

DESCRIPTION

Title of Invention

DUST COLLECTING DEVICE AND AIR-CONDITIONING APPARATUS

Technical Field

5 [0001]

The present invention relates to a dust collecting device that generates static electricity by friction to collect dust, and also relates to an air-conditioning apparatus that includes the dust collecting device.

Background Art

10 [0002]

Examples of dust collecting devices that collect dust in the air include an electric dust collector. The electric dust collector includes a charging unit that applies a high voltage from a high-voltage supply to a wire electrode to cause a corona discharge, and uses the resulting ions to electrically charge dust in the air, and
15 a dust collecting unit that applies a high voltage between plate-like electrodes from the high-voltage supply to form an electrostatic field, and electrostatically collects the electrically charged dust on the plates. With this electrostatic collecting mechanism, the electric dust collector achieves a high level of dust collecting efficiency with low pressure loss. When dust collected by the electric dust collector accumulates on the
20 electrodes, the resulting discharge (inverse ionization) in the dust layer typically degrades the dust collecting performance. Consequently, the electric dust collector typically requires maintenance, such as electrode cleaning, every several months. The electric dust collector is difficult to handle, because it requires application of a high voltage from the high-voltage supply to the electrodes. Regular maintenance is
25 also required in this respect.

[0003]

A dust collecting device is often used in conjunction with a ventilator or an air-conditioning apparatus such as an air conditioner. In recent years, such an air-conditioning apparatus has often been installed in a high place in the room or above
30 the ceiling. Thus, access to the installed apparatus for maintenance purposes may

not necessarily be easy. Consequently, there has been a demand for dust collecting devices that do not require frequent maintenance, or more specifically, dust collecting devices that require no maintenance for such a long period as several years to more than a decade.

5 [0004]

As an example of dust collecting devices that collect dust in the air without application of a high voltage, Patent Literatures 1 and 2 each describe a dust collecting device that uses a dust collecting body electrically charged by friction to electrostatically collect dust with Coulomb force.

10 Citation List

Patent Literature

[0005]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2002-336733

15 Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2002-186879

Summary of Invention

Technical Problem

[0006]

20 The dust collecting devices of a frictional charging type, described in Patent Literatures 1 and 2, have the advantage of being easy to handle because they do not use a high voltage. However, every time the collecting efficiency is lowered by accumulation of dust on the dust collecting body, the dust collecting devices require maintenance that involves removing dust adhering to the dust collecting body to
25 restore the collecting efficiency. Consequently, it is difficult to achieve a long-term, maintenance-free operation.

[0007]

The present invention has been made to solve the problems described above. An object of the present invention is to provide a dust collecting device that has a long
30 maintenance interval.

Solution to Problem

[0008]

A dust collecting device according to an embodiment of the present invention includes a housing accommodating an air passage that allows air to pass through the air passage, an unwinder configured to supply, into the air passage, a film conveyed along a path that crosses the air passage, a friction body configured to apply friction to the film fed from the unwinder to electrically charge the film, and a winder configured to wind, onto the winder, the film electrically charged and placed in the air passage.

Advantageous Effects of Invention

[0009]

The dust collecting device according to an embodiment of the present invention includes a housing accommodating an air passage that allows air to pass through the air passage, a film electrically charged by friction and conveyed along a path that crosses the air passage, an unwinder configured to supply the film into the air passage, a friction body configured to apply friction to the film fed from the unwinder to electrically charge the film, and a winder configured to wind, onto the winder, the film conveyed into the air passage. With this configuration, a dust collecting device having a long maintenance interval can be provided.

Brief Description of Drawings

[0010]

[Fig. 1] Fig. 1 is a schematic cross-sectional view of a dust collecting device according to Embodiment 1 of the present invention.

[Fig. 2] Fig. 2 is a schematic cross-sectional view of a dust collecting device according to Embodiment 2 of the present invention.

[Fig. 3] Fig. 3 is a schematic cross-sectional view of a dust collecting device according to Embodiment 3 of the present invention.

[Fig. 4] Fig. 4 is a schematic cross-sectional view of an air-conditioning apparatus according to Embodiment 4 of the present invention.

[Fig. 5] Fig. 5 is a flow chart illustrating an operation of the air-conditioning apparatus according to Embodiment 4 of the present invention.

[Fig. 6] Fig. 6 is a diagram illustrating a modification of the air-conditioning apparatus according to Embodiment 4 of the present invention.

5 [Fig. 7] Fig. 7 is a schematic cross-sectional view of an air-conditioning apparatus according to Embodiment 5 of the present invention.

[Fig. 8] Fig. 8 is a schematic cross-sectional view of a dust collecting device according to Embodiment 6 of the present invention.

Description of Embodiments

10 [0011]

Hereinafter, preferred embodiments of a dust collecting device according to the present invention will be described using the drawings. Note that the same or corresponding parts are denoted by the same reference signs throughout the drawings.

15 [0012]

Embodiment 1

Fig. 1 is a schematic diagram illustrating a dust collecting device 1 according to Embodiment 1. The dust collecting device 1 includes a housing 4 accommodating an air passage 3 that allows air containing dust 2 to pass through the air passage 3, a film 5 conveyed along a series of paths that cross the air passage 3, electrically charged by friction, and electrostatically collecting the dust 2 in the air that passes through the air passage 3, friction bodies 6 each configured to apply friction to the film 5 to electrically charge the film 5, an unwinder 7 configured to feed the film 5, a winder 8 configured to wind the film 5 onto the winder 8, and a controller 9 configured to control the unwinder 7 and the winder 8.

25 [0013]

The film 5 is an 80 μm thick and 200 mm wide film made of polypropylene (PP) that tends to be negatively charged by friction. By being guided by a plurality of guides 10 disposed outside the air passage, the film 5 is placed to cross the air passage 3 multiple times. In the air passage 3, the film 5 is placed in multiple layers

30

spaced apart at regular intervals. The guides 10 are stainless rods with a diameter of 10 mm. The guides 10 are arranged to allow the film 5 to cross the air passage 3 at intervals of 10 mm. The side periphery of the air passage 3 is provided with a plurality of 1 mm wide slits 11 that allow passage of the film 5. The film 5 is conveyed from the unwinder 7 to the winder 8 along a series of paths (from point A to point B in the drawing) that cross the air passage 3.

[0014]

The unwinder 7 and the winder 8 are disposed in respective spaces opposite to each other across the air passage 3. A film roll, including a core and an unused part of the film 5 wound around the core, is attached to the unwinder 7. A core for winding, around the core, a used part of the film 5 having the dust 2 adhering to the part, or a film roll including a core and a used part of the film 5 wound around the core, is attached to the winder 8. The winder 8 includes a servomotor that controls the rotation frequency. As the winder 8 rotates, a used part of the film 5 is wound onto the winder 8. This operation causes the unwinder 7 to rotate, and causes an unused part of the film 5 to be pulled out of the unwinder 7.

[0015]

The friction bodies 6 are each a brush of polyamide 6 (PA 6) fibers that tend to be positively charged by friction. The brush is 0.2 mm in fiber diameter and 10 mm in thickness. The friction bodies 6 are disposed between the unwinder 7 and the air passage 3. Before the film 5 fed from the unwinder 7 is supplied to the air passage 3, the friction bodies 6 each apply friction to the film 5 to electrically charge it. The film 5 is provided with friction bodies 6 on both sides of the film 5, and each of the friction bodies 6 applies friction to the corresponding side of the film 5.

[0016]

The film 5 is also provided with grounded conductors 12, each disposed opposite to the corresponding one of the friction bodies 6 across the film 5. The grounded conductors 12 are 10 mm thick stainless blocks electrically grounded. The grounded conductors 12 are each disposed to face the corresponding one of the friction bodies 6, with the film 5 interposed between the grounded conductor 12 and

the friction body 6. The grounded conductors 12 and the friction bodies 6 are secured with bolts to the apparatus.

[0017]

A partition 13 is disposed between the air passage 3 and the unwinder 7.

[0018]

An operation of the dust collecting device 1 according to Embodiment 1 will be described below. When the dust collecting device 1 is operated for the first time or for the first time in a long time, such as one month or more, a film change mode is executed. In the film change mode, the winder 8 and the unwinder 7 are rotated in accordance with instructions from the controller 9. Thus, the film 5 in the air passage 3 is wound onto the winder 8, and an unused part of the film 5 is pulled out of the unwinder 7 toward the air passage 3 at a speed of 50 mm/s. The film 5 pulled out of the unwinder 7 is electrically charged by friction applied to both sides of the film 5 by the friction bodies 6 and supplied to the air passage 3. The film 5 is folded back at each of the guides 10 to cross the air passage 3 multiple times, in such a manner that the film 5 is placed in multiple layers spaced apart at regular intervals.

[0019]

When the unused part of the film 5 is thoroughly distributed in the air passage 3, the rotation of both the unwinder 7 and the winder 8 is stopped. The controller 9 controls when to stop the rotation. For example, from the overall length of the film 5 that crosses the air passage 3 (i.e., the film length from point A to point B in Fig. 1) and the roll diameter and roll thickness of the film 5, the number of rotations of the winder 8 required to replace the entire used film in the air passage 3 with the unused film is determined in advance. Then, when the number of rotations of the winder 8 reaches the predetermined value, the rotation of the winder 8 is stopped under control of the controller 9. The film change mode ends here.

[0020]

After the film change mode ends, air containing dust is passed through the air passage 3 to start dust collection. In the air passage 3, air flows in a ventilation direction 14 that is the depth direction of the drawing. The unwinder 7, the winder 8,

and the film 5 are at rest, at this point, under control of the controller 9. As air passes through the air passage 3, the dust 2 in the air is electrostatically attracted to and collected on the surface of the film 5 by an electrostatic field formed by the electric charge on the film 5 placed in the air passage 3.

[0021]

The efficiency of collecting dust in the air gradually decreases as the collected dust 2 accumulates on the film 5. The rate of decrease in the collecting efficiency of the film 5 varies depending on the concentration of dust in the atmosphere, temperature, and humidity. After use for several tens of days, the collecting efficiency of the film 5 decreases from 0.7 to 0.4. When the dust 2 accumulates on the surface of the film 5, as the electrical resistance of the dust 2 is lower than that of the film 5, the apparent electrical resistance on the surface of the film 5 decreases, and the electric charge generated by frictionally charging the film 5 is conducted through the dust 2 and leaks out of the apparatus. At the same time, as the surface of the film 5 is covered with the dust 2, the electrostatic field on the surface of the film 5 is blocked. From this mechanism, the collecting efficiency of the film 5, achieved by the electrostatic field, decreases with time.

[0022]

The decrease in collecting efficiency is detected using a particle sensor 15 disposed each upstream and downstream of the air passage 3. The particle sensors 15 are each a sensor that measures the concentration of dust (PM 2.5) using a light scattering method. The particle sensors 15 measure the dust concentrations found upstream and downstream of the air passage 3, and transmit the measurement results to the controller 9 through cables. The controller 9 calculates a collecting efficiency E using the following mathematical formula (1).

[0023]

[Math. 1]

$$E = 1 - \left(\frac{M_2}{M_1} \right) \cdot \cdot \cdot (1)$$

M_1 and M_2 are particle concentrations (g/m_3) measured downstream and upstream, respectively, of a filter.

[0024]

In Embodiment 1, when air passes through the air passage 3 at a speed of 0.5 m/s, the collecting efficiency E obtained immediately after frictional charging is about 0.7. When the value of the collecting efficiency of the dust collecting device 1 calculated by the controller 9 falls below a predetermined threshold (0.4 in Embodiment 1), the dust collecting device 1 enters the film change mode in accordance with instructions from the controller 9. Then, the used part of the film 5 having the dust 2 adhering to the part is wound onto the winder 8, and an unused part of the film 5 is supplied from the unwinder 7. It is thus possible to easily restore the collecting efficiency and perform the dust collection at a high level of collecting efficiency again. As the used part of the film 5 having the dust 2 adhering to the part is regularly conveyed out of the air passage, an increase in pressure loss over time, which results from clogging of the air passage 3 caused by accumulation of the dust 2, can be reduced. When the film change mode is regularly executed as described above, maintenance, such as electrode cleaning, is not required until the end of the film roll attached to the unwinder 7.

[0025]

The total film length L (m) required is expressed by the following mathematical formula (2), where M (m) is the length of the film used for each film change, that is, in Fig. 1, length from point A immediately after the point where the film 5 is fed from the unwinder 7 to point B just before the point where the film 5 is wound onto the winder 8, T_1 (in hours) is a maintenance interval (i.e., time that elapses until the end of the film roll attached to the unwinder 7), T_2 (in hours) is the execution interval of the film change mode (i.e., time that elapses after film change until the collecting efficiency decreases to a predetermine value).

[0026]

[Math. 2]

$$L = \frac{M \times T_1}{T_2} \quad \cdot \cdot \cdot (2)$$

When the total film length L is determined, a diameter D (m) of the film roll can be expressed by the following mathematical formula (3).

[0027]

5 [Math. 3]

$$D = \sqrt{\frac{4tL}{\pi} + d^2} \quad \cdot \cdot \cdot (3)$$

t (m) is the film thickness, and d (m) is the diameter of the core.

[0028]

10 An air-conditioning apparatus installed together with the dust collecting device typically has a life of about 10 years. Consequently, to avoid maintenance, a film for 10 years is preferably loaded in the dust collecting device. When the average daily operating time is 12 hours, the maintenance interval T_1 corresponds to the mathematical formula of 12 hours $\times$ 365 days $\times$ 10 years, which equals to 43800 hours. The length of time before the collecting efficiency decreases to a
15 predetermined value varies depending on the usage environment. When the film change interval T_2 is 500 hours, an automatic film change operation needs to be performed 88 times to avoid maintenance. When the film length M from point A to point B in Fig. 2 is 10 m, the total film length L is 876 m. When the core diameter d equals to 0.03 m, a film roll diameter D equals to 0.4 m on the basis of the
20 mathematical formula (3). That is, with a film roll 0.4 m in diameter, it is possible to eliminate the need for maintenance.

[0029]

In the dust collecting device of Embodiment 1, an energy of 1 mJ or less is stored by electric charge generated by frictional charging, in space between layers of the film 5. This energy is sufficiently smaller than an energy of several tens of mJ or more that is typically required for ignition. Consequently, under atmosphere where a flammable gas or dust is present between layers of the film 5, even when a discharge of accumulated electric charge occurs between layers of the film, fire is extremely

unlikely to be caused. As no corona discharge is caused, there is no danger of ozone generation, which may be harmful to human health. Thus, the dust collecting device of Embodiment 1 can reduce the risk of fire and ozone generation more effectively than some electric dust collectors that use corona discharge or electrostatic field.

[0030]

As described above, the dust collecting device of Embodiment 1 is configured in such a manner that the film 5 electrically charged by friction is placed in the air passage 3 for dust collection, a used part of the film 5 having the dust 2 adhering to the part is wound onto the winder 8, and an unused part of the film 5 fed from the unwinder 7 and electrically charged by friction is supplied into the air passage 3. A dust collecting device that has a long maintenance interval can thus be provided.

[0031]

In the dust collecting device of Embodiment 1, where the film 5 is sandwiched between the friction bodies 6 and the grounded conductors 12 to apply friction to the film 5, the amount of charge on the film 5 can be increased. This will be described below.

[0032]

In the region where the film 5 is sandwiched between the friction bodies 6 and the grounded conductors 12, the grounded conductors 12 are in contact with the film 5. Microscopically, however, some gaps are created between the grounded conductors 12 and the film 5. These gaps allow capacitors to be formed in the gaps between the grounded conductors 12 and the film 5, and high capacitance is achieved in parts of the film 5.

[0033]

When capacitors in the gaps between the grounded conductors 12 and the film 5 are ideal, the relation between the surface potential V (V) of the film, the amount of charge Q (C) in the film, and the capacitance C (F) of the film can be expressed by the following mathematical formula (4).

[0034]

[Math. 4]

$$V = \frac{Q}{C} \quad \cdot \cdot \cdot (4)$$

As the capacitance C increases, the amount of charge Q that can be stored in the film 5 increases. When the friction bodies 6 apply friction to the film 5, with the capacitors being partially formed and the capacitance C being increased, the film 5 can obtain a larger amount of charge.

[0035]

The capacitors described above are formed only in the microscopic gaps created between the grounded conductors 12 and the film 5 that are in contact.

Consequently, when the film 5 is moved by unwinding and winding, some capacitors are cancelled in parts of the surface of the film 5 brought out of contact with the grounded conductors 12, and the capacitance is immediately reduced. On the other hand, the amount of charge applied to parts of the surface of the film 5, with the capacitance being increased, is not immediately lost. Consequently, as expressed by the mathematical formula (4), a high surface potential appears on the film 5 and an electrostatic field with a high field intensity is produced. This configuration enables more efficient collection of particles in the air than that in a case in which the grounded conductors 12 are not provided.

[0036]

Although Embodiment 1 presents an example where the film is sandwiched between the grounded conductors 12 made of stainless blocks and the friction bodies 6, the configuration is not necessarily limited to this example. For example, grounded friction bodies may be used as the grounded conductors 12.

[0037]

The dust collecting device of Embodiment 1 accommodates an unused film in a roll form. This configuration can reduce adhesion of dust and water to the unused film. As described above, the dust collecting device of the present invention aims to achieve a long-term, maintenance-free operation. When an unused film is stored in the dust collecting device for a long time, the unused film is typically deteriorated by

adhesion of fine dust or water to the film. In Embodiment 1, on the other hand, an unused film is stored as a roll. Consequently, even when dust or water adheres to the top layer of the film roll, the other layers under the top layer are covered by upper layers and protected from adhesion of fine dust or water. That is, even when the film is stored outside the air passage for a long time, it is possible to reduce adhesion of dust and water to the unused film.

[0038]

When fine dust or water adheres to the surface of the unused film, the electrical resistance on the film surface is reduced. As described above, when the film is sandwiched between the friction bodies 6 and the grounded conductors 12 to apply friction to the film, the film with reduced electrical resistance cannot be frictionally charged because the electric charge of the film is immediately lost through the grounded conductors 12. In the present invention, where an unused film is stored as a film roll, layers under the top layer of the film roll are protected from adhesion of dust or water. Consequently, even when the unused film is stored in the dust collecting device for a long time, it is possible to reduce a decrease in the resistance of the film and reduce loss of electric charge through the grounded conductors 12.

[0039]

In the dust collecting device of Embodiment 1, where the partition 13 is disposed between the air passage 3 and the unwinder 7, dust in the air that passes through the air passage 3 and dust that scatters from the film 5 that is being used can be prevented from adhering to the unused part of the film 5 on the unwinder 7. Alternatively, the partition 13 may be disposed between the air passage 3 and the winder 8. In this case, dust that scatters from the used part of the film wound on the winder 8 can be prevented from adhering to the film that is placed in the air passage 3 and is being used and to the unused part of the film on the unwinder 7.

[0040]

Although Embodiment 1 presents an example in which the film 5 is a PP film, the film 5 may be made of any material as long as it is electrically charged by friction with the friction bodies 6. For example, a polytetrafluoroethylene (PTFE) or

polyethylene (PE) film may be used. Also, the film thickness is not necessarily 80 μm . For example, a 20 μm to 1 mm thick film may be used. A thinner film is preferred as long as the material strength permits. When a thin film is used, a film for satisfying a required maintenance interval can be loaded in the dust collecting device with improved compactness.

[0041]

Although Embodiment 1 presents an example in which the friction bodies 6 are PA 6 fiber brushes, fiber brushes such as polyacrylonitrile (PAN) fiber brushes may be used. To reduce charge saturation of the friction bodies 6, it is preferable that the conductivity of the friction bodies 6 be high. For example, a material obtained by adding carbon to the material described above may be used to improve conductivity. Also, the friction bodies 6 are not necessarily brushes, and may be, for example, sponge-like bodies, plate-like bodies, cylindrical bodies, film-like bodies, or nonwoven bodies.

[0042]

Although friction is applied to one side of the film 5 at a time in Embodiment 1, friction may be applied to both sides of the film 5 at the same time. For example, the film 5 may be sandwiched between a plurality of friction bodies 6 to simultaneously apply friction to both sides. This configuration can save installation space for the friction bodies 6.

[0043]

Embodiment 1 presents an example in which the film 5 is negatively charged, but the film 5 may be positively charged. For example, PA 6 that tends to be positively charged may be used as a material for the film 5, or PTFE that tends to be negatively charged may be used as a material for the friction bodies 6.

[0044]

Embodiment 1 presents an example in which the guides 10 are stainless rods with a diameter of 10 mm, and the film 5 is placed along the guides 10 in such a manner as to cross the air passage 3 at intervals of 10 mm. However, the interval at which the film crosses the air passage, that is, the diameter of the guides 10, is not

limited to 10 mm. As the diameter of the guides 10 decreases, the film interval becomes narrower. This configuration reduces the distance that dust travels to the film surface by electrostatic force. When the travel distance, which is important for dust collection, is reduced, the level of collecting efficiency can be improved. Note that as this configuration increases the film quantity in the air passage, the guide diameter and the guide arrangement may be determined depending on the required level of collecting efficiency and the cost limit.

[0045]

In Embodiment 1, the concentrations of particles to be collected in the air are detected by the particle sensors 15 disposed upstream and downstream of the air passage 3, and the collecting efficiency E is calculated from the detected concentrations. Then, control is performed in such a manner that the film change mode is executed when the collecting efficiency E falls below the threshold. However, the control method is not necessarily limited to this method. For example, the film change mode may be executed on the basis of the difference between the upstream and downstream concentrations. The particle sensor may be provided only downstream in the air passage and the film change mode may be executed on the basis of the downstream concentration. Without using a particle sensor, the film change mode may be set to be executed at regular time intervals.

[0046]

As described above, the dust collecting device of Embodiment 1 is configured to collect dust with a film electrically charged by friction and placed in the air passage. Also, the dust collecting device of Embodiment 1 is configured to wind, onto the winder 8, a used part of the film having dust adhering to the part, and supply, to the air passage, an unused part of the film fed from the unwinder and electrically charged by friction. With this configuration, a dust collecting device having a long maintenance interval can be provided.

[0047]

Embodiment 2

Fig. 2 is a schematic cross-sectional view illustrating a configuration of a dust collecting device according to Embodiment 2. The dust collecting device according to Embodiment 2 differs from Embodiment 1 in that a positively charged film and a negatively charged film are disposed to face each other in the air passage 3, and other parts are the same as those of Embodiment 1. The following description will primarily focus on the difference.

[0048]

The dust collecting device of Embodiment 2 includes a plurality of film units each composed of a film, the unwinder 7, and the winder 8. Some of the film units each include a first film 16 positively charged by friction with the friction bodies 6, and the other film units each include a second film 17 negatively charged by friction with the friction bodies 6. Examples of the first film 16 include a polyamide (PA 6) film that tends to be positively charged by friction, and examples of the second film 17 include a polypropylene (PP) film that tends to be negatively charged by friction.

[0049]

The first film 16 and the second film 17 are disposed to face each other in the air passage. When there are three or more film units, the manner in which the first films 16 and the second films 17 are arranged is not particularly limited. For example, positively and negatively charged films may be alternately arranged, or a plurality of positively charged films may alternate with an equal number of negatively charged films. Positively charged films may be greater in number than negatively charged films or vice versa.

[0050]

For changing the films in the air passage 3, as in the film change mode described in Embodiment 1, the winder 8 and the unwinder 7 of each film unit are rotated to feed an unused part of the film from the unwinder 7 toward the air passage 3 at a speed of 50 mm/s. Each film is electrically charged by friction applied to both sides of the film by the friction bodies 6 and supplied into the air passage. The first film 16 is positively charged by friction with the friction bodies 6, and the second film 17 is negatively charged by friction with the friction bodies 6.

[0051]

Of particles to be collected in the air, negatively charged particles are typically collected on a positively charged film, and positively charged particles are typically collected on a negatively charged film. When either positively or negatively charged films alone are used, the corresponding ones of positively and negatively charged particles alone are collected, and the other ones cannot be sufficiently collected.

[0052]

In the dust collecting device of the Embodiment 2, which includes both the first film 16 and the second film 17, negatively charged particles can be collected on the first film 16 and positively charged particles can be collected on the second film 17. Thus, collection of both positively and negatively charged particles is facilitated, and makes it possible to achieve a higher collecting efficiency than that in a case in which only one type of film is used.

[0053]

An average field intensity E (V/m) in the region interposed between the first film 16 and the second film 17 in the air passage 3 is expressed by the following mathematical formula (5).

[0054]

[Math. 5]

$$E = \frac{\rho_+ + \rho_-}{\epsilon_0} \quad \dots (5)$$

ρ_+ is the charge density (C/m²) of the first film 16, ρ_- is the charge density (C/m²) of the second film 17, and ϵ_0 is a dielectric constant 8.85×10^{-12} (F/m) in a vacuum.

[0055]

The mathematical formula (5) shows that as the charge density ρ_+ of the first film 16 and the charge density ρ_- of the second film 17 increase, the average field intensity E in the air passage 3 increases and a higher electrostatic collecting efficiency is achieved. When films made of the same material are disposed to face each other, the average field intensity is theoretically zero in the mathematical formula

(5). In practice, however, the amount of charge on the film surface varies from one point to another. As this variation generates a field intensity, a certain level of average field intensity exists in practice.

[0056]

5 In the dust collecting device of Embodiment 2, as described above, the first film positively charged and the second film negatively charged are disposed to face each other. As this configuration makes it easier to collect both positively and negatively charged particles than does that in a case in which only one type of film is used, it is possible to achieve a higher collecting efficiency. Additionally, the average field
10 intensity in the air passage 3 is increased, and a higher collecting efficiency is achieved.

[0057]

Respective different types of friction bodies 6 may be used for the first film 16 and the second film 17. For example, a first friction body 18 made of PP that tends
15 to be negatively charged by friction may be used to apply friction to the first film 16, and a second friction body 19 made of PA 6 that has a stronger tendency to be positively charged by friction than does the first friction body 18, may be used to apply friction to the second film 17. This configuration enables more efficient electrical charging of both films.

20 [0058]

Embodiment 3

Fig. 3 is a schematic cross-sectional view illustrating a configuration of a dust collecting device according to Embodiment 3. The dust collecting device according to Embodiment 3 is the same as that of Embodiment 1, except that it includes a
25 drying unit 20 that dries the film. The following description will primarily focus on the difference.

[0059]

As illustrated in Fig. 3, the dust collecting device of Embodiment 3 includes the drying unit 20 that dries the film 5. The film 5 fed from the unwinder 7 is dried by the

drying unit 20 before the film 5 is subjected to friction by the friction bodies 6. The drying unit 20 described here is a hot wire heater made of metal plates.

[0060]

For changing the film in the air passage, as in the film change mode described in Embodiment 1, the winder 8 and the unwinder 7 are rotated to feed an unused part of the film from the unwinder 7 toward the air passage 3 at a speed of 50 mm/s. Before the friction bodies 6 apply friction to the film 5, the metal plates used as the drying unit 20 are heated to 80 degrees C. During passage of the film 5 between the plates, the surfaces of the film 5 are dried by contact heating. This operation allows water on the surfaces of the film 5 to evaporate and increases the surface resistance of the film 5. It is thus possible to reduce decay of electric charge caused by conduction, for example, through the grounded conductors 12 to the outside, and maintain a highly charged state. The highly charged state can be stably maintained regardless of the ambient humidity.

[0061]

The temperature of the drying unit 20 is not limited to 80 degrees C and may be any temperature lower than the melting point of the film 5. Higher temperatures are preferable to improve efficiency in drying the film 5.

[0062]

The drying unit 20 is not limited to a hot wire heater made of metal plates, and heating units of other types, or drying units not involving heating, may be used. For example, the film may be dried by blowing hot air from a dryer onto the film surface, or by blowing air from a compressor or desiccant dehumidifier installed in a space outside the air passage. In any of these cases, the drying unit 20 is configured to dry the film before the film 5 is subjected to friction by the friction bodies 6.

[0063]

As described above, in Embodiment 3, the film 5 is dried by the drying unit 20 before the film 5 is subjected to friction by the friction bodies 6. This configuration increases the surface resistance of the film 5, reduces decay of electric charge, and makes it possible to maintain a highly charged state.

[0064]

Embodiment 4

Embodiment 4 is an air-conditioning apparatus that includes the dust collecting device 1 of Embodiment 1. The air-conditioning apparatus of Embodiment 4 includes a heat exchange ventilator. The heat exchange ventilator is a kind of air-conditioning apparatus and has an energy saving function, as well as the ventilation function that supplies outdoor air into a room and exhausts air from the room to the outside. The energy saving function reduces energy burden on an indoor temperature regulator, such as an air conditioner, by recovering heat from exhaust air and giving the heat to air to be supplied.

[0065]

Fig. 4 is a schematic view of an air-conditioning apparatus according to Embodiment 4. The air-conditioning apparatus of Embodiment 4 includes the dust collecting device 1 of Embodiment 1 and a heat exchange ventilator 21. The dust collecting device 1 and the heat exchange ventilator 21 are housed inside a lowered ceiling 22 in the room in a house. As illustrated in Fig. 4, the lowered ceiling 22 refers to a lowered part of a ceiling. For better appearance of the interior space, as illustrated in Fig. 4, air-conditioning devices are housed together inside the lowered ceiling 22 in many houses. When air-conditioning devices are installed inside the lowered ceiling 22, the installation space that can be secured is larger than that in a case in which the air-conditioning devices are typically installed in a room.

[0066]

With reference to Fig. 4, the outdoor wall has an outdoor inlet 23 and an outdoor outlet 24, and the lowered ceiling 22 in the room has an indoor inlet 25 and an indoor outlet 26. The outdoor inlet 23 and the indoor inlet 25 are connected by a duct 31, with the heat exchange ventilator 21 interposed between the outdoor inlet 23 and the indoor inlet 25. The outdoor outlet 24 and the indoor outlet 26 are connected by another duct 31, with the heat exchange ventilator 21 interposed between the outdoor outlet 24 and the indoor outlet 26. The heat exchange ventilator 21 has two internal fans, one of the internal fans is configured to move air

from the outdoor space toward the indoor space, and the other of the internal fans is configured to move air from the indoor space toward the outdoor space. By operating these fans, air is supplied into and exhausted from the room.

[0067]

5 The dust collecting device 1 is interposed between the heat exchange ventilator 21 and the outdoor inlet 23 and connected by the duct 31. A side of the dust collecting device 1 connected to the outdoor inlet 23 corresponds to the upstream side in wind flow. Outdoor air flows inside the dust collecting device 1 in the ventilation direction 14 (i.e., rightward in the drawing). The dust collecting device 10 1 is provided with the particle sensor 15 disposed each upstream and downstream of the dust collecting device 1, for sensing the concentration of dust in the air. The dust collecting device 1 is further provided with the controller 9 that controls the operation of the dust collecting device 1. The dust collecting device 1 and the heat exchange ventilator 21 are electrically connected to the controller 9 to operate in conjunction 15 with each other.

[0068]

An operation of the air-conditioning apparatus according to Embodiment 4 of the present invention will be described below. Fig. 5 is a flow chart illustrating the operation. When the apparatus is operated for the first time or for the first time in a 20 long time, such as one month or more, the film change mode is executed as in Embodiment 1 to rotate the unwinder 7 and the winder 8 to wind a used part of the film and supply an unused part of the film. In the film change mode, the fans of the heat exchange ventilator 21 are at rest under control of the controller 9.

[0069]

25 Next, the fans of the heat exchange ventilator 21 are operated to start ventilation. At this point, air taken in from the outdoors flows in the ventilation direction 14 in the air passage 3 of the dust collecting device 1. At this point, 7, the winder 8, and the film 5 are at rest under control of the controller 9. As the air passes through the air passage 3, dust in the air is electrostatically attracted to and

collected on the surface of the film 5 by an electrostatic field formed by the electric charge on the film 5 placed in the air passage 3.

[0070]

During operation of the apparatus, as in Embodiment 1, the concentrations of dust in the air are detected by the particle sensors 15 disposed upstream and downstream of the air passage, and the collecting efficiency E is calculated. When the value of the collecting efficiency E falls below a set value (0.4 in Embodiment 4), the film change mode is started in accordance with instructions from the controller 9. Then, the unwinder 7 and the winder 8 are rotated to wind a used part of the film and supply an unused part of the film. This operation makes it possible to perform dust collection at a high level of collecting efficiency again. When the film change mode is regularly executed as described above, maintenance, such as electrode cleaning, is not required until the end of the film roll attached to the unwinder 7. For example, when a film roll for 10 years is loaded on the unwinder 7, no maintenance is required for 10 years.

[0071]

As illustrated in Fig. 6, an air filter 27 may be provided downstream of the dust collecting device 1. The air filter 27 is, for example, a HEPA filter formed by molding a PP melt-blown charged nonwoven fabric into a pleated shape. The HEPA filter has a high dust collecting efficiency, but due to its high fiber density, it is relatively quickly clogged with collected dust and suffers an increase in pressure loss. It is thus recommended that maintenance (filter replacement) be performed every several months. As the air filter 27 is disposed downstream of the dust collecting device 1, the dust load on the air filter 27 can be reduced by removing dust upstream of the air filter 27. As this operation slows down the increase in pressure loss caused by clogging of the air filter 27, it is possible to maintain the high dust collecting efficiency of the air filter 27 for a long time and increase the maintenance interval of the air filter 27.

[0072]

As described above, with the air-conditioning apparatus of Embodiment 4, which uses the dust collecting device of Embodiment 1, a dust collecting device having a long maintenance interval can be provided. In a case of long-term, maintenance-free use of a ceiling-embedded air-conditioning apparatus, such as that of Embodiment 4, the low risk of fire and ozone generation, achieved by not using a high voltage, is a particularly significant advantage.

[0073]

Embodiment 5

Embodiment 6 is obtained by incorporating the dust collecting device 1 of Embodiment 1 into an air-conditioning apparatus that is different from Embodiment 4. Fig. 7 is a schematic cross-sectional view of an air-conditioning apparatus according to Embodiment 6.

[0074]

As illustrated in Fig. 7, in Embodiment 5, the air-conditioning apparatus is a room air conditioner that regulates the indoor temperature and humidity. The room air conditioner is composed of an air-conditioning-apparatus indoor unit 28 installed inside the lowered ceiling 22, and an air-conditioning-apparatus outdoor unit 29 installed outdoors. In the lowered ceiling 22, the dust collecting device 1 is connected to the bottom of the air-conditioning-apparatus indoor unit 28.

[0075]

An operation of the air-conditioning apparatus according to Embodiment 5 will be described below. By operating the air-conditioning-apparatus indoor unit 28, air is taken in from the room by rotation of a fan in the air-conditioning-apparatus indoor unit 28. The air flows in the ventilation direction 14 inside the air passage of the dust collecting device 1. As the air passes through the air passage 3, dust in the air is electrostatically attracted to and collected on the surface of the film 5 by an electrostatic field formed by the electric charge on the film 5 placed in the air passage 3. After removal of dust, the resulting clean air is taken into the air-conditioning-apparatus indoor unit 28, cooled or warmed by heat exchange through refrigerant pipes of the air-conditioning-apparatus indoor unit 28, and released into the room.

[0076]

Then, as in Embodiment 1, the film change mode is regularly executed to rotate the unwinder 7 and the winder 8 to wind the used part of the film and supply an unused part of the film. Thus, there is no need to perform maintenance, such as electrode cleaning, until the end of the film roll attached to the unwinder 7. For example, when a film roll for 10 years is loaded on the unwinder 7, no maintenance is required for 10 years.

[0077]

As described above, with the air-conditioning apparatus of Embodiment 5, which uses the dust collecting device 1 of Embodiment 1, a dust collecting device having a long maintenance interval can be provided. In a case of long-term, maintenance-free use of a ceiling-embedded air-conditioning apparatus, such as that of Embodiment 5, the low risk of fire and ozone generation, achieved by not using a high voltage, is a particularly significant advantage.

[0078]

Embodiment 6

A dust collecting device according to Embodiment 6 is obtained by adding a fan 30 to the dust collecting device 1 of Embodiment 1.

[0079]

Fig. 8 is a schematic cross-sectional view illustrating a configuration of the dust collecting device according to Embodiment 6. As illustrated in Fig. 8, the dust collecting device according to Embodiment 6 includes the fan 30 for generating an air flow that passes through the air passage 3. By operating the fan 30, indoor air is taken into the air passage 3 and flows in the ventilation direction 14. As the air passes through the air passage 3, dust in the air is collected on the surface of the film 5 by an electrostatic field formed by the film 5. This operation reduces dust and the resulting clean air is released into the room.

[0080]

Then, the film change mode is regularly executed, as in Embodiment 1, to rotate the unwinder 7 and the winder 8 to wind the used part of the film and supply an

unused part of the film. When the film change mode is regularly executed as described above, maintenance, such as electrode cleaning, is not required for a long time until the end of the film roll attached to the unwinder 7. For example, when a film roll for 10 years is loaded on the unwinder 7, no maintenance is required for 10 years.

[0081]

As described above, the dust collecting device of Embodiment 6 can provide a dust collecting device having a long maintenance interval. Also, the dust collecting device can perform dust collection independently without being connected to an air-conditioning apparatus.

[0082]

Although the present invention has been described with reference to Embodiments 1 to 6, the present invention is not limited to Embodiments 1 to 6. Embodiments 1 to 6 and their modifications may be freely combined, or Embodiments 1 to 6 may be modified or omitted as appropriate within the scope of the invention.

Reference Signs List

[0083]

1 dust collecting device, 2 dust, 3 air passage, 4 housing, 5 film, 6 friction body, 7 unwinder, 8 winder, 9 controller, 10 guide, 11 slit, 12 grounded conductor, 13 partition, 14 ventilation direction, 15 particle sensor, 16 first film, 17 second film, 18 first friction body, 19 second friction body, 20 drying unit, 21 heat exchange ventilator, 22 lowered ceiling, 23 outdoor inlet, 24 outdoor outlet, 25 indoor inlet, 26 indoor outlet, 27 air filter, 28 air-conditioning-apparatus indoor unit, 29 air-conditioning-apparatus outdoor unit, 30 fan, 31 duct

CLAIMS

[Claim 1]

A dust collecting device, comprising:

5 a housing accommodating an air passage that allows air to pass through the air passage;

a film electrically charged by friction and conveyed along a path that crosses the air passage;

an unwinder configured to supply the film into the air passage;

10 a friction body configured to apply friction to the film fed from the unwinder to electrically charge the film;

a winder configured to wind, onto the winder, the film conveyed into the air passage; and

15 a grounded conductor disposed in contact with the film to be conveyed, the grounded conductor being opposite the friction body, with the film interposed between the grounded conductor and the friction body.

[Claim 2]

20 The dust collecting device of claim 1, further comprising a controller configured to regularly execute a film change mode in which the film conveyed into the air passage is wound onto the winder and an unused part of the film is supplied from the unwinder into the air passage.

[Claim 3]

The dust collecting device of claim 2, further comprising a particle sensor configured to detect a concentration of particles to be collected in the air that passes through the air passage,

25 wherein the controller is configured to execute the film change mode on a basis of the detected concentration.

[Claim 4]

The dust collecting device of claim 3, wherein the particle sensor is provided each upstream and downstream of the air passage, and

the controller is configured to execute the film change mode when a collecting efficiency calculated from concentrations detected by the particle sensors falls below a threshold.

[Claim 5]

5 The dust collecting device of any one of claims 1 to 4, further comprising a partition disposed between the air passage and the unwinder.

[Claim 6]

10 The dust collecting device of any one of claims 1 to 5, further comprising a plurality of guides configured to guide the film to allow the film to cross the air passage multiple times.

[Claim 7]

15 The dust collecting device of any one of claims 1 to 6, further comprising:
a first film unit including a first film positively charged by friction with the friction body, an unwinder configured to supply the first film, and a winder configured to wind the first film onto the winder; and

a second film unit including a second film negatively charged by friction with the friction body, an unwinder configured to supply the second film, and a winder configured to wind the second film onto the winder,

20 wherein the first film unit and the second film unit are disposed to allow the first film and the second film to face each other in the air passage.

[Claim 8]

25 The dust collecting device of claim 7, wherein the friction body includes
a first friction body configured to apply friction to the first film, and
a second friction body configured to apply friction to the second film, the second friction body having a stronger tendency to be positively charged than does the first friction body.

[Claim 9]

30 The dust collecting device of any one of claims 1 to 8, further comprising a drying unit configured to dry the film before the friction body applies friction to the film.

[Claim 10]

The dust collecting device of any one of claims 1 to 9, further comprising an air filter disposed downstream in the air passage.

[Claim 11]

An air-conditioning apparatus, comprising:

5 a housing accommodating an air passage that allows air to pass through the air passage;

a film conveyed along a path that crosses the air passage and electrically charged by friction;

an unwinder configured to supply the film into the air passage;

10 a friction body configured to apply friction to the film fed from the unwinder to electrically charge the film;

a winder configured to wind, onto the winder, the film electrically charged and conveyed into the air passage;

15 an air sending unit configured to generate an air flow that passes through the air passage; and

a grounded conductor disposed in contact with the film to be conveyed, the grounded conductor being opposite the friction body, with the film interposed between the grounded conductor and the friction body.

[Claim 12]

20 The air-conditioning apparatus of claim 11, wherein the air-conditioning apparatus is installed inside a ceiling in a room.