ABSTRACT: The present invention relates to an apparatus (1) for removal of particulate matter from a gas, wherein the apparatus comprises, a casing (3) comprising an inlet (5) for receiving a contaminated gas (7a) comprising particulate matter, and for inducing a swirl to said contaminated gas, an ionization zone (9) disposed inside the inlet (5) in a first flow-path (11) of the contaminated gas (7a) for ionizing the particulate matter of the contaminated gas (7a) by producing a corona discharge, a separation zone (15) disposed in a second flow-path (17) of the contaminated gas (7a) downstream of the inlet (5) for separating a portion of the ionized particulate matter from the swirl-induced contaminated gas (7a) by centrifugal action and by means of an electrical field to produce a partially clean gas (7b), and a separation electrode (22) for producing an additional electric field in at least a portion of the separation zone (15), wherein the separation electrode (22) is electrically connected to an electrical potential provided to the ionization zone (15) for producing the corona discharge.

FIG 1

[Continued on next page]
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Description

Apparatus for removal of particulate matter from a gas

The present invention relates to removal of particulate matter from a gas, and in particular, to an improvement in the use of centrifugal action and electrostatic force for particle removal from a gas.

Fuel and flue gas generated from the thermo-chemical conversion processes mostly contain dust particles having a wide range of sizes. These gases should be free of dust particles either to meet the end application or to meet the environmental norms.

Cyclone separators are well-known devices for removing particulates from a gas stream. In principle, a stream of particle-laden raw gas is introduced tangentially into a cyclonic separation zone so that the particles experience a centrifugal force in the ensuing swirling flow. The particles are collected on the outer wall of the separation zone and a resultant clean gas exits from a central exhaust duct. Cyclones are considered suitable for removing particles larger than 10 μm from a gas stream due to centrifugal force, which is responsible for particle separation. However, their low collection efficiency with respect to separation of particles smaller than 5 to 10 μm puts an additional requirement for further cleaning of the gas to the desired levels. Conceptually, cyclones can be designed to remove sub-micron particles but the associated pressure drop would be prohibitively high resulting in considerable power consumption. Also, depending on the extent of dust loading i.e. concentration of dust particles, there is a possibility of choking at the entry of the cyclone. Hence, the best cyclone design is essentially a trade-off between performance i.e. collection efficiency and the allowable pressure drop.
To make a gas free of particulate matter, a series of pollution control equipment including cyclone, scrubbers, electrostatic precipitators (ESP) are generally employed. In this arrangement, the cyclone removes the larger particles from the gas to reduce load on the subsequent equipment like scrubber, ESP and filters where removal of the smaller particles takes place.

Due to strict environmental regulations, most of the industrial applications use dust filters, such as woven textile bag filter, or ceramic candle filter, to remove dust particles. However, the pressure drop across the filter, and problems related to the regeneration of filter, make this technology less attractive compared to other available options. Electrostatic precipitators are considered very effective in removal of smaller particles because of dominancy of electrical forces and have been used mainly in thermal power plants for fly ash removal. Pressure drop across an ESP is significantly lower than for any other pollution control equipment. Thus the resulting energy consumption is lower making the ESP a favorable option.

Accordingly, a combination of cyclone and electrostatic precipitator has been suggested to improve the collection efficiency of the cyclone. The charging and collection of particle due to electrostatic separation and separation due to centrifugal action can happen simultaneously inside the cyclone or can be implemented as independent stages.

The object of the present invention is to improve the particle separation efficiency of an apparatus involving centrifugal action and electrostatic force.

The above object is achieved by the apparatus according to claim 1.

As the ionization zone is provided at the inlet of the casing, all the particulate matter in the contaminated gas is
charged or ionized in the ionization zone. As all the particulate matter is charged, the electric field generated in the separation zone forces the charged particulate matter to migrate towards the wall of the casing. Further the electric field assists in preventing re-entrainment of particles removed from the wall of the casing due to drag forces. Thus, the particulate matter is separated from the contained gas more efficiently to produce the partially clean gas. Additionally, as the ionization electrode is disposed within the inlet of the casing, the compact design of the apparatus can be achieved.

According to an embodiment, further comprising an outlet in flow communication with the separation zone for the partially clean gas to egress, the outlet being electrically insulated from the casing, wherein the separation electrode comprises the outlet (23), wherein the outlet (23) is electrically conductive. This results in producing the additional electric field in the separation zone without the requirement of disposing an additional structure in the separation zone.

According to another embodiment, the apparatus further comprises an feed-through arrangement (29) for passing the corona initiation electrical potential to the ionization zone, the feed-through arrangement being electrically insulated from the casing and being disposed in a third flow-path of the partially clean gas. This assists in insulting the feed-through arrangement in the third flow-path of the partially clean gas and thus prevent short circuit of the insulation as the deposition of particulate matter on the surface of the insulation is reduced.

According to another embodiment, the ionization zone comprises an ionization electrode for producing the corona discharge. Ionization electrode comprises means for producing the corona discharge.
According to another embodiment, the ionization electrode is electrically connected to the feed-through arrangement. The feed-through arrangement provides the corona initiation electrical potential to the ionization electrode.

According to another embodiment, the ionization electrode comprises at least one rod and at least one sharp edged member electrically connected to the at least one rod. Sharp edges enable in producing efficient corona discharge and also reduce the electrical potential required for producing the corona discharge.

According to another embodiment, the separation electrode is electrically connected to the feed-through arrangement. Thus, the electrical potential provided to the ionization electrode for producing the corona discharge can be provided to the separation electrode.

According to another embodiment, the ionization electrode is electrically connected to the separation electrode. As the separation electrode and the ionization electrode are to be maintained at the same electrical potential, the ionization electrode can be electrically connected to the separation electrode and the corona initiation electrical potential can be passed on to the separation electrode.

According to another embodiment, the casing is electrically grounded and the electrical field is created between the ionized particulate matter and the casing, and the additional electric field is created between the separation electrode and the casing. The casing being grounded enables in producing the electrical field and the additional electrical field.

According to another embodiment, the apparatus further comprises an additional electrode disposed inwardly in the outlet, the additional electrode extending out of the outlet such that an additional volume of the additional electrica
field can be created. This assists in enhanced separation of charged particulate matter.

According to another embodiment, the additional electrode is electrically connected to the feed-through arrangement. This provides the electrical potential being provided for producing the corona discharge to the additional electrode.

According to another embodiment, the additional electrode extends into at least a portion of the separation zone. This enables in increasing the volume of the additional electrical field, and thus, prevents re-entrainment of the particulate matter more efficiently.

According to another embodiment, the apparatus further comprises an additional ionization zone along the third flow-path of the partially clean gas for ionizing the particulate matter remaining in the partially cleaned gas by producing an additional corona discharge in the flow-path 25. Thus, the particulate matter remaining in the partially clean gas can be charged electrically and thereafter removed at a subsequent separation stage.

According to another embodiment, the additional ionization zone comprises a first portion of the additional electrode. The additional corona discharge for ionizing or charging the particulate matter can be produced by the first portion of the additional electrode. Additionally, extending the first portion of the additional electrode into the additional ionization zone enables in easy construction without the requirement of an additional structure for producing the additional corona discharge.

According to another embodiment, the additional ionization zone comprises an additional ionization electrode electrically connected to the feed-through arrangement 27 for producing the additional corona discharge in the flow-path 25.
The present invention is further described hereinafter with reference to illustrated embodiments shown in the accompanying drawings, in which:

5 FIG 1 is a schematic diagram of an apparatus for removal of particulate matter from a gas according to an embodiment herein,

FIG 2 illustrates an ionization electrode of an apparatus according to another embodiment,

FIG 3 illustrates a top view of an apparatus according to an embodiment herein,

10 FIG 4 illustrates an apparatus for removal of particulate matter from a gas according to another embodiment,

FIG 5 illustrates an apparatus for removal of particulate matter from a gas according to yet another embodiment, wherein the apparatus comprises an additional ionization zone,

15 FIG 6 illustrates an apparatus according to yet another embodiment herein,

20 FIG 7 illustrates a second portion of a second electrode extending into an additional ionization zone according to an embodiment here, and

25 FIG 8 illustrates an apparatus 10 according to yet another embodiment herein.

Referring now to FIG 1 is illustrated an apparatus 1 for removal of particulate matter from a gas according to an exemplary embodiment of the present invention. The illustrated apparatus 1 provides a compact solution combining a cyclone electrostatic precipitation to increase the overall particle collection efficiency with increased insulation by reducing
precipitation of charged particulate matter on the insulators. The apparatus 1 comprises a casing 3 having an inlet 5 for receiving a contaminated gas 7a that comprises particulate matter. The gas 7a to be cleaned may include a hot gas, such as an industrial flue gas, or a fuel gas, such as producer gas or synthetic gas, derived from biomass, coal or any other solid fossil fuel. The particulate matter contained in the contaminated gas 7a may include, for example ash and dust particles in a wide range of sizes, including large sized particles (> 10 µm), intermediate sized particles (> 1 µm) and small sized particles (sub-micron).

The inlet 5 is designed to induce a swirl to the incoming particle-laden gas 7a as it is introduced tangentially into the casing 3. At the inlet 5, the particulate matter contained in the contaminated gas 7a, is ionized by an ionization zone 9 disposed along a first flow-path 11 of the contaminated gas 7a. In the shown example of FIG 1, the inlet 5 includes a duct, illustrated as the inlet duct 6a. The ionization zone 9 comprises means for charging or ionizing the particulate matter in the contaminated gas 7a. In the shown example of FIG 1, to achieve this, an ionization electrode 13 is disposed inside the inlet duct 6 along the first flow-path 11. The ionization electrode 13 is disposed such that a gap is maintained between the ionization electrode 13 and the wall 6a of the inlet duct 6 in the ionization zone 9. For example, the ionization electrode 13 can be disposed substantially coaxially and can be substantially centered in the ionization zone 9. The ionization electrode 13 is connected to a high-voltage source, preferably of negative polarity, which is capable of providing a corona initiation electrical potential. As a result of the corona initiation electrical potential applied to the ionization electrode 13, a corona discharge is produced in the first flow-path 11 that ionizes the particulate matter in the gas flowing through it. In the shown example of FIG 1, the ionization electrode 13 comprises a metallic rod. However, the ionization electrode 13 may comprise a plurality of metallic rods and additional electri-
cally conductive members having sharp edges, such as thin sheets, being connected to one or more of these metallic rods, to aid in the production of a corona discharge. As the ionization electrode 13 is disposed inside the inlet 5, all the particulate matter contained in the gas 7a is ionized. According to an aspect, advantageously, the ionization electrode 13 can be disposed substantially at the end of the inlet 5, such that, the flow-path of the contaminated gas 7a comprising the charged particulate matter inside the inlet is minimum. This further enables in avoiding precipitation of the charged particulate matter on the wall 6a of the inlet duct 6.

The gas flowing out of the ionization zone 9 thus comprises charged or ionized particulate matter. This charged or ionized particulate matter is separated from the gas subsequently at a separation zone 15 along a second flow-path 17 downstream of the inlet 5. The swirl imparted to the gas 7a tends to concentrate the charged or ionized particulate matter, particularly large sized particles towards the wall 19 of the casing 3 by centrifugal action. Additionally, the wall 19 of the casing 3 can be electrically grounded. As the wall 19 of the casing 3 is grounded, an electric field is produced between the ionized or charged particulate matter of the gas 7a and the wall 19 of the casing 3. This electric field further assists in migration of charged or ionized particles towards the grounded wall 19 of the casing 3. The combination of the centrifugal action and the electrical field increases the tendency of the particulate matter, particularly large sized particles, to concentrate towards the wall 19 of the casing 3, to produce a resultant partially clean gas 7b. The particulate matter that concentrates on the wall 19 and can be removed either using some impulse/force in case of a dry system, for example by rapping on the wall 19, or liquid such as water in the case of a wet system and can be collected in a particle collection box 21.
Referring still to FIG 1, according to an embodiment, an additional electric field can be produced in at least a portion of the separation zone 15. To achieve this, an electrically conducting separation electrode 22 can be disposed in the portion of the separation zone 15 for producing the additional electric field. The separation electrode 22 can be electrically connected to an electric potential provided to the ionization electrode 13 of the ionization zone 9 for producing the corona discharge. As the separation electrode 22 is electrically connected to the same electric potential to which the ionization electrode 13 is connected, an additional electric field is created between the wall 19 of the casing 3 and the separation electrode 22. The additional electrical field results in additional electrostatic force acting on the charged or ionized particulate matter, and thus, further assists in migration of the charged or ionized particles towards the wall 19 of the casing 3. The additional electric field assists in preventing re-entrainment of particles removed from the wall 19 of the casing 3 due to drag forces. As the particles are very likely charged or will be charged due to agglomeration with charged particles in the second flow-path 17, the particles removed from the wall 19 due to drag forces will be forced to migrate towards the wall 19 again due to the additional electric field. Thus, re-entering of the particles separated from the gas 7b is prevented and this provides increase efficiency in removing the particulate matter from the gas 7a.

Referring still to FIG 1, the partially clean gas 7b reverses its flow direction to exit the casing 3. An outlet 23, also known as a vortex finder, electrically insulated with the casing 3, is disposed radially inwardly in a third flow-path 25 of the partially clean gas 7b exiting the casing 3. Advantageously, the outlet 23 can be in the form of a duct as illustrated in FIG 1. In the shown example of FIG 1, the outlet 23 is insulated from the casing 3 via the insulators 27a and 27b. Thus, the outlet 23 can be made of an electrically conductive material, for example, the outlet 23 can be made of
the same material of which the casing 3 is made of. This simplifies the manufacturing process as both the casing 3 and the outlet 23 can be made of the same material. However, the outlet 23 can be made of an insulating material also. In the shown example, the outlet 23 is made of an electrically conductive material and the separation electrode 22 comprises the outlet 23 for producing the additional electric field in the separation zone 15. Thus, the additional electric field in the separation zone is produced between the outlet 23 and the wall 19 of the casing 3. This eliminates the requirement of disposing an additional structure for producing the additional electric field. Additionally, as the outlet 23 is conductive and electrically connected to the electrical potential provided to the ionization electrode 13 for producing the corona discharge, the ionization electrode 13 can be electrically connected to the outlet 23 for receiving the corona initiation electrical potential. The partially clean gas 7b exits the casing 3 via the outlet 23, as illustrated by the third flow-path 25.

Alternatively, if the outlet 23 is not made of an electrically conducting material, the separation electrode 22 can comprise an additional electrically conducting structure and can be disposed in the separation zone 15. For example, the separation electrode 22 can be disposed outside the outlet 23 along the length of the outlet 23.

Referring still to FIG 1, according to an embodiment herein, the corona initiation electrical potential to the ionization electrode 13 of the ionization zone 9 is provided from an feed-through arrangement 29 disposed in the third flow-path 25 of the partially clean gas 7b. The feed-through arrangement 29 is insulated from the casing 3 using an insulator 30. As the feed-through arrangement is disposed in the flow-path 25 of the partially clean gas 7b, the insulator 30 can advantageously be mounted in the third flow-path 25 of the partially clean gas 7b. Since, the insulator 30 encounters only the partially clean gas 7b, precipitation of particulate mat-
ter on surfaces of the insulator 30 is reduced. This enables in preventing electrical short circuit between the feed-through arrangement 29 and the casing 3. According to an embodiment, the feed-through arrangement 29 can extend into the outlet 23 for passing the corona initiation electrical potential to the ionization electrode 13 of the ionization zone 9. For example, in an implementation, the feed-through arrangement 29 can be disposed coaxially in the outlet 23 and the ionization electrode 13 can be electrically connected to the feed-through arrangement 29. In another implementation, where the outlet 23 is made of electrically conductive material, the feed-through arrangement 29 can be electrically connected to the outlet 23, referenced as 31, and the ionization electrode 13 can be electrically connected to the outlet 23.

According to an embodiment, in order to increase a volume of the additional electric field in the separation zone 15, means can be provided for producing the additional electric field in the lower part of the casing 3. To achieve this, according to an embodiment, for example, if the separation electrode comprises the additional structure, the length of the structure can be such that it extends into the lower part of the casing 3. According to another embodiment, the separation electrode can comprise an additional electrode 33 disposed inwardly in the outlet 23. The additional electrode 33 can be mounted such that it is substantially at the centre of the outlet 23 or can be mounted along the side of the outlet 23. According to an aspect, the end 34 of the additional electrode 33 proximal to the bottom of the casing 3 can be blunt as only an electric field is to be produced with respect to the electrically grounded casing 3 and no corona discharge is to be produced. Advantageously, as illustrated in FIG 1, the additional electrode 33 can be electrically connected to the outlet 23 if the outlet is electrically connected to the feed-through arrangement 29. Thus, an increased volume of the additional electric field can be created in the separation zone 15 between the additional electrode 33 and the wall 19 of the casing 3. Advantageously, the more the ad-
ditional electrode 33 is extended into the separation zone 15, the volume of the additional electric created can be increased. The increased volume of the additional electric field in the separation zone 15 provides more efficient prevention of the re-entrainment of the separated particulate matter.

Alternatively, if the outlet 23 is not electrically connected to the feed-through arrangement 29, the additional electrode 33 can be electrically connected to the feed-through arrangement 29. Thus, in this case, the increased volume of the additional electric field will be created by the electric field produced by the additional structure and the second electrode 33.

The embodiments described herein charge all the particulate matter contained in the contaminated gas 7a and thereafter the charged or ionized particulate matter are separated from the contaminated gas 7a by using centrifugal action and by means of electrostatic forces. The charged particulate matter will be forced to migrate towards the wall 19 of the casing as the wall 19 of the casing 3 is grounded. Additionally, this prevents the deposition of the charged particulate matter onto the surface of the insulator 27 insulating the outlet 23 from the casing 3. Additionally, the additional electric field produced by the separation electrode 22 in the separation zone 15 further assists the migration of the charged particulate matter towards the wall 19 of the casing. Moreover, as explained previously, the additional electric field will prevent the re-entrainment of the particulate matter removed from the contaminated gas 7a to produce a resulting partially clean gas 7b. Thus, the particulate matter in the gas 7a is more efficiently removed to produce the partially clean gas 7b.

Additionally, as the feed-through arrangement 29 is disposed in the third flow-path 25 of the partially clean gas 7b, the insulation of the feed-through arrangement 25 can be disposed
in the third flow-path 25 of the partially clean gas 7b. As the insulator 30 is mounted in the third flow-path 25 of the partially clean gas 7b, deposition of particulate matter onto the surface of the insulator 30 is reduced. The particulate matter in the partially clean gas is reduced as a portion of the particulate matter is separated from the contaminated gas 7a in the separation zone 15.

Further, advantageously, as the ionization zone 9 is disposed inside the inlet 5 an additional separate ionization stage is not required prior to the inter 5 of the casing 3. This achieves in reducing the footprint. Additionally, the mounting of the additional electrode 33 and the electrical connection to the additional electrode 33 is simplified as the additional electrode 33 is connected to the same electrical potential as the feed-through arrangement 29, thus, avoiding complex insulation requirement.

FIG 2 illustrates an ionization electrode of the apparatus 1 according to another embodiment. The ionization electrode 13 can comprise sharp edged members 13a along the length of the ionization electrode 13. For example, the sharp edges members 13a can be a plurality of discs arranged along the length of the ionization electrode 13. These sharp edged members 13a reduce the corona initiation electrical potential required for producing the corona discharge.

FIG 3 illustrates a top view of the apparatus 1 of FIG 1 according to an embodiment herein. In the shown example of FIG 2, it can be seen that casing 3 is insulated from the outlet 23 using the insulators 27, illustrated as the hatched portion. The feed-through arrangement 29 is electrically connected to the outlet 23, referenced as 31, insulated from the casing 3 through the insulator 30, and the ionization electrode 13 is electrically connected to the outlet 23.
Several advantageous embodiments of the present invention may be considered, as illustrated referring to FIGS 2-6, wherein like reference signs refer to like elements.

FIG 4 illustrates the apparatus 1 according another embodiment herein. The outlet 23 can be insulated from the casing 3 using a single insulator 27. As illustrated in the example of FIG 4, the insulator 27 can be disposed coaxially around the outlet 23 to insulate the outlet 23 from the casing 3. Thus, the insulation of the outlet 23 from the casing 3 can be achieved depending on the construction of the casing 3.

In the shown example of FIG 5, the apparatus 1 comprises an additional ionization zone 35 for ionizing or charging the particulate matter remaining in the partially clean gas and a particle collection zone 39 for removing the charged remaining particulate matter. While the separation zone 15 is effective for removing large sized particles, smaller and intermediate sized particles would experience lesser centrifugal force or may not be ionized appropriately and therefore would remain with the partially clean gas 7b. Removal of such remaining small and intermediate sized particulate matter from the partially clean gas 7b is carried out by the additional ionization zone 35 and the particle collection zone 39.

Referring still to FIG 5, the additional ionization zone 35 is disposed along the third flow-path 25 of the partially clean gas 7b and comprises means for charging or ionizing the particulate matter remaining in the partially clean gas 7b. Accordingly, in the present example, the additional ionization zone 35 is illustrated as being disposed in the outlet 23. According to an aspect, the means for charging or ionizing the particulate matter can be achieved, by extending the additional electrode 33 into the additional ionization zone 35 as illustrated in the shown example of FIG 5. The first portion 37 of the additional electrode 33 extended into the additional ionization zone 35 can comprise sharp edges to aid
the production of the corona discharge. The first portion of the additional electrode produces a corona discharge in the third flow-path of the partially clean gas 7b to ionize or charge the particulate matter remaining in the partially clean gas 7b. Advantageously, the cross-sectional area of the flow-path, i.e., of the outlet 23 is designed to be sufficiently small such that the gas flowing there through has a high velocity (i.e., high energy), which, in turn increases the particle charging efficiency. Additionally, in case the outlet 23 is maintained at the same electric potential as the additional electrode 33, the possibility of particle collection within the outlet 23 is reduced.

The gas 7b flowing out of the additional ionization zone thus comprises charged or ionized particulate matter. This charged or ionized particulate matter is separated from the gas 7b subsequently at a particle collection zone 39. The particle collection zone can be formed by disposing an additional casing 41 in the fourth flow-path of egress of the partially clean gas 7b from the outlet 23. At the particle collection zone 39, the velocity of the gas is suitably reduced in order to provide enough residence time for particle separation. Accordingly, the cross-sectional area of the fourth flow-path 43 is increased relative to that of the third flow-path 25. The additional casing 41, having an increased cross-sectional area is disposed downstream of the outlet 23 in fluid communication with the outlet 23. In the illustrated embodiment, the additional casing 41 is disposed coaxially with respect to the outlet 23 and such that the partially clean gas 7b flowing out of the outlet 23 can enter the additional casing 41. The additional casing 41 is electrically grounded and is insulated from the outlet 23 using the insulator 27. As the additional casing 41 is electrically grounded the charged or ionized particles in the partially clean gas 7b will migrate towards the additional casing 41. Once the charged particles are deposited at the additional casing 41 they may be removed either using some impulse/force in case of a dry system or liquid such as water in the case
of a wet system. Since the velocity of particles in the outlet 23 is high, the deposition particles in the outlet 23 would be comparatively low and this can be cleaned by using some rapping mechanism at the end of operation.

According to an embodiment, the insulator 30 can be mounted onto the additional casing 41 and the feed-through arrangement can be disposed into the casing 3 thereon. As only the partially clean gas 7b enters the additional casing 41, the deposition of particulate matter of the insulator 30 is reduced and thus, preventing short circuit of the insulator 30.

FIG 6 illustrates the apparatus 1 according to another embodiment herein. In the shown example of FIG 6, a second portion 45 of the additional electrode 33 is extended into the additional casing 41 such that a gap is maintained between the casing 41 and the portion 45 of the electrode 33. The portion 45 of the additional electrode 33 extended into the additional casing 41 will produce a radial electric field between the portion 45 and the additional casing 41. This further assists in migration of charged particles towards the casing 41.

FIG 7 illustrates the second portion 37 of the additional electrode 33 extending into the additional ionization zone 35 according to an embodiment here. The portion 37 can comprise additional structures including a plurality of discs 37a having sharp edges along the length of the portion 37. Advantageously, these additional structures reduce the corona initiation electrical potential required for producing the corona discharge.

FIG 8 illustrates the apparatus 1 according to another embodiment herein. In the shown example of FIG 8, the additional ionization zone 35 comprises an additional ionization electrode 47 for producing the corona discharge. The additional ionization electrode 47 can electrically be connected to the outlet 23, the additional electrode 33 or to the feed-
through arrangement 29. The additional ionization electrode 47 can comprise a metallic rod having sharp edges to aid in the production of the corona discharge. The additional electrode 33 can extend into the additional ionization zone 35 and into the additional casing 41. However, as the corona discharged is produced by the additional ionization electrode 47, the portions 37 and 45 of the additional electrode may produce only a radial electric field.

While this invention has been described in detail with reference to certain preferred embodiments, it should be appreciated that the present invention is not limited to those precise embodiments. Rather, in view of the present disclosure which describes the current best mode for practicing the invention, many modifications and variations would present themselves, to those of skilled in the art without departing from the scope and spirit of this invention. The scope of the invention is, therefore, indicated by the following claims rather than by the foregoing description. All changes, modifications, and variations coming within the meaning and range of equivalency of the claims are to be considered within their scope.
Patent claims

1. An apparatus (1) for removal of particulate matter from a gas, comprising:
   - a casing (3) comprising an inlet (5) for receiving a contaminated gas (7a) comprising particulate matter, and for inducing a swirl to said contaminated gas,
   - an ionization zone (9) disposed inside the inlet (5) in a first flow-path (11) of the contaminated gas (7a) for ionizing the particulate matter of the contaminated gas (7a) by producing a corona discharge,
   - a separation zone (15) disposed in a second flow-path (17) of the contaminated gas (7a) downstream of the inlet (5) for separating a portion of the ionized particulate matter from the swirl-induced contaminated gas (7a) by centrifugal action and by means of an electrical field to produce a partially clean gas (7b), and
   - a separation electrode (22) for producing an additional electric field in at least a portion of the separation zone (15), wherein the separation electrode (22) is electrically connected to an electrical potential provided to the ionization zone (15) for producing the corona discharge.

2. The apparatus (1) according to claims 1, further comprising an outlet (23) in flow communication with the separation zone (15) for the partially clean gas (7b) to egress, the outlet (23) being electrically insulated from the casing (3), and wherein the separation electrode (22) comprises the outlet (23), wherein the outlet (23) is electrically conductive.

3. The apparatus (1) according to anyone of the claims 1 or 2, further comprising an feed-through arrangement (29) for passing the corona initiation electrical potential to the ionization zone (9), the feed-through arrangement (9) being electrically insulated from the casing (3) and being disposed in a third flow-path (25) of the partially clean gas (7b).
4. The apparatus (1) according to anyone of the claims 1 to 3, wherein the ionization zone (9) comprises an ionization electrode (13) for producing the corona discharge.

5. The apparatus (1) according to claim 4, wherein the ionization electrode (13) is electrically connected to the feed-through arrangement (29).

6. The apparatus (1) according to claims 4 or 5, wherein the ionization electrode (13) comprises at least one rod and at least one sharp edged member (13a) electrically connected to the at least one rod.

7. The apparatus (1) according to anyone of the claims 3 to 6, wherein the separation electrode (22) is electrically connected to the feed-through arrangement (29).

8. The apparatus (1) according to anyone of the claims 1 to 7, wherein the ionization electrode (13) is electrically connected to the separation electrode (22).

9. The apparatus (1) according to anyone of the claims 1 to 8, wherein the casing (3) is electrically grounded and the electrical field is created between the ionized particulate matter and the casing (3), and the additional electric field is created between the separation electrode (22) and the casing (3).

10. The apparatus (1) according to anyone of the claims 1 to 9, further comprising an additional electrode (33) disposed inwardly in the outlet (23), the additional electrode (33) extending out of the outlet (23) such that an additional volume of the additional electrical field can be created.

11. The apparatus (1) according to claim 10, wherein the additional electrode (33) is electrically connected to the feed-through arrangement (29).
12. The apparatus (1) according to claims 10 or 11, wherein the additional electrode (33) extends into at least a portion of the separation zone (15).

13. The apparatus (1) according to anyone of the claims 1 to 12, further comprising an additional ionization zone (35) along the third flow-path (25) of the partially clean gas (7b) for ionizing the particulate matter remaining in the partially cleaned gas (7b) by producing an additional corona discharge in the flow-path 25.

14. The apparatus (1) according to claim 13, wherein the additional ionization zone (35) comprises a first portion (37) of the additional electrode (33) for producing the additional corona discharge.

15. The apparatus (1) according to claim 13, wherein the additional ionization zone (35) comprises an additional ionization electrode (47) electrically connected to the feed-through arrangement (29) for producing the additional corona discharge in the flow-path 25.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. B03C3/15 B03C3/14 B03C3/41 B03C3/49 B03C3/02
B03C3/86

ADD.

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)
B03C

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>GB 1 421 969 A (NISSAN MOTOR) 21 January 1976 (1976-01-21) page 2, line 8 - line 127 page 5, line 29 - line 53 figures 1-3, 8, 9</td>
<td>1,4,6,8, 10-15</td>
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<tr>
<td>X</td>
<td>DE 37 23 153 AI (NAVSAT GMBH [DE]) 26 January 1989 (1989-01-26) column 3, line 25 - line 60 figures 1-3</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search 11 January 2012

Date of mailing of the international search report 19/01/2012

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer Menck, Anja

Form PCT/ISA/210 (second sheet) (April 2005)
### Documents Considered to Be Relevant

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<th>Category</th>
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<td>US 5 968 231 A (PARMENTIER MICHEL [FR] ET AL) 19 October 1999 (1999-10-19) column 2, line 66 - column 3, line 46 figure 1</td>
<td>1-15</td>
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<td>X</td>
<td>US 4 352 681 A (DIETZ PETER W) 5 October 1982 (1982-10-05) column 2, line 28 - column 3, line 57 figures 1, 3, 4</td>
<td>1,4-6,8,10-15</td>
</tr>
<tr>
<td>A</td>
<td>EP 0 995 494 A2 (GOLDEN SHOWCASE INTELLECTUAL P [MY]) 26 April 2000 (2000-04-26) figure 1</td>
<td>1-15</td>
</tr>
<tr>
<td>Patent document cited in search report</td>
<td>Publication date</td>
<td>Patent family member(s)</td>
</tr>
<tr>
<td>---------------------------------------</td>
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<td>-------------------------</td>
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<tr>
<td>GB 1421969 A</td>
<td>21-01-1976</td>
<td>CA 1014864 A1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 2332418 A1</td>
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<tr>
<td></td>
<td></td>
<td>FR 2333575 A1</td>
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<td></td>
<td></td>
<td>GB 1421969 A</td>
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<td></td>
<td></td>
<td>US 3853512 A</td>
</tr>
<tr>
<td>US 2009101009 A1</td>
<td>23-04-2009</td>
<td>NONE</td>
</tr>
<tr>
<td>DE 3723153 A1</td>
<td>26-01-1989</td>
<td>NONE</td>
</tr>
<tr>
<td>US 5968231 A</td>
<td>19-10-1999</td>
<td>NONE</td>
</tr>
<tr>
<td>US 4352681 A</td>
<td>05-10-1982</td>
<td>NONE</td>
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<tr>
<td></td>
<td></td>
<td>US 2008060522 A1</td>
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<tr>
<td></td>
<td></td>
<td>WO 2008033190 A1</td>
</tr>
<tr>
<td>US 2009277325 A1</td>
<td>12-11-2009</td>
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<tr>
<td>EP 0995494 A2</td>
<td>26-04-2000</td>
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