

CELLULOSE NANOFIBRIL SURFACE MODIFICATION DEVICE AND METHOD

FIELD

[0001] The subject matter relates to surface modifications, and more particularly, to a cellulose nanofibril (CNF) surface modification device and a CNF surface modification
5 method.

BACKGROUND

[0002] CNFs are a kind of biomass material based on natural fibers of nanometric size. Despite the small size, the CNFs also have excellent properties such as high
10 strength, making them suitable for reinforcing composite materials. When incorporated into a polymer matrix, the CNFs add strength and stiffness to the polymer material, making them an attractive choice for a variety of structural applications.

[0003] The CNFs have strong hydrophilicity due to a large amount of hydroxyl groups on the surface, which affects the dispersion effect in the polymer material. Thus,
15 a surface modification such as hydrophobic modification needs to be applied on the CNFs before the CNFs are mixed with the polymer material. However, the existing surface modification may result in a large consumption of the surface modification agent and the generation of waste liquid. Also, the surface modification process may be complex, resulting in high manufacture cost.

SUMMARY

[0004] To overcome the above shortcomings, a CNF surface modification device and method are needed.

5 **[0005]** The present application provides a CNF surface modification device for performing a surface modification on CNFs. The device includes a surface modification mechanism, a spray drying mechanism, and a surface modification agent supplying mechanism. The spray drying mechanism is configured to receive a suspension having the CNFs, atomize the suspension into an aerosol, and dry the aerosol to obtain CNF
10 powders. The spray drying mechanism is connected to the surface modification mechanism and further configured to provide the CNF powders to the surface modification mechanism. The surface modification agent supplying mechanism is connected to the surface modification mechanism and configured to supply an active gas having a surface modification agent into the surface modification mechanism, thereby
15 enabling the surface modification agent to react with the CNF powders to perform the surface modification.

[0006] The present application further provides a CNF surface modification method for performing a surface modification on CNFs. The method includes atomizing a suspension having the CNFs into an aerosol, and drying the aerosol to obtain CNF

powders. The CNF powders are introduced into a surface modification mechanism. An active gas having a surface modification agent is supplied into the surface modification mechanism, thereby enabling the surface modification agent to react with the CNF powders to perform the surface modification.

5 **[0007]** According to the present application, the spray drying mechanism dries the suspension into the CNF powders, and the surface modification mechanism performs the surface modification on the dried CNF powders by the active gas having the surface modification agent. Since the surface modification is performed in a dried environment, the consumption of the surface modification agent can be reduced, and the generation of
10 waste liquid after the surface modification can be avoided. Furthermore, the device has lower requirements on the concentration of the CNFs in the raw material. Thus, an additional process for condensing the suspension before the surface modification is not required, and an additional process for drying the CNFs after the surface modification is also not required, which simplifies the manufacture process and reduces the cost.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Implementations of the present technology will now be described, by way of example only, with reference to the attached figures.

[0009] FIG. 1 is a diagrammatic view of a CNF surface modification device according to an embodiment of the present disclosure.

[0010] FIG. 2 is a diagrammatic view of another surface modification mechanism of the CNF surface modification device shown in FIG. 1.

5 **[0011]** FIG. 3 is a top diagrammatic view of the surface modification mechanism shown in FIG. 2.

[0012] FIG. 4 is a diagrammatic view of another surface modification mechanism of the CNF surface modification device shown in FIG. 1.

[0013] FIG. 5 is a top diagrammatic view of the surface modification mechanism
10 shown in FIG. 4.

[0014] FIG. 6 is a diagrammatic view of a surface modification agent supplying mechanism of the CNF surface modification device shown in FIG. 1.

[0015] FIG. 7 is a diagrammatic view of another surface modification agent supplying mechanism of the CNF surface modification device shown in FIG. 1.

15 **[0016]** FIG. 8 is a diagrammatic view of yet another surface modification agent supplying mechanism of the CNF surface modification device shown in FIG. 1.

[0017] FIG. 9 is a flowchart of a CNF surface modification method according to an embodiment of the present application.

DETAILED DESCRIPTION

5 **[0018]** It will be appreciated that for simplicity and clarity of illustration, where appropriate, reference numerals have been repeated among the different figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the embodiments described herein. However, it will be understood by those of ordinary skill in the art that the
10 embodiments described herein can be practiced without these specific details. In other instances, methods, procedures, and members have not been described in detail so as not to obscure the related relevant feature being described. Also, the description is not to be considered as limiting the scope of the embodiments described herein. The drawings are not necessarily to scale and the proportions of certain parts may be exaggerated to
15 better illustrate details and features of the present disclosure.

[0019] The term “comprising,” when utilized, means “including, but not necessarily limited to”; it specifically indicates open-ended inclusion or membership in the so-described combination, group, series, and the like.

[0020] Referring to FIG. 1, a CNF surface modification device 1 is provided according to an embodiment of the present application. The device 1 is used for performing a surface modification on CNFs. In at least one embodiment, the device 1 is used for performing a hydrophobic modification on the CNFs, such that the CNFs after
5 the hydrophobic modification can be uniformly dispersed in and mixed with a polymer material.

[0021] The device 1 includes a spray drying mechanism 10, a surface modification mechanism 30, and a surface modification agent supplying mechanism 40.

[0022] The spray drying mechanism 10 receives a suspension having the CNFs.
10 The spray drying mechanism 10 can atomize the suspension into an aerosol and dry the aerosol to obtain CNF powders. In at least one embodiment, the suspension may be a water suspension having the CNFs in a very low mass ratio less than 1% in the water suspension. In other embodiments, the mass ratio of the CNFs in the suspension may not be limited. For example, the suspension may be a slurry obtained during the
15 preparation of the CNFs in an aqueous media.

[0023] In at least one embodiment, the spray drying mechanism 10 includes a spray drying chamber 11, a first inlet 12 communicating with the spray drying chamber 11, and a loading channel 13 communicating with the spray drying chamber 11. The spray drying mechanism 10 further includes an atomizer 14 communicating with the spray

drying chamber 11. The atomizer 14 includes a second inlet 141 for introducing the suspension and a third inlet 142 for introducing a spray gas. The suspension and the spray gas are mixed in the atomizer 14 and atomized to form the aerosol. The aerosol is then introduced from the atomizer 14 into the spray drying chamber 11. A heated air or
5 other heated gas that will not cause damage to the CNFs is introduced into the spray drying chamber 11 through the first inlet 12. The aerosol in the spray drying chamber 11 is dried and dehydrated by the heated air to form the CNF powders. The spray drying chamber 11 can further provide the CNF powders into the surface modification mechanism 30 through the loading channel 13.

10 **[0024]** The spray drying mechanism 10 is connected to the surface modification mechanism 30, for example, the spray drying mechanism 10 is directly or indirectly connected to the loading channel 13 of the surface modification mechanism 30. The surface modification mechanism 30 can receive the CNF powders from the loading channel 13 of the spray drying mechanism 10.

15 **[0025]** The surface modification agent supplying mechanism 40 is connected to the surface modification mechanism 30. The surface modification agent supplying mechanism 40 can supply an active gas having a surface modification agent into the surface modification mechanism 30. The surface modification agent can be in contact with and react with the CNF powders in the surface modification mechanism 30, thereby

performing the surface modification on the CNF powders. The surface modification agent supplying mechanism 40 may be a container suitable for storing the surface modification agent. The surface modification agent may be in gas form under room temperature and atmospheric pressure. The surface modification agent may also be in a liquid form under room temperature and atmospheric pressure, and in this case, the surface modification agent needs to be transformed into a gas form.

[0026] In at least one embodiment, the surface modification mechanism 30 includes a surface modification chamber 31, a first inlet channel 32, and a second inlet channel 33.

The first inlet channel 32 connects the spray drying mechanism 10 to the surface modification chamber 31. The second inlet channel 33 connects the surface modification agent supplying mechanism 40 to the surface modification chamber 31, and the surface modification agent supplying mechanism 40 provides the active gas into the surface modification chamber 31 through the second inlet channel 33. The surface modification chamber 31 may be made of a material with corrosion-resistant ability, heat-resistant ability, not easily scratched, and easy to be processed into smooth surfaces. For example, the surface modification chamber 31 may be made of stainless steel or glass. The overall shape of the surface modification chamber 31 may be cylindrical or other suitable shapes.

[0027] In at least one embodiment, when the surface modification is hydrophobic

modification, the surface modification agent may include a material selected from a group consisting of hexamethyl disiloxane, 3-aminopropyltriethoxysilane, vinyltrimethoxysilane, silicon 3-methoxypropyl methylacrylate, 3-(trimethoxysilyl)propyl ether, n-octyl triethoxysilan, and any combination thereof.

5 Some materials, such as hexamethyl disiloxane and n-octyl triethoxysilan, allow the CNF powders to have hydrophobicity after the surface modification. Some materials, such as 3-aminopropyltriethoxysilane, allow the CNF powders to have enhanced bonding ability with resin materials such as polyurethane, epoxy resin, and phenolic resin after the surface modification. Some materials, such as vinyltrimethoxysilane, allow the CNF
10 powders to have enhanced bonding ability with resin materials such as epoxy resin, acrylic resin, and polyurethane after the surface modification. Some materials, such as silicon 3-methoxypropyl methylacrylate, allow the CNF powders to have enhanced bonding ability with resin materials such as acrylate after the surface modification. Some materials, such as 3-(trimethoxysilyl)propyl ether, allow the CNF powders to have
15 enhanced bonding ability with resin materials containing amino and phenolic structures after the surface modification.

[0028] In related arts, the slurry obtained during the preparation of the CNFs in an aqueous media needs to be condensed, and then a surface modification agent is added into the condensed slurry, thereby performing the surface modification on the CNFs.

Then, an organic solvent is needed to remove the redundant surface modification agent, and the CNFs are dried to obtain the final product. However, the above surface modification may result in the generation of waste liquid, and the additional condensing and drying steps make the manufacture process more complex and increase the cost.

5 **[0029]** The device 1 of the present application includes the spray drying mechanism 10 and the surface modification mechanism 30. The spray drying mechanism 10 dries the suspension into the CNF powders, and the surface modification mechanism 30 performs the surface modification on the dried CNF powders by the active gas having the surface modification agent. Since the surface modification is performed in a dried 10 environment, the consumption of the surface modification agent can be reduced, and the generation of waste liquid after the surface modification can be avoided. Furthermore, the device 1 has lower requirements on the concentration of the CNFs in the raw material. For example, the device 1 may directly use the slurry or the suspension, which is obtained during the preparation of the CNFs in an aqueous media, as the raw material. 15 Thus, an additional process for condensing the suspension before the surface modification is not required, and an additional process for drying the CNFs after the surface modification is also not required, which simplifies the manufacture process and reduces the cost.

[0030] In at least one embodiment, the surface modification mechanism 30 further

includes an outlet channel 34. The outlet channel 34 connects the surface modification chamber 31 to the first inlet channel 32. As an example, the surface modification chamber 31 includes a top wall 311, a bottom wall 312 opposite to the top wall 311, and a sidewall 313 connected with the top wall 311 and the bottom wall 312. Each of the first
5 inlet channel 32 and the second inlet channel 33 is connected to the sidewall 313 and adjacent to the bottom wall 312 of the surface modification chamber 31. In another embodiment, the position of the second inlet channel 33 may be varied. Referring to FIG. 2, the second inlet channel 33 may be connected to the bottom wall 312. The outlet channel 34 is connected to the top wall 311 of the surface modification chamber 31.
10 After the surface modification agent in the active gas reacts with the CNF powders in the surface modification chamber 31, the mixture of the CNF powders and the active gas may successively flow through the outlet channel 34 and the first inlet channel 32, and then enter the surface modification chamber 31. Thus, the CNF powders may react with the surface modification agent in the surface modification chamber 31 again, thereby
15 reducing the risk of incomplete reactions. That is, the CNF powders are enabled to circulate through the outlet channel 34, the first inlet channel 32, and the surface modification chamber 31.

[0031] The device 1 may further include a separation mechanism 20, a collection unit 50, and a recovery mechanism 60. The separation mechanism 20 is connected with

the loading channel 13 of the spray drying mechanism 10, the first inlet channel 32, and the outlet channel 34. As an example, the bottom portion of the separation mechanism 20 is connected to the first inlet channel 32, and the top portion of the separation mechanism 20 is connected to the outlet channel 34. The separation mechanism 20 receives the CNF powers from the spray drying mechanism 10 through the loading channel 13, and provides the CNF powers to the surface modification chamber 31 through the first inlet channel 32, thereby allowing the CNF powers to react with the surface modification agent in the surface modification chamber 31. The separation mechanism 20 further receives the mixture of the CNF powders and the active gas through the outlet channel 34, and further provides the mixture into the surface modification chamber 31 again through the first inlet channel 32. Thus, in this embodiment, the CNF powders are enabled to circulate through the outlet channel 34, the separation mechanism 20, the first inlet channel 32, and the surface modification chamber 31, thereby reducing the risk of incomplete reactions. After the surface modification is completed, the separation mechanism 20 separates the CNF powders from the mixture. In at least one embodiment, the separation mechanism 20 has a loading door 21, which can be opened or closed relative to the separation mechanism 20 manually or by control commands. The loading door 21 faces the loading channel 13. When the loading door 21 is opened, the loading channel 13 communicates with the separation mechanism 20

and can provide the CNF powders to the separation mechanism 20. When the loading door 21 is closed, the loading door 21 isolates the separation mechanism 20 from the loading channel 13.

5 **[0032]** The collection unit 50 is connected to the separation mechanism 20, and collects the CNF powders from the separation mechanism 20 after the surface modification. In at least one embodiment, the collection unit 50 has a collection door 51, which can be opened or closed relative to the collection unit 50 manually or by control commands. When the collection door 51 is opened, the collection unit 50 communicates with the separation mechanism 20, and can collect the CNF powders
10 which are dropped into the collection unit 50 such as by gravity. When the collection door 51 is closed, the collection door 51 isolates the collection unit 50 from the separation mechanism 20. The collection unit 50 may be a container suitable for collecting and storing the CNF powders. For example, the collection unit 50 may be a collection bottle.

15 **[0033]** The recovery mechanism 60 is connected to the separation mechanism 20, and stores an adsorbent agent for adsorbing the surface modification agent in the active gas exited from the separation mechanism 20. For example, the recovery mechanism 60 is connected to the separation mechanism 20 through a first tube 61. The first tube 61 may be connected to the top portion of the separation mechanism 20. After the CNF

powders are separated from the mixture, the remaining active gas flows into the recovery mechanism 60 through the first tube 61. Then, the adsorbent agent in the recovery mechanism 60 can adsorb the surface modification agent in the active gas. Therefore, the redundant surface modification agent that does not react with the CNF powders can be dissolved or adsorbed by the adsorbent agent, and the adsorbed surface modification agent can be recycled, thereby reducing the manufacture cost. The adsorbed surface modification agent may also be discarded according to actual needs.

[0034] In at least one embodiment, the surface modification mechanism 30 further includes a first heater 35 for heating the surface modification chamber 31 to a temperature suitable for the surface modification. Such the temperature can also maintain the surface modification agent in a gas form. The first heater 35 may be mounted to the outer surface or the inner surface of the sidewall 313 of the surface modification chamber 31.

[0035] In at least one embodiment, the second inlet channel 33 can connect with a first gas source (not shown). The second inlet channel 33 receives a carrier gas from the first gas source. Since the second inlet channel 33 also receives the active gas, such that the active gas can be driven by the carrier gas into the surface modification chamber 31. The first gas source may be integrated into the device 1, and may also be independent from the device 1. The carrier gas may be an inert gas such as argon, nitrogen, and

helium.

[0036] Referring to FIGS. 2 and 3, in another embodiment, the surface modification mechanism 30 further includes at least one third inlet channel 36 connected to the surface modification chamber 31. Each third inlet channel 36 can connect with a second gas source (not shown). The third inlet channel 36 receives an inert gas, such as argon, nitrogen, and helium, from the second gas source. Thus, the active gas and the CNF powders in the surface modification chamber 31 stirred by the inert gas in a preset direction. For example, the inert gas can stir the active gas and the CNF powders in a direction from bottom to top or from bottom to side, thereby preventing the CNF powders from accumulating in the surface modification chamber 31 and allowing the CNF powders to mix with the active gas more uniformly. The second gas source may be integrated into the device 1, and may also be independent from the device 1.

[0037] Referring to FIG. 2, the third inlet channel 36 may be connected to the sidewall 313 and adjacent to the bottom wall 312 of the surface modification chamber 31, such that the inert gas introduced through the third inlet channel 36 can fully stir the active gas and the CNF powders in the surface modification chamber 31. In at least one embodiment, the number of the third inlet channels 36 are four, and the four third inlet channels 36 are spaced from each other along the periphery direction of the surface modification chamber 31.

[0038] Referring to FIGS. 4 and 5, in yet another embodiment, each of the first inlet channel 32 and the second inlet channel 33 may be connected to the sidewall 313, and the third inlet channel 36 may be connected to the bottom wall 312. The second inlet channel 33 may be adjacent to the bottom wall 312. In this case, the surface modification mechanism 30 further includes a mesh board 37 located in the surface modification chamber 31 and adjacent to the bottom wall 312. The mesh board 37 has pores 370 with a diameter less than that of the CNF particles. The first inlet channel 32 is located at a side of the mesh board 37 facing the top wall 311, and each of the second inlet channel 33 and the third inlet channel 36 is located at another side of the mesh board 37 facing the bottom wall 312. Thus, when the CNF particles are introduced into the surface modification chamber 31 through the first inlet channel 32 above the mesh board 37, the CNF particles will not pass through the mesh board 37 to accumulate at the bottom wall 312 after the surface modification. In at least one embodiment, the mesh board 37 may be formed by drilling pores in a metal board (e.g., stainless steel or copper) or a ceramic board. The mesh board 37 may also be a woven net.

[0039] Referring to FIGS. 1 and 6, in at least one embodiment, the surface modification agent is in a liquid form under room temperature and atmospheric pressure. In this case, the surface modification agent supplying mechanism 40 includes a liquid container 41 and a gas generation unit 42. The liquid container 41 stores the liquid

having the surface modification agent. The gas generation unit 42 connects the liquid container 41 to the surface modification mechanism 30, and receives the liquid from the liquid container 41 and transform the liquid into the active gas. The gas generation unit 42 further provides the active gas to the surface modification chamber 31. Referring to

5 FIG. 6, the gas generation unit 42 may be a second heater 421 for heating the liquid to a temperature higher than a boiling point of the liquid (usually less than or equal to 250 degrees Celsius), thereby transforming the liquid into the active gas. That is, the gas generation unit 42 transforms the liquid into the active gas by heating. In at least one embodiment, the liquid container 41 is connected to the outlet channel 34 through a

10 second tube 410. The second heater 421 may be mounted on the outer surface or the inner surface of the second tube 410. In at least one embodiment, the surface modification agent supplying mechanism 40 also includes a pump 43 connected with the second tube 410 and located between the liquid container 41 and the second heater 421. The pump 43 can force the liquid in the liquid container 41 to flow toward the second

15 heater 421 and the outlet channel 34.

[0040] Referring to FIG. 7, in another embodiment, the gas generation unit 42 may further include an activation element 422 located in a gas flowing path between the second heater 421 and the surface modification mechanism 30. For example, the activation element 422 may be located in the outlet channel 34 or the second tube 410.

The activation element 422 activates the active gas by at least one of high-temperature cracking, discharging (e.g., dielectric barrier discharging or radio frequency discharging), irradiation (e.g., ultraviolet irradiation, laser irradiation, or radioactive irradiation), and plasma spraying, thereby enabling the active gas to produce reactive free radicals. Such the reactive free radicals may easily react with the hydroxyl and other functional groups on the surface of CNF powders to form stable chemical bonds. Referring to FIG. 8, in at least one embodiment, the activation element 422 may be a jet-typed plasma generator for activating the active gas by plasma spraying. The raw material gas for producing the plasma may be nitrogen, argon, or helium for safety considerations.

10 **[0041]** FIG. 9 illustrates a flowchart of a CNF surface modification method for applying a surface modification on CNFs in accordance with an embodiment. The method is provided by way of embodiments, as there are a variety of ways to carry out the method. Each step shown in FIG. 9 represents one or more processes, methods, or subroutines carried out in the method. Furthermore, the illustrated order of steps may be
15 changed. Additional steps may be added or fewer steps may be utilized, without departing from this disclosure. The method begins at step S1.

[0042] At step S1, a suspension having the CNFs is atomized into an aerosol, and the aerosol is dried to obtain CNF powders.

[0043] In at least one embodiment, the suspension is atomized by a spray drying

mechanism 10, and the aerosol is dried also by the spray drying mechanism 10. The spray drying mechanism 10 includes a spray drying chamber 11 and an atomizer 14 communicating with the spray drying chamber 11. In this case, the step S1 is carried out by introducing the suspension and a spray gas into the atomizer 14, thereby allowing
5 the suspension and the spray gas to be mixed in the atomizer 14 and atomized to form the aerosol. Then, the aerosol is introduced from the atomizer 14 into the spray drying chamber 11, and the heated air or other heated gas is also introduced into the spray drying chamber 11, thereby allowing the aerosol to be dried and dehydrated in the spray drying chamber 11 by the heated air to form the CNF powders.

10 **[0044]** In at least one embodiment, a separation mechanism 20 connects the spray drying chamber 11 to the surface modification mechanism 30. The separation mechanism 20 has a loading door 21, which can be opened or closed relative to the separation mechanism 20 manually or by control commands. Before the suspension is atomized, the loading door 21 is opened. When the loading door 21 is opened, the
15 loading channel 13 communicates with the separation mechanism 20.

[0045] A collection unit 50 is further connected to the separation mechanism 20. The collection unit 50 has a collection door 51, which can be opened or closed relative to the collection unit 50 manually or by control commands. Before the suspension is atomized, the collection door 51 is closed. When the collection door 51 is closed, the

collection door 51 isolates the collection unit 50 from the separation mechanism 20.

[0046] In at least one embodiment, after the collection door 51 is closed, the method further includes supplying a carrier gas and an inert gas toward the surface modification chamber 31.

5 **[0047]** At step S2, the CNF powders are introduced into the surface modification mechanism 30.

[0048] In at least one embodiment, the surface modification mechanism 30 includes a surface modification chamber 31, a first inlet channel 32, and a second inlet channel 33. The first inlet channel 32 connects the spray drying mechanism 10 to the surface
10 modification chamber 31, and the CNF powders are introduced into the surface modification mechanism 30 through the first inlet channel 32. The second inlet channel 33 connects the surface modification agent supplying mechanism 40 to the surface modification chamber 31. After the CNF powders are introduced into the surface modification mechanism 30, the loading door 21 is closed.

15 **[0049]** Before the CNF powders are introduced into the surface modification mechanism 30, the surface modification chamber 31 may be heated to a temperature suitable for the surface modification.

[0050] At step S3, an active gas having a surface modification agent is supplied into the surface modification mechanism 30.

[0051] The active gas may be supplied into the surface modification chamber 31 through the second inlet channel 33. Therefore, the surface modification agent can react with the CNF powders to perform the surface modification. Wherein, the carrier gas can drive the active gas into the surface modification chamber 31. The inert gas can stir
5 the active gas and the CNF powders in the surface modification chamber 31, thereby preventing the CNF powders from accumulating in the surface modification chamber 31 and allowing the CNF powders to mix with the active gas more uniformly.

[0052] In at least one embodiment, the surface modification mechanism 30 further includes an outlet channel 34. The outlet channel 34 connects the surface modification
10 chamber 31 to the first inlet channel 32. Thus, the CNF powders are circulated through the outlet channel 34, the first inlet channel 32, the separation mechanism 20, and the surface modification chamber 31, thereby reducing the risk of incomplete reactions.

[0053] In at least one embodiment, after the surface modification lasts for a preset duration, the method stops supplying the active gas and stops heating the surface
15 modification chamber 31, and a mixture of the CNF powders and the active gas exited from the outlet channel 34 is received in the surface modification chamber 31. Then, the collection door 51 is opened, and the method further includes separating the CNF powders from the mixture by the separation mechanism 20 and collecting the CNF powders by the collection unit 50. Also, the remaining active gas of the mixture is

forced toward an adsorbent agent, thereby causing the adsorbent agent to adsorb the surface modification agent in the active gas. Therefore, the redundant surface modification agent that does not react with the CNF powders can be dissolved or adsorbed by the adsorbent agent, and the adsorbed surface modification agent can be recycled, thereby reducing the manufacture cost. Finally, the method stops supplying the carrier gas and the inert gas.

[0054] In at least one embodiment, the surface modification agent may be in gas form under room temperature and atmospheric pressure. The surface modification agent may also be in a liquid form under room temperature and atmospheric pressure, and the surface modification agent needs to be transformed into a gas form. In this case, supplying the active gas into the surface modification mechanism 30 may include transforming a liquid having the surface modification agent into the active gas, and forcing the active gas into the surface modification mechanism 30. For example, in at least one embodiment, the liquid is transformed into the active gas by heating.

[0055] After heating the liquid into the active gas, the method may further include activating the active gas by at least one of high-temperature cracking, discharging, irradiation, and plasma spraying, thereby enabling the active gas to produce reactive free radicals. Such the reactive free radicals may easily react with the hydroxyl and other functional groups on the surface of CNF powders to form stable chemical bonds.

[0056] The method of the present application dries the suspension into the CNF powders, and performs the surface modification on the dried CNF powders by the active gas having the surface modification agent. Since the surface modification is performed in a dried environment, the consumption of the surface modification agent can be reduced, and the generation of waste liquid after the surface modification can be avoided. Furthermore, the method has lower requirements on the concentration of the CNFs in the raw material. Thus, an additional process for condensing the suspension before the surface modification is not required, and an additional process for drying the CNFs after the surface modification is also not required, which simplifies the manufacture process and reduces the cost.

[0057] Even though information and advantages of the present embodiments have been set forth in the foregoing description, together with details of the structures and functions of the present embodiments, the disclosure is illustrative only. Changes may be made in detail, especially in matters of shape, size, and arrangement of parts within the principles of the present exemplary embodiments, to the full extent indicated by the plain meaning of the terms in which the appended claims are expressed.

CLAIMS

What is claimed is:

1. A cellulose nanofibril (CNF) surface modification device for performing a surface modification on CNFs, the device comprising:

5 a surface modification mechanism;

 a spray drying mechanism configured to receive a suspension having the CNFs, atomize the suspension into an aerosol, and dry the aerosol to obtain CNF powders, the spray drying mechanism connected to the surface modification mechanism and further configured to provide the CNF powders to the surface modification mechanism; and

10 a surface modification agent supplying mechanism connected to the surface modification mechanism and configured to supply an active gas having a surface modification agent into the surface modification mechanism, thereby enabling the surface modification agent to react with the CNF powders to perform the surface modification.

2. The CNF surface modification device according to claim 1, wherein the surface
15 modification mechanism comprises a surface modification chamber, a first inlet channel connecting the spray drying mechanism to the surface modification chamber, a second inlet channel connecting the surface modification agent supplying mechanism to the surface modification chamber, and an outlet channel connecting the surface modification

chamber with the first inlet channel, thereby enabling the CNF powders to circulate through the outlet channel, the first inlet channel, and the surface modification chamber.

3. The CNF surface modification device according to claim 2, further comprising:

5 a separation mechanism connecting with the spray drying mechanism, the first inlet channel, and the outlet channel, the separation mechanism configured to receive the CNF powers from the spray drying mechanism and provide the CNF powers to the surface modification chamber through the first inlet channel, the separation mechanism further configured to receive a mixture of the CNF powders and the active gas through the outlet channel, and separate the CNF powders from the mixture;

10 a collection unit connected to the separation mechanism and configured to collect the CNF powders from the separation mechanism after the surface modification; and

a recovery mechanism connected to the separation mechanism and configured to store an adsorbent agent for adsorbing the surface modification agent in the active gas exited from the separation mechanism.

15 4. The CNF surface modification device according to claim 2,

wherein the second inlet channel is configured to connect with a first gas source and receive a carrier gas from the first gas source, whereby the active gas is carried by the carrier gas into the surface modification chamber.

5. The CNF surface modification device according to claim 2, wherein the surface

modification mechanism further comprises a third inlet channel connected to the surface modification chamber,

the third inlet channel is configured to connect with a second gas source to receive an inert gas from the second gas source, whereby the active gas and the CNF powders are
5 stirred by the inert gas in the surface modification chamber.

6. The CNF surface modification device according to claim 2, wherein the surface modification chamber comprises a top wall, a bottom wall opposite to the top wall, and a sidewall connected with the top wall and the bottom wall; the outlet channel is connected to the top wall, each of the first inlet channel and the third inlet channel is connected to
10 the sidewall, and the second inlet channel is connected to the bottom wall.

7. The CNF surface modification device according to claim 2, wherein the surface modification chamber comprises a top wall, a bottom wall opposite to the top wall, and a sidewall connected with the top wall and the bottom wall; the outlet channel is connected to the top wall, each of the first inlet channel and the second inlet channel is connected to
15 the sidewall, and the third inlet channel is connected to the bottom wall;

the surface modification mechanism further comprises a mesh board located in the surface modification chamber, the mesh board has pores with a diameter less than that of the CNF particles, the first inlet channel is located at a side of the mesh board facing the top wall, and each of the second inlet channel and the third inlet channel is located at

another side of the mesh board facing the bottom wall.

8. The CNF surface modification device according to claim 2, wherein the surface modification mechanism further comprises a first heater configured to heat the surface modification chamber to a temperature suitable for the surface modification.

5 9. The CNF surface modification device according to claim 1, wherein the surface modification agent supplying mechanism comprises:

a liquid container for storing a liquid having the surface modification agent; and

a gas generation unit connecting the liquid container to the surface modification mechanism, and configured to receive the liquid from the liquid container and transform
10 the liquid into the active gas.

10. The CNF surface modification device according to claim 9, wherein the gas generation unit comprises a second heater configured to heat the liquid into the active gas.

11. The CNF surface modification device according to claim 9, wherein the gas
15 generation unit further comprises an activation element located in a gas flowing path between the second heater and the surface modification mechanism, and the activation element is configured to activate the active gas by at least one of high-temperature cracking, discharging, irradiation, and plasma spraying.

12. A cellulose nanofibril (CNF) surface modification method for applying a surface

modification on CNFs, the method comprising:

atomizing a suspension having the CNFs into an aerosol, and drying the aerosol to obtain CNF powders;

introducing the CNF powders into a surface modification mechanism; and

5 supplying an active gas having a surface modification agent into the surface modification mechanism, thereby enabling the surface modification agent to react with the CNF powders to perform the surface modification.

13. The CNF surface modification method according to claim 12, wherein the surface modification mechanism comprises a surface modification chamber, a first inlet channel, 10 a second inlet channel, and an outlet channel, each of the first inlet channel, the second inlet channel, and the outlet channel is connected to the surface modification chamber, and the outlet channel is further connected to the first inlet channel;

wherein the CNF powders are introduced into the surface modification chamber through the first inlet channel, the active gas is supplied into the surface modification 15 chamber through the second inlet channel, and the CNF powders are circulated through the outlet channel, the first inlet channel, and the surface modification chamber.

14. The CNF surface modification method according to claim 13, further comprising:

receiving a mixture of the CNF powders and the active gas through the outlet channel, and separating the CNF powders from the mixture;

collecting the CNF powders after the surface modification; and

forcing the active gas of the mixture toward an adsorbent agent, thereby causing the adsorbent agent to adsorb the surface modification agent in the active gas.

15. The CNF surface modification method according to claim 14, wherein the CNF
5 powders are separated from the mixture by a separation mechanism, the separation mechanism is provided with a loading door;

wherein before atomizing the suspension into the aerosol and drying the aerosol to obtain the CNF powders, the method further comprises:

opening the loading door, thereby allowing the CNF powders to be introduced into
10 the separation mechanism;

wherein after introducing the CNF powders into the surface modification mechanism, the method further comprises:

closing the loading door.

16. The CNF surface modification method according to claim 14, wherein the CNF
15 powders are collected by a collection unit, the collection unit is provided with a collection door, wherein before atomizing the suspension into the aerosol and drying the aerosol to obtain the CNF powders, the method further comprises:

closing the collection door, thereby isolating the collection unit from the separation mechanism;

wherein after the surface modification, the method further comprises:

stopping supplying the active gas, and opening the collection door to collect the CNF powders by the collection unit.

17. The CNF surface modification method according to claim 13, further comprising:

5 supplying a carrier gas toward the surface modification chamber, thereby causing the carrier gas to drive the active gas into the surface modification chamber; and/or

supplying an inert gas into the surface modification chamber, thereby causing the inert gas to stir the active gas and the CNF powders in the surface modification chamber.

18. The CNF surface modification method according to claim 13, wherein before
10 introducing the CNF powders into the surface modification mechanism, the method further comprises:

heating the surface modification chamber to a temperature suitable for the surface modification.

19. The CNF surface modification method according to claim 12, wherein supplying the
15 active gas into the surface modification mechanism comprises:

transforming a liquid having the surface modification agent into the active gas; and
forcing the active gas into the surface modification mechanism.

20. The CNF surface modification method according to claim 19, wherein transforming the liquid into the active gas comprises:

heating the liquid into the active gas; and

activating the active gas by at least one of high-temperature cracking, discharging, irradiation, and plasma spraying.