

METHOD OF MANUFACTURING NANOFILTRATION MEMBRANE AND SYSTEM THEREFOR

Field of the Invention

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[0001] The present invention relates to water purification and wastewater treatment. More specifically, the present invention relates to a system and method for manufacturing nanofiltration membrane for water purification wastewater.

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Background

[0002] Conventional water purification processes may require the use of multiple processes to remove total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), and organic compounds present in the raw water which results in a large footprint due to the number and size of process equipment used and high cost. The process may also be prone to high chemical usage, sludge production resulting in poor effluent quality. Furthermore, providing multiple processes may also mean that capital cost and operating cost are comparatively higher than to achieve the same production rate. In addition, the use of flocculants or coagulants to remove total dissolved solids or heavy metal, may result in secondary pollution.

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[0003] Nanofiltration membrane is developed to remove small organic contaminants with low energy consumption in water purification process. The formation

of nanofiltration membrane is highly depending on the membrane manufacturing processes.

[0004] Presently, nanofiltration membrane manufacturing processes include roll-
5 to-roll casting manufacturing of spiral wound thin film composite (TFC) membranes and
layer-by-layer assembly manufacturing of polyelectrolytes multilayer (PEM) hollow
fiber nanofiltration membranes. Such manufacturing processes involve complicated
steps and time consuming. Thus, there is a need to provide a manufacturing process to
produce cost effective and reliable hollow fiber nanofiltration membranes.

10 **[0005]** US publication no. US2014/0141176 disclose a method of depositing
alternative charges layers to form a composite thin film, then into a nano particle solution
to form a nanoparticles layer on the membrane to form the desired thin firm composite.
It is achieved through simple immersing and rinsing process for form a nano particle
15 layer.

[0006] It is therefore desired to provide a scalable system and method to fabricate
selective surface charged nanofiltration membrane that offer improved performance

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Summary

[0007] One aspect of the present invention provides a method of producing
selective surface charged nanofiltration membrane. The method comprises submerging
a membrane within a first sealed tank having a first charged polymeric solution under
controlled environment for a prescribed period to forming a surface modified membrane;
25 rinsing the surface modified membrane within purified water under controlled
environment for a prescribed period; submerging the surface modified membrane within

a second sealed tank with a second charged polymeric solution different from that of the previous charged polymeric solution under controlled environment to form a further surface modified membrane; rinsing the further surface modified membrane with purified water under controlled environment for prescribed period; and soaking the further modified membrane into a cross linker solution to form the selective surface charged nanofiltration membrane.

[0008] In one embodiment, the method further comprises repeating the steps of submerging the surface modified membrane within a sealed tank with a charged polymeric solution different from that of the previous charged polymeric solution under controlled environment to form a further surface modified membrane; and rinsing the further surface modified membrane with purified water under controlled environment for prescribed period. It is possible that the steps of submerging in the charged polymeric solution different from the previous charged polymeric solution immediately before the cross-linked process determines a resulting charge of the selective charged nanofiltration membrane.

[0009] In another embodiment, the method may further comprise transferring the surface modified membrane into a centrifuge for removing the excess solution from the membrane after each rinsing step.

[0010] In a further embodiment, the controlled environment includes about 0.1 to 1.0 bar pressure, the prescribe period include about 10-60mins and an operating temperature of about 25°C to 60°C.

[0011] In yet another embodiment, the sealed tanks includes a rotate shaking at about 20-100 rpm operationally.

[0012] In an alternative embodiment, the selective surface charge nanofiltration
 5 comprises positive or negative surface charged achieving an rejection rate of about 90 to 99% of micropollutants, colour, magnesium chloride, magnesium sulphate, calcium chloride and calcium sulphate.

[0013] In a further alternative embodiment, the membrane is made of charged
 10 polymeric materials, further comprising polycationic polymer materials, polyanionic polymer materials or mixture of both.

[0014] In yet another embodiment, the charged polymeric solution include cyclopentadienyl and methylamine, thereby enhancing membrane surface charged, ionic
 15 strength and reduce membrane surface pores. It is also possible that the polycationic polymer includes poly(ethyleneimine), poly(allylamine), poly(L-lysine), poly(dimethyldiallylammonium chloride), poly(allylamine hydrochloride), poly(acrylamide), polyglutamic acid, gelatin, chitosan or chitosan derivatives, with concentration 0.01 to 1wt% in aqueous solution contained dissolved salts (sodium
 20 chloride or calcium chloride). Alternatively, the polyanionic polymer may comprise of sodium poly(styrene sulfonate), sodium polystyrene sulfonate-maleic acid, poly(acrylic acid), hyaluronic acid, alginate, pectin, heparin, modified graphene oxide, nanotubes or mixtures, with concentration 0.01 to 1wt% in aqueous solution contained dissolved salts.
 It is also possible that a polymer molecular weight of the polycationic and polyanionic
 25 ranges from 1,000 to 1,000,000 Da.

[0015] In a further embodiment, the cross linker solution includes any of glutaraldehyde, dopamine, siloxanes, zwitterionic compound with different functional groups, aldehyde, carboxy, phosphate, sulphonate and ether. It may have concentration of about 0.1 to 2.0wt% in aqueous solution with 0.1 to 0.5wt% of sulphuric acid or other acid. The cross linker solution may comprise concentration is 0.1 to 2.0wt% in aqueous solution with 0.1 to 0.5wt% of sulphuric acid or other acid. The surface functional groups may comprise amino, carboxyl or sulphonate groups.

[0016] In another aspect, there is also provided a system for fabricating selective surface charged nanofiltration membrane. The system comprises a plurality of sealable tanks for submerging a membrane therein to process the same under controlled environment. In another embodiment, the system the selective surface charged nanofiltration membrane is fabricated based on the aforesaid methods.

Brief Description of the Drawings

[0017] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0018] Fig. 1 illustrates a schematic diagram showing manufacturing system of selective surface charged hollow fiber nanofiltration membrane according to one embodiment of the present invention; and

[0019] Fig. 2 illustrates a flow chart of manufacturing process of selective charges hollow fiber nanofiltration membrane according to an embodiment of the present invention.

Detailed Description

[0020] In line with the above summary, the following description of a number of specific and alternative embodiments are provided to understand the inventive features of the present invention. It shall be apparent to one skilled in the art, however that this invention may be practiced without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals will be used throughout the figures when referring to the same or similar features common to the figures.

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[0021] The present invention provides a pressure or vacuum assisted tank, containing different types of polymer charges and concentration and cross-linking solution to form selective surface charges nanofiltration membrane. The nanofiltration membrane has posed several advantages in water purification and wastewater treatment, particularly chlorine resistance, high heavy metal rejection, and high throughput.

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[0022] Fig. 1 illustrates a hollow fiber nanofiltration membrane manufacturing system **100** according to an embodiment of the present invention. The system **100** comprises a first tank **110**, a second tank **120**, a third tank **130**, a forth tank **140**, a fifth tank **150**, a first centrifuge **160** and a second centrifuge **170**. An ultrafiltration membrane is to be processed under each of these tanks and centrifuges through a process of the present invention to produce a selective charged hollow fiber nanofiltration membrane.

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[0023] All of the tanks **110-150** are sealable tanks so that the membranes **160** can be processed under controlled environment. The membranes **160** are hollow fiber membranes. The membranes **160** can also be ultrafiltration membranes.

5 [0024] In one embodiment, the membranes **160** comprise charged polymeric materials. It may comprise polycationic polymer materials, polyanionic polymer materials or mixture of both.

[0025] The membrane **160** is placed in the first tank **110** and submerged in
 10 charged polymeric solution **112**. A charged polymeric stream **114** can be injected into the first tank **110** to completely submerge the membrane **160** in the first tank **110**. The first tank **110** is then sealed for a prescribed period whereby the membrane **160** is under a surface modification to charge the membrane **160**. In the first tank **110**, the membrane **160** reacts with the charged polymeric solution **112** to tighten surface pores
 15 of the membrane **160**. In one embodiment, the charged polymeric solution **112** and stream **114** may comprise conductivity of around 30 to 50mS.

[0026] It is desired that the surface modification to charge the membrane **160** is carried out under a controlled environment, and hence with a sealed tank for soaking the
 20 membrane **160**. In a further embodiment, the membrane **160** is soaked under an operating pressure of about 0.1 to 1.0 bar for about 10-60 minutes. The soaking is further controlled under an operating temperature of about 25°C to 60°C. In a further embodiment, the soaking is done under a radial shaking/vibrating speed at about 20-100 rpm. Under the radial vibrations, bubbles on the membrane surface can be removed
 25 effectively and further to ensure that chemicals (i.e. the charged polymeric solutions) are fully in contact with the membrane surfaces.

[0027] The membrane **160** is then transferred to the first centrifuge **115**. Operationally, the first centrifuge **115** spins to evenly spread the solution across the
5 membrane **160**, and further to remove excess solution from the membrane **160** surface. In one embodiment, the first centrifuge **115** is operated at a spinning speed of about 2000-5000 rpm with a duration of about 2-10 minutes.

[0028] In the above process, the soaked membrane **160** is subjected to
10 shake/vibration within the first (sealed) tank **110** for better permeation of the charged polymeric solution mixing through the membrane **160**. The soaked membrane **160** (now labeled membrane **162** in the figure) is then transferred to centrifuge **115** then operatively spins the membrane **162** therein at high speed to removed extra residual solution. The high-speed spins further spread the solution to cover all membrane surfaces.

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[0029] The membrane **162** is then transferred to the second tank **120** filled with purified water **122** to clean the unreacted or excess charged polymeric solution from the first tank **110**. In one embodiment, the purified water **122** may have a conductivity of around 50 to 200 μS . Operationally, the second tank **120** is also sealed to processed the
20 membrane **162** under a controlled environment operationally.

[0030] In a further embodiment, the membrane **162** is soaked under an operating pressure of about 0.1 to 1.0 bar for about 10-60 minutes. The soaking is further controlled under an operating temperature of about 25°C to 60°C. In a further
25 embodiment, the soaking is done under a rotary shaking speed at about 20-100rpm.

[0031] The cleaned membrane **162** is then transferred to the third tank **130**. The third tank **130** contains a second type of charged polymeric solution **132**. A second charged polymeric stream **134** can be injected into the third tank **130** to completely submerge the cleaned membrane **162** therein. The third tank **130** is then sealed to soak the membrane **162** under a controlled environment. In one embodiment, the charged polymeric solution **132** and stream **134** may have a conductivity of around 30 to 50 mS.

[0032] In a further embodiment, the membrane **162** is soaked under an operating pressure of about 0.1 to 1.0 bar for about 10-60 minutes. The soaking is further controlled under an operating temperature of about 25°C to 60°C. In a further embodiment, the soaking is done under a rotary shaking speed at about 20-100rpm.

[0033] Then the soaked membrane **162** (now labelled as membrane **164**) is then transferred to the second centrifuge **170**. Operationally, the second centrifuge **135** spins to evenly spread the solution across the membrane **164**, and to remove excess solution from the membrane **164** surface. In one embodiment, the second centrifuge **135** is operated at a spinning speed of 2000-5000 rpm with a duration of 2-10 minutes. The second centrifuge **135** is can be a same type of centrifuge as the first centrifuge **115**.

[0034] The membrane **154** is then transferred to the forth tank **140** filled with purified water **142** to rinse the unreacted or excess charged polymeric solution from the forth tank **140**. In one embodiment, the purified water **142** may have a conductivity of around 50 to 200 μ S. Operationally, the forth tank **140** is also sealed to rinsed the membrane **154** under a controlled environment.

[0035] In a further embodiment, the membrane **154** is rinsed under an operating pressure of about 0.1 to 1.0 bar for about 10-60 minutes. The soaking is further controlled under an operating temperature of about 25°C to 60°C. In a further
5 embodiment, the soaking is done under a rotary shaking speed at about 20-100rpm.

[0036] The rinsed membrane **164** is then transferred to the fifth tank **150**. The fifth tank **150** comprises a cross-linker solution **152** and a cross-linker stream **154** is injected to submerge the membrane **164** therein. The fifth tank **150** is then sealed to soak
10 the membrane **150** under a controller environment to crosslink the polymers of the membrane **164** to form a selective surface charge nanofiltration membrane.

[0037] In one embodiment, the fifth tank **150** soaks the membrane **164** at about 0.1 to 1.0 bar with a rotary shaking speed of 20-100 rpm for at least 120 to 300 minutes
15 to complete cross-linking of the polymer of the membrane **164** to form selective surface charge nanofiltration membrane.

[0038] In a further embodiment, the ratios of membrane volume to charged polymeric solution or purified water in above all the tanks are maintained at least 0.3 or
20 more to avoid sharp concentration drop and sufficient removal of excess charged polymeric solution on the membrane.

[0039] Fig. 2 illustrates a flowchart of a manufacturing method for fabricating a selective surface charge nanofiltration membrane in accordance with an embodiment of
25 the present invention. At step **210**, an ultrafiltration membrane is submerged in a charged polymeric solution within a sealed tank for surface modification. In the sealed tank, the

ultrafiltration membrane is soaked under a controlled environment for a prescribed period. Thereafter, at step **220**, the surface modified membrane is then transferred to a centrifuge for expelling excessive charged polymeric solution remains on surface modified membrane. At step **230**, the surface modified membrane is transferred to
 5 another sealed tank for rinsing the surface modified membrane. The surface modified membrane is rinsed under a controlled environment to remove the charged polymeric solution remains on the surface modified membrane.

[0040] According to the embodiments of the present invention, the charged
 10 polymeric solution is polycationic or polyanionic. In one embodiment, the charged polymeric solution includes cyclopentadienyl and methylamine for enhancing membrane surface charged, ionic strength and reduce membrane surface pores.

[0041] In a further embodiment, a polycationic polymer may include
 15 poly(ethyleneimine), poly(allylamine), poly(L-lysine), poly(dimethyldiallylammonium chloride), poly(allylamine hydrochloride), poly(acrylamide), polyglutamic acid, gelatin, chitosan or chitosan derivatives, with concentration 0.01 to 1wt% in aqueous solution contained dissolved salts (sodium chloride or calcium chloride).

[0042] In yet a further embodiment, a polyanionic polymer may include sodium
 20 poly(styrene sulfonate), sodium polystyrene sulfonate-maleic acid, poly(acrylic acid), hyaluronic acid, alginate, pectin, heparin, modified graphene oxide, nanotubes or mixtures, with concentration 0.01 to 1wt% in aqueous solution contained dissolved salts

[0043] In another embodiment, a polymer molecular weight of the polycationic
 25 and polyanionic ranges from 1,000 to 1,000,000 Da.

[0044] In yet another embodiment, the cross-linker solution includes any of glutaraldehyde, dopamine, siloxanes, zwitterionic compound with different functional groups, aldehyde, carboxy, phosphate, sulphonate and ether.

5 **[0045]** The steps of submerging membrane in charged polymeric solution **210**, centrifugal spinning the membrane **220** and rinsing the membrane **230** are collectively to nanonize and selectively charged the membrane. The type of charge is determined by the type of charged polymeric solution used to soak the membrane. For simplicity, the three steps **210**, **220** and **230** are collective referred as selective charged and nanonization
10 process.

[0046] As shown, the steps of selective charged and nanonization can be repeated to refine the membrane. Once the membrane has reached a desired result or specification, i.e. desired pore size and charge, the membrane is transferred to submerge in a
15 crosslinking tank to crosslink the polymer of the membrane. Once the polymer crosslink process is completed, the selective surface charge nanofiltration membrane is formed. In one embodiment, the polymer crosslink process is done in a sealed tank, i.e. controlled environment.

20 **[0047]** There is provided a manufacturing method for fabricating a selective surface charged nanofiltration membrane, the method comprises nanonizing pores of the a ultrafiltration membrane by submerging the ultrafiltration membrane in a charged polymeric solution within a sealed tank; spinning the membrane with a centrifuge; rinsing the charged polymeric membrane under a controlled environment in a sealed tank;
25 and crosslinking the charged polymeric membrane by soaking the same within a crosslinking solution under a controlled environment in another sealed tank, wherein

nanonizing process can be repeated with a charged polymeric solution different from the previous charged polymeric soaking process.

[0048] It is desired that the layer coating of the membranes under the charged polymeric solutions is performed under different charged solution from the previous charged polymeric soak alternatively. This is to allow the charged polymeric solution coated on the membrane reacts with the charged polymeric solution for further surface modification. Multiple charged polymeric coatings of different solutions makes a membrane that provide better solute rejection.

[0049] It is further desired that each time when the membrane is soaked in a charged polymeric solution, the soaking tank vibrates/shakes operationally to improve the performance of the surface modification. It is also further desired that all soaked membranes are transferred to a centrifuge to remove excessive solution remains on the membrane, then rinsed accordingly.

[0050] In one embodiment, the ultrafiltration membrane may consist of molecular weight cut-off (MWCO) sized in the ranges from 10,000 to 60,000 Da. Further, it can be made of polyethersulfone (PES) or modified PES with hydrophilic additives such as sulfonated polysulfone, calcium chloride and cellulose. The ultrafiltration membrane can be modified with ligands to enhance membrane surface ionic strength towards charged polymeric solutions. The ligands may consist of cyclopentadienyl and methylamine which have designated surface functional group to electrostatically adhere to charged polymeric solutions.

[0051] It is understood to a skilled person that ordinary hollow fiber membrane, such as UF membrane, is not usable out-of-box for nanofiltrations. Therefore, suitable charged polymeric solution is adopted to provide a layer of coating to create denser membrane at the nano level suitable for nanofiltrations. Through extensive research by the inventors of the present invention over years, the method and system as herein disclosed have successfully improve the nanofiltrations.

[0052] **Examples**

10 [0053] The following illustrate examples, not limitation to the embodiments of the present invention.

[0054] **Example 1 - Domestic Water Purification**

15 [0055] The selective charged nanofiltration membrane prepared by the method as disclosed herein was used to filter domestic water has shown to have better divalent ionic rejection and was more effective in removing organic compounds.

[0056] In this example, two types of influent raw water were used in separate experiments, the first was influent from surface water [TABLE 1] and the second was the influent from ground water [TABLE 2]. The influent was used to test the performance of the selective surface charges hollow fiber membrane in removing total suspended solid (TSS), total dissolved solids (divalent ions) and bacteria. The ground water was used to the test the performance of the selective surface charges hollow fiber membrane in removing heavy metals. The outcome thereof is also compared against requirements according to China GB. The quality of the influent raw water and removal rate were as follows:

[TABLE 1]

No	Pollutant (from surface water)	Amount	Removal Rate (%)	
			Requirement according to China GB	Present Invention
1	Total suspended solid (TSS)	20 NTU	< 0.5 NTU	80-90%
2	Total dissolved solid (TDS)	155 mg/L	< 500 mg/L	40-70%
3	Total hardness (CaCO ₃)	124 mg/L	< 250 mg/L	60-80%
4	Total organic carbon (TOC)	10 mg/L	< 4 mg/L	50-80%
5	Bacteria count	1,500 CFU/ml	N.D	99.5-99.9 %

[TABLE 2]

	Pollutant (from ground water)	Amount		
6	Arsenic (As)	30 mg/L	≥83%	88.6%
7	Cadmium (Cd)	0.03 mg/L	≥83%	99.7%
8	Chromium (Cr)	0.15 mg/L	≥67%	97.4%
9	Fluoride (F)	8.0 mg/L	≥75%	98.5%
10	Lead (Pb)	0.15 mg/L	≥90%	99.6%
11	Nitrate (NO ₃)	30 mg/L	≥67%	96.9%
12	Tetrachloromethane (CCl ₄)	78 µg/L	≥98%	99.9%
13	Trichloromethane (CHCl ₃)	300 µg/L	≥95%	96.0%

[0057] Example 2 - Industrial Wastewater Treatment

[0058] Industrial wastewater treated by the selective nanofiltration membrane as disclosed herein was shown to meet regulatory Discharge Permit Limits.

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[0059] In this example, the influent wastewater was derived from textile industrial. The membrane module used was 1 unit of 8-inch standard membrane module. The results of the treatment are shown in TABLE 3 below.

10 [TABLE 3]

Parameters	Actual Influent	Discharge Permit Limit (Singapore)	Actual Average Effluent
COD (mg/L)	3000	600	500
Colour (Pt-Co)	100	-	< 5
Total suspended solids (mg/L)	500	400	300
Total dissolved solid (mg/L)	4000	3000	2500

[0060] The disclosed hollow fiber nanofiltration membrane manufacturing process provides various competitive advantages over conventional spiral wound membrane. Hence, industrial applicability is taken to be self-evident.

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[0061] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the invention.

Claims

1. A method of producing selective surface charged nanofiltration membrane, the method comprising:
 - 5 submerging a membrane within a first sealed tank having a first charged polymeric solution under controlled environment for a prescribed period to forming a surface modified membrane;
rinsing the surface modified membrane within purified water under controlled environment for a prescribed period;
 - 10 submerging the surface modified membrane within a second sealed tank with a second charged polymeric solution different from that of the previous charged polymeric solution under controlled environment to form a further surface modified membrane;
transferring the surface modified membrane into a centrifuge to operationally spin the membrane therein for removing the excess solution from the membrane;
 - 15 rinsing the further surface modified membrane with purified water under controlled environment for prescribed period; and
soaking the further modified membrane into a cross linker solution to form the selective surface charged nanofiltration membrane.
- 20 2. A method according to claim 1, further comprising repeating the steps of:
 - submerging the surface modified membrane within a sealed tank with a charged polymeric solution different from that of the previous charged polymeric solution under controlled environment to form a further surface modified membrane; and
rinsing the further surface modified membrane with purified water under
25 controlled environment for prescribed period.

3. The method according to claim 2, wherein the steps of submerging in the charged polymeric solution different from the previous charged polymeric solution immediately before the cross-linked process determines a resulting charge of the selective charged nanofiltration membrane.
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4. The method according to claim 1, wherein the centrifuge operationally spins at about 2000-5000 rpm.
- 10 5. The method according to claim 1, wherein operationally, the controlled environment includes about 0.1 to 1.0 bar pressure, the prescribe period include about 10-60mins and an operating temperature of about 25°C to 60°C.
6. The method according to claim 1, wherein the sealed tanks includes a rotate shaking at about 20-100 rpm operationally.
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7. The method according to claim 1, wherein the selective surface charge nanofiltration comprises positive or negative surface charged achieving an rejection rate of about 90 to 99% of micropollutants, color, magnesium chloride, magnesium sulphate, calcium chloride and calcium sulphate.
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8. The method according to claim 1, wherein the membrane is made of charged polymeric materials, further comprising polycationic polymer materials, polyanionic polymer materials or mixture of both.

9. The method according to claim 1, wherein the charged polymeric solution include cyclopentadienyl and methylamine, thereby enhancing membrane surface charged, ionic strength and reduce membrane surface pores.
- 5 10. The method according to claim 9, wherein the polycationic polymer includes poly(ethyleneimine), poly(allylamine), poly(L-lysine), poly(dimethyldiallylammonium chloride), poly(allylamine hydrochloride), poly(acrylamide), polyglutamic acid, gelatin, chitosan or chitosan derivatives, with concentration 0.01 to 1wt% in aqueous solution contained dissolved salts (sodium chloride or calcium chloride).
- 10 11. The method according to claim 9, wherein the polyanionic polymer is comprised of sodium poly(styrene sulfonate), sodium polystyrene sulfonate-maleic acid, poly(acrylic acid), hyaluronic acid, alginate, pectin, heparin, modified graphene oxide, nanotubes or mixtures, with concentration 0.01 to 1wt% in aqueous solution contained
- 15 dissolved salts.
12. The method according to claim 9, wherein a polymer molecular weight of the polycationic and polyanionic ranges from 1,000 to 1,000,000 Da.
- 20 13. The method according to claim 1, wherein the cross linker solution includes any of glutaraldehyde, dopamine, siloxanes, zwitterionic compound with different functional groups, aldehyde, carboxy, phosphate, sulphonate and ether. It may have concentration of about 0.1 to 2.0wt% in aqueous solution with 0.1 to 0.5wt% of sulphuric acid or other acid.

14. The method according to claim 13, wherein the cross linker solution comprises concentration is 0.1 to 2.0wt% in aqueous solution with 0.1 to 0.5wt% of sulphuric acid or other acid.
- 5 15. The method according to claim 1, wherein said the surface functional groups comprises amino, carboxyl or sulphonate groups.
16. A system for fabricating selective surface charged nanofiltration membrane, the system comprising:
- 10 a plurality of sealable tanks for submerging a membrane therein to process the same under controlled environment; and
- one or more centrifuges for removing excessive solution from the membrane, whereby spinning the membrane within the centrifuge further evenly spread the solution across the membrane surfaces.
- 15 17. The system according to claim 16, wherein the selective surface charged nanofiltration membrane is fabricated in accordance with any one of claim 1-15.