

[001]. Title

[002]. ELECTRODE AND SYSTEM FOR INDUSTRIAL SCALE MEMBRANE BASED FREE-FLOW ISOELECTRIC FOCUSING

[003]. CROSS-REFERENCE TO RELATED APPLICATION

[004]. This application claims benefit of, and priority from, Singapore patent application No. 201104869-1, filed on 1 July 2011, the contents of which are hereby incorporated herein by reference.

[005]. Field

[006]. Industrial Scale Membrane based Free-Flow Isoelectric Focusing (FFIEF)

[007]. Background introduction

[008]. The production of biomolecules is a large and growing industry. As an industrial average, 90-95% of production costs of biomolecules come from the separation and purification processes. Traditionally gel based isoelectric focusing has been used in laboratories for protein separation. Such methods require casting pH gradient gels that would introduce the possibility of variation and is not suitable for industrial scale separation and purification.

[009]. Another method uses ultrafiltration (UF) membrane separation technology, porous ion exchange membranes have been extensively examined owing to their possibilities for biomolecular separations [1~2]. However, it is laborious work for breaching the bottleneck of low flux and low selectivity based on the currently used ultrafiltration (UF) technology. Since most ultrafiltration (UF) membranes fabricated by the phase-inversion method possess a very wide pore size distribution on the selective skin. On the other hand, only when the ratio of molecular weights (MW) of two biomolecules is larger than 10, the separation selectivity based on the size-exclusive effects can reach an acceptable level [3]. Moreover, it is very difficult to realize the continuous operation for most membrane filtration methods. This is due to the fact that the processes are usually disturbed by elution, regeneration or backwash steps to get rid of the effects of adsorption, saturation and fouling [4~5].

Therefore, many investigations have primarily concentrated on the development of membrane materials with high separation performance and low fouling.

[0010]. Devices of continuous operation for membrane-based biomolecule separations have not received much attention. Most of the existing membrane-based biomolecular separation devices are designed only for a binary mixture. Some devices for electrophoresis where pH imbedded gel like membranes were applied as separation medium, have obtained high selectivity and reasonable fluxes for some specific samples. However, gel-like membranes have a short life time [6~18] and the neutral UF membranes do not have high enough selectivity [19~20]. Therefore the electrophoresis technology has not been widely applied in industry because of the bottle neck of membrane technology. Previous research has proven that, isoelectric focusing conditions combined with highly charged ion-exchange membrane will be very effective in obtaining pure charging products, such as proteins, hormones, RNA, DNA. The difficulty with this method is designing large scale equipment for manufacturing.

[0011]. In multi-compartment electrophoresis, in order to obtain a linear pH gradient along the electric field, most researchers' apply pH imbedded gel membranes to separate chambers. This will give a high resolution in short time operation. However, the imbedded pH component would deplete in a few hours. For one batch of loading, this technology requires the customer to cast more than ten membranes with more than 10 different compositions correspondingly, which is tedious, inconstant and difficult to handle. These problems are escalated on an industrial scale.

[0012]. The inventor has overcome the above disadvantage through the use of homogenous membranes. By applying a series of identical membranes inside an electric field. Through the synergetic effect of the special designed pH control system and the buffer, it is possible to maintain the linear pH gradient a longer time than currently available, which is essential for isoelectric focusing on an industrial scale. The method is more convenient and user friendly.

[0013]. When this method was done on a large scale the circulation loop had serious short circuits within an individual chamber resulting in a lightening phenomenon within the

chamber, which can destroy the whole chamber, or even may cause injury or fatality. However, forced circulation is very important and necessary for the process. This is due to the fact that bio-macromolecules will precipitate at its isoelectric point which could lead to clogging the chamber.

[0014]. An object of the invention is to ameliorate some of the difficulties of the prior art to allow protein separation and or purification on an industrial scale.

[0015]. **Summary**

[0016]. An aspect of the invention includes an electrode for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles comprising a cathode and an anode wherein a portion of the cathode that comes into contact with an electrolyte solution when in use, is coated with a metal protective layer and a polymer protective layer and a portion of the anode that comes into contact with the electrolyte solution when in use, is coated with a metal protective layer and a polymer protective layer.

[0017]. Preferably the cathode forms one wall of a chamber for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles, and the anode forms another opposite wall of the chamber.

[0018]. Preferably the cathode and the anode comprise a soft, high conductivity, oxidation resistant materials selected from the group consisting of brass, carbon-amorphous, graphite, copper, copper graphite, copper tellurium, copper tungsten, copper zirconium diboride, gold or gold alloy, electrographite, metal graphite, molybdenum, palladium or palladium alloys, platinum or platinum alloys, plated base metal, resin bonded graphite, silver or silver alloys, silver copper, silver cadmium oxide, silver graphite, silver molybdenum, silver nickel, silver tin oxide, silver tungsten, silver tungsten carbide, tungsten, and tungsten carbide.

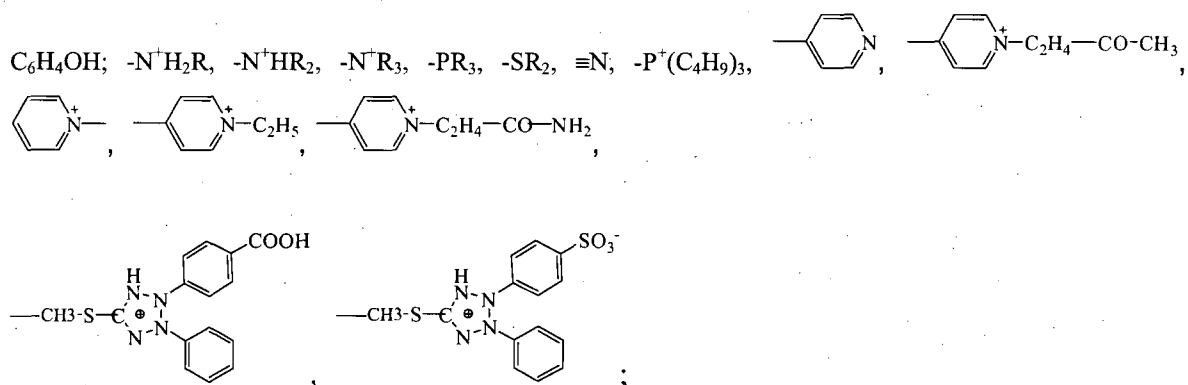
[0019]. Preferably the metal protective layer comprises a sintered powder of an oxy-compound of any one of titanium, tantalum, zirconium, vanadium, niobium, hafnium, aluminum, silicon, tin, chromium, molybdenum, tungsten, lead, manganese, beryllium, iron, cobalt, nickel, platinum, palladium, osmium, iridium, rhenium, technetium, rhodium, ruthenium, gold, silver, cadmium, copper, zinc, germanium, arsenic, antimony, bismuth, boron, scandium and metals of the lanthanide and actinide series.

[0020]. Preferably the polymer protective layer comprises a conductive polymer.

[0021]. The conductive polymer may include a charged polymer, such as a positively charged resin, a negatively charged resin, a conjugate polymer like a polypyrrole or a polyaniline, an electropolymerized Polypyrrole/polyacrylonitrile, polyaniline/polyacrylonitrile, or poly(3,4-ethylenedioxythiophene).

[0022]. Another aspect of the invention provides a System for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles comprising the electrode of the invention and a series of homogenous membranes applied in parallel between the cathode and the anode within a chamber.

[0023]. Preferable the homogenous membrane comprise hydrocarbon or partially halogenated hydrocarbon polymers, such as a PPO (poly(2,6-dimethyl-1,4-phenylene)), a polysulfone, polyethersulfone, polystyrene, polyacrylnitrile and their halogenated interim; perfluorocarbon polymers modified with $-\text{SO}_3^-$, $-\text{COO}^-$, $-\text{PO}_3^{2-}$, $-\text{PHO}^{2-}$, $-\text{AsO}_3^{2-}$, $-\text{SeO}_3^-$, $-\text{SH}$, -



or any other conductive polymers such as polyaniline, polypyrrole and other conjugated polymers.

[0024]. Preferably each membrane further comprises a sequence of one or more inner pockets.

[0025]. Preferably a pocket outlet is positioned between each inner pocket membrane to allow a precipitate to pass though and to allow collection of the precipitate outside the chamber. The pocket outlets are preferably made of various engineering plastic tubing such as PE, PP, PVC, PTFE, PSF, PES, silicon, PVDF, etc.

[0026]. On one embodiment a chamber spacer in the form of a socket is positioned on the side of a frame, to allow the pocket outlet tubing of the inner pocket to pass through, where collection of the precipitate may be obtained outside the chamber.

[0027]. Preferably the system provides a buffer solution for Free-Flow Isoelectric Focusing of water soluble charged molecules in a system of the invention comprising a synthetic polyelectrolyte a multi -COOH groups and a multi -NH₂ groups.

[0028]. Preferably the multi -COOH groups and the multi -NH₂ groups are amino acids, short peptides and/or derivatives of amino acids.

[0029]. In one embodiment of the system the series of homogenous membranes between the cathode and the anode are wound in a spiral. Where the membranes are preferably flat sheet porous ion-exchange membranes. The membranes may have individual outlets. Preferably the electrodes comprise a soft sheet distribution matrix and the chamber is a cylinder. The system may further comprise an insulator stack.

[0030]. Other aspects of the invention include those apparent to a person skilled in the art with reference to the description and figures of the preferred embodiments.

[0031]. Brief Description Of The Drawings

[0032]. **Figure 1** (A) The schematic diagram of the FFIEF device with dense membranes between the cathode and the central electrolyte solution and between the anode and the central electrolyte solution.(B) A schematic diagram of the FFIEF system. (C) A schematic diagram of the electrode.

[0033]. **Figure 2** Multi-chamber and electrode designs for industrial scale FFIEF.

[0034]. **Figure 3A** Design of individual chamber and inlets, outlets module, **Figure 3B** Design of individual inner pockets and outlets

[0035]. **Figure 4** The design of the electrode

[0036]. **Figure 5** The design of FFIEF in spiral wound module

[0037]. **Figure 6** Proteins standards and egg white components

[0038]. **Figure 7** HPLC results of egg white components separated by the M-IN membrane in the FFIEF system at 30mA for **A.** 10 hours, **B.** 18 hours and **C.** 27 hours.

[0039]. **Figure 8** HPLC results of porcine blood plasma before **A** and after FFIEF purification **B** and Immunoglobulin separation after FFIEF **C** and separated via the pockets **D**

[0040]. **Figure 9** Gel electrophoresis of individual fractions of porcine blood plasma

[0041]. **Detailed description**

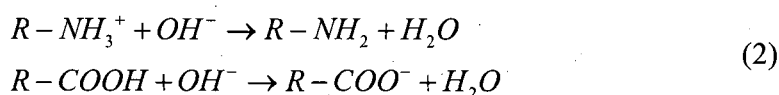
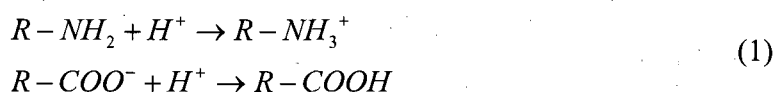
[0042]. This system is designed, and fabricated for industrial scale FFIEF equipment that produces high flux, high selectivity bio-macromolecule products preferably at low cost.

[0043]. The advantages of the system include low capital investment and low operation cost compared to systems currently available. Particularly these costs are much lower than the conventionally used chromatography technology for drug preparation purposes; a combination of industrial ion exchange membranes and free-flow isoelectric focusing (FFIEF) technology for high-flux and high-selectivity protein separation, in which we use industry scale ion exchange membranes as the separation media. Extensive experiments have been conducted in the laboratory scale FFIEF device, where the feasibility, effectiveness, efficiency, reproducibility has been verified. Here we provide a unique design of industrial equipment for bulk amounts of biomedical loading for separation of high purity products. The design of half flat electrodes (15) with anti-corrosive layers (16 &18), avoids a short circuit occurring in the chamber circulations, the design allows a synergetic effect of pH control system and high capacity buffer solutions combined in the FFIEF industrial equipment.

[0044]. All water soluble charged molecules and particles could be purified in this process. Such molecules and particles include: Proteins, DNAs, RNAs, heparin and most charged bio-molecules; Vitamins (Vitamin C, B6, B12, etc.), hormones; Antibiotics e.g.(penicillin, cephalosporin, erythromycin, colistin sulphate, gibberellin, etc.); Bio-pesticides purification and concentration (Ninamycin, Polyoxorim, Kasugamycin, etc.); Recombinant gene expressed drugs; Most organic acids and organic bases; Most organics having clear dipoles; or Enantiomeric mixture.

[0045]. Working principle of the FFIEF system

[0046]. The net charge of proteins is the sum of all positive and negative charges provided by amino acid chains. When the pH value of a protein solution is lower than the isoelectric point (pI) of the protein (i.e., $\text{pH} < \text{pI}$), the protein molecules carry positive charges, as shown in Eq. (1). On the contrary, when the pH value of a protein solution is higher than the pI value of the protein (i.e., $\text{pH} > \text{pI}$), the protein molecules carry negative charges, as shown in Eq. (2).



[0047]. The theoretical protein separation device is demonstrated in Figure1. The model mixture of BSA (bovine serum albumin) and Mb (myoglobin) is applied here to illustrate the mass transfer through the membrane. As shown in Figure1, the feed and permeate chambers are partitioned by an Ultra filtration (UF) on an ion exchange membrane (IEM) (8) which only allows the opposite charged ions to pass through due to the electrostatic attraction. Meanwhile, this membrane may prevent the back flow from the permeate side. When bovine serum albumin (BSA) and myoglobin (Mb) proteins are mixed in the feed chamber with a pH value of 7.0, BSA molecules carry negative charge, while Mb molecules is zero charged due to its pI value of 7.0. Therefore, Mb molecules stay at the feed chamber due to zero electric driving force, whilst BSA molecules with positive charges diffuse through the porous ion exchange membrane under the electric driving force and reach the permeate chamber (with a pH value of 4.8). The net charge of BSA molecules reduces to zero in the permeate chamber, thus preventing BSA molecules from further migration. Therefore, in principle, a high-purity BSA may be obtained at the permeate chamber.

[0048]. Figure 1 has two extra membranes CEM is a commercial dense cation exchange membrane (12) which resists or protects the protein from the anode, and AEM is a commercial dense anion exchange membrane (14) which resists or protects the protein from the cathode.

[0049]. Industrial design

[0050]. This is a combination of membrane technology and IEF electrophoresis technology. It employs membranes as mass transfer media instead of gel strip in electrophoresis, enabling electrophoresis concept enlarged to industrial scale. This process provides measures for purifications of bio-macromolecular products in pharmaceutical applications, such as protein drugs, DNAs, RNAs, heparin and other recombinant gene expressed drugs and all those listed above or known to those skilled in the art.

[0051]. The Figure. 1 is only a very preliminary study for the feasibility and effectiveness of FFIEF process. The design in Figure.1 is acceptable for an academic research, because no long time continuous operation work is conducted. However, this will not be acceptable for industrial scale work. Therefore, we designed an anti-corrosion half electrode (15) to overcome the problem of reduced conductivity in the system.

[0052]. Compared to our previous work, our new design for industrial applications, solves the problem of 1) electrode corrosion through a covering of two layers of conductive materials; 2) short circuit phenomena in case of online circulations through a new design in circulation loops; 3) The stability of linear pH gradient under longer time operation via the newly designed strong buffer capacities.

[0053]. Firstly, we apply the CEM (12 in Figure1) and AEM (14 in Figure 1) to protect the electrodes from biomolecules clogging on the surface of the electrode. CEM is a commercial dense cation exchange membrane (12) which resists the protein from going through to the anode. AEM is a commercial dense anion exchange membrane (14) which resists the protein from going into the cathode chamber. When the electrodes are directly exposed to acidic and basic potions of the electrolyte solutions, the electrodes are easily corroded. To overcome this problem we protected the electrodes with a protective layer of metal (16) and a second protective layer of conductive polymer (18). The Figure. 2 shows the industrial plate-frame design of the FFIEF cell.

[0054]. Secondly, a circulation design can unload the precipitate in time and keep the buffer capacity. In a preferred embodiment, a special device for grounding of every circulation loop is included in the design. A chamber outlet (6) in the form of tubing allows

the collection of the precipitate outside the chamber (Figure 3A). The chamber outlet (6) may be any shape however; preferably it is tubing made of any material, glass, plastic that is sufficiently rigid to allow the precipitate to pass through to allow collection of the precipitate outside the chamber. The fabrication material could include acrylic polymers, PTFE, PE, PP, PVC, PAN, PVDF, PES, PSF, PI, PEI, and all other polymers suitable for molding.

[0055]. In a preferred embodiment the chamber outlet (6) is transparent so that the user can see the precipitate passing through.

[0056]. Thirdly, a more stable pH gradient is desired for IEF application. Automatic pH adjust system can improve the stability of pH gradient to almost 5 hrs. Combining pH adjust system, ion-exchange membranes and some synthetic multi-electrolyte, the linear pH gradient can last up to 15 hrs.

[0057]. Electrode

[0058]. The electrode (15) must be suitable for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles comprising a cathode and an anode wherein a portion of the cathode that comes into contact with an electrolyte solution when in use, is coated with a metal protective layer (16) and a polymer protective layer (18) and a portion of the anode that comes into contact with the electrolyte solution when in use, is coated with a metal protective layer (16) and a polymer protective layer (18) (Figure 1C).

[0059]. The electrode material is selected from a relatively cheaper metal such as Titanium (Ti). Preferably a Ti metal plate is used for both cathode and anode material. Other suitable electrode materials include any soft, high conductivity, oxidation resistant materials such as brass, carbon-amorphous, graphite, copper, copper graphite, copper tellurium, copper tungsten, copper zirconium diboride, gold or gold alloy, electrographite, metal graphite, molybdenum, palladium or palladium alloys, platinum or platinum alloys, plated base metal, resin bonded graphite, silver or silver alloys, silver copper, silver cadmium oxide, silver graphite, silver molybdenum, silver nickel, silver tin oxide, silver tungsten, silver tungsten carbide, tungsten, and tungsten carbide.

[0060]. The electrode material is treated or coated with anti-corrosion treatments or anti-corrosion materials to make it suitable for use in a free flow isoelectric focusing chamber.

The anti-corrosion materials form protective layers on the electrode material (Figure 4). The criteria of selection of protective material are 1) electrical conductivity, 2) ability to adhere to the electrode material, and 3) surface reaction under strong electro-chemical environment. Only the portion of the electrode surface that will come into contact with an electrolyte solution needs to have an anticorrosive protection. On a portion of the electrode that may come into contact with the electrolyte solution the electrode portion is modified by coating with a metal protective layer (16) and a polymer protective layer (18).

[0061]. The metal protective layer (16) can be formed of metal oxide sintered layer which is inert to electrochemical reaction but highly conductive and can be used under acidic anode solution. Alternatively a matrix of sintered powders of an oxy-compound of at least one metal selected from the group consisting of titanium, tantalum, zirconium, vanadium, niobium, hafnium, aluminum, silicon, tin, chromium, molybdenum, tungsten, lead, manganese, beryllium, iron, cobalt, nickel, platinum, palladium, osmium, iridium, rhenium, technetium, rhodium, ruthenium, gold, silver, cadmium, copper, zinc, germanium, arsenic, antimony, bismuth, boron, scandium and metals of the lanthanide and actinide series can be used.

[0062]. The polymer protective layer (18) should be electrically conductive polymer that can effectively prevent the attachment of proteins or other biomolecules, and may be applied as a secondary protective layer. The main classes of conductive polymers are charged poly-resins, polyacetylene, polypyrrole and polyaniline. Of these conductive polymers, those known to prevent biomolecular attachment include; electropolymerized pyrrole propyl acid Polypyrrole/polyacrylonitrile; polyaniline/polyacrylonitrile; polymers with carboxylate, sulphate, phosphoric, or amine groups attached to the polymer effectively making the polymer become charged either negatively or positively effectively protecting it from protein attachment and poly(3,4-ethylenedioxythiophene)/polyacrylonitrile.

[0063]. In order to obtain the large scale equipment for industrial application, large scale metal plates were applied and used to function as both the electrode and structure support of the FFIEF chamber. Effectively the electrodes preferably have the anode for a first side of the chamber and the cathode for a second side of the chamber opposite the first side effectively forming an electric field between the first and second side of the chamber.

[0064]. Membranes

[0065]. The criterion of selection of membrane materials is that the materials should be easily modified to positive charge or negative charge, such as polyimide, PPO (2, 6-dimethyl-1,4-phenylene oxide), polysulfone, polyethersulfone and other similar modifiable materials known to those in the art. Functional groups, such as $-\text{COOH}$, $-\text{SO}_3$, $-\text{NH}_4$, $-\text{N}(\text{CH}_3)_4^+$, $-\text{NR}_2$, $-\text{PO}_3$ were used to modify the membrane materials. The ion-exchange capacity (IEC) which is related to separation performance and is measurable. Fortunately, we found that porous charged membranes appear to have non-observable fouling phenomena for protein purification process under conditions of FFIEF.

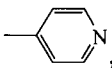
[0066]. Further the membranes (8) may be formed with a sequence of one or more inner pockets (22) (Figure 3B). The inner pockets (22) of the membranes (8) can be about 1cm to 1mm apart or even closer provided they are far enough apart to allow pocket outlet (23) between each inner pocket (22) to pass through a socket (24a) on a frame that forms the chamber by plugging the pocket outlets (23) through a male tubing holder (24b). Preferably this unique membrane device comprises multi-layers of membranes queuing in certain sequence, sealed and partially isolated from the circulation of the chamber. The advantage of having a membrane (8) with a sequence of one or more inner pockets (22) is that it allows proteins with very similar properties to be separated clearly. It provides a possibility of a high flux and high selectivity for separations of multi-component, biomolecular mixtures simultaneously.

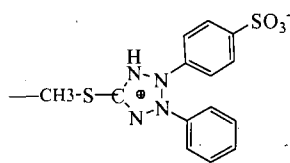
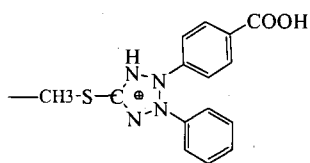
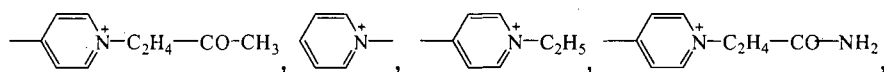
[0067]. Preferably the inner pockets 22 are made of resin layer interspersed with a spacer.

[0068]. The pocket outlet (23) may be any shape however; preferably it is tubing made of any material, glass, plastic that is sufficiently rigid to allow the precipitate to pass through to allow collection of the precipitate outside the chamber. The fabrication material could include acrylic polymers, PTFE, PE, PP, PVC, PAN, PVDF, PES, PSF, PI, PEI, and all other polymers suitable for molding.

[0069]. In a preferred embodiment the pocket outlet (23) is transparent so that the user can see the precipitate passing through.

[0070]. The unique design for the pocket outlet (23) and the sockets, 24a, 24b), provides the added advantage that without opening the whole system, one can collect samples from the inner pockets (22) simply outside the system. And the collection of products from individual pockets (22) could be easily driven by a peristaltic pump.

[0071]. To create a potential charge difference across the inner pockets (22) the pore sizes can be varied. The formation of a pore can be induced by means known in the art for example through the phase inversion membrane casting process by varying the ratio of charged polymers; by varying the membrane formation time or any other means known. Other types of pore structure can be produced by stretching of crystalline polymers. The structure of a porous membrane is related to the characteristics of the interacting polymer and solvent, components concentration, molecular weight, temperature, and storing time in solution. Pore size is generally determined by passing a series of standard molecular weight solutions through the membrane and statistically determining the pore size. The membrane surface zeta-potential can be measured to determine the charge of the membrane. Preferable the homogenous membrane (8) and the membrane inner-pockets (22) comprise polarized hydrocarbon or partially halogenated hydrocarbon polymers, such as a PPO (poly(2,6-dimethyl-1,4-phenylene oxide)), a polysulfone, polyethersulfone, polystyrene, polyacrylnitrile and their halogenated interim; perfluorocarbon polymers modified with $-\text{SO}_3^-$, $-\text{COO}^-$, $-\text{PO}_3^{2-}$, $-\text{PHO}^{2-}$, $-\text{AsO}_3^{2-}$, $-\text{SeO}_3^-$, $-\text{SH}$, $-\text{C}_6\text{H}_4\text{OH}$; $-\text{N}^+\text{H}_2\text{R}$, $-\text{N}^+\text{HR}_2$, $-\text{N}^+\text{R}_3$, $-\text{PR}_3$, $-\text{SR}_2$, $\equiv\text{N}$, $-\text{P}^+(\text{C}_4\text{H}_9)_3$, ,



; or any other conductive polymers such as polyaniline, polypyrrole and other conjugated polymers.

[0072]. Buffer

[0073]. The synthetic polyelectrolytes with multi -COOH groups and with multi -NH_2 groups (with $\text{pI}=3.0$ and $\text{pI}=10.0$ individually) are mixed in a certain ratio as a buffer solution. Since their relative small molecular weight, they are easy to be separated from purified proteins in any post treatment. Preferably the multi -COOH groups and the multi -NH_2 groups are amino acids, short peptides and/or derivatives of amino acids.

[0074]. Chamber

[0075]. The chamber spacer (7) comprises a nylon or other strong plastic material formed as a frame. The electrode also can form walls of the opposite ends of the chamber (7). The inlets (4) and outlets (6) are made as standard modules which can be dismounted from chambers. The Figure 4 shows the design concept of the electrode. As has been shown in Figure 4, there is a grounding device inserted in the outlet module, which is connected to a common bus-bar (20) and finally connected to a plug or electric socket (26).

[0076]. As shown in Figure 4, the current from power supply is distributed into few directions along the wings of the distributor. Wires 21 connect between the distributor wings and the T-shape bars, where T bars make the homogenous current distribution on the electrode plate. There is only one side of the electrode surface that will come into contact with the electrolyte solution. Hence the half electrode is strictly sealed to prevent liquid passing. On one half electrode, only the surface facing the electrolyte is modified with metal protective layer (16) and the polymer protective layer (18).

[0077]. The separation process was controlled by the feedback pH adjusting system. The combination of pH online monitoring and the high capacity polyelectrolyte buffer enables the linear pH gradient to last up to 15 hours. Therefore, a cheaper high capacity buffer allows stable FFIEF processing. We synthesize a group of polyelectrolytes for this purpose.

[0078]. The sub-chamber thickness (10) between each membrane (8), and the buffer capacity could be reduced to improve or enhance the invention. The combination of pH adjusting system and the special buffer we syntheses allow a stable pH gradient in operation period.

[0079]. Ultra thin chamber series with good circulation allows high flux separation finished in short time.

[0080]. The spiral wound design (Figure 5) provides a measurement to obtain a thin chamber and large separation area simultaneously. Separation area for this approach could reach above 10 square meters. All of electrodes' buffer chambers and separation chambers are wrapped in one compact cylinder.

[0081]. All of buffer chambers could be fed by same or gradient buffers through varying the mode of a feeder (Fig 5A).

[0082]. All of the products could be separately collected from individual chambers through imbedded outlets 6 (Fig 5B).

[0083]. Both of the electrode buffer chambers are strictly separated with each other and with separation chambers to ensure the electrical potential across the membrane matrix.

[0084]. Two flat sheet electrodes 15 are strictly insulated from each other to avoid short circuit. In this embodiment the entire electrode 15 will come into contact with the electrolyte solution, hence, the entire surface is treated or coated with anti-corrosion treatments or anti-corrosion materials to make it suitable for use in a free flow isoelectric focusing as described above. The available conductive area of the flat sheet electrodes 15 could be the same as the mass transfer area of membrane 8, which could ensure the homogeneous current density across the membrane matrix (Fig 5D).

[0085]. A Current distribution matrix is spread across the whole flat sheet electrode surface 15, ensuring the homogeneity of the current distribution and the tight packing of the whole wound-up design.

[0086]. The chamber spacer will apply low surface tension materials such as PTFE, PFA+, PFA, EPTFE, PVDF, and all other fluorinate materials to reduce the possible surface interaction of biomaterials with spacer and only allow the surface interaction with membranes.

[0087]. The diagonal arrangement of inlets and outlets of individual chambers allows the liquid flow across the membrane surface area.

[0088]. The construction of this embodiment can be seen in Figure 5D where the layers are arranged with a first electrode layer 15 followed by a dense AEX layer 26; then a spacer

layer 30 in this case a mesh; a series of one or more membrane layers 8; a dense CEX layer 28; a second electrode layer 15 coated with the anticorrosive layers 16 and 18. The construction is then rolled together in the direction of the arrow around the inner cylinder depicted in Figure 5A and capped with an end cover 32 to hold the construction together. The construction can then be placed in an outer cylinder forming a chamber 7.

[0089]. The system of spiral wound electrolyser allows a switch mode of the buffer feeding to vary from the same buffer to a gradient buffer.

[0090]. The electrode buffer compositions for slow depletion are more suitable for this embodiment, including acid, base, water soluble polymers and high osmotic pressure materials.

[0091]. The system allows a stable and large size process for bulk amount of protein purification;

[0092]. High efficiency and reproducibility leads to assured high product quality.

[0093]. Example 1

Performance test for egg white protein separation

Materials

[0094]. Brominated poly(2,6-dimethyl-1,4-phenyleneoxide) (BPPO) with 90% (m/m) bromination was obtained from Shandong Tianyi Imp. & Exp. Co., Ltd. China. The egg white powder was procured from Sigma-Aldrich, Singapore. Electrophoresis grade Tris was obtained from Bio-Rad, Singapore. Udel P3500NT polysulfone (PSf) was provided by Solvay, Germany. Tetrahydrofuran (THF) and triethylamine (TEA) were from Fisher Scientific, UK; N-methyl-2-pyrrolidone (NMP), was from Panreac E.U.; isopropanol (IPA) was from Chedelco Pte. Ltd. Singapore; Methanol, phosphoric acid (H₃PO₄), sodium hydroxide (NaOH) trifluoroacetic acid (TFA), dichloromethane (DCM), chlorosulfonic acid and potassium chloride (KCl) were all in analytical grade (AR) and purchased from Merck Singapore. For high performance liquid chromatography (HPLC) analyses, GR (guaranteed reagent) grade ACN and water were used, while for other occasions, deionized water

(electrical resistance $R > 18.2M_{\Omega}$) was used. The ultrapure water used for HPLC was produced by a “Milli-Q plus 185” pure water system in our lab.

[0095]. Ovalbumin occupies 54% (w/w) of the dry mass of the composition of egg white. Since this large component may interfere with the separation of other components, the protein solution was pretreated to remove ovalbumin and reduce the complexity using the following procedure. The egg white aqueous solution was adjusted to pH= 4.5 and stored in a refrigerator at 5 °C overnight so that most ovalbumin could be precipitated and hence easily removed by filtration. Figure 6 demonstrates the HPLC results of the protein solution after pre-treatment and compares with the standards of reagent grade ovalbumin, ovotransferrin, lysozyme and ovomucoid peaks. Comparing those spectra between the feed and standards in Figure 6, four protein peaks in the egg white mixture can be identified. They are ovomucoid at 6.8 min, lysozyme at 10.5 min, ovotransferrin at 11.0–12 min, and ovalbumin at 14.5–17.0 min. The analyses of commercial protein products also imply that it is very difficult to separate ovomucoid from ovalbumin.

[0096]. In order to investigate the evolution of fractionation as a function of operation time, samples from the FFIEF process partitioned by the membrane M-IN were collected at 10 h, 18 h and 27 h. The corresponded HPLC results were summarized in Figure 7. The protein separation performance after 10-h operation of FFIEF under a constant direct current of 30 mA is shown in Figure 7A. The egg white protein can be partially separated by MIN and three relatively purer components can be obtained after a 10-h operation; they are ovalbumin, ovomucoid and at least one unknown component. As the FFIEF process proceeds to 18 h, Figure 7B four purer components are obtained and they are ovotransferrin, lysozyme, ovomucoid and at least one unknown component. A continuation of the FFIEF process to 27 h elucidates much higher protein purities within each individual chamber as shown in Figure 7C they are ovotransferrin, ovomucoid and one unknown component. In summary, at least five pure proteins can be obtained from the M-IN partitioned FFIEF.

[0097]. Example 2

[0098]. Performance test for plasma separation

[0099]. A similar experiment was conducted on plasma to extract the different protein components in plasma. Globulin in human biochemistry is one of the three types of serum proteins, the others being albumin and fibrinogen. Some globulins are produced in the liver, while others are made by the immune system. The term globulin encompasses a heterogeneous group of proteins with typical high molecular weight, and both solubility and electrophoretic migration rates lower than for albumin. The normal concentration in blood is 2.2 to 3.9 g/dl. Protein electrophoresis is used to categorize globulins into the four categories:

- IgA1, IgA2
- Beta globulins
- Gamma globulins (immunoglobulins, that function as antibodies)
- IgM

[00100]. As the globulins are generally similar molecular weights and charges they have very similar PI values and as such are difficult to separate in a normal membrane FFIEF systems. The inner pockets of the membranes of the current system help to separate such proteins that have such similar characteristics by distilling the individual proteins within the sub-chambers between the inner pockets. Figure 3B is a diagram of the system including the inner pockets. In Figure 8, 8A demonstrates the blood plasma before FFIEF separation, while 8B demonstrates the PSA after FFIEF process. Comparing the HPLC results of separations both with (Figure 8C) and without (Figure 8D) the inner pockets, we found that the inner pockets are a more effective measure for the separation of those proteins having pI values very close together. Further, Figure 9 depicts gel electrophoresis of individual fractions of porcine blood plasma results before and after separation. Example of gel electrophoresis images of different chamber is shown in Figure 9A and marked electrophoresis gel plates to show single component obtained from FFIEF in Figure 9B.

[00101]. It can be clearly seen that the separation on an industrial scale, of proteins with similar characteristics, such as globulins can be greatly enhanced with the inner pockets together with the current system.

[00102]. Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. The invention includes all such variation and modifications. The invention also includes all of

the steps, features, formulations and compounds referred to or indicated in the specification, individually or collectively and any and all combinations or any two or more of the steps or features.

[00103]. Each document, reference, patent application or patent cited in this text is expressly incorporated herein in their entirety by reference, which means that it should be read and considered by the reader as part of this text. That the document, reference, patent application or patent cited in this text is not repeated in this text is merely for reasons of conciseness.

[00104]. Any manufacturer's instructions, descriptions, product specifications, and product sheets for any products mentioned herein or in any document incorporated by reference herein, are hereby incorporated herein by reference, and may be employed in the practice of the invention.

[00105]. The present invention is not to be limited in scope by any of the specific embodiments described herein. These embodiments are intended for the purpose of exemplification only. Functionally equivalent products, formulations and methods are clearly within the scope of the invention as described herein.

[00106]. The invention described herein may include one or more range of values (eg size, concentration etc). A range of values will be understood to include all values within the range, including the values defining the range, and values adjacent to the range which lead to the same or substantially the same outcome as the values immediately adjacent to that value which defines the boundary to the range.

[00107]. Throughout this specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers. It is also noted that in this disclosure and particularly in the claims and/or paragraphs, terms such as "comprises", "comprised", "comprising" and the like can have the meaning attributed to it in U.S. Patent law; e.g., they can mean "includes", "included", "including", and the like; and that terms such as "consisting essentially of" and "consists essentially of" have the meaning ascribed to them in U.S. Patent law, e.g., they

allow for elements not explicitly recited, but exclude elements that are found in the prior art or that affect a basic or novel characteristic of the invention.

[00108]. Other definitions for selected terms used herein may be found within the detailed description of the invention and apply throughout. Unless otherwise defined, all other scientific and technical terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which the invention belongs.

[00109]. While the invention has been described with reference to specific methods and embodiments, it will be appreciated that various modifications and changes may be made without departing from the invention.

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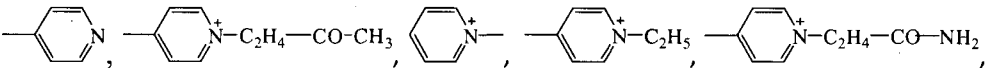
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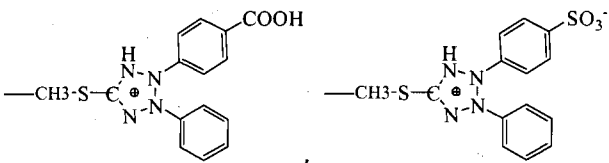
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I Claim:

1. An electrode for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles comprising a cathode and an anode wherein a portion of the cathode that comes into contact with an electrolyte solution when in use, is coated with a metal protective layer and a polymer protective layer and a portion of the anode that comes into contact with the electrolyte solution when in use, is coated with a metal protective layer and a polymer protective layer.
2. The electrode of claim 1 wherein the cathode forms one wall of a chamber for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles, and the anode forms another opposite wall of the chamber.
3. The electrode of claim 1 or 2 wherein the cathode and the anode comprise a soft, high conductivity, oxidation resistant materials selected from the group consisting of brass, carbon-amorphous, graphite, copper, copper graphite, copper tellurium, copper tungsten, copper zirconium diboride, gold or gold alloy, electrographite, metal graphite, molybdenum, palladium or palladium alloys, platinum or platinum alloys, plated base metal, resin bonded graphite, silver or silver alloys, silver copper, silver cadmium oxide, silver graphite, silver molybdenum, silver nickel, silver tin oxide, silver tungsten, silver tungsten carbide, tungsten, and tungsten carbide.
4. The electrode of claim 1 or 2 wherein the cathode and the anode comprises titanium.
5. The electrode of any one of claims 1 or 2 wherein the metal protective layer comprises a sintered powder of an oxy-compound of any one of titanium, tantalum, zirconium, vanadium, niobium, hafnium, aluminum, silicon, tin, chromium, molybdenum, tungsten, lead, manganese, beryllium, iron, cobalt, nickel, platinum, palladium, osmium, iridium, rhenium, technetium, rhodium, ruthenium, gold, silver, cadmium, copper, zinc, germanium, arsenic, antimony, bismuth, boron, scandium and metals of the lanthanide and actinide series.
6. The electrode of any one of claims 1 to 5 wherein the polymer protective layer comprises a conductive polymer.

7. The electrode of claim 6 wherein the conductive polymer comprises a charged polymer, a polyacetylene, a polypyrrole or a polyaniline.
8. The electrode of claim 6 wherein the conductive polymer comprises a negative charged polymer resin, a positively charged polymer resin, an electropolymerized pyrrole propylic acid Polypyrrole/polyacrylonitrile, polyaniline/polyacrylonitrile, or poly(3,4-ethylenedioxythiophene)/polyacrylonitrile
9. A System for Free-Flow Isoelectric Focusing of water soluble charged molecules and particles comprising the electrode of any one of claims 1 to 8, and a series of homogenous membranes applied in parallel between the cathode and the anode within a chamber.
10. The system of claim 9 wherein the homogenous membrane comprises a polyimide, a PPO (2, 6-dimethyl-1,4-phenylene oxide), a polysulfone, or a polyethersulfone modified with COOH , SO_3^- , NH_4^+ , $\text{N}(\text{CH}_3)_4^+$, PO_3^- or NR_2 functional groups.
11. The system of claim 9 wherein the homogenous membrane comprises
 - a. hydrocarbon or partially halogenated hydrocarbon polymers, such as a PPO (poly(2,6-dimethyl-1,4-phenylene)), a polysulfone, polyethersulfone, polystyrene, polyacrylnitrile and their halogenated interim;
 - b. perfluorocarbon polymers modified with SO_3^- , COO^- , PO_3^{2-} , PHO^{2-} , AsO_3^{2-} , SeO_3^- , SH , $\text{C}_6\text{H}_4\text{OH}$; $\text{N}^+\text{H}_2\text{R}$, N^+HR_2 , N^+R_3 , PR_3 , SR_2 , $\equiv\text{N}$, $\text{P}^+(\text{C}_4\text{H}_9)_3$,




 ; or
 - c. other conductive polymers such as polyaniline, polypyrrole and other conjugated polymers without modification.

12. The system of any one of claims 9 to 11 wherein each membrane further comprises a sequence of one or more inner pockets.
13. The system of claim 12 wherein a pocket outlet is positioned between each inner pocket membrane to allow a precipitate to pass through and to allow collection of the precipitate outside the chamber.
14. The system of any one of claims 9 to 13 further comprising a buffer solution comprising a synthetic polyelectrolyte a multi -COOH groups and a multi -NH₂ groups.
15. The system of claim 14 wherein the multi -COOH groups and the multi -NH₂ groups are amino acids, short peptides and/or derivatives of amino acids.
16. The system of claim 9 wherein the series of homogenous membranes between the cathode and the anode are wound in a spiral.
17. The system of claim 16 wherein the membranes are flat sheet porous ion-exchange membranes.
18. The system of claim 17 wherein the membranes have individual outlets.
19. The system of anyone of claims 16 to 18 wherein the electrodes comprise a soft sheet distribution matrix.
20. The system of anyone of claims 16 to 19 wherein the chamber is a cylinder.
21. The system of anyone of claims 16 to 20 further comprising an insulator stack.