

FLUOROPOLYMERS AND MEMBRANES COMPRISING FLUOROPOLYMERS (III)

BACKGROUND OF THE INVENTION

[0001] Membranes comprising fluoropolymers are being considered for filtering a variety of fluids, for example, for removing gases dispersed in fluids. Some of these membranes are characterized by low surface energy values or critical wetting surface tension (CWST) values and/or high resistance to organic solvents and aggressive chemicals. Despite the one or more of the advantages of these membranes, there exists a need for fluoropolymers and membranes comprising such fluoropolymers with improved properties such as low CWST values and/or increased resistance to organic solvents and/or aggressive chemicals.

BRIEF SUMMARY OF THE INVENTION

[0002] The invention provides fluoropolymers with low CWST values and membranes made from the fluoropolymers. In an embodiment, the invention provides a fluoropolymer comprising polymerized monomeric units of the formula A-X-CH₂-B, wherein A is C₆F₁₃-(CH₂)₂, X is O or S, and B is vinylphenyl, and the fluoropolymer has a weight average molecular weight (Mw) of at least 100 Kd and/or a glass transition temperature of at least 33 °C copolymer.

[0003] The fluoropolymer is a superhydrophobic polymer and can be used to impart oleophobic properties, i.e., a CWST of as low as 15 dynes/cm, to material surfaces. The invention also provides a method of preparing a porous membrane comprising the copolymer disposed on a porous support. The invention further provides a method of degassing fluids, particularly fluids containing gases dissolved or dispersed therein. For example, the porous membranes are suitable for removing gaseous impurities present in fluids at a concentration below 1 ppb, or below the detection limit of most instruments.

[0004] The fluoropolymer membrane of the invention has one or more of the following advantages: oleophobic membranes with surface tensions of 15-23 dynes/cm are produced from a one-step coating process without post treatment of the membranes. Oleophobic membranes produced from this process are stable to acid, bases, oxidizers, and/or heat. Oleophobic membranes retain at least 80% of their porosity. The membranes are stable to withstand vacuum holds of 15 mmHg, e.g., for 15 hours or more. Polymer concentrations as low as 0.25% are able to produce oleophobic membranes with a surface tension value of 23 dynes/cm. The polymer coating is adaptable to coat on many, if not all, porous support

membranes and thin films. It does not require extensive investment in equipment to cast membranes since the method uses already existing machinery with little or no modifications. The invention provides a homopolymer that when coated on a membrane has a surface tension 23 dynes or less without post treatment of the membrane. The membrane is porous with high water breakthrough pressure and/or high air flow rate.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0005] Fig. 1A depicts the contact angle of a drop of water on a fluoropolymer membrane in accordance with an embodiment of the invention. Fig. 1B depicts the contact angle of a drop of IPA on a fluoropolymer membrane in accordance with an embodiment of the invention.

[0006] Fig. 2A depicts the contact angle of a drop of water on a fluoropolymer membrane in accordance with an embodiment of the invention. Fig. 2B depicts the contact angle of a drop of IPA on a fluoropolymer membrane in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0007] In accordance with an embodiment, the invention provides a fluoropolymer comprising polymerized monomeric units of the formula



wherein A is $C_6F_{13}-(CH_2)_2$, X is O or S, and B is vinylphenyl, and the fluoropolymer has a weight average molecular weight (Mw) of at least about 100 Kd and/or a glass transition temperature of at least about 33 °C copolymer.

[0008] In accordance with the invention, B is meta- vinylphenyl, para- vinylphenyl, or a mixture thereof. For example, the fluoropolymer comprises meta- [perfluorohexylethylenethiomethyl] styrene, para- [perfluorohexylethylenethiomethyl] styrene, or a mixture thereof, as monomeric unit(s). In a further example, the fluoropolymer comprises meta-[perfluorohexylethyleneoxymethyl] styrene, para-[perfluorohexylethyleneoxymethyl] styrene, or a mixture thereof.

[0009] In an embodiment, the fluoropolymer has an Mw of at least about 100 Kd, at least about 400 Kd, at least about 600 Kd, at least about 800 Kd, or at least about 1000 Kd. For example, the fluoropolymer has an Mw of about 100 to about 4000 Kd, preferably about 500 to about 1500 Kd, and more preferably about 1100 to about 1300 Kd.

[0010] In an embodiment, the fluoropolymer has a number average molecular weight (M_n) of at least about 60 Kd, at least about 200 Kd, at least about 400 Kd, at least about 600 Kd, or at least about 1000 Kd. For example, the fluoropolymer has an M_n of about 100 to about 2000 Kd, preferably about 200 to about 1500 Kd, and more preferably about 400 to about 1400 Kd, and in another embodiment, about 60 to about 1200 Kd.

[0011] In any of the above embodiments, the fluoropolymer has a polydispersity index (M_w/M_n) of about 1.5 to about 5, about 1.5 to about 4, or about 1.5 to about 3.

[0012] In a particular embodiment, the fluoropolymer has an M_w of at least about 98 Kd.

[0013] The monomer can be prepared by reacting $C_6F_{13}-(CH_2)_2-Y$, wherein Y is SH or OH, with a haloalkyl styrene.

[0014] The fluoropolymer can be prepared from the monomer by any suitable method. For example, free radical polymerization can be used, particularly by the use of an initiator in combination with a radical stabilizer. In an embodiment, the fluoropolymer can be prepared by the self-initiated thermal polymerization of the monomer at a temperature of about 130 °C to about 180 °C.

[0015] In accordance with an embodiment, the use of (2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) for the polymerization allows a slow growth rate of the polymer chain and a recombination of the shorter chains resulting in a polymer with narrow molecular weight distributions.

[0016] The monomers are synthesized from perfluorohexyl ethyl thiol, perfluorohexyl ethyl alcohol or their eight carbon fluorinated analogue and chloromethylstyrene, by a special process disclosed herein. The process disclosed herein simplifies the synthesis and purification of the monomer and polymer, making it available for industrial application.

[0017] A preferred method to synthesize the monomer and subsequent polymer is as follows: A 263 mmol of the fluorinated thiol is mixed with 238 mmol equivalent of chloromethylstyrene with 100 mL of DMF and 33 mL of 8 M sodium hydroxide in a 500 mL round bottom flask. The reaction mixture is stirred at room temperature for 1 hour and separated in a reparatory funnel. The resulting product is distilled at 140⁰C at 2 mbar, e.g., with 85% yield.

[0018] The fluoropolymers are soluble in halogenated solvents like chloroform; dichloromethane; 1,2-dichloroethane; 1,1,1,3,3,3-hexafluoro-2-propanol; 1,1,2-trichloro-1,2,2-trifluoroethane and 1,1,1,2,2-pentafluoro-3,3-dichloropropane. However, some of these solvents may be toxic or may not provide the optimal CWST values.

[0019] Examples of suitable solvents include methoxybutanes such as $(\text{CF}_3)_2\text{CF}-\text{CF}_2\text{OCH}_3$, $\text{CF}_3\text{CF}_2\text{CF}_2\text{CF}_2\text{OCH}_3$, or mixtures thereof, by themselves or in combination with isopropanol (IPA). Such solvents are environmentally friendly. Some of these are commercially available as engineered solvents, e.g., Novec 7100™ (methoxy-nanofluorobutanes) or Novec™ 71IPA methoxy-nanofluorobutanes in combination with IPA, which are environmentally friendly and less hazardous, and are preferred.

[0020] The use of fluorinated solvents or engineered solvents improves the adhesion of the fluoropolymer to the porous support.

[0021] The present invention further provides a porous membrane comprising a fluoropolymer described above, wherein the porous membrane is free standing or is disposed on a porous support, e.g., a porous polymeric support.

[0022] In an embodiment, the porous polymeric support is selected from PVC/PAN, polysulfone, polyamide, cellulose, polyester, polyethersulfone, polyolefin, e.g., polypropylene or polyethylene, in particular HDPE, PET, PPS, PPSU (polyphenyl sulfone), PTFE, PVDF, PVF (polyvinyl fluoride), PCTFE (polychlorotrifluoroethylene), FEP (fluorinated ethylene-propylene), ETFE (polyethylenetetrafluoroethylene), ECTFE (poly ethylenechlorotrifluoroethylene), PFPE (perfluoropolyether), PFSA (perfluorosulfonic acid), perfluoropolyoxetane, polyimide, polyether imide, polycarbonate, and polystyrene.

[0023] The porous membrane is oleophobic, and in an embodiment, with a CWST of about 23 dynes/cm or less, e.g., 15-23 dynes/cm, in particular, 15, 16, 17, 18, 19, 20, 21, 22, and 23 dynes/cm.

[0024] The porous membrane can be prepared in situ by polymerizing the monomer on a porous support, e.g., by a polymerizing radiation such as UV or e-beam. Alternatively, and preferably, the porous membrane is prepared by coating a porous support with a solution of the fluoropolymer.

[0025] The CWST of the membrane can be measured by any suitable method. In an embodiment, the method relies on a set of solutions of certain composition. Each solution has specific surface tension. The solutions' surface tension values range from 15 to 92 dyne/cm in small non-equivalent increments. To measure the surface tension, the membrane is positioned on top of a white light table, one drop of a solution of certain surface tension is applied to the porous membrane surface and the time the drop takes to penetrate the porous membrane and become bright white, an indication of light going through the porous membrane, is recorded. It is considered instant wetting when the time the drop takes to

penetrate the porous membrane is ≤ 10 seconds. The solution that gives instant wetting defines the CWST of the porous membrane. If the time > 10 seconds, the solution is considered to partially wet the porous membrane.

[0026] In accordance with an embodiment of the invention, the porous membrane is a porous membrane, e.g., a nanoporous membrane, for example, a porous membrane having pores of diameter between 1 nm and 100 nm, or a microporous membrane having pores of diameter between 1 μm and 10 μm .

[0027] Aspects of the invention include, but are not limited to:

[0028] a) Porous oleophobic membranes derived from a one-step surface coating with the polymers poly[p/m-[(perfluorohexylethylene)thio]methyl]-styrene and poly[p/m-[(perfluorohexylethylene)oxy]methyl]-styrene, and with surface tensions between 15 and 23 dynes/cm;

[0029] b) Porous oleophobic membranes with surface tensions between 15 and 23 dynes/cm derived from a surface coating with the monomers perfluorohexylethylenethiomethyl styrene, and perfluorohexylethyleneoxymethyl styrene, and subsequently irradiated with E-beam energy to obtain oleophobic surfaces;

[0030] c) Porous oleophobic membranes derived from one-step surface coating with the polymers poly[p/m-[(perfluorohexylethylene)thio]methyl]-styrene and poly[p/m-[(perfluorohexylethylene)oxy]methyl]-styrene, and with surface tensions between 15 and 23 dynes/cm, and with post coating drying temperature ranging from 20° to 150°C; and

[0031] d) A modified method that simplifies the synthesis of perfluorohexylethylenethiomethyl styrene and the subsequent synthesis of poly[p/m-[(perfluorohexylethylene)thio]methyl]-styrene for preparing porous membranes useful in commercial and industrial applications.

[0032] The porous membrane can comprise the fluoropolymer in one of many ways. For example, the porous membrane may include a coating comprising the copolymer. The porous membrane can be prepared by dissolving 2% polymer in a suitable solvent, e.g., acetone, and a porous support, such as PTFE, is dipped in the polymer solution for 2 seconds. The coated support is dried in an oven at 80 °C for 20 minutes, and the product is soaked in IPA for 2 hours, dried in an oven for 30 minutes at 80 °C to obtain the porous membrane. SEM micrographs of the surface of a PTFE support and a porous membrane coated on the support are depicted in Fig. 1-2, respectively.

[0033] Membranes can be spin coated, drip coated, spray coated, dip coated or print coated. The coating can also be carried out without additionally drying with heat. The additional heating, however, is preferred since, for example, it can improve the robustness of the membrane. It is able to withstand negative pressures, e.g., up to 15 mm Hg.

[0034] In accordance with embodiments of the invention, the porous membrane can have a variety of configurations, including planar, flat sheet, pleated, tubular, spiral, and hollow fiber. In one embodiment, the porous membrane is a hollow-fiber membrane.

[0035] Porous membranes according to embodiments of the invention are typically disposed in a housing comprising at least one inlet and at least one outlet and defining at least one fluid flow path between the inlet and the outlet, wherein at least one inventive membrane or a filter including at least one inventive membrane is across the fluid flow path, to provide a filter device or filter module. In an embodiment, a filter device is provided comprising a housing comprising an inlet and a first outlet, and defining a first fluid flow path between the inlet and the first outlet; and at least one inventive membrane or a filter comprising at least one inventive membrane, the inventive membrane or filter comprising at least one inventive membrane being disposed in the housing across the first fluid flow path.

[0036] Preferably, for crossflow applications, at least one inventive membrane or filter comprising at least one inventive membrane is disposed in a housing comprising at least one inlet and at least two outlets and defining at least a first fluid flow path between the inlet and the first outlet, and a second fluid flow path between the inlet and the second outlet, wherein the inventive membrane or filter comprising at least one inventive membrane is across the first fluid flow path, to provide a filter device or filter module. In an illustrative embodiment, the filter device comprises a crossflow filter module, the housing comprising an inlet, a first outlet comprising a concentrate outlet, and a second outlet comprising a permeate outlet, and defining a first fluid flow path between the inlet and the first outlet, and a second fluid flow path between the inlet and the second outlet, wherein at least one inventive membrane or filter comprising at least one inventive membrane is disposed across the first fluid flow path.

[0037] The filter device or module may be sterilizable. Any housing of suitable shape and providing an inlet and one or more outlets may be employed.

[0038] The housing can be fabricated from any suitable rigid impervious material, including any impervious thermoplastic material, which is compatible with the fluid being processed. For example, the housing can be fabricated from a metal, such as stainless steel,

or from a polymer, e.g., transparent or translucent polymer, such as an acrylic, polypropylene, polystyrene, or a polycarbonate resin.

[0039] The porous membranes according to embodiments of the invention can be used to filter air and/or gas and/or can be used for venting applications (e.g., allowing air and/or gas, but not liquid, to pass therethrough).

[0040] The porous membrane, according to embodiments of the invention, can also be used in a variety of applications, including, for example, diagnostic applications (including, for example, sample preparation and/or diagnostic lateral flow devices), ink jet applications, lithography, e.g., as replacement for HD/UHMW PE based media, filtering fluids for the pharmaceutical industry, metal removal, production of ultrapure water, treatment of industrial and surface waters, filtering fluids for medical applications (including for home and/or for patient use, e.g., intravenous applications, also including, for example, filtering biological fluids such as blood (e.g., virus removal)), filtering fluids for the electronics industry (e.g., filtering photoresist fluids in the microelectronics industry and hot SPM), filtering fluids for the food and beverage industry, beer filtration, clarification, filtering antibody- and/or protein-containing fluids, filtering nucleic acid-containing fluids, cell detection (including *in situ*), cell harvesting, and/or filtering cell culture fluids. Porous membranes according to embodiments of the inventions can be used in a variety of devices, including surgical devices and products, such as, for example, ophthalmic surgical products. An example of a degassing application is degassing of intravenous (IV) fluids. If IV fluids are not degassed properly before injection, it can introduce air embolus into the circulatory system, which can be fatal under circumstances.

[0041] One preferred use of this invention is for coating of the porous membranes for venting applications in the biopharma and medical industry. Alternatively, the oleophobic coating can be used for anti-icing or for ice-phobic surfaces, and can be coated on fiber glass, metal and aluminum surfaces, power lines, boat hulls and airplane wings.

[0042] Non-porous films can be coated using the polymers poly[p/m-[(perfluorohexylethylene)thio]methyl]-styrene and poly[p/m-[(perfluorohexylethylene)oxy]methyl]-styrene and their higher carbon fluorinated analogues to achieve oleophobic surfaces with high surface energy. Coating can be done by spin coating, drip coating, spray coating, dip coating or print coating.

[0043] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE 1

[0044] This example illustrates the preparation of a monomer in accordance with an embodiment of the invention.

[0045] Preparation of *p*-[[perfluorohexylethylene]thio]methyl]-Styrene PFOMS): 2-perfluorohexyl ethyl thiol (1000 g, 2.63 M) was dissolved in DMF (1L) in a 3 L reactor, and aqueous 8 M NaOH (330 mL) was added at 350 rpm (exothermic), followed by the addition of vinyl benzyl chloride (364 g, 2.39 M). The reaction mixture was stirred at 80 °C for 15 hours. After cooling down, the resulting mixture was separated using a 2L separatory funnel (the product is denser). The H₂O/DMF layer was further extracted with hexane (600 mL). The combined organic layers were washed with 7% aqueous sodium bicarbonate, and sodium bicarbonate layer re-extracted with hexane (300 mL). The thus obtained product was further washed with saturated sodium chloride (1L), and dried with anhydrous sodium sulfate. The product was filtered through silica gel (750 g in hexane), and eluted with hexane (3L). After concentration, the final product obtained weighed (1.115 kg, 2.25 M, 86% yield). ¹H NMR (CDCl₃ in ppm): δ 2.25 (m, 2H), 2.60 (d, 2H), 3.70 (s, 2H), 5.25 (d, 1H), 5.75 (d, 1H), 6.69 (dd, 1H), 7.25 (d, 2H), 7.40 (d, 2H).

EXAMPLE 2

[0046] This example illustrates the preparation of a fluoropolymer, poly[*p*-[[perfluorohexylethylene]thio]methyl] styrene] (PST-S), in accordance with an embodiment of the invention.

[0047] *p*-[[perfluorohexylethylene]thio]methyl]-styrene (1.115 kg, 2.25 M) in a 2L Flask was mixed with toluene (350 g) and azobisisobutyronitrile ((AIBN) 11 g, 674 mmol, 3 mol %), and degassed with nitrogen gas at 0°C for 45 minutes. The reaction mixture was stirred at 60°C for 14 hours. The resulting product was precipitated slowly in methanol (9 L) over 2 hours, and mixed for additional 1 hour. The solvent was decanted and the product was re-dissolved in chloroform (2 L), and reprecipitated in fresh methanol (15 L). After 5 hours of mixing, the product was filtered through a frittered funnel or filter paper using house vacuum, and rinsed with methanol (500 mL). The product was allowed to dry under house vacuum for 1 hour, and in a vacuum oven overnight or until completely dry at 30°C. The polymer obtained weighed 912 g, 82% yield by weight of the monomer.

EXAMPLE 3

[0048] This example illustrates the preparation of another fluoropolymer, poly[*p*-[(perfluorohexylethylene)oxy]methyl]-styrene] P(PFOMS), in accordance with an embodiment of the invention.

[0049] The monomer PFOMS (15.2 g, 31.7 mmol) was taken into a 250 mL round-bottomed flask with 2,2'-Azobis(2-methylpropionitrile) (AIBN) (207.7 mg, 1.23 mmol) and tetrahydrofuran (THF) (7.5 g, 104 mmol). After stirring at 60 °C for 12 h, the reaction mixture was poured into methanol, and the precipitate obtained was purified by several precipitations from solvent NovecTM 71IPA into methanol. Yield: 85%.

[0050] Table 1 lists the glass transition temperatures (T_g) of the homopolymers.

Table 1. Glass transition temperatures of the fluorinated polymers

Glass Transition Temperature of Homopolymers	
Polymer	T _g 1, °C
P(PFOMS)	40
P(PFOTMS)	33

EXAMPLE 4

[0051] This example illustrates a coating procedure in accordance with an embodiment of the invention.

[0052] Melt blown polyester backed PTFE and non supported PTFE membranes 20 nm, 0.1 μm, 0.2 μm, 0.45 μm, or 1 μm were cut into 5 inch x 5 inch sheets. Several sheets of membranes were placed into a stainless steel tray. The coating solution with the polymer concentration of 0.5, 0.75, 1.0, 1.5, 2.0, 2.5 or 3.0 % in chloroform, NovecTM 71IPA, or NovecTM 7100 was poured into the tray and gently shaken to make sure the membranes were thoroughly soaked by the coating solution. The membrane samples were removed from the soaking solution and dried in an oven at 80⁰C for 20 min, followed by testing for membrane performance. Table 2 below shows test results from a 0.2μm polyester backed PTFE membrane.

Table 2. Air Flow Rates, Water Break through pressure (psi), and CWST values

Poly(pftoms) coated PTFE Membranes						
	1.2 μm supported	0.2 μm supported	0.2 μm unsupported	20 nm unsupported	0.2 μm control	1.2 μm control
AFR at 13.5 PSI	107	23.8	NA		26	>201
WBT	8.4	21.62			50	10.9
CWST (dynes/cm)	21.62	21.62	20.14	20.14	26	26

EXAMPLE 5

[0053] This example illustrates the preparation of an oleophilic membrane in accordance with an embodiment of the invention.

[0054] Polyester backed polyethersulfone (PES) and non-supported PES membranes having pores of 0.1 μm , 0.2 μm , 0.45 μm , 1 μm or 5 μm diameter were cut into 5 inch x 5 inch sheets. Several sheets of such membranes were placed in a stainless steel tray. The coating solution with polymer concentration of 0.5, 0.75, 1.0, 1.5, 1.75, 2.0, 2.25, 2.5 or 3.0 % in NovecTM 71IPA, or NovecTM 7100 was poured into the tray and gently shaken to ensure the membranes were thoroughly soaked by the coating solution. The membrane samples were removed from the soaking solution and dried in an oven at 70°C, 80°C, 90°C, 100°C, 120°C, or 140°C for 20 min. Tables 2-4 below set forth the testing results from such membrane at 70°C and at 120°C.

EXAMPLE 6

[0055] This example illustrates the preparation of oleophilic membranes from PVDF and Nylon membranes in accordance with an embodiment of the invention.

[0056] Polyester backed PVDF and non-supported Nylon membranes or cellulose depth sheets, 0.2 μm , 0.45 μm , 1 μm or 5 μm pore diameter were cut into 5 inch x 5 inch sheets. Several sheets of membranes were placed in a stainless steel tray. The coating solution with polymer concentration of 0.5, 0.75, 1.0, 1.5, 2.0, 2.5 or 3.0 % in NovecTM 71IPA, or

Novec™ 7100 was poured into the tray and gently shaken to make sure the membranes were thoroughly soaked by the coating solution. The membrane samples were removed from the soaking solution and dried in an oven at 70°C, 80°C, 90°C, 100°C, 120°C, or 140°C for 20 min. Table 5 below sets forth the testing results from such membranes at 70°C.

EXAMPLE 7

[0057] This example illustrates the preparation of oleophilic membranes from Nylon, HDPE and PTFE membranes in accordance with an embodiment of the invention.

[0058] Nylon membranes 5 nm, PTFE membranes 5 nm and 10 nm, and HDPE membranes 5nm and 10 nm pore diameter were cut into 5 inch x 5 inch sheets. Several sheets of membranes were placed in a stainless steel tray. The coating solution with a polymer concentration of 0.4 % in Novec™ 7100 was poured into the tray and gently shaken for 10 seconds. The membrane samples were removed from the soaking solution and dried in an oven at 130°C for 20 min.

Table 3. Air Flow Rates, Water Break Through pressure (psi), and CWST values

Poly(pftoms) coated 0.2µm PES membrane						
	Polyester supported 0.2µm PES Membrane				Unsupported PES	
	1% conc. @ 70C Dry	1% conc. @ 120C Dry	0.75% Conc. @ 70C. Dry	0.75% conc. @120C. Dry	Coated unsupported 0.2µm PES	Uncoated Control 0.2µm PES
AF		12	9.75	9.75	9.2	20
WBT		45.32	46.84	46.8	NA	NA
CWST (dynes/cm)	21.62	21.62	21.62	21.62	20.14	85

Table 4. Air Flow Rates, Water Break Through pressure (psi), and CWST values

Poly(pftoms) coated 0.2µm PES membrane						
	Polyester supported 0.2µm PES Membrane				Unsupported PES	
	1% conc. @ 70C Dry	1% conc. @ 120C Dry	0.75% Conc. @ 70C. Dry	0.75% conc. @120C. Dry	Coated unsupported 0.2µm PES	Uncoated Control 0.2µm PES
AF		12	9.75	9.75	9.2	20
WBT		45.32	46.84	46.8	NA	NA
CWST (dynes/cm)	21.62	21.62	21.62	21.62	20.14	85

Table 5. Air Flow Rates, Water Break Through pressure (psi), and CWST values

Poly(pfoms) coated PES Membrane			
	1% conc. On unsupported 0.2µm PES	1% conc. On Supported 0.2µm PES	1.5% conc. On unsupported 0.8µm PES
AFR @13.2	12	12	NA
WBT	NA	46.04	NA
CWST (dynes/cm)	21.62	21.62	21.62

Table 6. Air Flow Rates, Water Break Through pressure (psi), and CWST values

Poly(pftoms) coated PVDF and Nylon			
Sample	CWST	AFR @ 13.5 PSI	W B T
PVDF membrane 3µm control	85	187	1.78
PVDF membrane 3µm	20.14	201	1.36
PVDF membrane 0.2 µm control	45	8.1	23.5
PVDF membrane 0.2 µm	21.62	8.3	29.16

Biodyne B (Nylon) 0.2µm	21.62	15.25	35.68
Biodyne B control 0.2µm	85	21.4	3.62
Biodyne A (Nylon) 0.2µm	20.14	6.8	1.22
Biodyne A control 0.2µm	85	10.75	1.26

Table 7. E-beam results from polymerization of *p*-[[(Perfluorohexylethylene)thio]methyl]-Styrene monomer on polyether sulfone and polytetrafluoroethylene membranes

E-Beam polymerization on Membrane using p- [[(Perfluorohexylethylene)thio]methyl]-Styrene monomer							
		CWST dynes/cm		AF (5 psi)		WBT	
Sample	Base membrane	Formulation		1	2	1	2
Control	0.2 µm MBM backed PTFE	NA	26	36	36	50	50
AC	0.2 µm MBM backed PTFE	3% PFOTMS	20.14	2.5 (13.5 psi)	2.5 (13.5 psi)	12.72	11.48
Control	Supor 200 (PES)	NA	85	22.5	22.5	NA	NA
Sample	Supor 200 (PES)	3% PFOTMS	23.83	5.0	5.5	8.26	12.12
Sample	Supor 200 (PES)	7% PFOTMS	23.85	3.5	3.5	12.56	11.80

[0059] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0060] The use of the terms “a” and “an” and “the” and “at least one” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term “at least one” followed by a list of one or more items (for example, “at least one of A and B”) is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), unless otherwise indicated herein or clearly

contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0061] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIM(S):

1. A fluoropolymer comprising polymerized monomeric units of the formula

$$A-X-CH_2-B,$$
wherein A is $C_6F_{13}-(CH_2)_2$, X is O or S, and B is vinylphenyl, and the fluoropolymer has a weight average molecular weight (Mw) of at least 100 Kd and/or a glass transition temperature of at least 33 °C.
2. The fluoropolymer of claim 1, wherein B is meta-vinylphenyl, para-vinylphenyl, or a mixture thereof.
3. The fluoropolymer of claim 1 or 2, wherein the monomeric unit is meta-[perfluorohexylethylenethiomethyl] styrene, para-[perfluorohexylethylenethiomethyl] styrene, or a mixture thereof.
4. The fluoropolymer of claim 1 or 2, wherein the monomeric unit is meta-[perfluorohexylethyleneoxymethyl] styrene, para-[perfluorohexylethyleneoxymethyl] styrene, or a mixture thereof.
5. The fluoropolymer of any one of claims 1-4, wherein the fluoropolymer has a an Mw of at least 200 Kd.
6. The fluoropolymer of any one of claims 1-5, wherein the fluoropolymer has an Mw of 400 to 1300 Kd.
7. The fluoropolymer of any one of claims 1-6, wherein the fluoropolymer has an Mw of 1100 to 1300 Kd.
8. A porous membrane comprising the fluoropolymer of any one of claims 1-7.
9. The porous membrane of claim 8, which includes a porous support.
10. The porous membrane of claim 9, wherein the porous support is a porous polymeric support.
11. The porous membrane of claim 10, wherein the porous polymeric support is selected from PVC/PAN, polysulfone, polyamide, cellulose, polyester, polyethersulfone, polyolefin, PET, PPS, PPSU (polyphenyl sulfone), PTFE, PVDF, PVF (polyvinyl fluoride),

PCTFE (polychlorotrifluoroethylene), FEP (fluorinated ethylene-propylene), ETFE (polyethylenetetrafluoroethylene), ECTFE (poly ethylenechlorotrifluoroethylene), PFPE (perfluoropolyether), PFSA (perfluorosulfonic acid), perfluoropolyoxetane, polyimide, polyether imide, polycarbonate, and polystyrene.

12. A method of preparing a porous membrane comprising a fluoropolymer of any one of claims 1-7, the method comprising:

- (i) dissolving the fluoropolymer in a solvent or mixture of solvents to obtain a solution comprising the fluoropolymer;
- (ii) coating the solution from (i) on a porous support; and
- (iii) evaporating the solvent or mixture of solvents from the coating to obtain the porous membrane.

13. The method of claim 12, wherein the solvent or mixture of solvents comprises a halogenated solvent, optionally in combination with an alcohol.

14. The method of claim 13, wherein the solvent or mixture of solvents is selected from methoxy nona-fluorobutane, methoxy nona-fluorobutane, chloroform, dichloromethane, 1,2-dichloroethane; 1,1,2-trichloro-1,2,2-trifluoroethane, 1,1,1,2,2-pentafluoro-3,3-dichloropropane, optionally in combination with isopropanol and/or 1,1,1,3,3,3-hexafluoro-2-propanol.

15. A porous membrane prepared by the method of any one of claims 12-14.

16. The porous membrane of any one of claims 8-11 or 15, which has a CWST of 15 to 23 dynes/cm.

17. A method of filtering a fluid, the method comprising passing the fluid through the porous membrane of any one of claims 8-11, 15, or 16.

18. The method of claim 17, wherein a gas present in the fluid is removed from the fluid.