function as anion or cation exchangers. The rates of adsorption of proteins by ion exchange were measured in an islands-in-the-sea (I/S) PBT nonwoven with average fiber diameter of approximately 1 μm in accordance with the present disclosure and in a commercially available PBT nonwoven with average fiber diameter of approximately 3 μm. Both nonwovens were grafted successfully with polyGMA and showed similar ion exchange equilibrium protein binding capacities at similar weight % grafting. However, the grafted I/S nonwoven membrane of the disclosure exhibited a substantially higher amount of protein binding in early stages and was able to reach equilibrium in a fraction of the time required by the grafted commercial nonwoven with larger fiber diameters. Although not bound by a theory of operation, the faster rate of protein adsorption observed with the I/S PBT nonwoven of the disclosure is believed to be the result of the thinner polyGMA graft layer thicknesses around the fibers compared to those in the commercial PBT with the same weight % grafting.

The disclosure provides a polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising a nonwoven web comprising a plurality of polyester fibers (e.g. polybutylene terephthalate fibers), having an average fiber diameter of less than about 1.5 microns (more typically about 1 micron or less), each of the plurality of polyester fibers having grafted thereon a plurality of polymer segments constructed of a methacrylate polymer (e.g., polyGMA), each polymer segment carrying a functional group adapted for binding to a target molecule. In certain embodiments, the methacrylate polymer is constructed from one or more monomers selected from the group consisting of glycidyl methacrylate, methacrylic acid, 2-(diethylamino)ethyl methacrylate, [2-(methacryloyloxy)ethyl]trimethyl-ammonium chloride, 2-hydroxyethyl methacrylate, 2-acrylamido-2-methylpropane sulfonic acid, 2-(dimethylamino)ethyl methacrylate, butyl methacrylate, 3-chloro-2-hydroxypropyl methacrylate, 2-ethylhexyl methacrylate, and combinations thereof. The functional group can vary depending on the target molecule, but will typically be a group adapted for cation or anion exchange with the target molecule.

In one aspect, there is provided a polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising a nonwoven web comprising a plurality of polyester fibers having an average fiber diameter of less than about 1.5 microns, each of the plurality of polyester fibers having grafted thereon a plurality of polymer segments constructed of a methacrylate polymer by exposing the nonwoven web and a solution comprising an initiator and at least one methacrylate monomer to ultraviolet light having intensities between 1 and 30 mW/cm^2, most preferably 5 mW/cm^2, each polymer segment carrying a functional group adapted for binding to a target molecule.

In certain embodiments, the nonwoven web comprises island fibers remaining after removal of sea component of islands-in-the-sea bicomponent fibers. The nonwoven web can have an exemplary specific BET surface area of at least about 1.5 m^2/g. Typically, the weight of the grafted polymer segments is about 2 to about 50% of the weight of the nonwoven web, most preferably between 5 and 25% weight gain.

In another embodiment, a method of bioseparation is provided, which comprises passing a solution comprising the target molecule, such as a protein, through the nonwoven membrane of the disclosure such that at least a portion of the target molecule in the solution binds to the nonwoven membrane.

In another aspect, there is provided a method of bioseparation comprising passing a solution comprising the target molecule through the nonwoven membrane as defined herein such that at least a portion of the target molecule in the solution binds to the nonwoven membrane.

In yet another aspect, the disclosure provides a method for preparing a polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising: receiving a nonwoven web comprising a plurality of islands-in-the-sea fibers or a plurality of island fibers remaining after removal of sea component of bicomponent islands-in-the-sea fibers; optionally, removing the sea component of the bicomponent islands-in-the-sea fibers to expose the island fibers thereof; grafting a methacrylate polymer onto the surface of the island fibers to form a plurality of polymer segments

covalently attached thereto, thereby forming grafted island fibers, the grafting step comprising contacting the nonwoven web with a solution comprising an initiator and at least one methacrylate monomer and exposing the nonwoven web to ultraviolet light having intensities between 1 and 30 mW/cm^2, most preferably 5 mW/cm^2 to initiate polymerization of the methacrylate monomer; and optionally, functionalizing the grafted island fibers to attach at least one functional group adapted for binding to a target molecule to each of the plurality of polymer segments of the grafted island fibers. The concentration of monomer in the grafting solution can vary, but is typically about 5 to about 50% v/v (most preferably 15 to 25% v/v) and the initiator, such as benzophenone, is typically present in a molar ratio of initiator to monomer of about 1:100 to about 1:5 (e.g., 1:20). The ultraviolet light source can have wavelengths ranging from 200 nm to 500 nm (most preferably 365 nm) to initiate polymerization. The specific wavelength to initiate polymerization depends on the photoinitiator used, as well as, the monomer that is to be grafted to the surface of the PBT. Additionally, the ultraviolet light source can have intensities between 1 and 30 mW/cm^2 (most preferably 5 mW/cm^2), depending on the energy required for grafting and the desired rate at which grafting is to be performed to achieve the desired degrees of polymerization.

The disclosure includes, without limitation, the following embodiments:

Embodiment 1: A polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising a nonwoven web comprising a plurality of polyester fibers having an average fiber diameter of less than about 1.5 microns, each of the plurality of polyester fibers having grafted thereon a plurality of polymer segments constructed of a methacrylate polymer, each polymer segment carrying a functional group adapted for binding to a target molecule.

Embodiment 2: The membrane of any preceding or subsequent embodiment, wherein the methacrylate polymer is constructed from one or more monomers selected from the group consisting of glycidyl methacrylate, methacrylic acid, 2-(diethylamino)ethyl methacrylate, [2-(methacryloyloxy)ethyl]trimethyl-ammonium chloride, 2-hydroxyethyl methacrylate, 2-acrylamido-2-methylpropane sulfonic acid, 2-(dimethylamino)ethyl methacrylate, butyl methacrylate, 3-chloro-2-hydroxypropyl methacrylate, 2-ethylhexyl methacrylate, and combinations thereof.

Embodiment 3: The membrane of any preceding or subsequent embodiment, wherein the polyester fibers are constructed of polybutylene terephthalate.

Embodiment 4: The membrane of any preceding or subsequent embodiment, wherein the average fiber diameter is about 1 micron or less.

Embodiment 5: The membrane of any preceding or subsequent embodiment, wherein the functional group is adapted for cation or anion exchange with the target molecule.

Embodiment 6: The membrane of any preceding or subsequent embodiment, wherein the nonwoven web comprises island fibers remaining after removal of the sea component of islands-in-the-sea bicomponent fibers.

Embodiment 7: The membrane of any preceding or subsequent embodiment, wherein the nonwoven web has a specific BET surface area of at least about 1.5 m^2/g.

CLAIMS

1. A polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising a nonwoven web comprising a plurality of polyester fibers having an average fiber diameter of less than about 1.5 microns, each of the plurality of polyester fibers having grafted thereon a plurality of polymer segments constructed of a methacrylate polymer by exposing the nonwoven web and a solution comprising an initiator and at least one methacrylate monomer to ultraviolet light having intensities between 1 and 30 mW/cm^2, most preferably 5 mW/cm^2, each polymer segment carrying a functional group adapted for binding to a target molecule.

2. The nonwoven membrane of claim 1, wherein the methacrylate polymer is constructed from one or more monomers selected from the group consisting of glycidyl methacrylate, methacrylic acid, 2-(diethylamino)ethyl methacrylate, [2-(methacryloyloxy)ethyl]trimethyl-ammonium chloride, 2-hydroxyethyl methacrylate, 2-acrylamido-2-methylpropane sulfonic acid, 2-(dimethylamino)ethyl methacrylate, butyl methacrylate, 3-chloro-2-hydroxypropyl methacrylate, 2-ethylhexyl methacrylate, and combinations thereof.

3. The nonwoven membrane of claim 1, wherein the polyester fibers are constructed of polybutylene terephthalate.

4. The nonwoven membrane of claim 1, wherein the average fiber diameter is about 1 micron or less.

5. The nonwoven membrane of claim 1, wherein the functional group includes amine groups, sulfonic acid groups, carboxylic acid groups, phosphate groups, and the like.

6. The nonwoven membrane of claim 1, wherein the nonwoven web comprises island fibers remaining after removal of sea component of islands-in-the-sea bicomponent fibers.

7. The nonwoven membrane of claim 1, wherein the nonwoven web has a specific BET surface area of at least about 1.5 m^2/g.

8. The nonwoven membrane of claim 1, wherein the weight of the grafted polymer segments is about 2 to about 50% of the weight of the nonwoven web.

9. A method of bioseparation comprising passing a solution comprising the target molecule through the nonwoven membrane of any one of claims 1 to 8 such that at least a portion of the target molecule in the solution binds to the nonwoven membrane.

10. The method of claim 9, wherein the target molecule is a protein.

11. A method for preparing a polymer-grafted and functionalized nonwoven membrane adapted for use in bioseparation processes, comprising:

    i) receiving a nonwoven web comprising a plurality of islands-in-the-sea fibers or a plurality of island fibers remaining after removal of sea component of bicomponent islands-in-the-sea fibers;

    ii) optionally, removing the sea component of the bicomponent islands-in-the-sea fibers to expose the island fibers thereof;

    iii) grafting a methacrylate polymer onto the surface of the island fibers to form a plurality of polymer segments covalently attached thereto, thereby forming grafted island fibers, the grafting step comprising contacting the nonwoven web with a solution comprising an initiator and at least one methacrylate monomer and exposing the nonwoven web to ultraviolet light having intensities between 1 and 30 mW/cm^2, most preferably 5 mW/cm^2 to initiate polymerization of the methacrylate monomer; and

    iv) optionally, functionalizing the grafted island fibers to attach at least one functional group adapted for binding to a target molecule to each of the plurality of polymer segments of the grafted island fibers.

12. The method of claim 11, wherein the island fibers are constructed of polybutylene terephthalate and the methacrylate polymer is polyglycidyl methacrylate (polyGMA).

13. The method of claim 11, wherein the concentration of monomer in the solution is about 5 to about 50% v/v and the initiator is present in a molar ratio of initiator to monomer of about 1:100 to about 1:5.

14. The method of claim 11, wherein the initiator is benzophenone.