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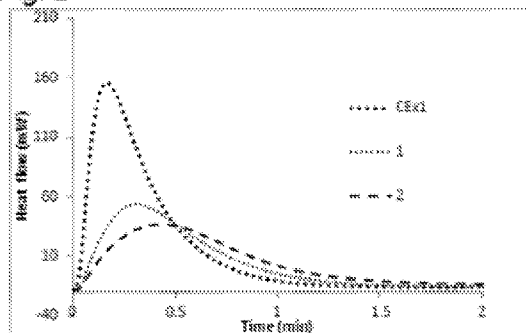
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Fig. 2



(57) **Abstract:** A membrane comprising polymer particles fused together and pores between the fused particles, wherein: (a) the polymer particles have an average diameter of 0.1 to 5,000nm; (b) the membrane having a mean flow pore size of 5nm to 5,000nm; and (c) the membrane has been obtained by a process comprising curing a composition comprising: (i) a monomer; (ii) an organic polymerisation retardant; and (iii) an inert solvent; 0.149. The membranes are useful for detecting metal ions and for filtering and/or purifying biomolecules and compositions comprising metal-ions.



MEMBRANES AND PROCESSES FOR THEIR PREPARATION AND USE

The present invention relates to membranes and to processes for their preparation and use, e.g. for detecting, filtering and/or purifying biomolecules and compositions comprising metal ions.

A number of techniques are known for the detection, filtration and purification of biomolecules (e.g. proteins, amino acids, nucleic acids, anti-bodies and endotoxins). These techniques include size-exclusion chromatography where biomolecules are separated and/or purified based on their size (i.e., physical exclusion) and in ion exchange chromatography where biomolecules are purified or separated according to the strength of their overall ionic interaction with ionic groups in a membrane. Thus membranes are needed for size-exclusion chromatography and also for detecting metal ions or for filtering and/or purifying compositions comprising metal-ions.

One of the problems with current processes for obtaining membranes is that the resultant membranes often suffer from pinholes. These pinholes reduce the selectivity of the membranes. The present invention seeks to provide membranes which are porous, have a good ion exchange capacity and water flux and few or no pinholes. The membranes can be used, for example, for the detection of metal ions, for the filtration and/or purification of compositions comprising metal ions and also for the detection, filtration and purification of biomolecules.

According to a first aspect of the invention there is provided a membrane comprising polymer particles fused together and pores between the fused particles, wherein:

- (a) the polymer particles have an average diameter of 0.1 to 5,000nm;
- (b) the membrane has a mean flow pore size of 5nm to 5,000nm; and
- (c) the membrane has been obtained by a process comprising curing a composition comprising:
 - (i) a monomer;
 - (ii) an organic polymerisation retardant; and
 - (iii) an inert solvent;

wherein the weight ratio of component (ii):component (i) is in the range 0.03 to 0.149.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a is a scanning electron microscope ("SEM") photograph of a cross-section through the comparative membrane obtained from CEx4 (lacking component (ii)) at a magnification of x10,000.

Fig. 1b is a SEM photograph of a cross-section through a membrane according to the present invention (Example 11) at a magnification of x10,000.

The membranes shown in Fig. 1a and 1b comprise a porous support.

A comparison of Fig 1a (component (ii) absent) with Fig. 1 b (component (ii) present) shows that inclusion of component (ii) results in an increase in the average diameter of the polymer particles from which the membrane is derived. Images 1a and 1b shows the increase in particle size produced when the polymerization retardant is used.

Fig. 2 is a UV-differential scanning calorimeter ("DSC") thermogram of the membranes obtained from Comparative Example 1 (CEx1) and Examples 1 and 2 of the invention showing the heat flow (mW) vs time (minutes). Numbers in legend represent sample number from examples. Fig. 2 shows that heat flow (integral value) decreases as the amount of organic polymerisation retardant increases. Furthermore, Fig. 2 also shows that time at which the maximum position of heat flow occurs also increases as the amount of component (ii) present in the composition increases. These two observations show that component (ii) delays polymerisation and therefore acts as an organic polymerisation retardant.

Fig. 3 is a graph showing the pore size flow distribution vs. pore size (nm) of the membranes obtained from Examples 1 and 2. The wet and dry curves were measured by obtaining the gas flow (l/min) vs. applied pressure (bar) with a Porolux™ porometer from Porometer N.V. Then a half-dry curve was calculated by dividing the obtained gas flow values from dry curve by two. By representing these curves in the same graph several parameters can be obtained, including the largest pore size and the mean flow pore size. The pore size flow distribution was also obtained from the measured wet and dry curves. The mean flow pore sizes were calculated from the associated pressure drop necessary to evacuate a wetted fluid from the pores of the membrane concerned.

The mean flow pore size may be measured by capillary flow porometry, e.g. by the standard test method ASTM F316-03(2011).

By comparing the results for Example 1 with Example 2, Fig. 3 shows that the peak of the pore size flow distribution is shifted to bigger pore sizes as the amount of component (ii) increases. Fig.3 also shows that the membrane arising from Example 2 has a bimodal pore size distribution.

In view of the results shown in the drawings (e.g. Fig.1), one may control the average diameter of the polymer particles by including more or less of component (ii) in the composition (increasing the wt% of component (ii) present in the composition increases the average particle size of resultant polymer particles).

Furthermore, the use of an organic (as opposed to inorganic) polymerisation retardant results in homogenous, single phase composition in which there is no inorganic polymerisation retardant to settle-out during storage or

use. The composition of the resultant membranes is also homogenous due to the single phase of the composition used to prepare them.

The use of an organic polymerisation retardants instead of, for example, inorganic cupric and ferrous salts, provides greater compatibility with the other organic components of the composition.

In view of the presence of component (ii) there is no need to include copper or iron salts in the composition. Thus the composition is preferably free from copper salts and free from iron salts. As a consequence the present invention also provides membranes which are free from copper salts and iron salts which can be advantageous in certain end uses (e.g. membranes for purifying foodstuffs, veterinary products and medicines, especially for patients with suffering from copper intolerances (such as Wilson's disease) and/or iron intolerance).

In this specification (including its claims), the verb "comprise" and its conjugations is used in its non-limiting sense to mean that items following the word are included, but items not specifically mentioned are not excluded. In addition, reference to an element by the indefinite article "a" or "an" does not exclude the possibility that more than one of the elements is present, unless the context clearly requires that there be one and only one of the elements. The indefinite article "a" or "an" thus usually means "at least one". Also the terms "curing" and "polymerisation" are used interchangeably in this specification. The phrase "mean flow pore size" is often abbreviated to "MFP size" for simplicity.

Component (i) preferably comprises one or more curable compounds, each such compound comprising one or more reactive groups, e.g. polymerisable groups. The polymerisable group(s) in the one or more curable compounds are typically be selected such they are reactive with each other and also with component (ii). For example, in one embodiment component (i) comprises one or more curable compounds comprising two or more ethylenically unsaturated groups and component (ii) comprises at least two thiol (-SH) groups.

Curing preferably causes the component (i) to cross-link, e.g. to form the membrane as a crosslinked, three dimensional polymer matrix.

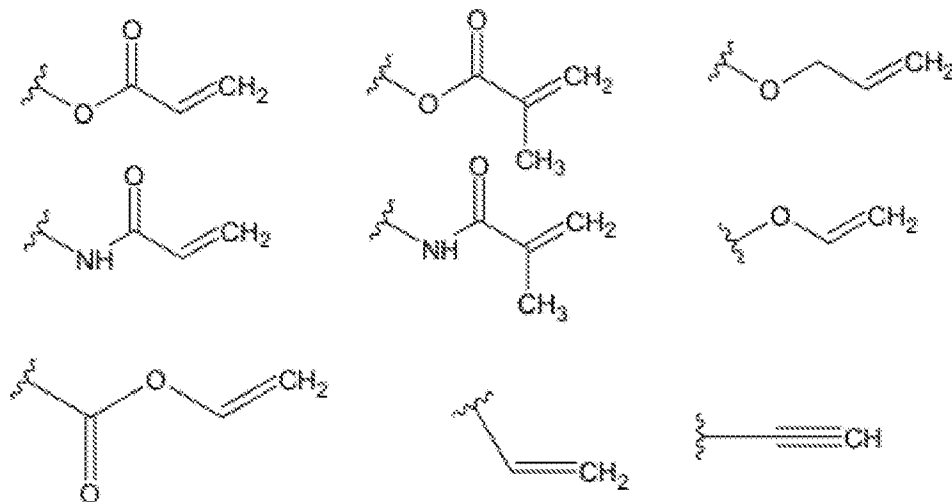
The polymerisable group(s) present in component (i) may all be chemically identical or they may be different.

Preferred ethylenically unsaturated groups are selected from (meth)acrylic groups and vinyl groups (e.g. vinyl ether groups, aromatic vinyl compounds, N-vinyl compounds and allyl groups).

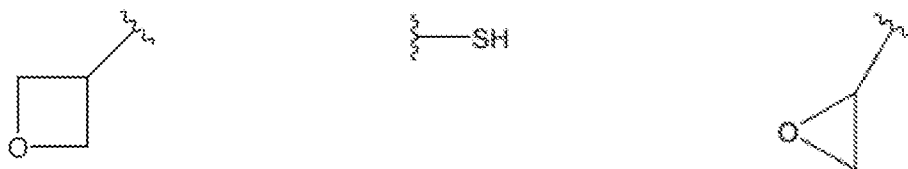
Examples of suitable (meth)acrylic groups include acrylate ($\text{H}_2\text{C}=\text{CHCO}-$) groups, acrylamide ($\text{H}_2\text{C}=\text{CHCONH}-$) groups, methacrylate ($\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{CO}-$) groups and methacrylamide ($\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{CONH}-$) groups. Acrylic groups are preferred over methacrylic groups because acrylic groups are more reactive.

Preferred ethylenically unsaturated groups are free from ester groups because this can improve the stability and the pH tolerance of the resultant membrane. Ethylenically unsaturated groups which are free from ester groups include (meth)acrylamide groups and vinyl ether groups ((meth)acrylamide groups are especially preferred).

As preferred examples of polymerisable groups there may be mentioned groups of the following formulae:



and



One or more cationic or anionic groups may also be present in component (i) and this is preferred because it can help the resultant membrane to distinguish between ionic species such as ionically charged biomolecules and also between different metal-ions.

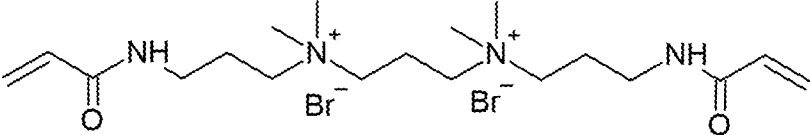
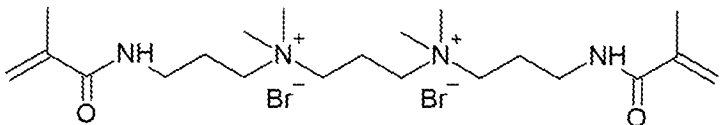
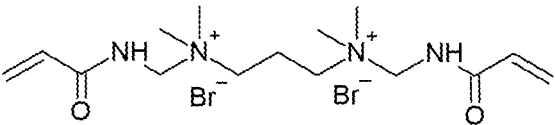
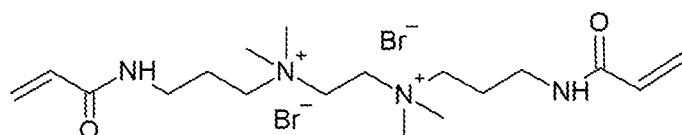
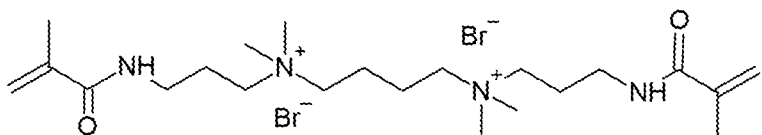
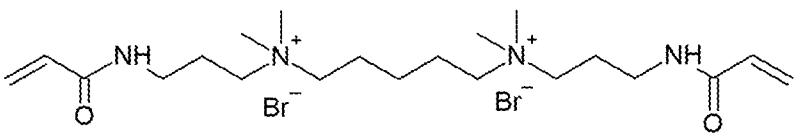
Preferred anionic groups include sulfate, phosphate, carboxylate, benzoate, phenolate and urate groups, especially sulfate groups.

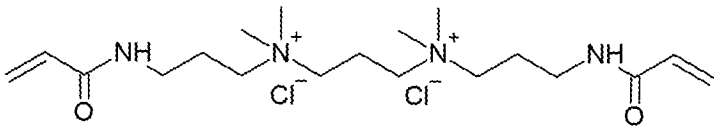
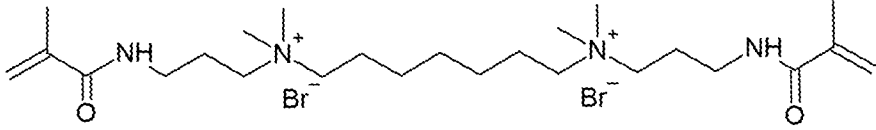
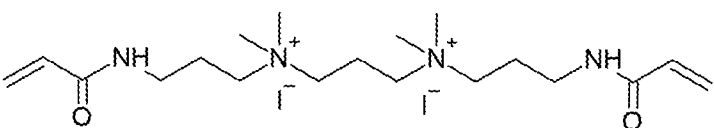
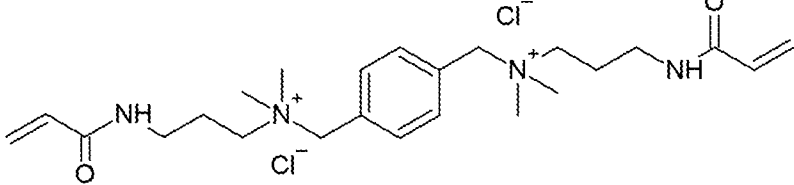
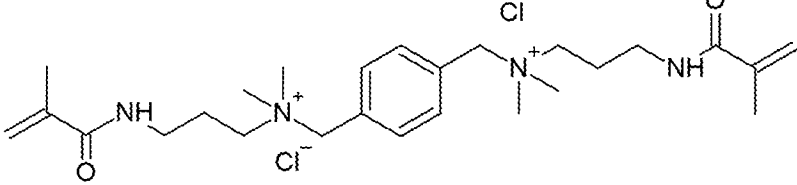
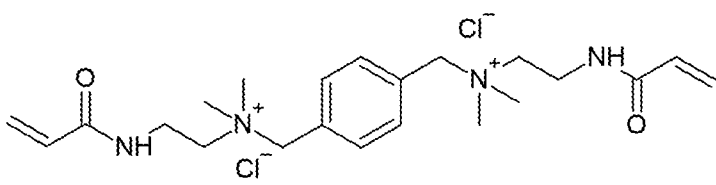
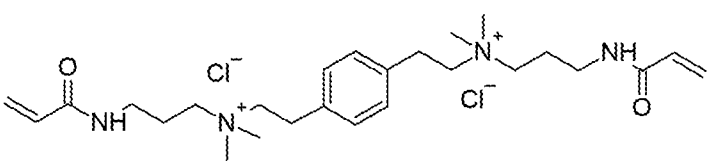
In one embodiment component (i) comprises one or more curable compounds, each such compound comprising a backbone, at least two polymerisable groups and at least one cationic and/or anionic group, preferably a pendant cationic or anionic group (e.g. the cationic or anionic group is attached to the backbone through a single covalent bond or through a spacer group).

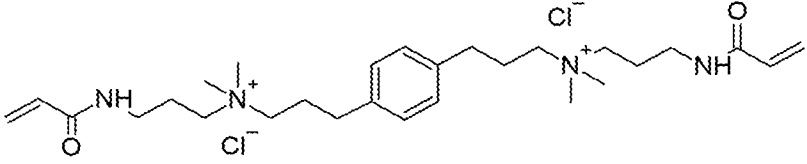
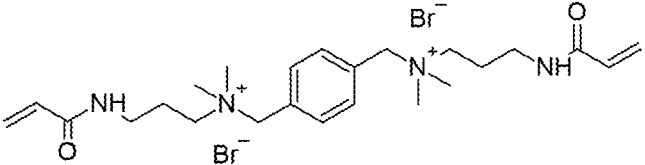
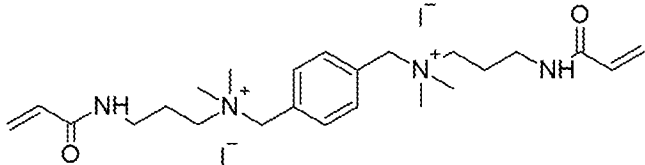
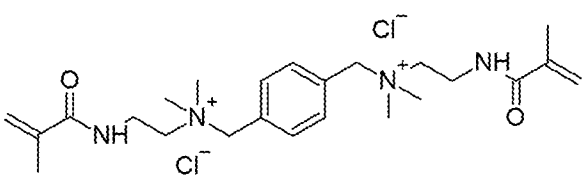
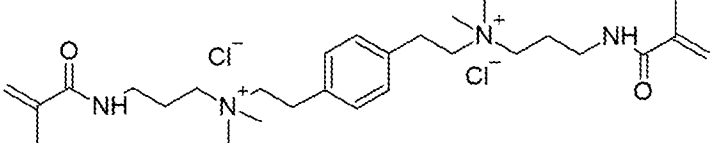
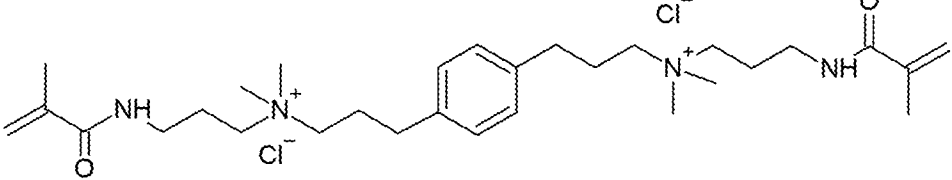
In another embodiment component (i) comprises one or more curable compounds, each such compound comprising at least two cationic or anionic

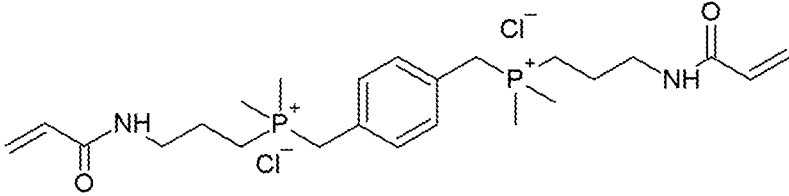
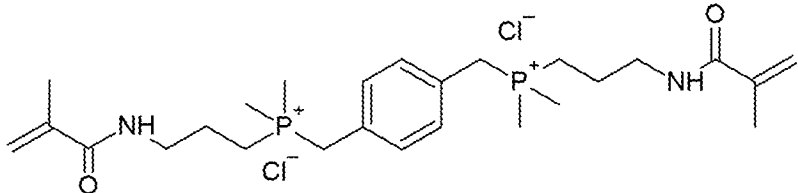
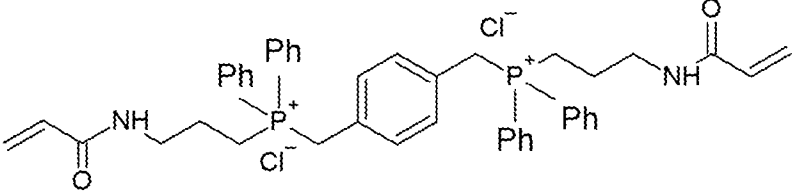
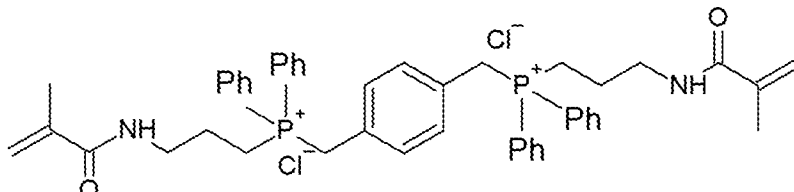
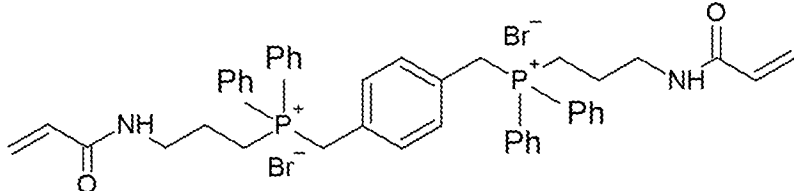
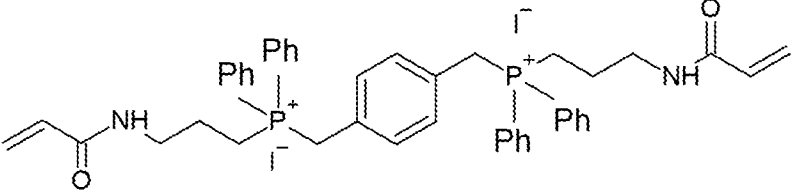
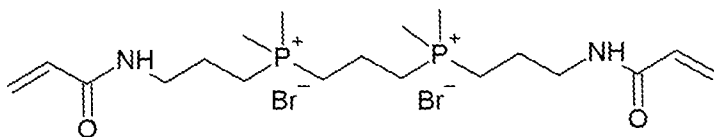
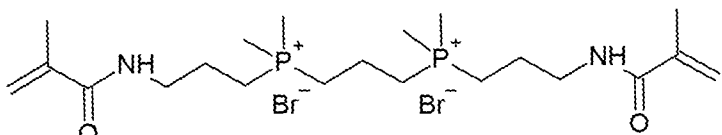
groups, e.g. two, three or four anionic groups. The cationic or anionic group(s) are preferably linked to the remainder of component (i) through a single covalent bond or through a spacer group.

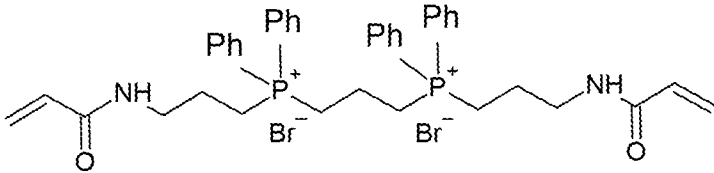
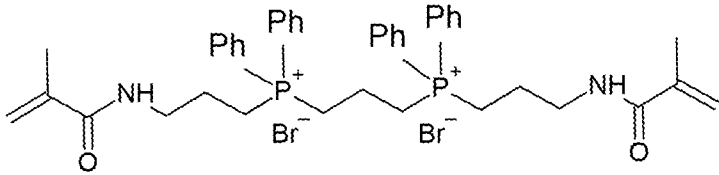
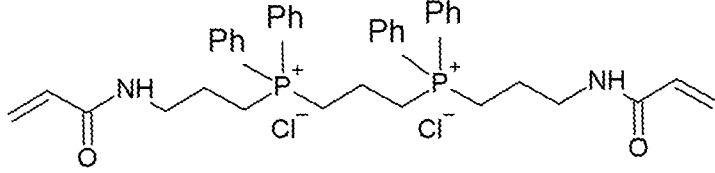
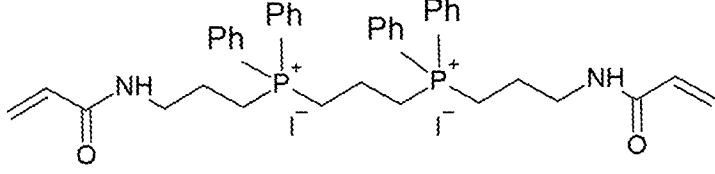
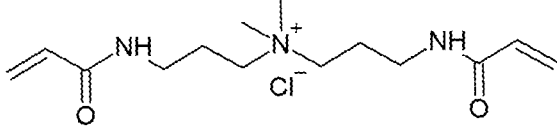
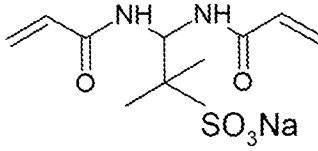
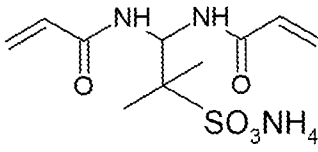
- 5 Preferred examples of component (i) include the cationic compounds (CM1) to (CM32) and the anionic compounds (AM1) to (AM10) below and mixtures comprising two or more thereof.

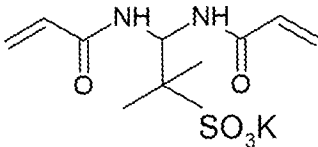
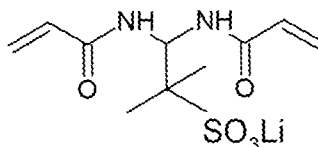
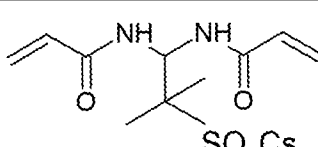
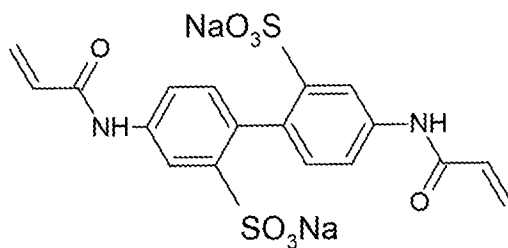
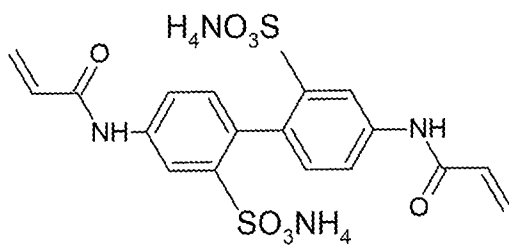
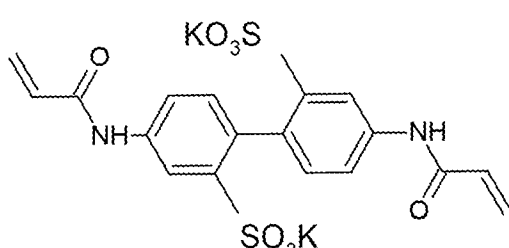
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	(AM9)
	(AM10)

The amount of component (i) present in the composition, relative to the total weight of the composition, is preferably 10 to 50wt%.

Preferably component (i) is completely dissolved in the composition.

5 The organic polymerisation retardant (ii) reduces the rate at which curable components of the composition cure and, as a result of the slower rate of cure, the average particle diameter of the polymer particles formed in the composition during curing increases (compared to when component (ii) is omitted from the composition). Furthermore, the slower rate of cure also increases the MFP size of
10 the resultant membrane. As the curing progresses these polymer particles fuse together to form the membrane and spaces between the particles are pores, defined by walls of the fused polymer particles. Thus one may select component (ii) to be co-polymerisable with component (i) and cause a reduction in the rate at which the curable components of the composition polymerise/cure.

15 Surprisingly the presence of component (ii) in the defined amount reduces the number of pinholes present in the resultant membrane and often there are no detectable pinholes in the membrane at all, resulting in membranes having excellent separation properties.

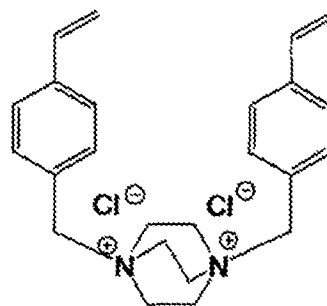
20 The effect of component (ii) can be seen from Fig.2, as described below in relation to the process according to the second aspect of the present invention.

Preferably component (ii) is a curable compound comprising one or more reactive groups which are different to the reactive group(s) present in component (i), e.g. at least one of the reactive groups present in component (ii) is less reactive than the reactive group(s) in component (i). Preferred examples of the reactive groups which are present in component (ii) include (poly)methacrylate,

(poly)methacrylamide, (poly)vinyl and (poly)allyl groups and especially thiol groups.

Optionally component (ii) comprises one or more ionic groups.

Examples of preferred organic polymerisation retardants which may be used as component (ii) include 1,2-benzenedithiol, 1,3-benzenedithiol, 1,4-benzenedithiol, 3,6-dichloro-1,2-benzenedithiol, toluene-3,4-dithiol, 2,3-dimercapto-1-propanol, sodium 2,3-dimercaptopropane sulfonate monohydrate, 2,2'-(ethylenedioxy)diethanethiol, poly(ethyleneglycol)dithiol, 1,5-pentanedithiol, 1,4-butanedithiol, 1,6-hexanedithiol, 1,8-octanedithiol, pentaerythritol tetrakis(3-mercaptopropionate), pentaerythritol tetrakis(3-mercaptoacetate), trimethylolpropane tris(3-mercaptopropionate), ethyleneglycol dimethacrylate, poly(ethyleneglycol) dimethacrylate, 1,3-butanediol dimethacrylate, tetraethylenglycol dimethacrylate, bisphenol A dimethacrylate, 1,6-hexanediol dimethacrylate, divinylsulfone, divinylbenzene, trimethylolpropane diallyl ether, diallyl maleate, allyl ether, diallyldimethylammonium chloride, 1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, 6-(dibutylamino)-1,3,5-triazine-2,4-dithiol, compounds of formula (PR1) as shown below and mixtures comprising two or more thereof:



(PR1)

The weight ratio of component (ii):component (i) is preferably 0.03 to 0.13.

The amount of component (ii) present in the composition is preferably 1.1 to 4.9wt%, more preferably 1.1 to 4wt%.

Preferably component (ii) is completely dissolved in the composition.

In this specification "inert" means non-polymerisable. Thus component (iii) is incapable of polymerising with component (i) or component (ii).

Component (iii) preferably consists of one inert solvent or comprises more than one inert solvent, especially a mixture comprising two or more miscible inert solvents. The inert character of component (iii) assists the formation of pores in the membrane.

Preferably all of the components present in the composition are soluble in component (iii) and the membrane is insoluble or has low solubility in component

(iii). In this way, the process may be performed such that particles of polymer phase-separate from the composition and the particles fuse together to form the membrane. The curing preferably comprises polymerisation-induced phase separation of the membrane from the composition.

5 Preferably component (iii) is a non-solvent for the membrane (the membrane is preferably insoluble in component (iii)). Component (iii) performs the function of dissolving component (i) and (ii). Component (iii) can also help to ensure that the membrane precipitates from the composition as it is formed, e.g. by a phase separation process.

10 The amount of component (iii) present in the composition, relative to the total weight of the composition, is preferably 10 to 90wt% and more preferably 50 to 90wt%.

In a preferred embodiment, component (iii) comprises less than 30wt% of water, relative to the total weight of the composition.

15 Examples of inert solvents which may be used as or in component (iii) include alcohol-based solvents, ether-based solvents, amide-based solvents, ketone-based solvents, sulfoxide-based solvents, sulfone-based solvents, nitrile-based solvents and organic phosphorus-based solvents, of which inert, aprotic, polar solvents are preferred.

20 Examples of alcohol-based solvents which may be used as or in component (iii) (especially in combination with water) include methanol, ethanol, isopropanol, n-butanol, ethylene glycol, propylene glycol, diethylene glycol, dipropylene glycol and mixtures comprising two or more thereof. Isopropanol is particularly preferred.

25 In addition, preferred inert, organic solvents which may be used as or in component (iii) include dimethyl sulfoxide, dimethyl imidazolidinone, sulfolane, N-methyl pyrrolidone, dimethyl formamide, acetonitrile, acetone, 1,4-dioxane, 1,3-dioxolane, tetramethyl urea, hexamethyl phosphoramidate, hexamethyl phosphotriamide, pyridine, propionitrile, butanone, cyclohexanone, tetrahydrofuran, tetrahydropyran, 2-methyltetrahydrofuran, ethylene glycol diacetate, cyclopentyl methyl ether, methylethylketone, ethyl acetate, γ -butyrolactone, heptane, ethanolamine and mixtures comprising two or more thereof. Dimethyl sulfoxide, N-methyl pyrrolidone, dimethyl formamide, dimethyl imidazolidinone, sulfolane, acetone, cyclopentyl methyl ether, methylethylketone, acetonitrile, tetrahydrofuran, 2-methyltetrahydrofuran, heptane, ethanolamine and
35 mixtures comprising two or more thereof are preferable.

In a preferred embodiment component (iii) comprises a composition comprising one or more inert solvents selected from list (iiia) and one or more inert solvents selected from list (iiib):

list (iiia): iso-propanol, methanol, ethanol, acetone, tetramethyl urea, hexamethyl phosphoramidate, hexamethyl phosphotriamide, butanone, cyclohexanone, methylethylketone, tetrahydrofuran, tetrahydropyran, 2-methyltetrahydrofuran, cyclopentyl methyl ether, propionitrile, acetonitrile, 1,4-dioxane, 1,3-dioxolane, ethyl acetate, γ -butyrolactone, ethanolamine, heptane, hexane, pentane or a mixture comprising two or more thereof; and

list (iiib): water, glycerol, ethylene glycol, dimethyl sulfoxide, sulfolane, dimethyl imidazolidinone, sulfolane, N-methyl pyrrolidone, dimethyl formamide, acetonitrile, acetone, 1,4-dioxane, 1,3-dioxolane, tetramethyl urea, hexamethyl phosphoramidate, hexamethyl phosphotriamide, pyridine, propionitrile, butanone, cyclohexanone, tetrahydrofuran, tetrahydropyran, 2-methyltetrahydrofuran, ethylene glycol diacetate, cyclopentylmethylether, methylethylketone, ethyl acetate and γ -butyrolactone, and among these, dimethyl sulfoxide, N-methyl pyrrolidone, N,N-dimethyl formamide, dimethyl imidazolidinone, N-methyl morpholine, acetone, cyclopentyl methyl ether, methylethylketone, acetonitrile, tetrahydrofuran, 2-methyltetrahydrofuran, heptane, hexane, pentane and mixtures comprising two or more thereof.

In one embodiment the composition comprises water and one or other more solvents from list (iiia) and/or list (iiib).

In a preferred embodiment, component (iii) comprises cyclopentyl methyl ether ("CPME").

In another preferred embodiment, component (iii) comprises 40 to 70wt% of inert solvent(s) selected from list (iiia) and 10 to 40wt% of inert solvent(s) selected from list (iiib), relative to the total weight of the composition.

In another preferred embodiment, component (iii) comprises isopropanol and water.

In another preferred embodiment, component (iii) comprises 10 to 70wt% of isopropanol and 10 to 70wt% of water, relative to the total weight of the composition.

In another preferred embodiment, component (iii) comprises heptane and one or more solvents from list (iiia) and/or list (iiib), especially heptane and cyclopentyl methyl ether.

In another preferred embodiment, component (iii) comprises 10 to 70wt% of heptane and 40 to 70wt% of cyclopentyl methyl ether, relative to the total weight of the composition.

Preferably component (iii) comprises water, or a mixture of water and an inert, organic solvent (preferably a water-miscible, inert organic solvent) having a water-solubility of at least 5wt%.

Preferably component (iii) comprises an organic amine (especially a C₂₋₆ - alcoholamine), for example methylamine, ethylamine, diethylamine, triethylamine and especially ethanolamine. The amount of organic amine present in the composition is preferably sufficient to neutralize at least 50%, more preferably at least 75% and especially all of the anionic groups present in component (i) (when present).

Thus a preferred composition comprises 1 to 80wt% of component (i), 1.1 to 4.9wt% of component (ii) and 15.1 to 97.9% of component (iii), more preferably 10 to 50wt% of component (i) and 1.1 to 4.9wt% of component (ii) and 45.1 to 88.9wt% of component (iii). In this preferred composition, the weight ratio of component (ii):component (i) is preferably in the range 0.03 to 0.149, especially 0.03 to 0.13.

In one embodiment component (iii) comprises 10 to 70wt% of isopropanol, 10 to 70wt% of water and optionally 0.01 to 10wt% of organic amine.

The composition may be cured by any suitable process, including thermal curing, photocuring and combinations of the foregoing. However the composition is preferably cured by photocuring, e.g. by irradiating the composition and thereby causing components (i) and (ii) and any other polymerisable components present in the composition to polymerise. Preferably the composition is cured by irradiating the composition more than once as this can improve the mechanical strength of the resultant membrane.

In one embodiment the composition is cured by irradiating the composition more than once such that the membrane is wet with water or a composition comprising water during the second irradiation (especially when the composition comprises heptane and/or cyclopentyl methyl ether).

Typically component (iii) is inert and does not polymerise, instead leaving pores in the resultant membrane.

Preferably the composition further comprises (iv) a polymerisation initiator, e.g. a thermal initiator and/or a photoinitiator.

Examples of suitable thermal initiators which may be included in the composition include 2,2'-azobis(2-methylpropionitrile) (AIBN), 4,4'-azobis(4-cyanovaleric acid), 2,2'-azobis(2,4-dimethyl valeronitrile), 2,2'-azobis(2-methylbutyronitrile), 1,1'-azobis(cyclohexane-1-carbonitrile), 2,2'-azobis(4-methoxy-2,4-dimethyl valeronitrile), dimethyl 2,2'-azobis(2-methylpropionate), 2,2'-azobis[N-(2-propenyl)-2-methylpropionamide], 1-[(1-cyano-1-methylethyl)azo]formamide, 2,2'-Azobis(N-butyl-2-methylpropionamide), 2,2'-Azobis(N-cyclohexyl-2-methylpropionamide), 2,2'-Azobis(2-methylpropionamidine)

dihydrochloride, 2,2'-Azobis[2-(2-imidazolin-2-yl)propane]dihydrochloride, 2,2'-Azobis[2-(2-imidazolin-2-yl)propane]disulfate dihydrate, 2,2'-Azobis[N-(2-carboxyethyl)-2-methylpropionamidine] hydrate, 2,2'-Azobis{2-[1-(2-hydroxyethyl)-2-imidazolin-2-yl]propane} dihydrochloride, 2,2'-Azobis[2-(2-imidazolin-2-yl)propane], 2,2'-Azobis(1-imino-1-pyrrolidino-2-ethylpropane) dihydrochloride, 2,2'-Azobis{2-methyl-N-[1,1-bis(hydroxymethyl)-2-hydroxyethyl]propionamide} and 2,2'-Azobis[2-methyl-N-(2-hydroxyethyl)propionamide].

Examples of suitable photoinitiators which may be included in the composition include aromatic ketones, acylphosphine compounds, aromatic onium salt compounds, organic peroxides, thio compounds, hexaarylbiimidazole compounds, ketoxime ester compounds, borate compounds, azinium compounds, metallocene compounds, active ester compounds, compounds having a carbon halogen bond, and an alkyl amine compounds. Preferred examples of the aromatic ketones, the acylphosphine oxide compound, and the thio compound include compounds having a benzophenone skeleton or a thioxanthone skeleton described in "RADIATION CURING IN POLYMER SCIENCE AND TECHNOLOGY", pp. 77-117 (1993). More preferred examples thereof include an alpha-thiobenzophenone compound described in JP1972-6416B (JP-S47-6416B), a benzoin ether compound described in JP1972-3981B (JP-S47-3981B), an alpha-substituted benzoin compound described in JP1972-22326B (JP-S47-22326B), a benzoin derivative described in JP1972-23664B (JP-S47-23664B), an aroylphosphonic acid ester described in JP1982-30704A (JP-S57-30704A), dialkoxybenzophenone described in JP1985-26483B (JP-S60-26483B), benzoin ethers described in JP1985-26403B (JP-S60-26403B) and JP1987-81345A (JP-S62-81345A), alpha-amino benzophenones described in JP1989-34242B (JP-H01-34242B), U.S. Pat. No. 4,318,791A, and EP0284561A1, p-di(dimethylaminobenzoyl)benzene described in JP1990-211452A (JP-H02-211452A), a thio substituted aromatic ketone described in JP1986-194062A (JP-S61-194062A), an acylphosphine sulfide described in JP1990-9597B (JP-H02-9597B), an acylphosphine described in JP1990-9596B (JP-H02-9596B), thioxanthenes described in JP1988-61950B (JP-S63-61950B), and coumarins described in JP1984-42864B (JP-S59-42864B). In addition, the photoinitiators described in JP2008-105379A and JP2009-114290A are also preferable. In addition, photoinitiators described in pp. 65 to 148 of "Ultraviolet Curing System" written by Kato Kiyomi (published by Research Center Co., Ltd., 1989) may be used.

The polymerisation initiator is preferably soluble in the composition. Water-soluble photoinitiators are preferred when the composition comprises water.

The composition preferably comprises 0.001 to 5wt%, more preferably 0.01 to 2wt%, of the polymerisation initiator (iv), based on the total weight of the

composition. The polymerisation initiator (iv) preferably has a water-solubility of at least 1wt%, more preferably at least 3wt%, when measured at 25°C.

Optionally the composition includes one or more further components, e.g. a surfactant, a polymer dispersant, a polymerization reaction controlling agent, a thickening agent, an anti-crater agent, or the like, in addition to the above-described components.

Optionally the membrane of the present invention further comprises a support, especially a porous support. Inclusion of a support can provide the membrane with increased mechanical strength. If desired the composition may be applied to the support between steps (a) and (b) of the process for preparing the membranes according to the second aspect of the present invention described below. In this way the porous support may be impregnated with the composition and the composition may then be polymerised on and/or within the support.

Examples of suitable supports include synthetic woven fabrics and synthetic non-woven fabrics, sponge-like films, and films having fine through holes. The material for forming the optional porous support can be a porous membrane based on, for example, polyolefin (polyethylene, polypropylene, or the like), polyacrylonitrile, polyvinyl chloride, polyester, polyamide, or copolymers thereof, or, for example, polysulfone, polyether sulfone, polyphenylene sulfone, polyphenylene sulfide, polyimide, polyetherimide, polyamide, polyamideimide, polyacrylonitrile, polycarbonate, polyacrylate, cellulose acetate, cellulose, polypropylene, poly(4-methyl-1-pentene), polyvinylidene fluoride, polytetrafluoroethylene, polyhexafluoropropylene, polychlorotrifluoroethylene, or copolymers thereof. Among these, in the present invention, polyolefin and cellulose are preferable.

As the commercially available porous support there may be used products from Japan Vilene Company, Ltd., Freudenberg Filtration Technologies, Sefar AG or Asahi-Kasei.

When the membrane comprises a support and the curing comprises photocuring then preferably the support does not shield the wavelength of light used to cure the composition.

The support is preferably a hydrophilic support, for example a support that has been subjected to a corona treatment, an ozone treatment, a sulfuric acid treatment, a silane coupling agent treatment or two or more of the foregoing treatments.

The membrane according to the present invention may optionally include more than one supports and the more than one support may be identical to each other or different.

The polymer particles preferably have an average diameter of 0.1nm to 5,000nm, more preferably 1nm to 2,000nm. The average diameter of the particles

may be determined by cross-sectional analysis of the membrane using Scanning Electron Microscopy (SEM), e.g. as described in more details in the Examples.

The membrane preferably has a MFP size of 50 to 4000nm, more preferably 100 to 2,000nm. Preferably the pores are deeper than their width.

5 The polymer particles from which the membrane is derived have an average diameter in the range of 0.1nm to 5,000nm. Preferably the polymer particles have an average diameter of 1nm to 2,000nm, most preferably, 10nm to 2,000nm.

10 The membrane preferably has a narrow pore size flow distribution. Preferably 90% of the pores have a size within +/- 50% of the MFP size.

When the membrane does not comprise a support, the membrane preferably has a porosity of 15 to 99%, preferably 20 to 99% and especially 20 to 85%.

15 When the membrane does not comprise a support, the membrane preferably has a porosity of 21 to 70%.

The porosity of the membrane may be determined by gas displacement pycnometry, e.g. using a pycnometer (especially the AccuPyc™ II 1340 gas displacement pycnometry system available from Micromeritics Instrument Corporation).

20 The porosity of the membrane is the amount of volume that can be accessed by external fluid or gas. This may be determined as described below. Preferably, the porosity of the membrane of the present invention is more than 20%.

25 When the membrane of the present invention includes a support, the thickness of the membrane including the support, in the dry state, is preferably 20µm to 2,000µm, more preferably 40µm to 1,000µm, and particularly preferably 70µm to 800µm.

30 When the membrane of the present invention does not comprise a support, the thickness of the membrane in a dry state is preferably 20µm to 2,000µm, more preferably 100µm to 2,000µm, and particularly preferably 150µm to 2,000µm.

When the membrane of the present invention includes a support, the thickness of the membrane including the support, when measured after storing for 12 hours in a 0.1 M NaCl solution, is preferably 10µm to 4,000µm, more preferably 20µm to 2,000µm and particularly preferably 20µm to 1,500µm.

35 When the membrane of the present invention does not comprise a support, the thickness of the membrane, when measured after storing for 12 hours in a 0.1 M NaCl solution, is preferably 10µm to 4,000µm, more preferably 50µm to 4,000µm and especially 70µm to 4,000µm.

40 According to a second aspect of the present invention there is provided a process for preparing a membrane according to the first aspect of the present

invention comprising curing the composition defined in the first aspect of the present invention.

Preferably the membrane according to the first aspect of the present invention is obtained by a process comprising the steps of:

- 5 (a) mixing component (i), (ii) and (iii) (and any other components of the composition) to form a composition comprising components (i), (ii) and (iii);
- (b) curing (e.g. irradiating) the composition arising from step (a) and thereby polymerising component (i) and component (ii) to form a membrane;
- (c) optionally washing the membrane arising from step (b); and
- 10 (d) optionally swelling the membrane in a solvent (e.g. from list (iiia) and/or or (iiib)) and performing a second curing step.

In a preferred embodiment the process according to the second aspect of the present invention further comprises the step of sandwiching the composition between sheets and performing the curing when the composition is sandwiched
15 between said sheets (i.e. between steps (a) and (b)).

Preferably the process used to prepare the membranes of the present invention comprise polymerisation-induced phase separation, more preferably photo-polymerization induced phase separation, e.g. of the membrane from the composition. In this process, preferably the polymer is formed due to a photo-polymerization reaction.
20

Optionally step (b) may be performed by one or more further irradiation and/or heating steps in order to fully cure the membrane.

Including component (iii) in the composition has the advantage of helping the polymerisation in step (b) proceed uniformly and smoothly.

25 In a preferred embodiment component (iii) acts as a solvent for components (i) and (ii) and assists the formation of the pores in the resultant membrane.

The process according to the second aspect of the present invention provides substantially uniform membranes, often with a substantially uniform bicontinuous structure. In some embodiments the curing causes component (i) and (ii) to form substantially uniform polymer particles which then fuse to form the membranes of the present invention. Gaps between the polymer particles provide
30 pores of the desired MFP size and a membrane of the desired porosity.

If desired the composition may be applied to a support (especially a porous support) between steps (a) and (b) of the process according to the second aspect
35 of the present invention. Step (b) may be performed on the composition which is present on and/or in the support. When the membrane is not required to comprise a support, the membrane may be peeled-off the support. Alternatively if the membrane is required to comprise a support then the membrane may be left on and/or in the support.

The composition may be applied to the support or immersed in the support by various methods, for example, curtain coating, extrusion coating, air knife coating, slide coating, nip roll coating, forward roll coating, reverse roll coating, dip coating, kiss coating, rod bar coating, and spray coating. Coating of a plurality of layers can be performed simultaneously or sequentially. In simultaneous multilayer coating, curtain coating, slide coating, slot die coating, or extrusion coating is preferable.

The composition may be applied to a support at a temperature which assists the desired phase separation of the membrane from the composition. The temperature at which the composition is applied to the support (when present) is preferably below 80°C, more preferably between 10 and 60°C and especially between 15 and 50°C.

When the membrane comprises a support, before the composition is applied to the surface of the support one may treat the surface of the support e.g. using a corona discharge treatment, a glow discharge treatment, a flame treatment, or an ultraviolet rays irradiation treatment. In this way one may improve the wettability and the adhesion of the support.

Step (b) optionally further comprises heating the composition.

Thus in a preferred process, the composition is applied continuously to a moving support, more preferably by means of a manufacturing unit comprising one or more composition application station(s), one or more irradiation source(s) for curing the composition, a membrane collecting station and a means for moving the support from the composition application station(s) to the irradiation source(s) and to the membrane collecting station.

The composition application station can be placed at the upstream position with respect to the irradiation source, and the irradiation source can be placed at the upstream position with respect to the composite membrane collecting station.

Preferably the curing of the composition of the present invention is initiated within 60 seconds, more preferably within 15 seconds, particularly preferably within 5 seconds and most preferably within 3 seconds from when the composition is applied to the support or from when the support has been impregnated with the composition (when a support is used).

Light irradiation for photocuring is preferably performed for less than 10 seconds, more preferably for less than 5 seconds, particularly preferably for less than 3 seconds and most preferably for less than 2 seconds. In a continuous for preparing the membrane, the membrane may be irradiated continuously. The speed at which the composition is moved through the irradiation beam created by the irradiation source then determines the cure time and radiation dose.

Preferably the composition is cured by a process comprising irradiating the composition with ultraviolet (UV) light. The wavelength of the UV light used

depends on the photoinitiator present in the composition and, for example, the UV light is UV-A (400nm to 320nm), UV-B (320nm to 280nm) and/or UV-C (280nm to 200nm).

When high intensity UV light is used to cure the composition a significant amount of heat may be generated. In order to prevent overheating, it is preferable to cool the lamp of the light source and/or the support/membrane with cooling air. When the composition is irradiated with a high dose of infrared light (IR light) together with a UV light, irradiation with UV light is preferably performed by using an IR reflecting quartz plate as a filter.

Examples of UV light sources include a mercury arc lamp, a carbon arc lamp, a low pressure mercury lamp, a medium pressure mercury lamp, a high pressure mercury lamp, a swirling flow plasma arc lamp, a metal halide lamp, a xenon lamp, a tungsten lamp, a halogen lamp, laser, and an ultraviolet ray emitting diode. A medium pressure or high pressure mercury vapor type ultraviolet ray emitting lamp is particularly preferable. Additionally, to modify the emission spectrum of a lamp, an additive such as metal halide may be present. A lamp having an emission maximum at a wavelength of 200nm to 450nm is particularly suitable.

The energy output of the radiation source is preferably 20W/cm to 1000W/cm and more preferably 40W/cm to 500W/cm, but if a desired exposure dose can be achieved, the energy output may be higher or lower than the aforementioned exposure dose. By the exposure intensity, curing of the film is adjusted. The exposure dose is measured in a wavelength range of UV-A by using a High Energy UV Radiometer (UV Power Puck (Registered Trademark) manufactured by EIT-Instrument Markets), and the exposure dose is preferably 40mJ/cm² or greater, more preferably 100mJ/cm² to 3,000mJ/cm², and most preferably 150mJ/cm² to 1,500mJ/cm². The exposure time can be freely selected, and is preferably short, and most preferably less than 2 seconds.

The membrane of the present invention is particularly useful for the separation and purification of biomolecules such as proteins, peptides, amino acids, anti-bodies and nucleic acids in biomedical applications.

The membranes of the present invention preferably have an ion-exchange capacity of 0.50meq/g to 8.00meq/g, more preferably 0.5meq/g to 6.00meq/g and especially 0.70meq/g to 4.00meq/g.

The ion-exchange capacity (IEC) of the membranes according to the present invention may be determined as described below.

The water flux of the membrane of the present invention is preferably more than 100l/m²/bar/h), more preferably more than 500l/m²/bar/hr and especially more than 1200l/m²/bar/hr.

The water flux of the membranes according to the present invention may be determined as described below.

The swelling of the membranes of the present invention may be determined by measuring the volume of the membrane when dry and when wet and when wet with water and performing the following calculation:

$$Swelling = \frac{Volume_{wet} - Volume_{dry}}{Volume_{dry}} \times 100\%$$

The swelling of the membranes in water was preferably less than 20%, more preferable less than 10% and especially less than 5%.

The weight ratio of component (ii):component (i) may be determined simply by dividing the weight of component (ii) present in the composition by the weight of component (i) present in the composition. Thus a wt ratio of component (ii):component (i) of 0.03 to 0.149 is equivalent to 0.03 to 0.149 grams of component (ii) for every 1g of component (i). Also where one only has the final membrane available and no information on the composition used to prepare it, one may measure the weight ratio of component (ii):component (i) of the membrane itself by, for example, characterization techniques from which elemental, molecular or structural information can be obtained. Preferred techniques include X-Ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscope/Energy Dispersive Using X-Ray (SEM-EDX), Time-of-Flight secondary ion mass spectrometry (TOF-SIMS), Fourier-transform infrared spectroscopy (FTIR), Nuclear Magnetic Resonance (NMR) or a combination of two or more thereof.

According to a third aspect of the present invention there is provided use of a membrane according to the first aspect of the present invention for detecting, filtering and/or purifying biomolecules.

The membranes according to the first aspect of the present invention may be used for filtering, and/or purifying biomolecules by eluting solutions containing biomolecules, especially biomolecules which carry a positive charge. The positive charge on such biomolecules is attracted to the negative charge on the membrane derived from component (i) and/or component (ii). The membranes may be used to separate biomolecules by a number of processes, including use of the membranes in size-exclusion chromatography (e.g. where the pores of the membrane are used to separate or purify biomolecules based on their size (i.e., physical exclusion)) and in ion exchange chromatography (e.g. where biomolecules are purified or separated according to the strength of their overall ionic interaction with the anionic groups in the membrane (i.e. electronic interactions)).

The membranes according to the first aspect of the present invention may be used for detecting biomolecules by techniques involving the detection of colour, especially when the biomolecules comprise a fluorescent or coloured marker.

Thus a further aspect of the present invention comprises a process for purifying a biomolecule and/or separating a biomolecule from other biomolecules comprising contacting the biomolecules with a membrane according to the present invention. Preferably the process for purifying a biomolecule and/or separating a biomolecule from other biomolecules comprises membrane size-exclusion chromatography or ion exchange chromatography.

According to a fourth aspect of the present invention there is provided use of a membrane according to the first aspect of the present invention for detecting metal ions or for filtering and/or purifying compositions comprising metal-ions.

The membranes according to the first aspect of the present invention may be used for detecting metal ions by techniques involving the detection of colour.

The membranes according to the first aspect of the present invention may be used for filtering, and/or purifying biomolecules by analogous techniques to those described above for biomolecules, especially membrane size-exclusion chromatography or ion exchange chromatography. Compositions comprising metal-ions (e.g. two or more metal ions and optionally contaminants), colloids containing metals or other agglomerates of metal-ions may be separated and/or purified based on their size (i.e., physical exclusion) or by ion exchange chromatography where compositions comprising metal-ions are purified or different metal ions are separated from each other according to the strength of their overall ionic interaction with anionic groups in the membrane of the present invention.

The membranes may of course be used for other purposes too.

Preferably the membranes of the present invention are stable at pH 1.0 to pH 10.0 for at least 12 hours, more preferably for at least 16 hours.

The invention will now be illustrated by the following, non-limiting examples.

The following abbreviations are used in the Examples:

FO-2223-10 a non-woven, polypropylene-based, porous cloth of thickness 100µm obtained from Freudenberg Group. This acts as a support.

IPA is isopropanol supplied by Sigma Aldrich (an inert solvent (iii)).

M282 is tetraethyleneglycol diacrylate supplied by Sigma-Aldrich (a monomer (i) comprising two reactive groups).

PEGDA400 is a poly(ethyleneglycol) diacrylate supplied by Sigma Aldrich (a monomer (i) comprising two reactive groups).

PEGDA600 is a poly(ethyleneglycol) diacrylate supplied by Sigma Aldrich (a monomer (i) comprising two reactive groups).

5	(CM10)	is a monomer (i) comprising two cationic group and two diacrylamide groups as reactive groups. This monomer was obtained from FUJIFILM and has the structure shown above in the description. (CM10) may be prepared by the method described in US20160367980, paragraph [257].
10	(AM6)	is a monomer (i) comprising two anionic group and two diacrylamide groups as reactive groups. This monomer was obtained from FUJIFILM and has the structure shown above in the description. (AM6) may be prepared by the method described in EP2965803, paragraph [211].
	Bdithiol	is a 1,3-benzenedithiol from Carbone Scientific (an organic polymerisation retardant (ii)).
	Tetrathiol	is pentaerythritol tetrakis(3-mercaptopropionate) from Sigma Aldrich (an organic polymerisation retardant (ii)).
15	EGdithiol	is 2,2'-(ethylenedioxy)diethanethiol from Sigma Aldrich (an organic polymerisation retardant (ii)).
	PEGDMA400	is poly(ethyleneglycol) dimethacrylate from Sigma Aldrich (an organic polymerisation retardant (ii)).
20	CPME	is cyclopentyl methyl ether supplied by Sigma Aldrich (an inert solvent (iii)).
	Heptane	supplied by Sigma-Aldrich
25	(PR1)	is an organic polymerisation retardant (ii) comprising two ionic group and two vinyl groups as reactive groups. This monomer was obtained from FUJIFILM and has the structure shown above. (PR1) may be prepared by the method described in JP2000-229917A or US2016-0001238, paragraphs 0212-0213.
	PSdithiol	is a sodium 2,3-dimercapto-1-propane sulfonate monohydrate (an organic polymerisation retardant (ii)) from Sigma Aldrich.
30	AMPS-Na	is the sodium salt of 2-acrylamido-2-methylpropane sulfonic acid from Sigma Aldrich (a monomer (i) comprising one reactive group).
	Ethanolamine was supplied by Sigma Aldrich.	
35	Irgacure TM 1173 is 2-hydroxy-2-methyl propiophenone, a photoinitiator (component (iv)).	

The components (i) used in Tables 4A and 8A contain cationic groups. The components (i) used in Tables 5A and 9A contain anionic groups. The component (i) used in the other Tables are free from ionic group.

The average particle diameter, MFP size, water or buffer flux, BET surface area, UV-DSC and presence of pinholes in the membranes described in the Examples were determined as described below:

5 I) Average Diameter of the Polymer Particles

The average diameter of the polymer particles was determined by performing a cross-sectional cut through the membrane and measuring the diameter of 20 polymer particles by SEM and then calculating the average of those 20 measurements. The Standard deviation (SD) of the 20 measurements was
10 calculated mathematically from the 20 measurements.

II) MFP size

The MFP size of the membranes was measured by the standard test method ASTM F316-03(2011) using a Porolux™ porometer. The membranes to
15 be tested were fully wetted using a wetting fluid (Porefil™ wetting Fluid, an inert, non-toxic, fluorocarbon wetting fluid with zero contact angle) and then the wetted membrane was placed in the sample holder of the porometer and a pressure of up to 35mbar was applied to the wetted membrane. The porometer was then used to
20 provide the MFP size of the membrane under test.

III) Water or buffer flux (L/m²/bar/Hr) of the membrane

The water flux of the membranes was measured using a device where the weight of water passing through the membrane was measured over time. A column of feed solution (pure water) was brought into contact with the membrane
25 under evaluation and the feed solution was forced through the membrane by a constant applied air pressure on top of the water column. By achieving a constant flow of water at a constant applied pressure, the water flux could be determined.

Typically the membrane under evaluation was stored for 12 hours in pure water prior to the measurements being performed. The feed solution (250ml of
30 pure water) was brought into contact with the membrane (film contact area of 12.19cm²). The water column was closed and pressurized with air pressure and the membrane was flushed with one water column (250ml). The feed solution was refreshed and a constant air pressure of 100mbar was applied for examples and comparative examples from Tables 1B to 3B, 6B and 7B. For membranes in
35 Table 4B and 8B a constant air pressure of 900mbar was used. For membranes from Table 5B and 9B a pressure of 20mbar was used. Finally, the measurements were performed by monitoring the weight by balance at a constant flow. A water flux of at least 1200l/m²/bar/hr was deemed to be acceptable.

40 IV) BET Surface Area

Prior to the BET surface area measurements, the membranes under test were degassed in vacuum at 25°C for 16 hours.

The BET Surface Area of the degassed membranes was measured at a temperature of 77K using by adsorption analysis using a Micromeritics TriStar II 3020 adsorption analyser with N₂ as adsorptive.

V) UV-DSC

The graph shown in Fig. 2 was generated as follows: the compositions described in Examples 1 and 2 and Comparative Example 1 (25µl) were allowed to equilibrate for 2 minutes and were then cured by irradiating with UV light for 3 minutes. The heat flow of the compositions was measured in a nitrogen inert atmosphere at 25°C in a Mettler Toledo DSC823e.

VI) Pinhole Detection Test

Circular portions of the membranes under test having a diameter of 2.5cm were swollen in water for 2 minutes. An aqueous dispersion containing coloured beads of diameter 10µm (2cm³) was filtered through the swollen membrane. The membranes were deemed to contain pinholes if the coloured beads were visible in the filtrate.

Examples 1 to 19

(ai) Preparation of Compositions

Compositions 1 to 19 were prepared by mixing the ingredients indicated in Tables 1A to 5A below in the specified amounts with each Table referring to a different component (i). In Tables 1A to 5A component (iv) is Irgacure™ 1173 (a photoinitiator). The test results for membranes derived from the compositions described in Tables 1A to 5A are provided in Tables 1B to 5B respectively further on in this specification.

Table 1A: Compositions containing M282 as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			water (wt%)	IPA (wt%)	
1	Bdithiol	0.050	40.59	23.89	0.01
2		0.100	39.91	23.49	0.01
3	Tetrathiol	0.050	40.58	23.90	0.01
4		0.100	39.91	23.49	0.01
5	EGdithiol	0.050	49.65	15.58	0.01
6	PEGDMA400	0.033	49.93	15.67	0.01
7		0.050	49.65	15.58	0.01
8		0.075	49.25	15.45	0.01
9		0.100	48.85	15.33	0.01

Table 2A: Compositions containing PEGDA400 as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			Heptane (wt%)	CPME (wt%)	
10	Bdithiol	0.030	15.02	47.24	0.01
11		0.050	14.91	46.90	0.01
12	Tetrathiol	0.050	14.91	46.90	0.01
13		0.075	14.77	46.48	0.01
14		0.100	14.65	46.06	0.01
15	EGdithiol	0.100	14.64	46.07	0.01

Table 3A: Compositions containing PEGDA600 as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			Heptane (wt%)	CPME (wt%)	
16	Tetrathiol	0.050	14.70	47.66	0.01
17		0.100	14.44	46.82	0.01

Table 4A: Composition containing (CM10) as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			IPA (wt%)	Water (wt%)	
18	(PR1)	0.050	60.31	13.05	0.01

5 Table 5A: Composition containing (AM6) and AMPS-Na as component (i)

Composition	Component (ii)	wt ratio Component (ii): Component (i)	Component (iii)			Component (iv) (wt%)
			IPA (wt%)	Water (wt%)	Ethanolamine (wt%)	
19	PSdithiol	0.050	25.12	42.13	0.32	0.04

* Component (i) wt ratio AM6/AMPS-Na is 4.86.

(a) Application of the Compositions to Supports

10 Sheets of porous supports (FO-2223-10) were attached to a polyethylene terephthalate sheet (when M282 was used as component (i)) or to a polyethylene sheet (when component (i) was not M282) and were then placed on an aluminium plate. The compositions described in Tables 1A to 5A above were each independently applied to such a support at 20°C using a tabletop coating machine (manufactured by TQC, Model AB3000 Automatic film applicator) at a speed of
15 about 1cm/sec using a wire bar (a stainless steel bar on which a wire of 150µm had been wound at 1 lap/3cm (length direction). Any excess composition was removed from the coated supports using a 12µm wire bar.

(b) Curing the Compositions to Form Membranes

20 The compositions present on the supports obtained in step (a) above were cured by irradiation with UV using a Light Hammer LH6 UV exposure machine

(manufactured by Fusion UV Systems, Inc.). The Light Hammer machine was fitted with a Model H-bulb (100% strength) and a D-bulb (80% strength). The coated supports were passed through the Light Hammer machine at a speed of 10 m/min to expose the composition to the UV light from both bulbs. The curing time was 0.8 seconds. The exposure time was twice 0.71 seconds. The first bulb performed most of the curing and the second bulb provided additional curing, thereby improving the mechanical strength of the resultant membrane. The resultant membrane was removed from the aluminium plate and was stored in a polyolefin bag.

(c) Curing of water swollen Membrane

Membranes derived from compositions comprising heptane and CPME mixtures were cured twice, the second time after swelling the membrane in water.

Properties of the Resultant Membranes

In the Tables SD mean Standard Deviation and "-" means not measured.

The membranes obtained from the compositions described in tables 1A to 5A, prepared as described in Step (b) and (c) above, had the properties described in Tables 1B to 5B below respectively:

Table 1B: Properties of the membranes Derived from Compositions containing M282 as component (i)

Example (derived from the composition of the same number)	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
1	979 $\pm$ 542	2239	-	18648	N
2	726 $\pm$ 296	4564	-	27709	N
3	466 $\pm$ 49	550	2.2	2397	N
4	562 $\pm$ 73	934	1.7	7153	N
5	-	1812	-	8074	N
6	-	297	-	2932	N
7	415 $\pm$ 41	355	-	4268	N
8	-	400	-	5388	N
9	-	491	-	6046	N

Table 2B: Properties of the membranes Derived from Compositions containing PEGDA400 as component (i)

Example (derived from the composition of the same number)	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
10	-	762	-	2477	N
11	506 $\pm$ 62	1555	-	8191	N
12	771 $\pm$ 133	644	2.3	2438	N
13	733 $\pm$ 210	799	-	4311	N
14	978 $\pm$ 435	1787	1.2	9110	N
15	-	1355	-	1744	N

5 Table 3B: Properties of the membranes Derived from Compositions containing PEGDA600 as component (i)

Example (derived from the composition of the same number)	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
16	831 $\pm$ 516	1174	0.6	5800	N
17	-	943	0.4	6597	N

Table 4B: Properties of a membrane Derived from Compositions containing (M10) as component (i)

Example (derived from the composition of the same number)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
18	1350	N

10 Table 5B: Properties of the membranes Derived from Compositions containing (AM6) as component (i)

Example (derived from the composition of the same number)	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
19	-	-	-	54,164	N

Note: the membrane of Example 19 in Table 5B has a much higher water flux than comparative membrane CEx9 in Table 9B.

Comparative Examples CEx1 to CEx9Preparation of Comparative Compositions CC1 to CC9

Comparative compositions CC1 to CC9 were prepared by mixing the ingredients indicated in Tables 6A to 9A below in the specified amounts.

5 Component (iv) was Irgacure™ 1173 in the amounts indicated.

10 The membranes of Comparative Examples CEx1 to CEx9 were prepared using the method described above for Examples 1 to 19 above, steps (aii), (b) and (c), except that the comparative compositions indicated in Tables 6A to 9A below were used. The support used in all cases was FO-2223-10. The test results for membranes derived from the compositions described in Tables 6A to 9A are provided in Tables 6B to 9B respectively.

Table 6A: Compositions used in the comparative examples containing M282 as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			water (wt%)	IPA (wt%)	
CC1	None	0	41.29	24.30	0.01
CC2		0	50.49	15.85	0.01
CC3	Tetrathiol	0.01	41.14	24.23	0.01

Table 7A: Compositions used in comparative examples containing PEGDA400 or PEGDA600 as component (i)

Composition	Component (i)	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
				heptane (wt%)	CPME (wt%)	
CC4	PEGDA400	None	0	15.19	47.77	0.01
CC5	PEGDA600	None	0	14.96	48.53	0.01
CC6	PEGDA600	EGdithiol	0.15	14.18	46.02	0.01

Table 8A: Compositions used in comparative examples containing (M10) Monomer as component (i)

Composition	Component (ii)	wt ratio Component (ii):Component (i)	Component (iii)		Component (iv) (wt%)
			water (wt%)	IPA (wt%)	
CC7	None	0	48.51	17.51	0.01
CC8	None	0	61.09	13.23	0.01

Table 9A: Compositions used in comparative examples containing (AM6) Monomer and AMPS-Na as component (i)

Composition	Component (ii)	wt ratio Component (ii): Component (i)	Component (iii)			Component (iv) (wt%)
			IPA (wt%)	Water (wt%)	Ethanolamine (wt%)	
CC9	None	0	25.53	42.8	0.32	0.01

* Component (i) wt ratio AM6/AMPS-Na is 4.86.

Table 6B: Membrane properties of comparative examples containing M282 monomer

Example (derived from the comparative composition of the same CC number)	Average Particle diameter (nm) ±SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
CEx1	-	-	0.2	9872	Y
CEx2	215 ± 37	243	-	1132	N
CEx3	201 ± 47	<100	4.9	180	N

Table 7B: Membrane properties of comparative examples containing PEGDA400 or PEGDA600 monomers

Example (derived from the comparative composition of the same CC number)	Average Particle diameter (nm) ±SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
CEx4	323 ± 35	638	3.2	3011	Y
CEx5	297 ± 42	367	2.3	579	Y
CEx6	-	-	-	30614	Y

Table 8B: Membrane properties of comparative examples containing (CM10)

Monomer

Example	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
CEx7	-	-	-	18	N
CEx8	-	-	-	298	N

Note: membranes CEx6 and CEx7 have very poor flux rates.

5

Table 9B: Membrane properties of comparative examples containing (AM6)

Monomer

Example	Average Particle diameter (nm) $\pm$ SD (nm)	MFP size (nm)	BET surface area (m ² /g)	Waterflux (l/m ² /bar/hr)	Pinholes (Y/N)
CEx9	-	-	-	10,771	N

Note: comparative membrane CEx9 has a much lower water flux than the membrane of Example 19

CLAIMS

1. A membrane comprising polymer particles fused together and pores between the fused particles, wherein:

(a) the polymer particles have an average diameter of 0.1 to 5,000nm;
 (b) the membrane has a mean flow pore size of 5nm to 5,000nm; and
 (c) the membrane has been obtained by a process comprising curing a composition comprising:

(i) a monomer;

(ii) an organic polymerisation retardant; and

(iii) an inert solvent;

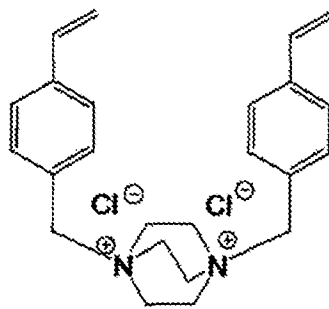
wherein the weight ratio of component (ii):component (i) is in the range 0.03 to 0.149.

2. A membrane according to claim 1 wherein the curing comprises polymerisation-induced phase separation of polymer particles from the composition such that the polymer particles fuse together to form the membrane.

3. A membrane according to any one of the preceding claims wherein the composition comprises 10 to 50wt% of component (i).

4. A membrane according to any one of the preceding claims wherein component (ii) comprises at least two thiol groups.

5. A membrane according to any one of the preceding claims wherein component (ii) comprises 1,2-benzenedithiol, 1,3-benzenedithiol, 1,4-benzenedithiol, 3,6-dichloro-1,2-benzenedithiol, toluene-3,4-dithiol, 2,3-dimercapto-1-propanol, sodium 2,3-dimercaptopropane sulfonate monohydrate, 2,2'-(ethylenedioxy)diethanethiol, poly(ethyleneglycol)dithiol, 1,5-pentanedithiol, 1,4-butanedithiol, 1,6-hexanedithiol, 1,8-octanedithiol, pentaerythritol tetrakis(3-mercaptopropionate), pentaerythritol tetrakis(3-mercptoacetate), trimethylolpropane tris(3-mercaptopropionate), ethyleneglycol dimethacrylate, poly(ethyleneglycol) dimethacrylate, 1,3-butanediol dimethacrylate, tetraethylenglycol dimethacrylate, bisphenol A dimethacrylate, 1,6-hexanediol dimethacrylate, divinylsulfone, divinylbenzene, trimethylolpropane diallyl ether, diallyl maleate, allyl ether, diallyldimethylammonium chloride, 1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, 6-(dibutylamino)-1,3,5-triazine-2,4-dithiol compounds of formula (PR1) as shown below and mixtures comprising two or more thereof:



(PR1)

6. A membrane according to any one of the preceding claims wherein the composition comprises 10 to 90wt% of component (iii).

7. A membrane according to any one of the preceding claims wherein component (iii) comprises less than 30wt% of water, relative to the total weight of the composition.

8. A membrane according to any one of the preceding claims wherein component (ii) is co-polymerisable with component (i) and causes a reduction in the rate at which the curable components of the composition cure.

9. A membrane according to any one of the preceding claims wherein component (iii) comprises water and a water-miscible organic solvent and component (i) and component (ii) are completely dissolved in the composition.

10. A membrane according to any one of the preceding claims wherein component (iii) comprises cyclopentyl methyl ether.

11. A membrane according to any one of the preceding claims wherein component (iii) comprises a one or more of inert solvents selected from list (iiia) and one or more inert solvents selected from list (iiib):

list (iiia): iso-propanol, methanol, ethanol, acetone, tetramethyl urea, hexamethyl phosphoramidate, hexamethyl phosphotriamide, butanone, cyclohexanone, methylethylketone, tetrahydrofuran, tetrahydropyran, 2-methyltetrahydrofuran, cyclopentyl methyl ether, propionitrile, acetonitrile, 1,4-dioxane, 1,3-dioxolane, ethyl acetate, γ-butyrolactone, ethanolamine, heptane, hexane, pentane or a mixture comprising two or more thereof; and

list (iiib): water, glycerol, ethylene glycol, dimethyl sulfoxide, sulpholane, dimethyl imidazolidinone, sulfolane, N-methyl pyrrolidone, dimethyl formamide, acetonitrile, acetone, 1,4-dioxane, 1,3-dioxolane, tetramethyl urea, hexamethyl phosphoramidate, hexamethyl phosphotriamide, pyridine, propionitrile, butanone, cyclohexanone, tetrahydrofuran, tetrahydropyran, 2-methyltetrahydrofuran, ethylene glycol diacetate, cyclopentylmethylether, methylethylketone, ethyl acetate and γ -butyrolactone, and among these, dimethyl sulfoxide, N-methyl pyrrolidone, N,N-dimethyl formamide, dimethyl imidazolidinone, N-methyl morpholine, acetone, cyclopentyl methyl ether, methylethylketone, acetonitrile, tetrahydrofuran, 2-methyltetrahydrofuran, heptane, hexane, pentane and mixtures comprising two or more thereof.

12. A membrane according to claim 11 wherein the component (iii) comprises 40 to 70wt% of inert solvent(s) selected from list (iiia) and 10 to 40wt% of inert solvent(s) selected from list (iiib), relative to the total weight of the composition.

13. A membrane according to any one of the preceding claims wherein component (iii) comprises isopropanol and water.

14. A membrane according to claim 13 wherein the component (iii) comprises 10 to 70wt% of isopropanol and 10 to 70wt% of water, relative to the total weight of the composition.

15. A membrane according to any one of the preceding claims wherein component (iii) comprises heptane and cyclopentyl methyl ether.

16. A membrane according to claim 15 wherein the component (iii) comprises 10 to 70wt% of heptane and 40 to 70wt% of cyclopentyl methyl ether, relative to the total weight of the composition.

17. A membrane according to any one of the preceding claims wherein the curing comprises photocuring.

18. A membrane according to any one of the preceding claims wherein the composition further comprises (iv) a photoinitiator.

19. A membrane according to claim 17 or 18 wherein the curing comprises polymerisation-induced phase separation of the membrane from the composition.

20. A membrane according to any one of the preceding claims which further comprises a porous support.

21. A membrane according to any one of the preceding claims wherein component (i) comprises a monomer comprising an ionic group and one or more polymerisable groups.

22. A process for obtaining a membrane according to any one of the preceding claims which comprises curing a composition comprising:

- (i) a monomer;
- (ii) an organic polymerisation retardant; and
- (iii) an inert solvent;

wherein the weight ratio of component (ii):component (i) is in the range 0.03 to 0.149.

23. A process according to claim 22 wherein the curing comprises phase induced separation of polymer particles from the composition such that the polymer particles fuse together to form the membrane.

24. A process according to claim 22 or 23 wherein the curing comprises polymerisation-induced phase separation of the membrane from the composition.

25. A process according to any one of claims claim 22 to 24 wherein the composition is as defined in any one of claims 3 to 18.

26. Use of a membrane according to any one of claims 1 to 21 for detecting, filtering and/or purifying biomolecules.

27. Use of a membrane according to any one of claims 1 to 21 for detecting metal ions or for filtering and/or purifying compositions comprising metal-ions.

28. A process for purifying a biomolecule and/or separating a biomolecule from other biomolecules comprising contacting the biomolecule(s) with a membrane according to any one of claims 1 to 21.

29. A process for purifying a mixture comprising metal-ions and/or separating metal-ions from other particles or ionic species, said process comprising contacting the metal-ions with a membrane according to any one of claims 1 to 21.

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30. A process according to claim 28 or 29 wherein the process comprises membrane size-exclusion chromatography and/or ion exchange chromatography.

Fig. 1a

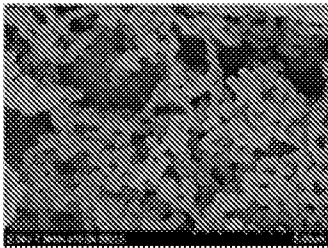


Fig. 1b

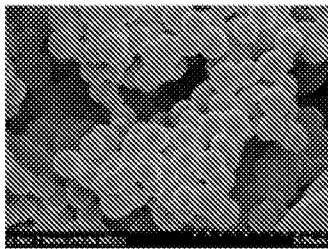


Fig. 2

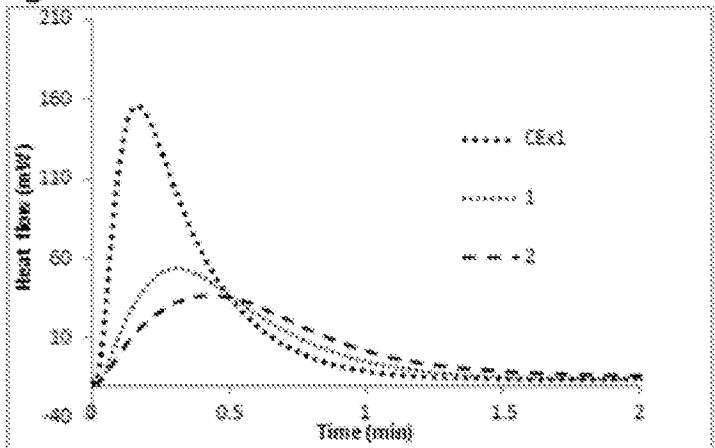
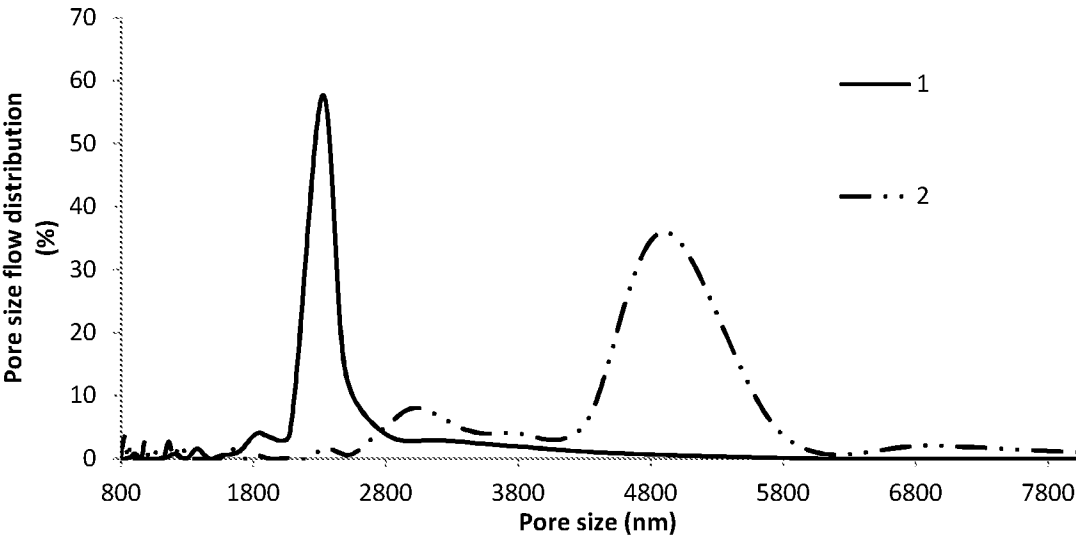


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2020/050773

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01D71/40

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

10 July 2020

Date of mailing of the international search report

16/07/2020

Name and mailing address of the ISA/

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Hoyer, Michael

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/050773

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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