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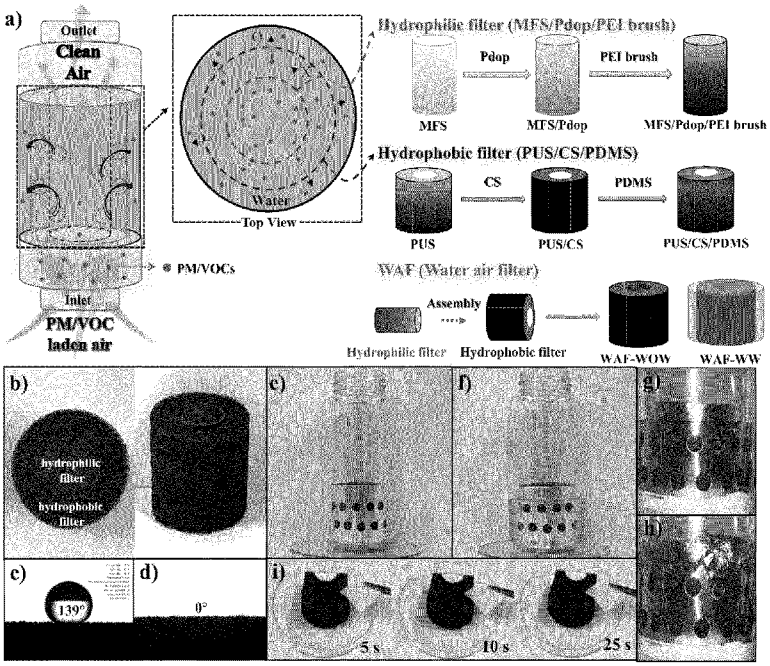
(54) Title: WET AIR FILTERS FOR REMOVING FINE DUST AND VOLATILE ORGANIC COMPOUNDS AND DUST COLLECTION DEVICES INCLUDING THE SAME



(57) Abstract: The present disclosure relates to a wet air filter including: a core-shell composite porous member that includes a hydrophilic porous member and a hydrophobic porous member formed on an outer peripheral surface of the hydrophilic porous member; a housing that accommodates the composite porous member; and a liquid layer that is filled between the composite porous member and the housing, and a dust collection device including the same, thereby simultaneously removing fine dust and volatile organic compounds contained in the air at a rapid rate and improving lifespan and safety.

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Description

Title of Invention: WET AIR FILTERS FOR REMOVING FINE DUST AND VOLATILE ORGANIC COMPOUNDS AND DUST COLLECTION DEVICES INCLUDING THE SAME

Technical Field

[1] The present disclosure relates to a wet air filter for removing fine dust and volatile organic compounds and a dust collection device including the same.

Background Art

[2] The generation amount of fine dust (particulate matter (PM)) is increasing worldwide due to combustion of biomass, vehicle emissions, and industrial emissions. Continuous exposure to the fine dust may cause various health problems such as a respiratory tract and cardiovascular diseases. Depending on the size of the particle, the fine dust may be classified into fine dust (PM10) with a diameter smaller than 10 mm, ultra-fine dust (PM2.5) with a diameter smaller than 2.5 mm, and nanoscale ultra-fine dust (PM0.3) with a diameter smaller than 0.3 mm. Among them, PM2.5 and PM0.3 are particularly small in size, so the fine dust easily enters the human body through the respiratory tract and accumulates in the human body.

[3] Meanwhile, volatile organic compounds (VOC), which collectively refer to liquid or gaseous organic compounds that are emitted from industry and easily evaporate into the atmosphere due to their low boiling point, are carcinogenic substances, and therefore, are very harmful to the human body. The VOC not only causes odors, but also generates toxic by-products, such as ozone, OH radicals, and NOx, through photochemical reactions, which may pose a fatal risk to the human body.

[4] Therefore, it is very important to develop an air filter that may purify polluted air by filtering volatile organic compounds and fine dust contained in the air.

[5] However, the conventionally commercialized dry air filter has a problem in that as particles accumulate in the filter when the dry air filter is used for a long period of time and the pressure drop of the filter increases, energy consumption increases and lifespan of a filter decreases and has limitations in quickly removing the fine dust and volatile organic compounds. Therefore, there is a need to develop an air filter capable of improving lifespan and purifying air by quickly filtering fine dust and volatile organic compounds.

Disclosure of Invention

Technical Problem

[6] An object of the present disclosure provides a wet air filter capable of quickly removing fine dust and volatile organic compounds and a dust collection device including the same.

[7] Another object of the present disclosure provides a wet air filter with improved lifespan and safety and a dust collection device including the same.

Solution to Problem

[8] In one general aspect, a wet air filter includes: a core-shell composite porous member that includes a hydrophilic porous member and a hydrophobic porous member formed on an outer peripheral surface of the hydrophilic porous member; a housing that accommodates the composite porous member; and a liquid layer that is filled between the composite porous member and the housing.

[9] At one end of the wet air filter, only an area of the hydrophilic porous member may be open, and at the other end, the entire area may be open.

[10] The hydrophobic porous member may be manufactured by performing carbon particle reinforcing treatment on a porous foam and then performing hydrophobic treatment on the carbon particle reinforced porous foam.

[11] The hydrophobic porous member may be manufactured by performing hydrophobic treatment on a surface of the porous foam and a surface of a foam cell.

[12] The hydrophobic treatment may include impregnating the carbon particle reinforced porous foam into a siloxane-based polymer solution.

[13] The carbon particle reinforcement may be treated with carbon particles containing any one or two or more selected from charcoal, carbon nanotube, graphite, fullerene, and amorphous carbon.

[14] The hydrophilic porous member may be manufactured by (a) impregnating a porous foam into a polymerization solution containing dopamine and polymerizing the porous foam to coat a surface with a dopamine-based polymer; and (b) impregnating the porous foam coated with the dopamine-based polymer into a solution containing an amine group-containing compound to manufacture the hydrophilic porous member.

[15] A density d_1 of the hydrophilic porous member and a density d_2 of the hydrophobic porous member may satisfy Expression 1 below.

[16] [Expression 1]

[17] $d_1 > d_2$

[18] The wet air filter may further include a perforated guard located between the outer peripheral surface of the composite porous member and the housing.

[19] A water contact angle of a surface of the hydrophilic porous member may be 50° or less, and a water contact angle of a surface of the hydrophobic porous member may be 100° or more.

[20] The present disclosure includes a filtration method using a wet air filter.

[21] The filtration method using a wet air filter includes: injecting gas or aerosol containing impurities into one side of the hydrophilic porous member of the wet air filter of any one of claims 1 to 10; removing the impurities by sequentially diffusing the gas or aerosol from the hydrophilic porous member to the liquid layer through the hydrophobic porous member; and discharging the gas or aerosol from which the impurities are removed to an outside of the wet air filter.

[22] The impurities may include fine dust, volatile organic compounds (VOC), or combinations thereof.

[23] In another general aspect, a dust collection device includes the wet air filter described above.

[24] The dust collection device may operate spontaneously without any external energy.

[25] In still another general aspect, a core-shell composite porous member includes: a hydrophilic porous member; and a hydrophobic porous member that is formed on an outer peripheral surface of the hydrophilic porous member.

[26] The hydrophobic porous member may be manufactured by performing carbon particle reinforcing treatment on a porous foam and then performing hydrophobic treatment on the carbon particle reinforced porous foam.

[27] The hydrophobic porous member may be manufactured by performing hydrophobic treatment on a surface of the porous foam and a surface of a foam cell.

[28] The hydrophobic treatment may include impregnating the carbon particle reinforced porous foam into a siloxane-based polymer solution.

[29] The carbon particle reinforced porous foam may reinforce the surface of the porous foam by being treated with any one or two or more carbon particles selected from charcoal, carbon nanotube, graphite, fullerene, and amorphous carbon.

[30] The hydrophilic treatment may include: (a) impregnating a porous foam into a polymerization solution containing dopamine and polymerizing the porous foam to coat a surface with a dopamine-based polymer; and (b) impregnating the porous foam coated with the dopamine-based polymer into a solution containing an amine group-containing compound to prepare the hydrophilic porous member.

[31] A density d_1 of the hydrophilic porous member and a density d_2 of the hydrophobic porous member may satisfy Expression 1 below.

[32] [Expression 1]

[33] $d_1 > d_2$

Advantageous Effects of Invention

[34] According to a wet air filter and a dust collection device including the same according to the present disclosure, it is possible to quickly remove fine dust and volatile organic compounds.

[35] In addition, it is possible to provide a wet air filter with improved lifespan and safety and a dust collection device including the same.

Brief Description of Drawings

[36] FIG. 1(a) is a schematic diagram illustrating a wet air filter and a manufacturing method thereof according to an embodiment, FIG. 1(b) is a photograph of a core-shell composite porous member according to an embodiment, FIG. 1(c) is a photograph measuring a water contact angle of a hydrophobic porous member, FIG. 1(d) is a photograph measuring a water contact angle of a hydrophilic porous member, and FIGS. 1(e) to 1(i) are photographs illustrating a wet air filter according to an embodiment.

[37] FIGS. 2(a) to 2(f) are scanning electron microscope (SEM) photographs of a core-shell composite porous member according to an embodiment, FIGS. 2(g) to 2(j) are energy dispersive X-ray spectroscopy (EDX) spectra of the core-shell composite porous member, and FIGS. 2(k) and 2(l) are diagrams illustrating Fourier-transform infrared spectroscopy (FT-IR) spectra of the core-shell composite porous member.

[38] FIG. 3(a) is a photograph illustrating a filtration method using a wet air filter according to an embodiment, and FIGS. 3(b) to 3(d) are graphs measuring fine dust removal efficiency of the wet air filter according to an embodiment.

[39] FIGS. 4(a) to 4(f) are graphs measuring the fine dust removal efficiency of the wet air filter according to an embodiment.

[40] FIGS. 5(a) to 5(c) are graphs measuring a change in fine dust concentration according to operating time of the wet air filter according to an embodiment, and FIGS. 5(d) and 5(e) are graphs measuring the fine dust removal efficiency according to air injection speed, and FIG. 5(f) is a graph measuring pressure drop according to the air injection speed.

[41] FIGS. 6(a) to 6(d) are graphs measuring long-term fine dust removal performance and resulting pressure drop of the wet air filter and a HEPA filter (H13 grade) according to an embodiment.

[42] FIG. 7(a) is a photograph illustrating the filtration method using a wet air filter according to an embodiment, and FIGS. 7(b) to 7(d) are graphs measuring volatile organic compound removal efficiency of the wet air filter according to an embodiment.

[43] FIGS. 8(a) and 8(b) are photographs illustrating results of a bacterial growth experiment of the wet air filter according to an embodiment, and FIGS. 8(c) to 8(e)

are graphs measuring the volatile organic compounds removal efficiency of the wet air filter according to an embodiment.

Best Mode for Carrying out the Invention

[44] A wet air filter for removing fine dust and volatile organic compounds and a dust collection device including the same according to the present disclosure will be described in detail. General terms that are currently widely used are selected as terms used in embodiments in consideration of functions in the present specification but may be changed depending on the intention of those skilled in the art or a judicial precedent, the emergence of a new technique, and the like. If there is no other definition in the technical and scientific terms used, they have the meaning commonly understood by those skilled in the art in the technical field to which the present disclosure belongs.

[45] In this specification and appended claims, the terms "include" or "have" means that a feature or element described in the specification is present, and unless specifically limited, it does not preclude in advance the possibility that one or more other features or components may be added.

[46] In the present specification and appended claims, singular forms include plural forms unless the context clearly indicates otherwise. In addition, plural forms include singular forms unless the context clearly indicates otherwise.

[47] In addition, numerical ranges as used herein include lower and upper limits and all values within these ranges, increments logically derived from forms and widths of defined ranges, all values doubly defined, and all possible combinations of upper and lower limits of numerical ranges defined in different forms. Unless otherwise defined in the specification of the present disclosure, values out of a numerical range that may occur due to experimental errors or rounding of values are also included in the defined numerical range.

[48] The terms "about" and the like used in this specification and the appended claims are used to encompass tolerance when tolerance exists.

[49] The generation amount of fine dust (particulate matter (PM)) is increasing worldwide due to combustion of biomass, vehicle emissions, and industrial emissions. Continuous exposure to the fine dust may cause various health problems such as a respiratory tract and cardiovascular diseases. Depending on the size of the particle, the fine dust may be classified into fine dust (PM_{10}) with a diameter smaller than 10 mm, ultra-fine dust ($PM_{2.5}$) with a diameter smaller than 2.5 mm, and nanoscale ultra-fine dust ($PM_{0.3}$) with a diameter smaller than 0.3 mm. Among them, $PM_{2.5}$ and $PM_{0.3}$ may be particularly small in size, so the fine dust easily enters the human body through the respiratory tract and accumulate in the human body.

[50] Meanwhile, volatile organic compounds (VOC), which collectively refer to liquid or gaseous organic compounds that are emitted from industry and easily evaporate into the atmosphere due to their low boiling point, are carcinogenic substances, and therefore, are very harmful to the human body. The VOC not only causes an odor, but also generates toxic by-products, such as ozone, OH radicals, and NOx, through photochemical reactions, which may pose a fatal risk to the human body. Therefore, it is very important to develop an air filter that may purify polluted air by filtering volatile organic compounds and fine dust contained in the air.

[51] The conventionally commercialized dry air filter has a problem in that as impurity particles accumulate in the filter when the dry air filter is used for a long period of time and the pressure drop of the filter increases, energy consumption increases and lifespan of a filter decreases, and at the same time has limitations in quickly removing the fine dust and volatile organic compounds.

[52] Accordingly, the present applicant has developed a wet air filter including a composite porous member in which a hydrophilic porous member and a hydrophobic porous member are combined to reduce a pressure drop and improve the lifespan, and quickly and efficiently remove fine dust and volatile organic compounds contained in gas or aerosol.

[53] The wet air filter according to the present disclosure includes: a core-shell composite porous member that includes a hydrophilic porous member and a hydrophobic porous member formed on an outer peripheral surface of the hydrophilic porous member; a housing that accommodates the composite porous member; and a liquid layer that is filled between the composite porous member and the housing.

[54] As the liquid layer includes the composite porous member including a hydrophilic porous member and a hydrophobic porous member formed on the outer peripheral surface of the hydrophilic porous member and is located between the composite porous member of the core-shell structure and the housing, impurity-containing gas or aerosol entering the wet air filter may pass through the composite porous member and move to the liquid layer. Since the gas or aerosol may move to the liquid layer through the composite porous member without separate external energy, the energy consumption required to remove impurities may be significantly reduced.

[55] In addition, the impurities contained in gas or aerosol are dissolved in the liquid layer, and the amount of impurity particles accumulated in pores of the composite porous member may be significantly reduced. Therefore, it is advantageous because the long-term stability and lifespan of the wet air filter may be improved.

[56] By using the composite porous member with the core-shell structure in which the hydrophobic porous member is located on the outer peripheral surface of the hydrophobic porous member, liquid components of the liquid layer in contact with the

hydrophobic porous member does not penetrate into the inside of the composite porous member, thereby improving impurity removal performance and durability.

[57] In an embodiment, a density d_1 of the hydrophilic porous member and a density d_2 of the hydrophobic porous member may satisfy Expression 1 below.

[58] [Expression 1]

[59] $d_1 > d_2$

[60] In other words, the hydrophilic porous member has a higher density than the hydrophobic porous member, so the pressure of the hydrophilic porous member may be higher than that of the hydrophobic porous member. As a pressure difference occurs due to a density difference between the hydrophilic porous member and the hydrophobic porous member, the gas or aerosol introduced into the wet air filter may spontaneously move from the hydrophilic porous member to the liquid layer through the hydrophobic porous member even without applying separate external energy. Therefore, it is possible to significantly reduce the energy required to remove impurities.

[61] In an embodiment, the wet air filter may further include a perforated guard located between the outer peripheral surface of the composite porous member and the housing. The perforated guard may allow enables the gas or aerosol containing impurities to pass from the composite porous member to the liquid layer and prevent the liquid component of the liquid layer from penetrating into the inside of the composite porous member.

[62] In an embodiment, at one end of the wet air filter, only an area of the hydrophilic porous member may be open, and at the other end, the entire area may be open. As a more specific example, the gas or aerosol containing impurities may be introduced into one end of the wet air filter, and the gas or aerosol from which the impurities have been removed may be discharged through the other end of the wet air filter. At one end of the wet air filter, only the area of the hydrophilic porous member may be open to sequentially pass the introduced gas or aerosol through the hydrophilic porous member and the hydrophobic porous member, thereby improving impurity removal efficiency.

[63] In an embodiment, the hydrophobic porous member may include a porous foam, a carbon particle layer located on the surface of the porous foam, and a hydrophobic layer located on the carbon particle layer. Specifically, the hydrophobic porous member may be manufactured by performing hydrophobic treatment on the surface of the porous foam and the surface of the foam cell. More specifically, the hydrophobic porous member may be manufactured by performing carbon particle reinforcing treatment on the porous foam to prepare a carbon particle layer and then performing hydrophobic treatment on the surface of the carbon particle reinforced porous foam.

[64] The carbon particle reinforced porous foam may reinforce the surface of the porous foam by being treated with one or two or more carbon particles selected from charcoal, carbon nanotube, graphite, fullerene, and amorphous carbon. In this case, the surface may be the outer and inner surfaces of the porous foam, or may mean part or all of the pore surfaces of the porous foam. By performing the carbon particle reinforced treatment on the porous foam, irregularities are formed on the surface of the porous foam, thereby improving the impurity filtration effect and absorbing odors derived from the impurities.

[65] The hydrophobic porous member can be manufactured by impregnating the carbon particle reinforced porous foam into a siloxane-based polymer solution and performing the hydrophobic treatment on the carbon particle reinforced porous foam. The siloxane-based polymer may include one or more selected from the group including polydimethylsiloxane (PDMS), diphenylpolydimethylsiloxane (DP), polymethylhydrosiloxane (PMHS), and hexamethyldisiloxane (HMDS), and may be preferably polydimethylsiloxane (PDMS). By performing the hydrophobic treatment on the porous foam with irregularities on the surface through the carbon particle reinforced treatment with the siloxane-based polymer, it is possible to improve the durability by maximizing the adhesion between the porous foam and the siloxane-based polymer and minimize the deterioration in the fine dust removal efficiency even if the impurity removal process is repeated.

[66] In an embodiment, the porous foam includes any one or two or more selected from the group consisting of a urethane-based resin, a phenol-based resin, a melamine-based resin, an acrylic resin, a styrene-based resin, an ester-based resin, and an olefin-based resin, and preferably include the urethane-based resin. Without limitation, the porous foam may be manufactured by foaming the polyurethane resin, but the present disclosure is not limited thereto.

[67] In an embodiment, the hydrophilic porous member may include a porous foam, a dopamine-based polymer layer located on the surface of the porous foam, and an amine group-containing polymer brush layer located on the dopamine-based polymer layer.

[68] Specifically, the hydrophilic porous member may be manufactured by (a) impregnating a porous foam into a polymerization solution containing dopamine and polymerizing the porous foam and polymerization solution to coat a surface with a dopamine-based polymer; and (b) impregnating the porous foam coated with the dopamine-based polymer into a solution containing an amine group-containing compound to prepare the hydrophilic porous member.

[69] Through step (a) above, the surface of the porous foam may be modified to be hydrophilic. In step (b), the porous foam coated with the dopamine-based polymer

may be impregnated into a solution containing an amine group-containing compound, thereby coating the surface of the porous foam with the amine group-containing polymer. The amine group-containing polymer may form polymer brushes on the surface of the porous foam coated with the dopamine-based polymer. The polymer brushes are collections of polymer chains with one end of the chain fixed to the surface or interface. The amine group-containing polymer may form the polymer brushes to secondarily modify the surface of the porous foam coated with the polydopamine. Therefore, the hydrophilic properties of the hydrophilic porous member may be maximized.

[70] In a specific example, examples of the amine group-containing compound may include one or two selected from the group consisting of diethylenetriamine (DETA), ethylenediamine (EDA), triethylenetetramine (TETA), tris(2-aminoethyl)amine (TAEA), diethylenetriamineurea (UDETA), polyethyleneimine, tris(2-aminoethyl)amine and 2,2'-(ethylenedioxy)bi s(ethylamine), and tris(hydroxymethyl)aminomethane), and preferably include tris(hydroxymethyl)aminomethane, polyethyleneimine, or a combination thereof, but the present disclosure is not limited thereto.

[71] In an embodiment, the porous foam may include any one or two or more selected from the group consisting of a urethane-based resin, a phenol-based resin, a melamine-based resin, an acrylic resin, a styrene-based resin, an ester-based resin, and an olefin-based resin, and preferably include the melamine-based resin.

[72] As a non-limiting and specific example, the melamine-based resin may include melamine formaldehyde, and the porous foam may be prepared by foaming a melamine formaldehyde pre-condensate using a foaming agent.

[73] The shape of the porous foam used in manufacturing the hydrophobic porous member and hydrophilic porous member is not particularly limited, and may be adjusted along with the size depending on the application field, but is preferably cylindrical, which may improve the impurity removal efficiency.

[74] In an embodiment, the water contact angle of the surface of the hydrophilic porous member may be 50° or less, preferably 30° or less, most preferably 10° or less, and without limitation, 0° or more. The water contact angle of the surface of the hydrophobic porous member may be 100° or more, preferably 110° or more, most preferably 120° or more, and may be 180° or less without limitation.

[75] In an embodiment, the liquid layer may include any solvent as long as the solvent may dissolve the impurities contained in gas or aerosol, without limitation, and may preferably include water. Water may quickly dissolve impurities such as fine dust and volatile organic compounds, which will be described later, and is non-toxic, so the stability of the wet air filter may be improved.

[76] The present disclosure includes a filtration method using a wet air filter. Since the wet air filter is the same as described above, detailed description thereof will be omitted.

[77] The filtration method according to the present disclosure includes: injecting gas or aerosol containing impurities into one side of the hydrophilic porous member of the wet air filter of any one of claims 1 to 10; removing the impurities by sequentially diffusing the gas or aerosol from the hydrophilic porous member to the liquid layer through the hydrophobic porous member; and discharging the gas or aerosol from which the impurities are removed to an outside of the wet air filter.

[78] As described above, as the gas or aerosol containing impurities is introduced into the hydrophilic porous member and moves to the liquid layer through the hydrophobic porous member, the impurities may be removed by being dissolved in the liquid layer, and the gas or aerosol from which the impurities have been removed may be filter the impurities out by being discharged to the outside of the wet air filter.

[79] As the wet air filter includes the liquid layer, the impurity particles may dissolved in the liquid layer without clogging the pores of the composite porous member of the wet air filter due to the accumulation of impurity particles inside the pores, thereby preventing the performance from deteriorating even if the impurities are repeatedly filtered for a long period of time.

[80] In an embodiment, the impurities may include fine dust, volatile organic compounds (VOC), or combinations thereof that have a very harmful effect on the human body. Specifically, the fine dust may have various sizes of particles such as fine dust (PM_{10}) with a diameter smaller than 10 mm, ultra-fine dust ($PM_{2.5}$) with a diameter smaller than 2.5 mm, and nanoscale ultra-fine dust ($PM_{0.3}$) with a diameter smaller than 0.3 mm. That is, the wet air filter according to the present disclosure may remove impurities with excellent efficiency regardless of the sizes of the impurity particles.

[81] The dust collection device according to the present disclosure includes the wet air filter described above. Since the wet air filter is the same as described above, detailed description thereof will be omitted.

[82] In the wet air filter of the present disclosure, the hydrophilic porous member may have a higher pressure than the hydrophobic porous member due to a density gradient between the hydrophobic porous member and the hydrophilic porous member. Therefore, in the dust collection device including the wet air filter of the present disclosure, the air or aerosol may move from the hydrophilic porous member to the liquid layer through the hydrophobic porous member due to the pressure difference, without applying a separate external force, and spontaneously remove the impurities contained in air or aerosol. Therefore, it has the advantage of significantly reducing the energy consumption.

[83] The core-shell composite porous member according to the present disclosure includes: a hydrophilic porous member; and a hydrophobic porous member that is formed on an outer peripheral surface of the hydrophilic porous member.

[84] Since the material, structure, shape, size, etc., of the hydrophilic porous member and hydrophobic porous member included in the core-shell composite porous member are the same or similar to those described above, detailed description thereof will be omitted.

[85] As described above, by adopting the core-shell structure in which the hydrophilic porous member included in the composite porous member is located in the core and the hydrophobic porous member is located on the outer peripheral surface of the hydrophilic porous member, the density gradient of the core and shell allows air or aerosol to move spontaneously from the core to the shell without any external force. At the same time, as the shell has hydrophobicity, the hydrophilic substances may be prevented from penetrating from the shell to the core, thereby improving the durability and lifespan, and providing the excellent impurity filtration performance.

[86] Hereinafter, the present disclosure will be described in more detail through Inventive Examples.

[87] (Example 1)

[88] **Manufacturing of Hydrophilic Porous Member**

[89] A mixed solution containing a sodium acetate solution (205 mg/50 mL), a sodium metaperiodate solution (112 mg/50 mL), and a dopamine hydrochloride solution (100 mg/50 mL) was prepared. A cylindrical porous melamine resin foam (Basotect®, BASF) with a diameter of 20 mm and a height of 40 mm was impregnated into the mixed solution and stirred for 6 hours. Thereafter, the porous melamine resin foam was taken out, washed three times with distilled water, and dried at 50°C to prepare the porous melamine resin foam coated with the polydopamine. Thereafter, the porous melamine resin foam coated with the polydopamine was put in a mixed solution of tris(hydroxymethyl)aminomethane (10 mM, pH 8.5) and 0.072 g of polyethyleneimine (PEI), and then was refluxed at 60°C for 3 hours. Thereafter, the porous melamine resin foam coated with the polydopamine was taken out, washed three times with distilled water, and dried at 50°C for 12 hours to manufacture the hydrophilic porous member.

[90] **Manufacturing of Hydrophobic Porous Members**

[91] Charcoal was burned using candles to obtain carbon particles. 0.3 g of carbon particles was added to 150 mL of acetone, and sonicated for 1 hour to prepare a carbon particle dispersion solution in which carbon particles were uniformly dispersed. Hollow cylindrical porous polyurethane foam having an outer diameter of 40 mm, an inner diameter of 20 mm, and a height of 40 mm was impregnated into the

carbon particle dispersion solution and sonicated for 1 hour. Thereafter, the porous polyurethane foam was taken out from the carbon particle dispersion solution and dried at a temperature of 50°C for 1 hour to enhance carbon particles.

[92] The carbon particle-reinforced porous polyurethane foam was impregnated in a polydimethylsiloxane (PDMS, Sylgard 184, Dow Chemical) solution for 1 hour and then heated at 100°C for 1 hour to prepare a hydrophobic porous member.

[93] **Manufacturing of Wet Air Filter**

[94] A core-shell composite porous member was manufactured by inserting and assembling the hydrophilic porous member into the hollow part of the hydrophobic porous member. In this case, a volume ratio of the hydrophilic porous member and the hydrophobic porous member was 1:3, An aluminum perforated guard including 24 holes with a diameter of 40 mm was installed under a 250 mL plastic housing. The diameter of the hole was 6 mm. Thereafter, the composite porous member was inserted into the aluminum perforated guard so that there were no gaps, and then 30 mL of water was filled between the housing and the perforated guard to form a liquid layer, thereby manufacturing the wet air filter.

[95] (Example 2)

[96] A wet air filter was manufactured in the same manner as Example 1, except that the volume ratio of the hydrophilic porous member and the hydrophobic porous member was 6:94.

[97] (Example 3)

[98] A wet air filter was manufactured in the same manner as Example 1, except that the volume ratio of the hydrophilic porous member and the hydrophobic porous member was 14:86.

[99] (Example 4)

[100] A wet air filter was manufactured in the same manner as Example 1, except that the volume ratio of the hydrophilic porous member and the hydrophobic porous member was 2:3.

[101] (Example 5)

[102] A wet air filter was manufactured in the same manner as Example 1, except that the height of the composite porous member was 2 cm.

[103] (Example 6)

[104] A wet air filter was manufactured in the same manner as Example 1, except that the height of the composite porous member was 6 cm.

[105] (Example 7)

[106] A wet air filter was manufactured in the same manner as Example 1, except that the aluminum perforated guard did not include a hole.

[107] (Example 8)

[108] A wet air filter was manufactured in the same manner as Example 1, except that the number of holes of the aluminum perforated guard is 12.

[109] (Example 9)

[110] A wet air filter was manufactured in the same manner as Example 1, except that the number of holes of the aluminum perforated guard is 18.

[111]

[112] (Comparative Example 1)

[113] A wet air filter was manufactured in the same manner as Example 1, except that the wet air filter did not include a composite porous member and included only a liquid layer.

[114] (Comparative Example 2)

[115] A wet air filter (All-PUS) was manufactured in the same manner as Example 1, except that only a hydrophobic porous member was inserted into an aluminum perforated guard.

[116] (Comparative Example 3)

[117] A wet air filter (All-MFS) was manufactured in the same manner as Example 1, except that only a hydrophilic porous member was inserted into an aluminum perforated guard.

[118] (Comparative Example 4)

[119] A dry air filter was manufactured in the same manner as in Example 1, but did not contain a liquid layer by not filling water between a housing and a perforated guard.

[120] (Comparative Example 5)

[121] A dry air filter using an H-13 grade HEPA filter was manufactured.

[122] (Comparative Example 6)

[123] A wet air filter was manufactured in the same manner as Example 1, except that the number of holes of the aluminum perforated guard is 30.

[124] FIG. 1(a) is a schematic diagram illustrating a wet air filter and a manufacturing method thereof according to Example 1, FIG. 1(b) is a photograph of a core-shell composite porous member manufactured by the method according to Example 1, FIG. 1(c) is a photograph measuring a water contact angle of a hydrophobic porous member, FIG. 1(d) is a photograph measuring a water contact angle of a hydrophilic porous member, and FIGS. 1(e) to 1(i) are photographs illustrating the wet air filter manufactured by the method according to Example 1.

[125] Referring to FIGS. 1(a), 1(b), 1(e), and 1(f), the composite porous member having the core-shell structure may be manufactured by assembling the hydrophilic porous member manufactured by performing the hydrophilic treatment on the porous foam and the hydrophobic porous member manufactured by performing the carbon particle reinforced treatment and the hydrophobic treatment on the porous foam. When the

gas or aerosol containing impurities is introduced into the wet air filter including the composite porous member, the gas or aerosol containing impurities may move from the hydrophilic porous member to the liquid layer through the hydrophobic porous member. The impurities are dissolved in the liquid layer, and the gas or aerosol from which the impurities have been removed is discharged to the outside of the wet air filter, thereby filtering the impurities.

[126] FIGS. 1(c) and 1(d) are photographs measuring the water contact angles of the hydrophobic porous member and the hydrophilic porous member, respectively. The water contact angles were measured using a contact angle meter (SEO Phoenix 300 Touch), and the contact angles were measured by dropping water with a volume of 20 ml on the hydrophobic porous member and the hydrophilic porous member, respectively. The water contact angle of the hydrophobic porous member was measured to be 139°, and the water contact angle of the hydrophilic porous member was measured to be 0°. The difference in the water contact angle between the hydrophobic porous member and the hydrophilic porous member is stark, so there is an advantage that the water in the liquid layer does not penetrate into the inside of the composite porous member.

[127] Referring to FIG. 1(i), since the surface of the hydrophobic porous member in contact with water does not become wet over time, the water in the liquid layer is not introduced into the inside of the composite porous member, so it can be seen that the durability is excellent. FIGS. 1(g) and 1(h) are photographs of the wet air filter manufactured by the method in Example 1, and it was confirmed that the air moving into the wet air filter passes through the composite porous member and is discharged to the liquid layer.

[128] FIGS. 2(a) to 2(c) are scanning electron microscope images observing the surface of the hydrophilic porous member, FIGS. 2(g) and 2(h) are energy dispersive X-ray spectroscopy (EDX) spectra of the hydrophilic porous member, and FIG. 2(k) is a graph showing Fourier-transform infrared spectroscopy (FT-IR) spectrum of the hydrophilic porous member.

[129] In addition, FIGS. 2(d) to 2(f) are scanning electron microscope images observing the surface of the hydrophobic porous member, FIGS. 2(i) and 2(j) are energy dispersive X-ray spectroscopy (EDX) spectra of the hydrophobic porous member, and FIG. 2(l) is Fourier-transform infrared spectroscopy (FT-IR) spectrum of the hydrophobic porous member.

[130] The scanning electron microscope and energy dispersive X-ray spectroscopy were performed using HITACHI's S-4800 device, and the FT-IR spectrum was obtained using a Sinco Nicolet IS5 instrument.

[131] Specifically, FIG. 2(a) is an observation of the surface of the melamine resin foam, and illustrates a three-dimensional porous network structure in which the melamine resin foam is interconnected, and it was confirmed that the surface has a smooth surface. Referring to FIG. 2(b) observing the surface of the foam after immersing the melamine resin foam in a dopamine-containing solution, it can be seen that the melamine resin foam was coated with the polydopamine. FIG. 2(c) is a view illustrating a state after synthesis of polyethyleneimine polymer with the porous melamine resin foam coated with the polydopamine, and it was confirmed that irregularities are generated on the surface of the porous melamine resin foam coated with polydopamine, and thus, the polyethyleneimine forms the polymer brushes. It can be seen that the hydrophilicity was reinforced by sequentially coating the surface of the porous melamine resin foam with polydopamine and polyethyleneimine.

[132] Likewise, the N content in FIG. 2(g) illustrating the EDX spectrum of the porous melamine resin foam coated with the polydopamine was only 25.80 atom%, but in FIG. 2(h) illustrating the EDX spectrum of the hydrophilic porous member manufactured by synthesizing the polyethyleneimine polymer with the porous melamine resin foam coated with the polydopamine, the N content increased to 49.03 atom% to confirm that the polyethyleneimine was coated.

[133] FIG. 2(k) is FT-IR spectra of a porous melamine resin foam (MPS), a porous melamine resin foam coated with polydopamine (MPS/Pdop), and a hydrophilic porous member (MPS/Pdop/PEI brush), respectively. In the porous melamine resin foam coated with the polydopamine, absorption peaks were observed at 1329 cm^{-1}(-CN-), 1138 cm^{-1}(-CN-), and 809 cm^{-1}(-NH-), so it could be seen that the polydopamine is coated on the surface of the porous melamine resin foam. It could be seen that, in the case of the hydrophilic porous member, the absorption peaks were observed at 3288 cm^{-1} (-NH-) and 1740 cm^{-1} (C=O), and the polyethyleneimine brush forms a covalent bond with polydopamine to form the hydrophilic porous member.

[134] FIGS. 2(d) to 2(f) are SEM images observing the surfaces of (d) porous polyurethane foam, (e) carbon particle reinforced porous polyurethane foam, and (f) hydrophobic porous member, respectively, and the surface of the polyurethane porous foam, which had a smooth surface, was subjected to the carbon particle reinforced treatment with charcoal to form irregularities on the surface of the porous foam. It was confirmed that the carbon particle reinforced porous foam was immersed in the polydimethylsiloxane solution, and subjected to the hydrophobic treatment by coating the polydimethylsilox ane on the surface of the carbon particle reinforced porous foam in a film-like form. In addition, it could be seen that the pore size of the hydrophobic porous member was

larger than that of the hydrophilic porous member, and thus, the hydrophilic porous member had a higher density than the hydrophobic porous member.

[135] Likewise, it could be seen that, in FIG. 2(i) illustrating the EDX spectrum of the carbon particle reinforced porous polyurethane foam, the carbon particle reinforced porous polyurethane foam does not contain Si, but in FIG. 2(j) illustrating the EDX spectrum of the hydrophobic porous member manufactured by treating the carbon particle-reinforced porous polyurethane foam with the polydimethylsiloxane, Si was present at 55.05 atom%.

[136] FIG. 2(l) is the FT-IR spectra of porous polyurethane foam (PUS), carbon particle reinforced porous polyurethane foam (PUS/CS), and hydrophobic porous member (PUS/CS/PDMS), respectively. The absorption peak of the carbon particle reinforced porous polyurethane foam overall increased in intensity compared to the absorption peak of the porous polyurethane foam, but there was no significant difference in the type of absorption peak. However, absorption peaks at 1258 cm^{-1} (Si—CH_3), 1078 cm^{-1} (Si-O-Si), and 798 cm^{-1} (Si-CH_3) were observed only in the hydrophobic porous member, so It was confirmed that the PDMS implements hydrophobic properties by bonding to the carbon particle reinforced porous polyurethane foam.

[137] (Experimental Example 1) Evaluation of Fine Dust Removal Performance

[138] As illustrated in FIG. 3(a), after installing the wet air filter manufactured by the method in Example 1, fine dust was formed by burning an incense stick in a 500 mL round bottom flask connected to a lower portion of the wet air filter, and then, air was injected to introduce air containing fine dust into the wet air filter connected to the round bottom flask. The air that passed through the wet air filter was discharged to the upper portion of the wet air filter. A fine dust concentration meter was installed on the upper portion of the wet air filter to calculate the fine dust removal efficiency.

[139] HT-9601 (Dongguan Xintai Instrument, China) was used as the fine dust concentration meter, and the measured fine dust concentration was confirmed and adjusted using a KTREBAM-Beta attenuated mass monitor (Met One Instruments, USA).

[140] The fine dust removal efficiency (PM-RE) was calculated using Expression 2 below. In Expression 2 below, C_0 (mg/cm3) and C_1 (mg/cm3) mean the concentration of the fine dust contained in the air before passing through the air filter and the air discharged after passing through the air filter, respectively.

[141] [Expression 2]

[142] $$PM\text{-}RE(\%)=\frac{(C_0-C_1)}{C_0}\times 100$$

[143] The pressure drop was measured by installing a differential pressure gauge (TESTO 510i, TESTO, Germany) at an air inlet and an air outlet of the wet air filter.

[144] In detail, FIG. 3(b) is a graph measuring the fine dust removal efficiency of wet air filters manufactured by the methods in Example 1 (WAF), Comparative Example 1 (Only water), Comparative Example 2 (Hydrophobic filter), and Comparative Example 3 (Hydrophilic filter), and compared to the wet air filters of Comparative Examples 1 to 3, the wet air filter of Example 1 was measured to have higher fine dust (PM10) and ultra-fine dust (PM2.5) removal efficiency. The wet air filter of Example 1 including the composite porous member was able to adsorb not only hydrophilic fine dust but also hydrophobic fine dust to the porous member, thereby improving the fine dust removal efficiency.

[145] FIG. 3(c) is a graph measuring the removal efficiency of the fine dust (PM10) and ultra-fine dust (PM2.5) of the wet air filters manufactured by the methods in Examples 1 to 4, and the wet air filter of Example 1, in which a volume ratio of hydrophilic porous member and hydrophobic porous member is 1:3, showed the most excellent fine dust and ultra-fine dust removal efficiency.

[146] FIG. 3(d) is a graph measuring the fine dust removal efficiency and pressure drop of the wet air filters manufactured by the methods in Example 1, Example 5, and Example 6, and it was confirmed that since the wet air filter of Example 1, in which the height of the composite porous member was 4 cm, has excellent fine dust and ultra-fine dust removal efficiency and at the same time has a low pressure drop of 26 Pa at a wind speed of 0.92 m/s, the a wet air filter with improved performance and lifespan was implemented.

[147] FIGS. 4(a) to 4(f) are graphs measuring the fine dust removal efficiency by the method in Experimental Example 1 using the wet air filter manufactured by the method according to an embodiment. In detail, FIG. 4(a) is a graph measuring the fine dust removal efficiency of the wet air filter manufactured by the methods according to Example 1, Example 7, Example 8, and Example 9, and as the number of holes in the aluminum perforated guard increased, the fine dust removal efficiency improved. In particular, the wet air filter of Example 1 with 24 holes showed the best fine dust removal efficiency. Among them, the fine dust removal efficiency of PM2.5 reached 99.0%. Although not illustrated in FIG. 4(a), the wet air filter of Comparative Example 6 in which the number of holes was increased to 30 was unable to perform the fine dust filtration function due to the penetration of water into the hydrophobic porous member.

[148] FIG. 4(b) is a graph of water in the liquid layer collected and analyzed using an ultraviolet-visible spectrophotometer (Agilent, Cary 8454) after operating the wet air filters manufactured by the methods according to Example 1 (WAF), Comparative Example 2 (All-PUS), and Comparative Example 3 (All-MFS), respectively, by

the method according to Experimental Example 1. Only in the case of Comparative Example 3 and Example 1, a peak was detected at a wavelength of 267 nm, which means that fine dust components exist in the water of the liquid layer. In Comparative Example 3 using only the hydrophilic porous member, the pore size of the hydrophilic porous member was smaller than that of the hydrophobic porous member, so the amount of fine dust that passed through the hydrophilic porous member and moved to the liquid layer was small. In the case of Comparative Example 2, only a hydrophobic porous member with large pore size was used, and the amount of fine dust moving to the liquid layer increased compared to Comparative Example 3. However, in the case of Example 1 including the composite porous member, air containing fine dust may move smoothly from the hydrophilic porous member to the hydrophobic porous member without separate external force due to the density gradient between the hydrophobic porous member and the hydrophilic porous member. As a result, as the amount of fine dust dissolved in the liquid layer increases compared to Comparative Examples 2 and 3, it can be seen that the fine dust removal efficiency is also very excellent as 96.9%, as illustrated in FIG. 4(c).

[149] FIGS. 4(d) to 4(f) are graphs measuring the fine dust removal efficiency of the wet air filter manufactured by the methods in Example 1 (WAF-WW) and Comparative Example 4 (WAF-WOW). In more detail, FIG. 4(d) is a graph measuring the fine dust removal efficiency when the concentration of PM2.5 contained in the air introduced into the wet air filter is 400 to 600 μg/m3, and FIG. 4(e) is a graph measuring the fine dust removal efficiency when the concentration of PM2.5 contained in the air introduced into the wet air filter is greater than or equal to 600,000 μg/m3. The fine dust removal efficiency of Example 1 including the liquid layer was higher than that of Comparative Example 4 which does not include the liquid layer, and showed high fine dust removal efficiency even if it contained the high-concentration fine dust. In particular, referring to FIG. 4(f), in the wet air filter of Example 1, the removal efficiency of not only PM10, which has a large particle size, but also the removal efficiency of ultra-fine dust (PM0.3), which has a very small particle size, was also measured as 93% or more. This means that the fine dust particles that passed through the composite porous member may be dissolved in the liquid layer, thereby improving the ultra-fine dust removal efficiency compared to Comparative Example 4 that does not include the liquid layer.

[150] FIGS. 5(a) to 5(c) are graphs measuring the change in fine dust concentration according to the operating time when removing fine dust in the air by the method according to Experimental Example 1 using the air filter according to Example 1 (WAF-WW), Comparative Example 4 (WAF-WOW), and Comparative Example 5 (Hepa filter), Referring to FIGS. 5 (a) to 5(c), it can be seen that the dry air filters

of Comparative Examples 4 and 5 have a slower removal rate of PM10 and PM2.5 compared to the wet air filter of Example 1. More specifically, after 30 seconds have passed since operating the air filter, in the dry air filters of Comparative Examples 4 and 5, the concentration of PM2.5 in the air is greater to or equal to 1000 μg/m3, but as the wet air filter of Example 1 included the liquid layer, the concentration of PM2.5 in the air decreased to 536 μg/m3 and the fine dust was removed at a significantly faster rate, and after 60 seconds, the concentration of PM2.5 decreased to 30 μg/m3, providing the significantly excellent fine dust removal effect compared to Comparative Examples 4 and 5.

[151] FIGS. 5(d) and 5(e) are graphs measuring fine dust removal efficiency according to changes in air injection speed and humidity supplied to the wet air filter manufactured by the methods in Example 1 and Comparative Example 4. Compared to the dry air filter of Comparative Example 4, which has low humidity, it can be seen that the wet air filter of Example 1 has high humidity, but has significantly higher fine dust removal efficiency than that of the dry air filter. FIG. 5(f) is a graph measuring the pressure drop of the air filter according to the injection speed of air supplied to the wet air filter manufactured by the method in Example 1. As the air injection speed increases, the pressure drop within the filter tends to increase. In particular, despite the high air injection speed, excellent pressure drop was observed, confirming that the durability of the wet air filter was improved.

[152] FIGS. 6(a) to 6(d) are graphs measuring the long-term fine dust removal performance of the air filters manufactured by the methods according to Example 1 (WAF-WW), Comparative Example 4 (WAF-WOW), and Comparative Example 5 (Hepa filter) and the resulting pressure drop. The evaluation of the long-term fine dust removal efficiency was performed for 100 cycles, and the PM removal efficiency and pressure drop were measured every 5 cycles.

[153] As illustrated in FIGS. 6(a) and 6(b), since the wet air filter of Example 1 has the highest average fine dust removal efficiency and also has a high removal efficiency of PM2.5 with small particle size, it was confirmed that the removal efficiency is excellent regardless of the particle size of fine dust, and the increase in pressure drop during 100 cycles is very low as 3 Pa. On the other hand, as illustrated in FIGS. 6(a) and 6(c), the dry air filter of Comparative Example 4 has low average fine dust removal efficiency. In particular, the dry air filters tended to have lower fine dust removal efficiency for PM2.5. The increase in pressure drop was also 6 Pa, showing a higher increase in pressure drop compared to Example 1. FIG. 6(d) is a graph measuring the fine dust removal efficiency and pressure drop when fine dust was removed for 100 cycles using the HEPA filter of Comparative Example 5, and illustrates that the fine dust removal efficiency was measured to be relatively high,

but the increase in pressure drop was 22 Pa, which was significantly higher than that of the wet air filter of Example 1. This is because, in the case of the wet air filter of Example 1, as impurities such as fine dust pass through the composite porous member and are dissolved in water, the amount of impurities accumulated in the pores of the composite porous member is significantly reduced. As a result, even though fine dust was filtered for a long period of time, the increase in pressure drop was significantly small. However, in the dry air filters of Comparative Examples 4 and 5, the fine dust that passed through the filter accumulates in the pores, and therefore, when the fine dust filtration is repeated, the pores of the filter are clogged by the fine dust and the increase in pressure drop significantly increases.

[154] Therefore, the wet air filter of the present disclosure not only removes the fine dust with high efficiency even after repeating the fine dust filtration, but also has a significantly small increase in pressure drop, improving lifespan and providing excellent long-term stability.

[155]

[156] (Experimental Example 2) Evaluation of Volatile Organic Compound Removal Efficiency

[157] As illustrated in FIG. 7(a), the wet air filter was installed, the air containing formaldehyde of a concentration of 5 ppm is injected into the wet air filter, and then the formaldehyde concentration of the air discharged through the wet air filter was measured, thereby evaluating the removal efficiency of the volatile organic compounds. The concentration of the formaldehyde was measured using a formaldehyde and volatile organic compound meter (BQ16, Trotec GmbH & Co. KG, Germany), and the removal efficiency of the formaldehyde was calculated in the same manner as Expression 2 described above.

[158] FIG. 7(b) is a graph measuring the change in formaldehyde concentration according to the operating time of the air filter manufactured by the methods in Example 1 (WAF-WW) and Comparative Example 4 (WAF-WOW). In the case of the dry air filter of Comparative Example 4 that did not include the liquid layer, the formaldehyde was not completely removed even after 90 minutes. On the other hand, the wet air filter of Example 1 showed excellent formaldehyde removal performance, with the formaldehyde concentration reaching 0 ppm within 17 minutes. Referring to the graph in FIG. 7(c), which illustrates spectrum analyzed with an ultraviolet-visible spectrophotometer (Agilent, Cary 8454) by removing formaldehyde contained in the air using the wet air filter of Example 1 and then collecting the water in the liquid layer, a new peak was detected at 267 nm to confirm that the formaldehyde that had passed through the composite porous member of the wet air filter was dissolved in water.

[159] FIGS. 7(d) to 7(f) are graphs measuring the long-term formaldehyde removal efficiency of the wet and dry air filters manufactured by the methods in Example 1 and Comparative Example 4. Specifically, FIGS. 7(d) and 7(e) measure the formaldehyde removal efficiency when using the wet air filter manufactured by the method in Example 1, and FIG. 7(f) is a graph measuring the formaldehyde removal efficiency when using the dry air filter of Comparative Example 4. Referring to FIG. 7(d) to 7(f), it was confirmed that, when using the wet air filter of Example 1, the concentration of formaldehyde in the air reaches 0 ppm within 8 minutes, and even after 50 cycles, the formaldehyde is completely removed within 13 minutes. On the other hand, when the dry air filter of Comparative Example 4 was used, it was measured that the formaldehyde is not completely removed even after 15 minutes elapses, and the formaldehyde removal performance was significantly lower than that of Example 1.

[160] (Experimental Example 3) Evaluation of Safety of Wet Air Filter

[161] The wet air filter manufactured in Example 1 filtered the formaldehyde contained in the air for 50 cycles by the method in Experimental Example 2, collected the water in the liquid layer, coated it evenly on an agar medium (Luria-Bertani (LB) liquid medium, 25 g/L), and then cultured bacteria at 37°C for 16 hours. The experimental results are illustrated in FIGS. 8(a) and (b).

[162] In the case of FIG. 8(a) where the distilled water was applied to the agar medium and the bacteria were cultured, bacterial colonies were formed, but in the case of FIG. 8(b) where the bacteria were cultured by applying the water in the liquid layer of Example 1 to the agar medium, bacterial colonies were not formed. Therefore, even though the wet air filter of the present disclosure contains the liquid layer and creates the environment in which bacteria grow, it can be seen that bacteria do not grow for 50 cycles and thus it is very safe for bacteria growth.

[163] FIG. 8(c) is a graph measuring the concentration of the volatile organic compounds contained in the air discharged when only the air was injected into the wet air filter for 10 minutes after injecting air containing 6.44 ppm of volatile organic compounds (TVOC 6.44 ppm), air containing 1.02 ppm of volatile organic compounds (TVOC 1.02 ppm), and air containing 0.08 ppm of formaldehyde (HCHO 0.08 ppm) into the wet air filters manufactured by the method in Example 1, respectively, and then filtering the volatile organic compounds contained in the air for 50 cycles. The filtration of the volatile organic compounds was performed in the same manner as Experiment 2 above.

[164] By filtering formaldehyde contained in the air for 50 cycles, the discharged air does not contain the volatile organic compounds even if the volatile organic compounds are dissolved in the liquid layer of the wet air filter, and the formaldehyde was measured at a very low level, close to the concentration of formaldehyde and volatile organic

compounds contained in laboratory air. Therefore, the volatile organic compounds dissolved in the liquid layer are not discharged outside the wet air filter, showing that the wet air filter of the present disclosure is safe.

[165] FIGS. 8 (d) and 8(e) measure the formaldehyde removal efficiency of the wet air filter of Example 1 and the dry air filter of Comparative Example 4 under the low-concentrations formaldehyde. Specifically, FIG. 8(d) is a graph measuring the concentration of formaldehyde contained in the air discharged after passing through the wet air filter of Example 1 with respect to the formaldehyde concentration (C_0) contained in the air before being injected into the wet air filter, and FIG. 8(e) is a graph measuring the concentration of formaldehyde contained in the air discharged after passing through the dry air filter of Comparative Example 4 with respect to the formaldehyde concentration (C_0) contained in the air before being injected into the air filter. Since the formaldehyde gas is easily dissolved in water, unlike the dry air filter of Comparative Example 4, it could be seen that the wet air filter of Example 1 removed formaldehyde more quickly and permanently, and removed the low-concentration formaldehyde quickly, and is also useful in everyday life.

[166] Therefore, the liquid layer located on the outer peripheral surface of the composite porous member of the core-shell structure of the present disclosure may increase the removal efficiency of fine dust and volatile organic chemicals, prevent overloading within the filter, and also extend the lifespan of the filter, thereby improving the overall performance of the wet air filter.

[167] Hereinabove, although the present disclosure has been described by specific matters, exemplary embodiments, and drawings, they have been provided only for assisting in the entire understanding of the present disclosure. Therefore, the present disclosure is not limited to the exemplary embodiments. Various modifications and changes may be made by those skilled in the art to which the present disclosure pertains from this description.

[168] Accordingly, the spirit of the present disclosure should not be limited to these embodiments, and the claims and all of modifications equal or equivalent to the claims are intended to fall within the scope and spirit of the present disclosure.

Claims

[Claim 1] A wet air filter, comprising:
a core-shell composite porous member that includes a hydrophilic porous member and a hydrophobic porous member formed on an outer peripheral surface of the hydrophilic porous member;
a housing that accommodates the composite porous member; and
a liquid layer that is filled between the composite porous member and the housing.

[Claim 2] The wet air filter of claim 1, wherein at one end of the wet air filter, only an area of the hydrophilic porous member is open, and at the other end, the entire area is open.

[Claim 3] The wet air filter of claim 1, wherein the hydrophobic porous member is manufactured by performing carbon particle reinforcing treatment on a porous foam and then performing hydrophobic treatment on the carbon particle reinforced porous foam.

[Claim 4] The wet air filter of claim 1, wherein the hydrophobic porous member is manufactured by performing hydrophobic treatment on a surface of the porous foam and a surface of a foam cell.

[Claim 5] The wet air filter of claim 3 or 4, wherein the hydrophobic treatment includes impregnating the carbon particle reinforced porous foam into a siloxane-based polymer solution.

[Claim 6] The wet air filter of claim 3, wherein the carbon particle reinforcement is treated with carbon particles containing any one or two or more selected from charcoal, carbon nanotube, graphite, fullerene, and amorphous carbon.

[Claim 7] The wet air filter of claim 1, wherein the hydrophilic porous member is manufactured by:
(a) impregnating a porous foam into a polymerization solution containing dopamine and polymerizing the porous foam to coat a surface with a dopamine-based polymer; and
(b) impregnating the porous foam coated with the dopamine-based polymer into a solution containing an amine group-containing compound to prepare the hydrophilic porous member.

[Claim 8] The wet air filter of claim 1, wherein a density (d_1) of the hydrophilic porous member and a density (d_2) of the hydrophobic porous member satisfy Expression 1 below.
[Expression 1]

$d_1 > d_2$

[Claim 9] The wet air filter of claim 1, further comprising:
a perforated guard located between the outer peripheral surface of the composite porous member and the housing.

[Claim 10] The wet air filter of claim 1, wherein a water contact angle of a surface of the hydrophilic porous member is 50° or less, and
a water contact angle of a surface of the hydrophobic porous member is 100° or more.

[Claim 11] A filtration method using a wet air filter, comprising:
injecting gas or aerosol containing impurities into one side of the hydrophilic porous member of the wet air filter of any one of claims 1 to 10;
removing the impurities by sequentially diffusing the gas or aerosol from the hydrophilic porous member to the liquid layer through the hydrophobic porous member; and
discharging the gas or aerosol from which the impurities are removed to an outside of the wet air filter.

[Claim 12] The filtration method of claim 11, wherein the impurities include fine dust, volatile organic compounds (VOC), or combinations thereof.

[Claim 13] A dust collection device comprising the wet air filter of any one of claims 1 to 10.

[Claim 14] The dust collection device of claim 13, wherein the dust collection device operates spontaneously without any external energy.

[Claim 15] A core-shell composite porous member, comprising:
a hydrophilic porous member; and
a hydrophobic porous member that is formed on an outer peripheral surface of the hydrophilic porous member.

[Claim 16] The core-shell composite porous member of claim 15, wherein the hydrophobic porous member is manufactured by performing carbon particle reinforcing treatment on a porous foam and then performing hydrophobic treatment on the carbon particle reinforced porous foam.

[Claim 17] The core-shell composite porous member of claim 15, wherein
the hydrophobic porous member is manufactured by performing hydrophobic treatment on a surface of the porous foam and a surface of a foam cell.

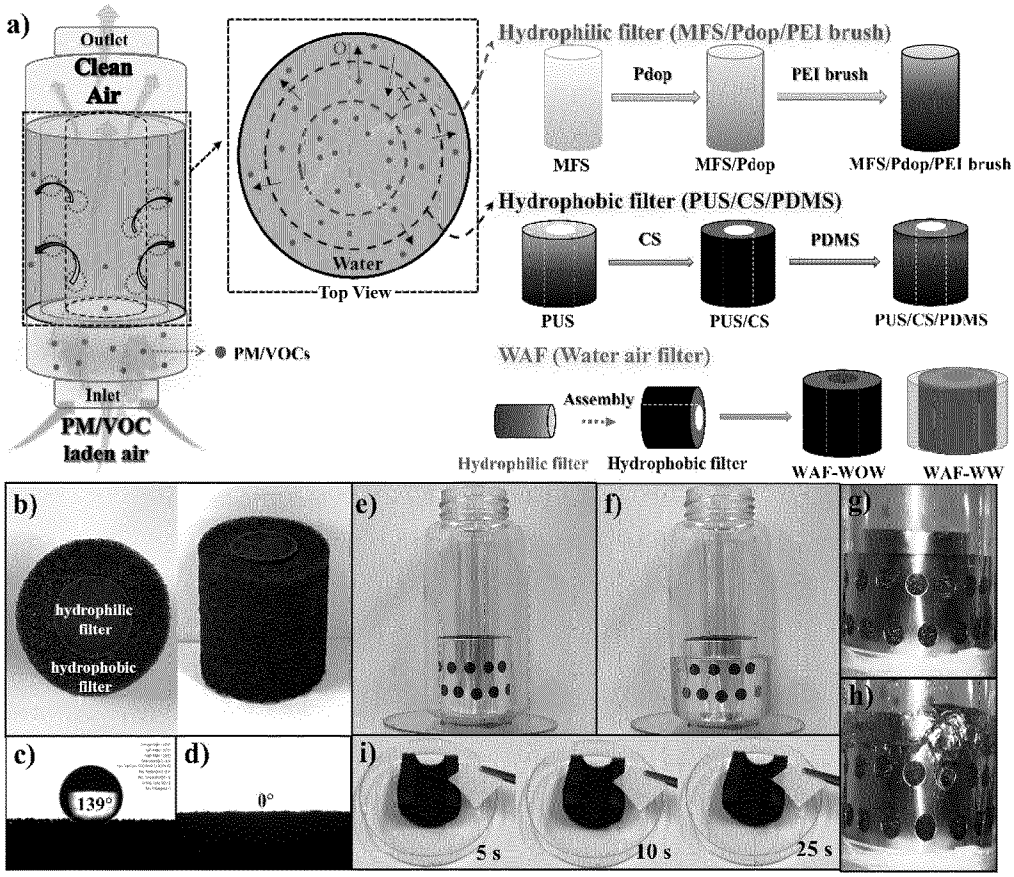
[Claim 18] The core-shell composite porous member of claim 16 or 17, wherein the hydrophobic treatment includes impregnating the carbon particle reinforced porous foam into a siloxane-based polymer solution.

[Claim 19] The core-shell composite porous member of claim 16, wherein the carbon particle reinforced porous foam reinforces the surface of the porous foam by being treated with any one or two or more carbon particles selected from charcoal, carbon nanotube, graphite, fullerene, and amorphous carbon.

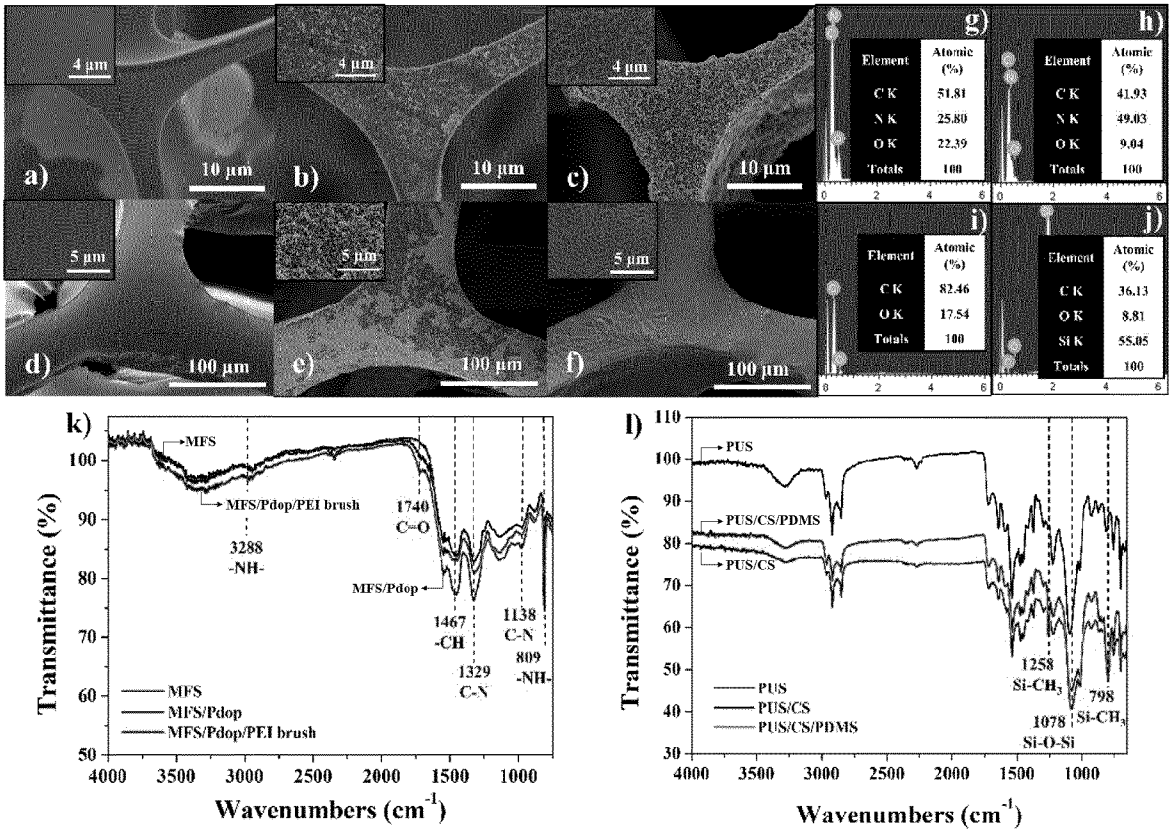
[Claim 20] The core-shell composite porous member of claim 15, wherein the hydrophilic treatment includes:
(a) impregnating a porous foam into a polymerization solution containing dopamine and polymerizing the porous foam to coat a surface with a dopamine-based polymer; and
(b) impregnating the porous foam coated with the dopamine-based polymer into a solution containing an amine group-containing compound to prepare the hydrophilic porous member.

[Claim 21] The core-shell composite porous member of claim 15, wherein a density (d_1) of the hydrophilic porous member and a density (d_2) of the hydrophobic porous member satisfy Expression 1 below.
[Expression 1]
$d_1 > d_2$

[Fig. 1]


a)
Outlet
Clean Air
Inlet
PM/VOC laden air
PM/VOCs
Top View
Water
Hydrophilic filter (MFS/Pdop/PEI brush)
MFS
Pdop
MFS/Pdop
PEI brush
MFS/Pdop/PEI brush
Hydrophobic filter (PUS/CS/PDMS)
PUS
CS
PUS/CS
PDMS
PUS/CS/PDMS
WAF (Water air filter)
Assembly
Hydrophilic filter
Hydrophobic filter
WAF-WOW
WAF-WW
b)
hydrophilic filter
hydrophobic filter
c)
139°
d)
0°
e)
f)
g)
h)
i)
5 s
10 s
25 s

[Fig. 2]


a)
b)
c)
d)
e)
f)
4 μm
10 μm
5 μm
100 μm
g)
h)
i)
j)
Element
Atomic (%)
C K 51.81
N K 25.80
O K 22.39
Totals 100
C K 41.93
N K 49.03
O K 9.04
Totals 100
C K 82.46
O K 17.54
Totals 100
C K 36.13
O K 8.81
Si K 55.05
Totals 100
k)
MFS
MFS/Pdop/PEI brush
3288
-NH-
1740
C=O
MFS/Pdop
1467
-CH
1329
C-N
1138
C-N
809
-NH-
Transmittance (%)
Wavenumbers (cm-1)
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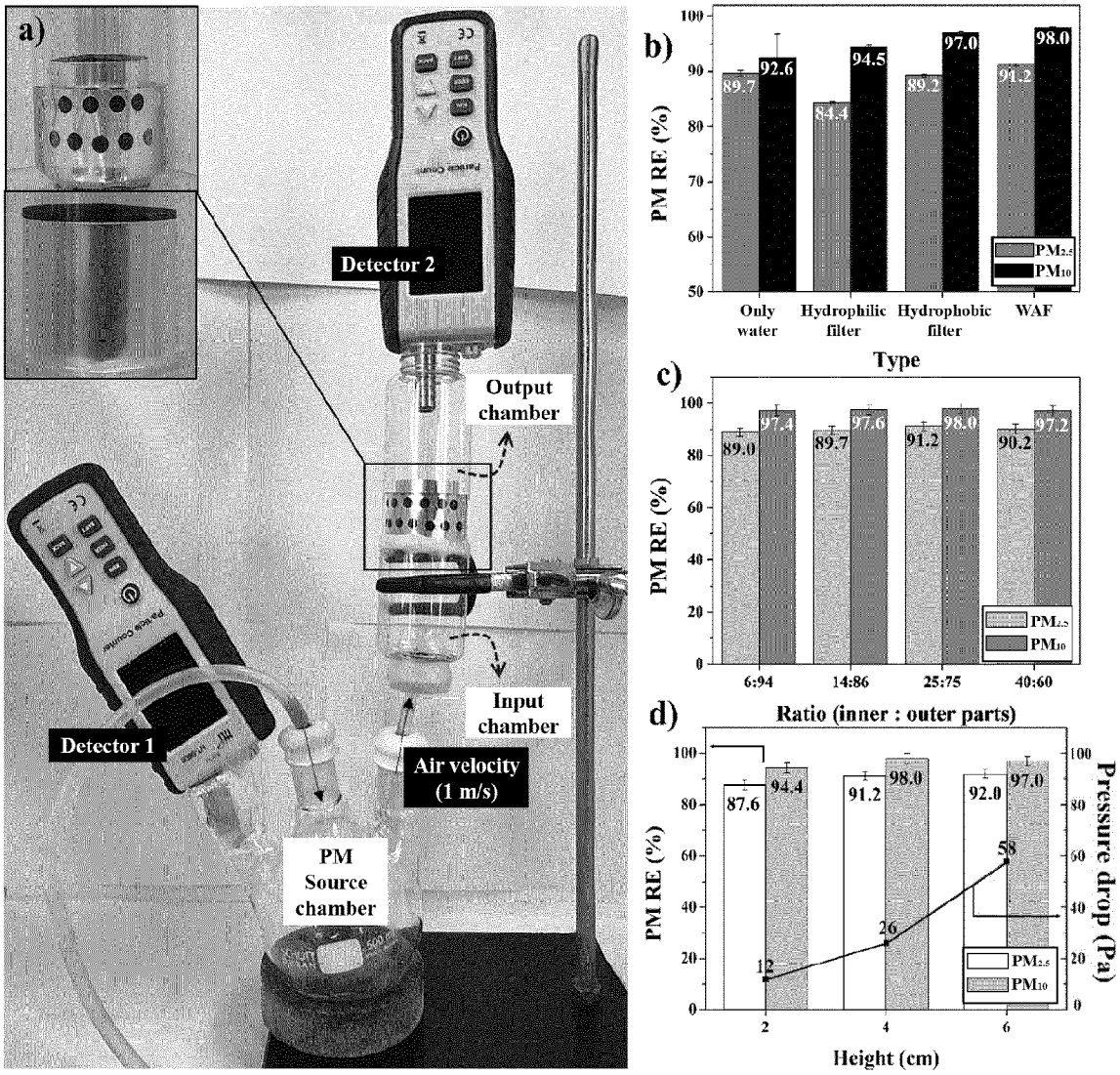
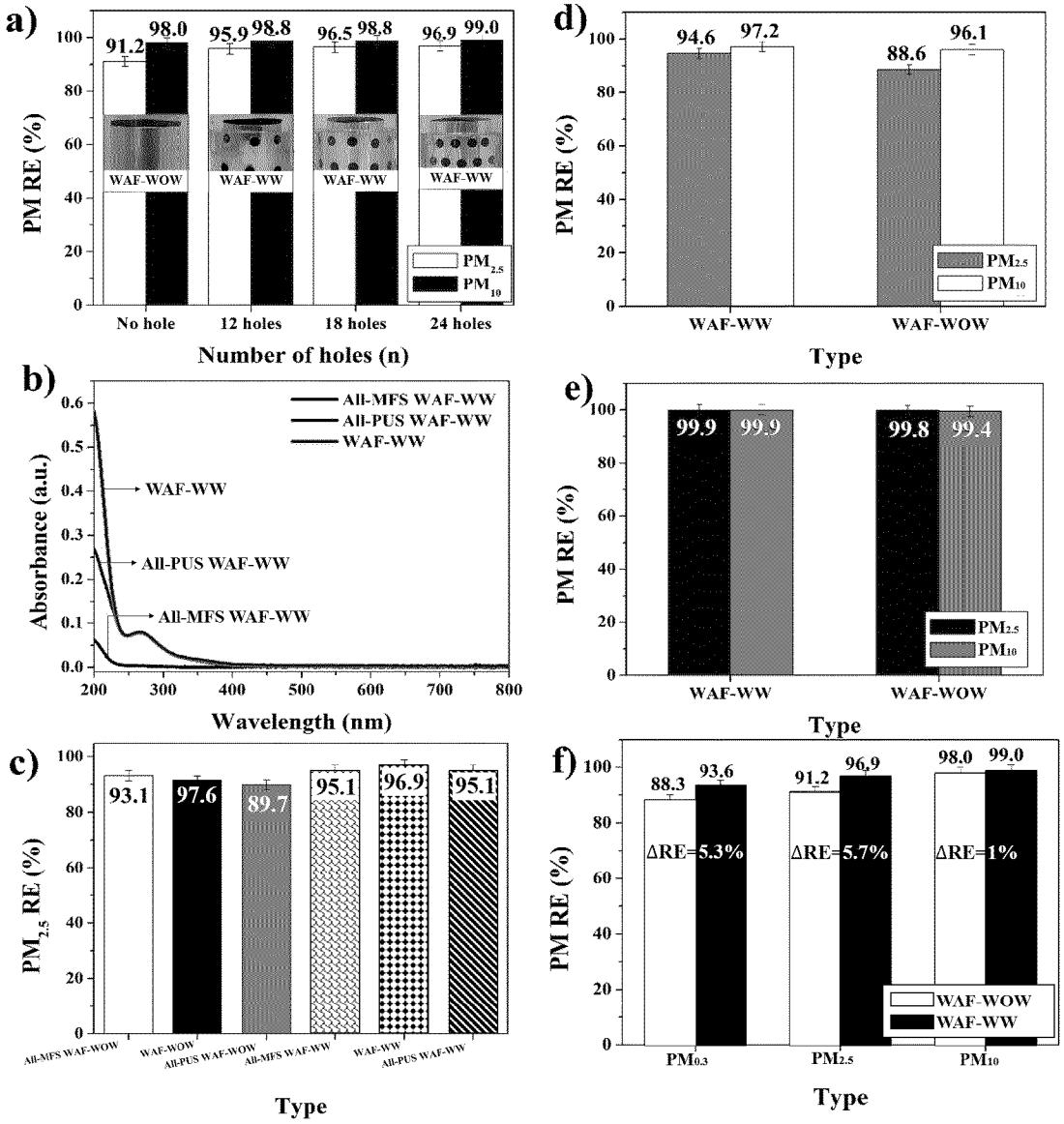
Si-CH3
1078
Si-O-Si

[Fig. 3]



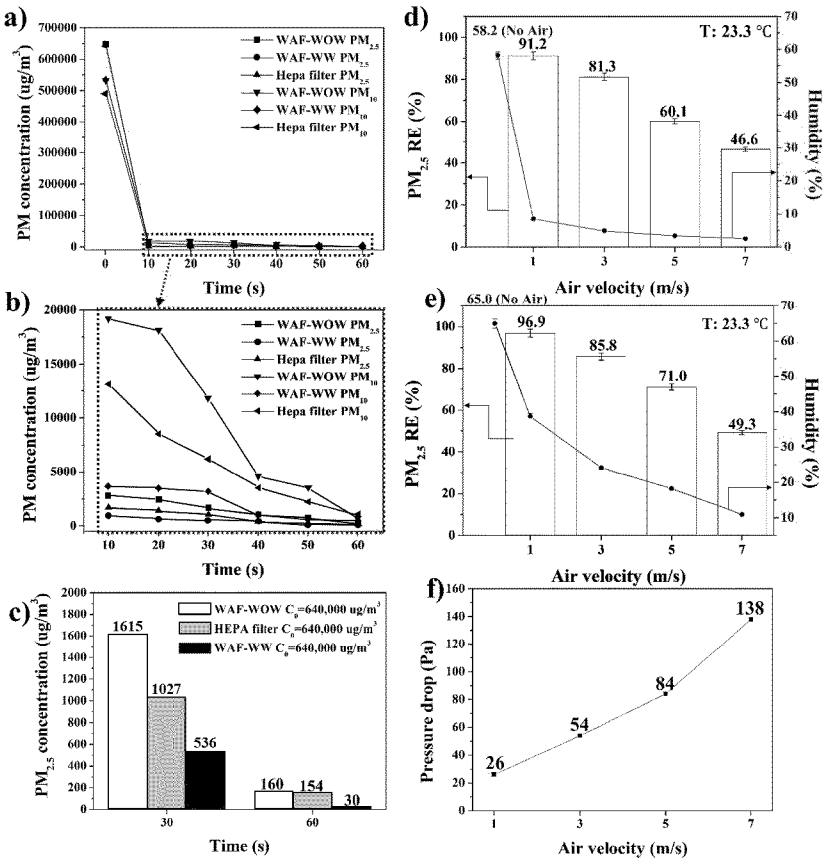
[Fig. 4]

Rule 91, 02.08.2024



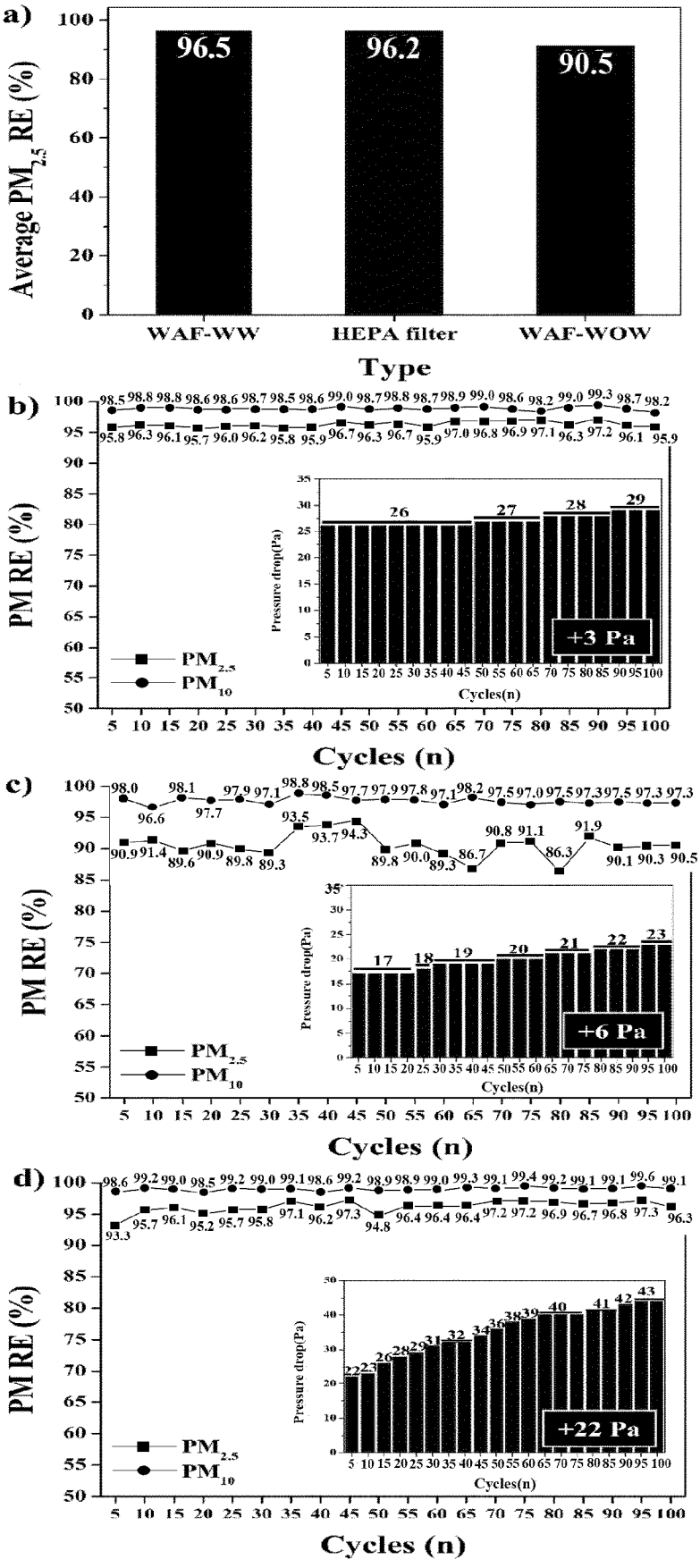
[Fig. 5]

Rule 91,
02.08.2024

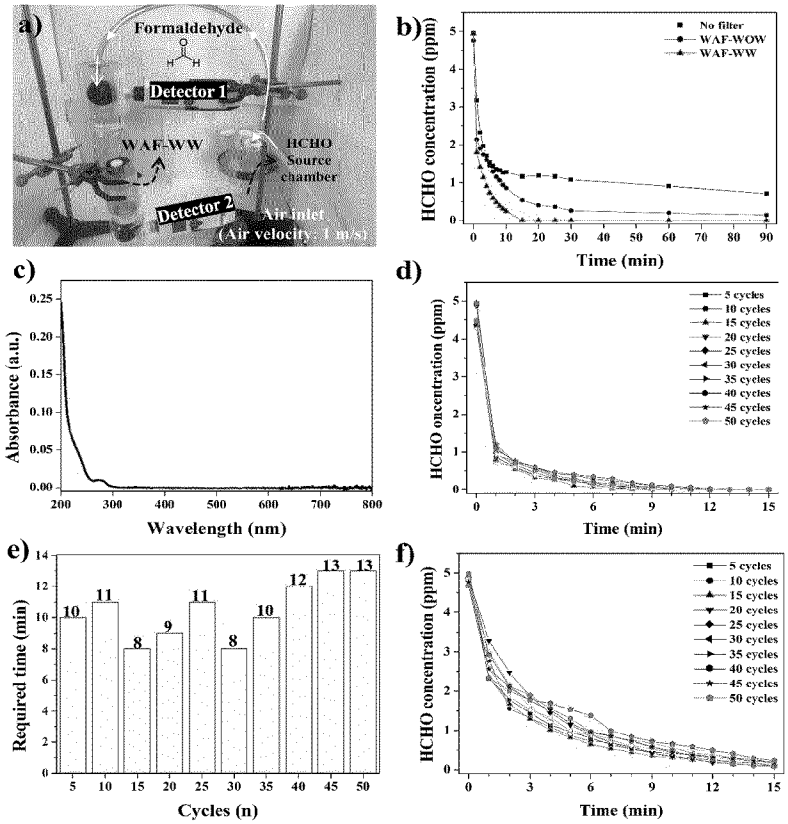


[Fig. 6]

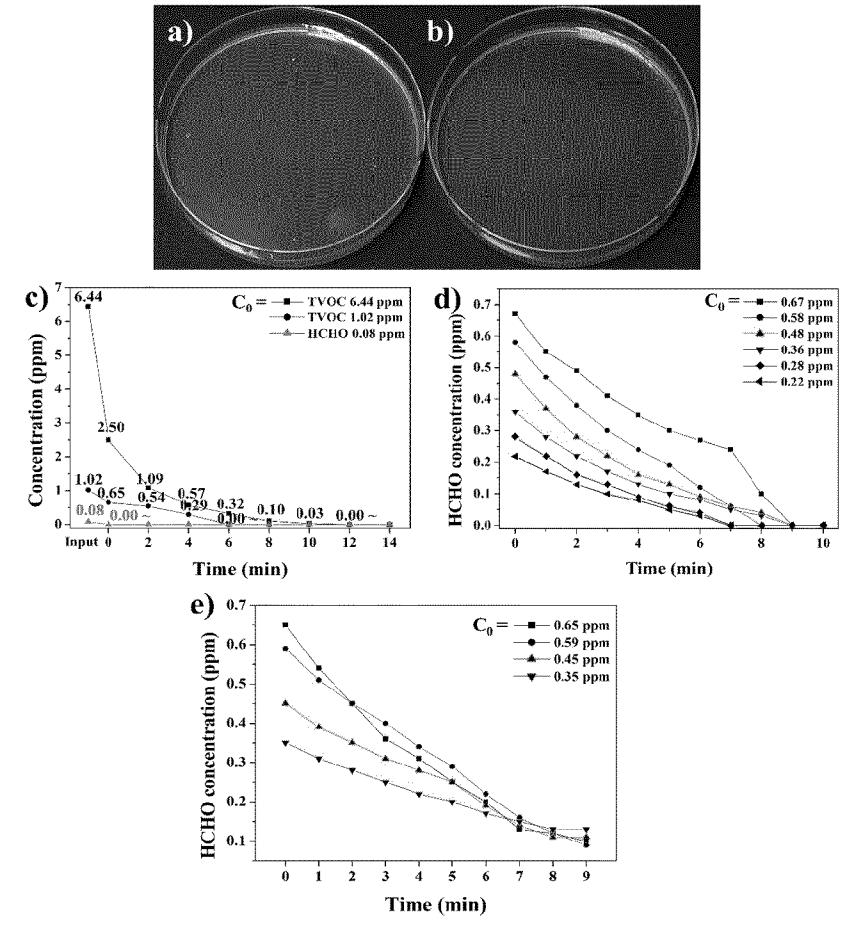
Rule 91,
02.08.2024



[Fig. 7]


a)
Formaldehyde
Detector 1
WAF-WW
HCHO Source chamber
Detector 2
Air inlet (Air velocity: 1 m/s)
b)
No filter
WAF-WOW
WAF-WW
HCHO concentration (ppm)
Time (min)
c)
Absorbance (a.u.)
Wavelength (nm)
d)
5 cycles
10 cycles
15 cycles
20 cycles
25 cycles
30 cycles
35 cycles
40 cycles
45 cycles
50 cycles
HCHO concentration (ppm)
Time (min)
e)
Required time (min)
10 11 8 9 11 8 10 12 13 13
Cycles (n)
f)
5 cycles
10 cycles
15 cycles
20 cycles
25 cycles
30 cycles
35 cycles
40 cycles
45 cycles
50 cycles
HCHO concentration (ppm)
Time (min)

[Fig. 8]


a)
b)
c)
C0 =
TVOC 6.44 ppm
TVOC 1.02 ppm
HCHO 0.08 ppm
6.44
2.50
1.02
1.09
0.65
0.54
0.57
0.29
0.32
0.10
0.03
0.00 ~
0.08
0.00 ~
Input 0
Concentration (ppm)
Time (min)
d)
C0 =
0.67 ppm
0.58 ppm
0.48 ppm
0.36 ppm
0.28 ppm
0.22 ppm
HCHO concentration (ppm)
Time (min)
e)
C0 =
0.65 ppm
0.59 ppm
0.45 ppm
0.35 ppm
HCHO concentration (ppm)
Time (min)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2024/008706

A. CLASSIFICATION OF SUBJECT MATTER

B01D 46/00(2006.01)i; **B01D 47/02**(2006.01)i

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)

B01D 46/00(2006.01); B01D 17/04(2006.01); B01D 39/04(2006.01); B01D 39/16(2006.01); C02F 1/38(2006.01); C02F 1/40(2006.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: air, filter, organic, hydrophilic, hydrophobic, core, shell

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 9309132 B2 (TARABARA, V. et al.) 12 April 2016 (2016-04-12) paragraphs [0014]-[0020]; claims 1-6; figures 3-4	15-21
A		1-10
Y	KR 10-2511800 B1 (HANBAT NATIONAL UNIVERSITY INDUSTRY-ACADEMIC COOPERATION FOUNDATION) 21 March 2023 (2023-03-21) paragraphs [0020]-[0025], [0042]-[0057]; claims 1-5	15-21
A	US 2015-0052864 A1 (AMERICAN AIR FILTER COMPANY, INC.) 26 February 2015 (2015-02-26) paragraphs [0017]-[0025]	1-10,15-21
A	US 2016-0361674 A1 (HOLLINGSWORTH & VOSE COMPANY) 15 December 2016 (2016-12-15) paragraphs [0021]-[0033]	1-10,15-21
A	US 2020-0009488 A1 (HOLLINGSWORTH & VOSE COMPANY) 09 January 2020 (2020-01-09) paragraphs [0024]-[0029]	1-10,15-21

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 September 2024	**26 September 2024**

Name and mailing address of the ISA/KR	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2024/008706

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☑ Claims Nos.: **12, 14**
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

Claims 12, 14 are regarded to be unclear because they refer to claims which do comply with PCT Rule 6.4(a).

3. ☑ Claims Nos.: **11, 13**
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2024/008706

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
US 9309132 B2	12 April 2016	US 2013-0146536 A1	13 June 2013
		WO 2012-024099 A1	23 February 2012
KR 10-2511800 B1	21 March 2023	KR 10-2022-0141118 A	19 October 2022
US 2015-0052864 A1	26 February 2015	WO 2015-027183 A1	26 February 2015
US 2016-0361674 A1	15 December 2016	None	
US 2020-0009488 A1	09 January 2020	US 10399024 B2	03 September 2019
		US 11266941 B2	08 March 2022
		US 2016-0136554 A1	19 May 2016
		US 2022-0249997 A1	11 August 2022