treated in the same manner as in Example 1.

(Example 4)

[0120] There was manufactured an exhaust gas treatment apparatus constituted in the same manner as in Example 1 except that the inner diameter of the tubular body was formed to be generally reduced in a spherical surface shape along an equipotential face in the range of 15 mm toward the downstream side of the flow passage without adding the aforementioned apparent drift velocity, and exhaust gas was treated in the same manner as in Example 1.

(Example 5)

[0121] There was manufactured an exhaust gas treatment apparatus constituted in the same manner as in Example 4 except that the inner diameter of the tubular body was formed to be generally reduced in the range from the face containing the central point of generation of corona discharge to the position of 20 mm toward the downstream side of the flow passage, and exhaust gas was treated in the same manner as in Example 1.

[0122] In the exhaust gas treatment apparatuses of Examples 2 to 5, the measurement results of the mass (g/hour) of particulate matter on the inlet side of the exhaust gas treatment apparatus and the number ($\times 10^7$ particulates/sec.), mass (g/hour, and average particle diameter (μm) of particulates on the outlet side during the exhaust gas treatment in the same manner as in Example 1 are shown in Table 2.

(Comparative Example 1)

[0123] There was manufactured an exhaust gas treatment apparatus constituted in the same manner as in Example 1 except that the tubular body had a circular cylindrical shape having a fixed size of 53.5 mm from the inlet side to the outlet side of the apparatus, and exhaust gas was treated in the same manner as in Example 1. The measurement results of the mass (g/hour) of particulate matter on the inlet side of the exhaust gas treatment apparatus and the number ($\times 10^7$ particulates/sec.), mass (g/hour, and average particle diameter (μm) of particulates on the outlet side during the exhaust gas treatment are shown in Table 2.

(Discussion)

[0124] Each of the exhaust gas treatment apparatuses of Example 1 to 5 had a high ratio of the reduced number of particulates in comparison with the exhaust gas treatment apparatus of Comparative Example 1, and the particulates could be agglomerated in a good condition inexhaustgas. Incidentally, since each of the exhaust gas treatment apparatuses of Examples 1 to 5 was constituted to have a shape where the inner diameter of the tubular body was reduced in the range from the central point of generation of corona discharge to the position of 15 mm, 20 mm, or 25 mm, the pressure loss was increased in comparison with the exhaust gas treatment apparatus of Comparative Example 1. However, the increase was small, and, even if it is installed in an exhaust system of a vehicle provided with a gasoline engine, exhaust gas can be treated in a good condition.

[0125] In addition, in the exhaust gas treatment apparatuses of Examples 1 to 3, by the tubular body where a drift velocity was added, a sufficient effect of reduction in the number could be obtained though the increase in pressure loss was minute. That is, by adding the drift velocity, the increase in pressure loss could be suppressed to be very small with respect to the effect in further reducing the number of particulates, and thereby high purification performance and reduction of strain to an engine or the like could be successfully combined further.

[0126] Incidentally, in the results shown in Table 2, the average particle diameter of the particulates on the outlet side of Examples 1 to 5 and Comparative Example 1 was 0.038 μm. However, from the results of measurement of the number for each particle size using the aforementioned ELPI, in exhaust gas treatment apparatuses of Examples 1 to 5, it was confirmed that the number of particulates having a relatively large average particle diameter among the particulates on the outlet side increased with the passage of time. Here, Table 3 shows the change of the number of the particulates for each particle diameter on the outlet side. Table 3 shows results of measurement where the particles measured on the outlet side of the exhaust gas treatment apparatus of Example 1 were classified into three particle diameter ranges (0.007 to 0.014 μm, 0.014 to 1.23 μm, and 1.23 to 6.27 μm) to measure the number of particulates contained in each particle diameter range. Incidentally, Table 3 shows the measurement results (before application) for 10 seconds before a voltage is applied and the measurement results (7 minutes after application) for 10 seconds from when 7 minutes passed after a voltage is applied.

[0127]

Table 3

		Particle diameter (μm)		
		0.007 to 0.014	0,014 to 1.23	1.23 to 6.27
Number of particulate matter	Before application	5.43×10^8	1.01×10^9	2.86×10^4
	7 min. after application	2.82×10^8	5.69×10^8	2.01×10^5

[0128] As shown in Table 3, in the results of the measurement when 7 minutes passed after application, the number of the particulates having small particle diameters in the range of 0.007 to 0.014 μm was reduced, while the number of the particulates having large particle diameters in the range of 1.23 to 6.27 μm was increased. By this, it was confirmed that, by the exhaust gas treatment apparatus of Example 1, plurality of particulates in exhaust gas, particularly, particulates having relatively small particle diameters were agglomerated to be bloated as particulates having larger particle diameters.

Industrial Applicability

[0129] An exhaust gas treatment apparatus of the present invention can be used as an exhaust gas treatment apparatus decreasing the number of the particulates present in exhaust gas by agglomerating and bloating the particulate matter in the exhaust gas discharged from internal combustion engines such as automobile engines, construction machine engines; industrial machine stationary engine and other combustion burning appliances.

Claims

1. An exhaust gas treatment apparatus comprising:

a tubular body functioning as a flow passage where exhaust gas passes, and
a discharge electrode disposed in an central portion in a cross section perpendicular to a flow direction of the flow passage inside the tubular body and causing corona discharge in the vicinity thereof by applying a voltage;
wherein the tubular body has a shape where an inner diameter of the tubular body is gradually reduced in a predetermined range from a face which contains a central point of generation of corona discharge generated by the discharge electrode and which is perpendicular to the flow passage toward the downstream side of the flow passage, and
the number of particulates suspended in the exhaust gas is decreased by charging the particulate matter contained in the exhaust gas passing through the tubular body by corona discharge caused by the discharge electrode, collecting the charged particulate matter on an inner wall face of the tubular body by the electric field generated from the discharge electrode toward the inner wall face of the tubular body to agglomerate the plural particulates, and allowing the agglomerated particulates to scatter again.

2. The exhaust gas treatment apparatus according to Claim 1, wherein the discharge electrode has a disc-like electrode support disposed perpendicularly to the flow direction of the flow passage and a needle-like discharger disposed perpendicularly to the electrode support and wherein the central point of generation of corona discharge is the central point of a face which contains the central point of generation of corona discharge of the tubular body and which is perpendicular to the flow passage.

3. The exhaust gas treatment apparatus according to Claim 2, wherein the tubular body has a shape where the inner diameter of the tubular body is reduced so that the distance from the central point of generation of corona discharge to the inner wall face of the tubular body in the predetermined range toward the downstream side of the flow passage is in the range of $\pm 10\%$ of a length from the central point of generation of corona discharge to the inner wall face of the tubular body in the face which contains the central point of generation of corona discharge of the tubular body and which is perpendicular to the flow passage.

4. The exhaust gas treatment apparatus according to Claim 3, wherein the tubular body has a shape where a moving velocity of the charged particulate matter proceeding in an exhaust gas flow direction and a drift velocity when the particulate matter is drawn to the inner wall face are taken into consideration.

5. The exhaust gas treatment apparatus according to any one of Claims 1 to 4, wherein the length in the predetermined range where the inner diameter of the tubular body is gradually reduced is 0.2 to 0.9 times the distance from the central point of generation of corona discharge of the tubular body to the inner wall face of the tubular body in the face perpendicular to the flow passage.

6. The exhaust gas treatment apparatus according to any one of Claims 1 to 5, wherein the discharge electrode is supported in the central portion of the flow passage by a porcelain bushing passing through the wall face of the tubular body and extended up to the central portion in a cross section perpendicular to the flow direction of the flow passage.

7. The exhaust gas treatment apparatus according to Claim 6, wherein the porcelain bushing has groove-shaped unevenness formed on the surface thereof.

8. The exhaust gas treatment apparatus according to any one of Claims 1 to 7, which is disposed in an exhaust system of a vehicle provided with a gasoline engine as a drive mechanism.

9. A method of treatment of exhaust gas, using an apparatus according to any one of claims 1 to 8.

FIG.1

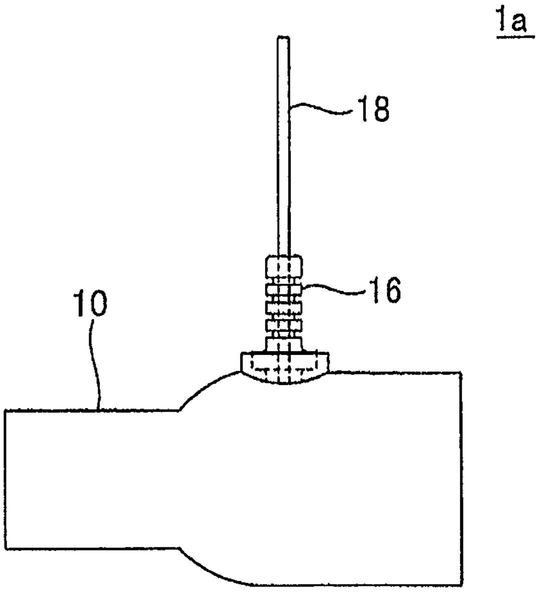


FIG.2

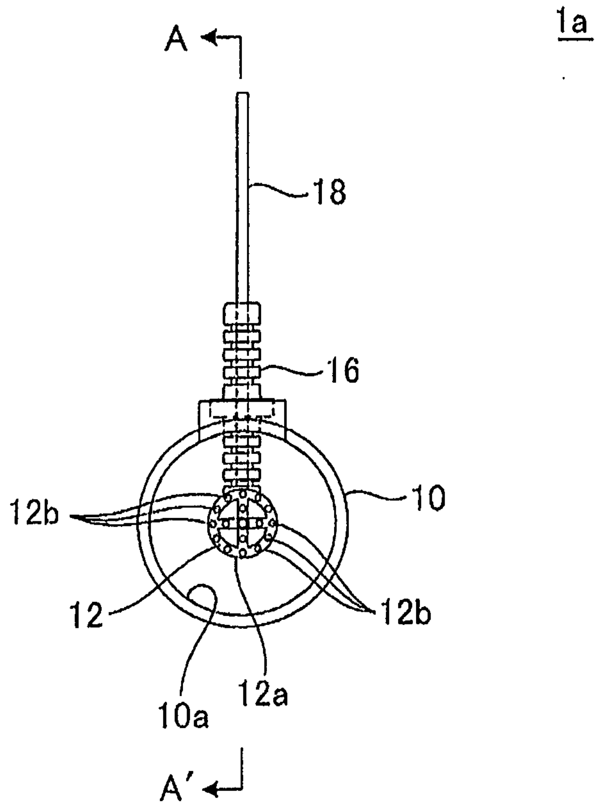


FIG.3

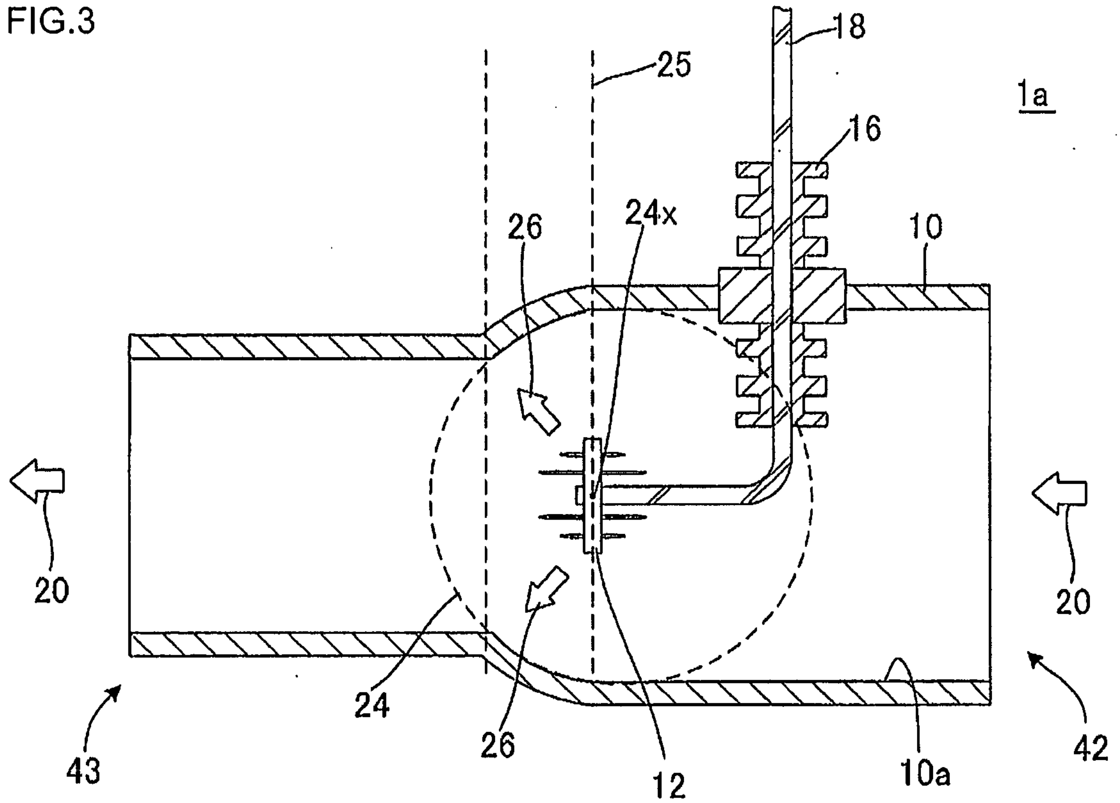
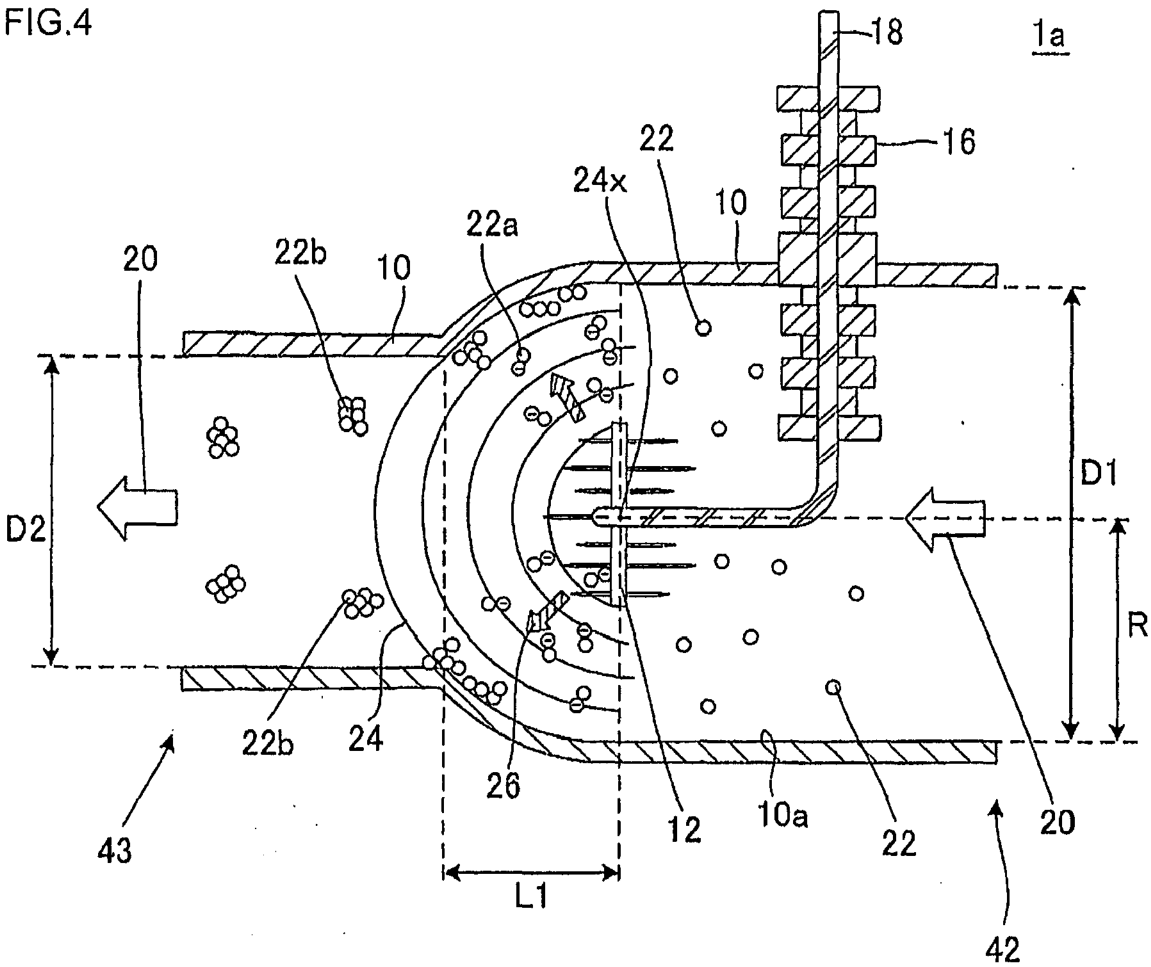


FIG.4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24x
10
22a
20
22b
10
D1
D2
R1
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22b
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26
12
10a
22
43
L1
42

FIG.5

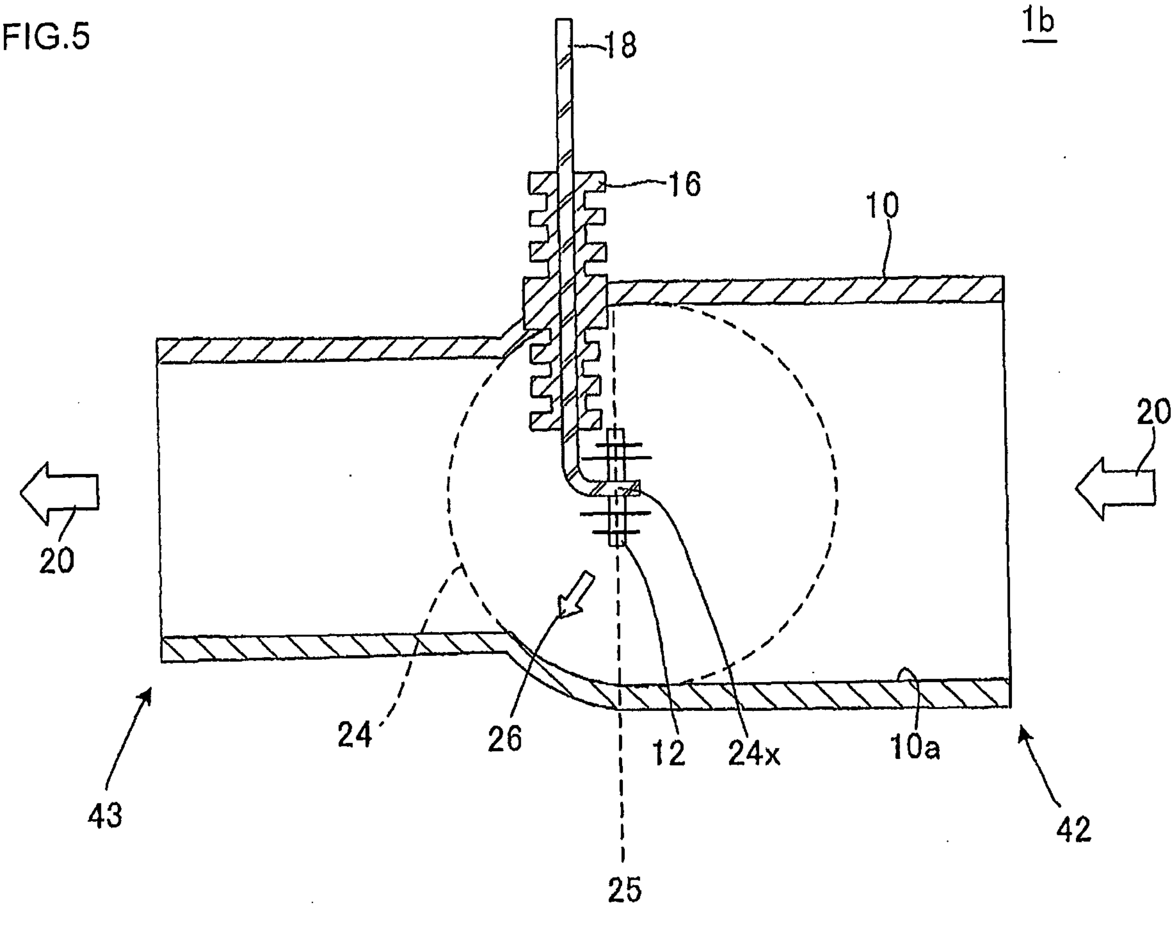
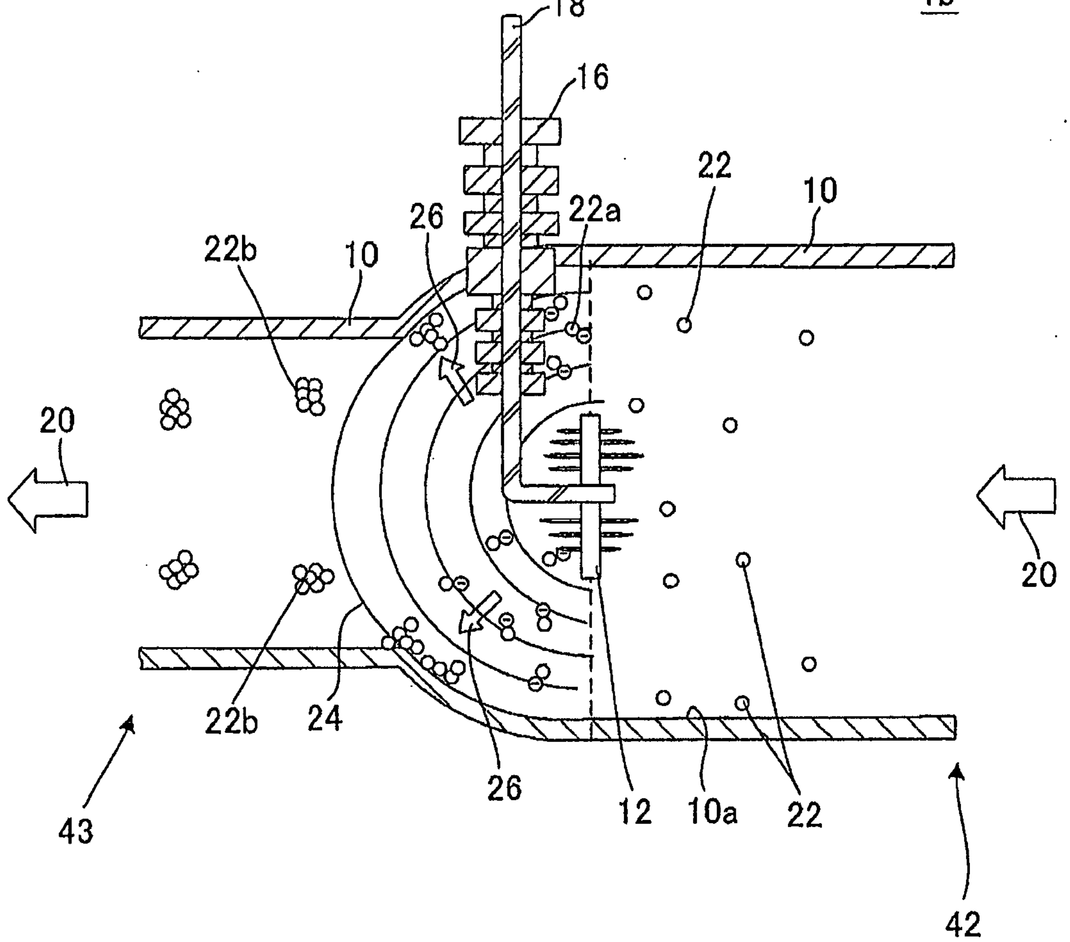


FIG.6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22b
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26
12
10a
22
43
42

FIG.7

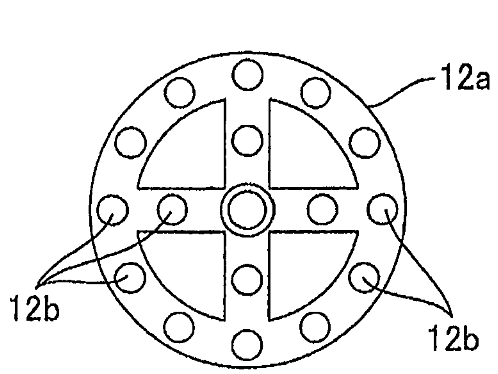

12
12a
12b
12b

FIG.8

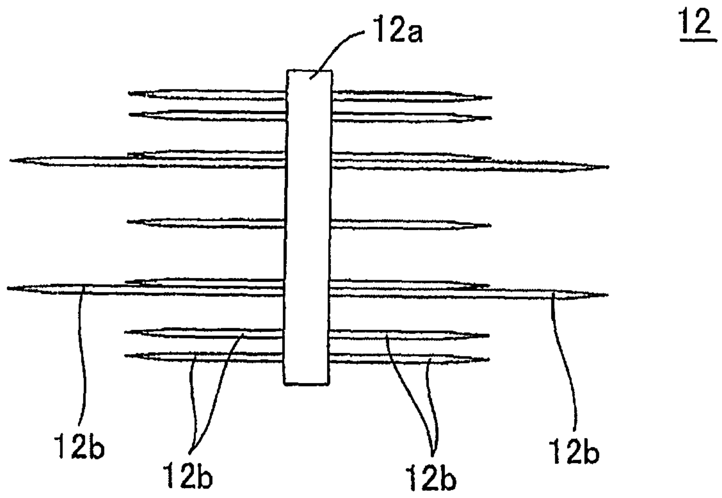


FIG.9

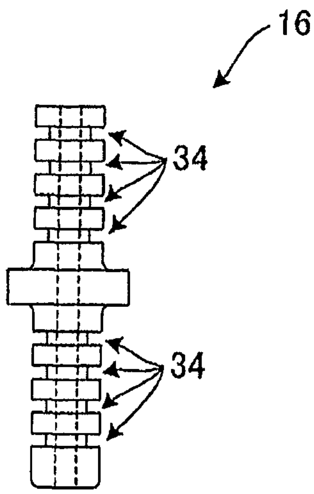


FIG.10

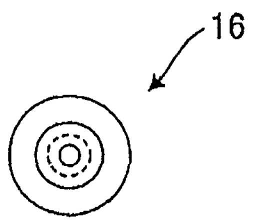


FIG.11

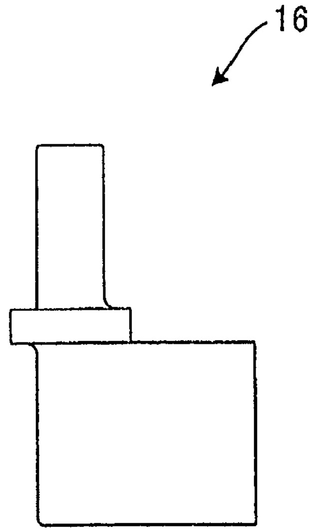
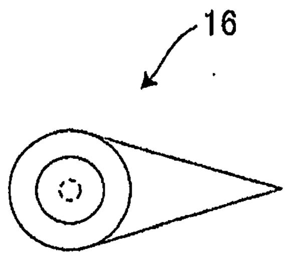


FIG.12



REFERENCES CITED IN THE DESCRIPTION

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