Green Membrane Preparation and Manufacturing Practices

Ramachandran Kasirajan[1], Abas Siraj Hamda[2] and Mani Jayakumar[2]
[1]School of Chemical Engineering, Jimma Institute of Technology, JimmaUniversity, Jimma, Ethiopia
[2]Department of Chemical Engineering, Haramaya Institute of Technology, Haramaya University, Dire Dawa, Ethiopia

Synonyms

Industrialized practices; Natural tissue; Synthesis

Definition

Green membrane film partition innovation practice, as the name itself clearly proposes, implies a novel partition strategy employing a film, which is extraordinarily fabricated and with particular transmission for partition, filtration, and concentration of the blend driven by outside constrain. Generally, the driving force for membrane transport is a gradient of some potential such as pressure driven, temperature driven, concentration driven or electric field driven.

Introduction

Industrial pollution and environmental deterioration are commonly regarded as two of the most serious problems today; the most pressing issues confronting our civilization today. The long-term consequences of industrial pollution necessitate our industries are inefficient, contaminate our groundwater and air, and make the Earth a less pleasant place to live in. It is more dangerous and unpleasant. Chemical and petrochemical industries are the most important contributors of pollution. Pollution from industry and environmental degradation are all around the world. They are created by communities through their day-to-day activities. During the entire operation, which is the central chemical reactions and separation procedures industries of chemical and petrochemical. Significant initiatives are being taken to help the environment. The advancements in chemical efficiency are causing complications in the process industries by their techniques for reactions and separation. Membrane technology is increasingly being used in a variety of industrial processes, including water management/purification and gas partition, the chemical industry, pharmaceutical sector, food processing and beverage production, hemodialysis, and textile processing (Xie et al. 2020; Dong et al. 2021). Traditional thermal separation methods are important in many industrial industries, but they use a lot of energy. Alternative membrane-based separation technologies consume less energy; however, membrane

C. Baskar et al. (eds.), *Encyclopedia of Green Materials*,
https://doi.org/10.1007/978-981-16-4921-9_268-1

manufacture is mostly based on petrochemical-based components (Alammar et al. 2022). Membranes have risen to prominence in chemical expertise and are employed in an extensive variety of appliances. The main intention of the segregation appliances is to permit one constituent of a blend to voluntarily filter in the course of the membrane while avoiding supplementary components from permeating. This study provides a detailed outline of modern advancement on universal green membrane preparation practices from the vision of ecological conservation, healthiness security, and sustainability. In addition, it also details green materials for membrane technology, green approaches for membrane technology, fabrication process and characterization of membrane from green materials, functions of membranes. It also contains the green solvent and its synthesis procedure as well as merits, demerits of various membrane manufacturing practices.

Functions of Green Membranes

A prevailing green membrane in the field of membrane technology is a barrier that allows for the selective conveyance of important information. Eradicating the contaminants in the vein of pigment molecules, serious metal ions, and brackish compounds from drinking or process water is necessary to provided that hygienic supply and processing industrial dissipate water depicted in Fig. 1.

Membrane Fabrication Methods

The pitch of a swarming green membrane, membrane technology acts as a barrier that accepts the discriminating transmission of important information. Because the final morphology of a green membrane is central to its performance, the materials for fabrication and fabrication techniques used contain a momentous impact on green film morphology. As a result, optimizing permeability requires controllability of the connections among green materials, morphology, and fabrication techniques (Abdelrasoul et al. 2015). Porous green polymeric membranes were widely under research to use in industrial practices due to the combined effects of special characteristics such as fouling resistance, permeability, selectivity, thermal and chemical reliability, relatively inexpensive, and ease of manufacture.

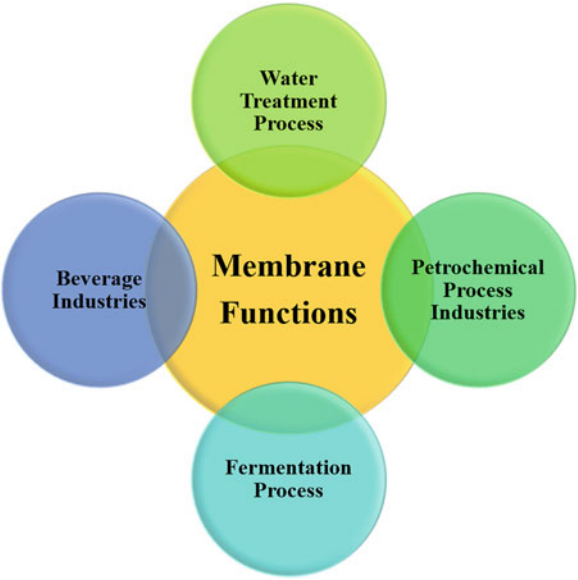
Membranes could be made in both a porous matrix and a spherical wound configuration. Artificial membranes have been made in two basic geometries:

- Cylindrical: used in coiled and capillary functionalities, as well as nonwoven modules.
- Flat sheet: used to make disc, flat sheet, plate, circularly wound, and frame modules.

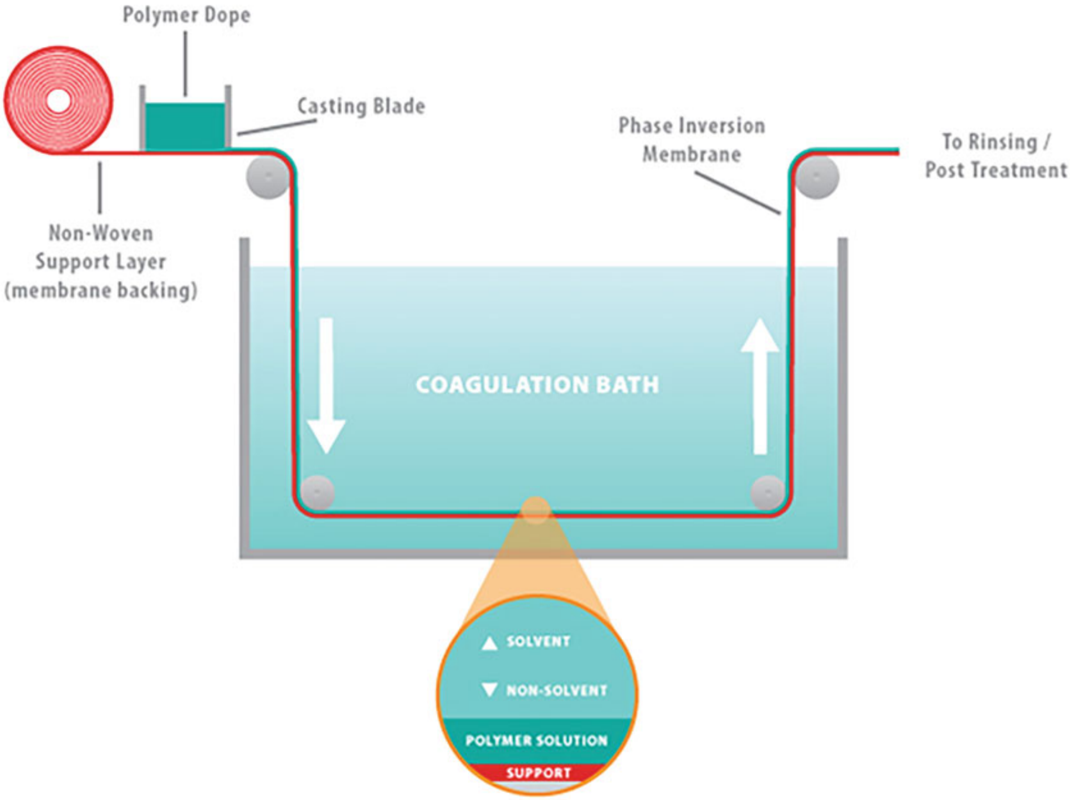
Membranes could be developed in a multitude of ways. Phase inversion, electro-spinning, melt-spinning and cold-stretching (MS-CS), sintering, and path etching are common approaches, whereas relatively new tools consider phase-segregation micro-molding (PSM), 3D printing, imprinting/soft molding, and manual pounding. To produce amorphous green polymeric membranes, each mechanism does have its own range of advantages, drawbacks, and permeability matching principle.

Phase Inversion

The phase inversion approach as shown in Fig. 2 is the most frequent and useful method of preparation, particularly for marketing membrane fabrication. Cooling, evaporation, fluidity in a molecule coagulant bath, and vapor ligand binding are all methods for precipitating polymer solutions during the phase inversion progression. The most commonly used technique for producing the present level of widely viable polymer membranes is phase inversion. Phase inversion is caused by the well-known procedure of fascination precipitation for preparing unbalanced biomaterials. A polymeric solution is featured onto a stable supply with a casting carving knife and afterward engrossed in a bath of coagulation in the practice. As a result of this process, an unbalanced layered membrane amid a dense upper surface stratum and a highly permeable porous sublayer is formed. Multiple factors in polymer



Green Membrane Preparation and Manufacturing Practices, Fig. 1 Functions of green membranes

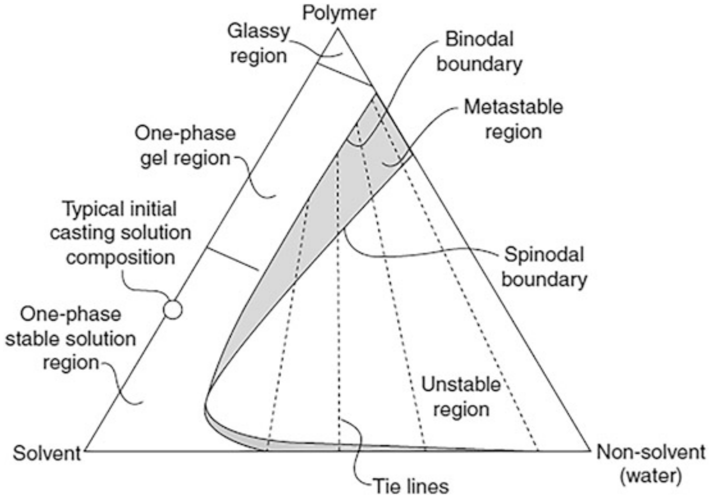


Green Membrane Preparation and Manufacturing Practices, Fig. 2 General phase inversion techniques casting solution, for instance, temperature of coagulant, composition, and additives, affect the formation of both layers upon layer. The cellulose solidifies into a solid substrate during this stage, known as de-mixing. This strategy is used to create porous as well as nonporous membranes. The phase inversion procedure is generally controlled in order to attain the intended membrane morphological characteristics and effectiveness. The World's favorite membranes were created by casting a 22–25% of solution of cellulose acetate on some kind of glass plate. Subsequent to a predetermined amount of solvent evaporation, the cast film must have been submerged in a pan of water to precipitate and construct the membrane. The above technique is used in the laboratory to prepare flat sheet membranes, but in commercial large-scale fabrication, casting equipment is typically utilized (Ren and Wang 2011). The casting axe casts the newly emerging film onto a movable nonwoven fabric web, exposes it over to a gas state for evaporation of the solvent prior to commencing the coagulation process bath, and finally forms the film by tempering in the process bath. The configuration of asymmetric membranes using the process of phase inversion is governed mostly by the kinetics and the thermodynamics associated in the process of phase inversion.

Nonsolvent-Induced Phase Segregation (NIPS)

NIPS is still nearly everyone's widely used technique due to its effectiveness and capability to prepare an extensive assortment of membranes (Mulder 1996). Polymer liquid solutions were to be submerged in a nonsolvent pool (bath of coagulation), characteristically water, where the solvent and water exchange transpire: the solvent relocates from polymer liquid solution to the bath of coagulation, whereas the water moved in the opposed trend, ensuing in configuration of membrane. Several more polymers could be used as raw materials as long as they are dissolvable in the solvent or in the mixture of substances. Membranes in both tubular and flat configurations are possible. In primary case, solution of plolymer is cast with a casting knife on support, characteristically a glass plate or spunbond polyester (Baker 2004), before being dipped into the dissolution medium. The content in coagulation, subject matter of casting solution, humidity, the contact period, and the temperature of air are perhaps the most essential aspects influencing the structure of the subsequent membrane. The texture of solution for casting, which is typically accustomed to the range of 10–100 of microns, also plays a major role in evaluating membrane characteristic features. In tubular configuration, the solution of polymer and bore fluid were being co-extruded from first to last with spinneret, resulting in a conscience arrangement that is categorized as hollow fiber (radius less than 0.25 mm) or capillary (radius between 0.25 and 2.5 mm) membrane based on the diameter. In relation to variables that influence the arrangement condition and recital of flat cell membrane, the following factors should be considered in the situation of tubular configuration: friction coefficient and deformation rate of solution of polymer, masterpiece of bore fluid, distance of air gap, bore fluid rate of feeding, and spinneret dimensions. Several key characteristics of NIPS, namely, the rate of exchange of nonsolvent with solvent and phase separation rate velocity, are associated with the kinetic parameters and have a heavy impact on the morphology of the membrane. However, thermodynamics is also important in phase segregation techniques. Theory of solubility variables describes the interrelations among solvent, polymer, and nonsolvent in terms of assimilation of free power. The phase diagram clearly illustrates the temperature dependence of mixture of three components (solvent, polymer, and nonsolvent) as shown in Fig. 3.

The triangle's corners portray the genuine components, while the parts are binary combinations. The triangle's components portray ternary combinations. Three distinct regions can also be recognized, isolated by binodal and spinodal boundaries: the territory to the left boundary of binodal reflect one-phase constant crystalline constituency, which is additionally sub alienated into gel, solution, and glassy constituency; the territory here among boundaries of binodal and spinodal is a metastable territory, thermodynamically unbalanced where neither phase segregation transpires; and the territory to the right boundary



Green Membrane Preparation and Manufacturing Practices, Fig. 3 Three component scheme phase diagram. (Reprinted from Baker (2004))

of spinodal is thermodynamically unbalanced. The solution of polymer impulsively segregates into a rich-polymer phase and a poor-polymer phase whose masterpieces are prearranged by the tie line intercepts with the boundary of binodal.

NIPS membrane configuration can be summarized as follows:

- When the solution of polymer gets in touch with a nonsolvent like water, the solvent/nonsolvent switch is set in motion.
- The content needs to enter the two-phase territory as the solution of polymer liquid misplaces solvent and becomes more nonsolvent enriched; polymer precipitate is formed, resulting in the generation of rich-polymer and poor-polymer phase.
- The interaction among solvent and nonsolvent continues, the rich-polymer phase's component shifts toward nonsolvent/polymer side, and the membrane is established.

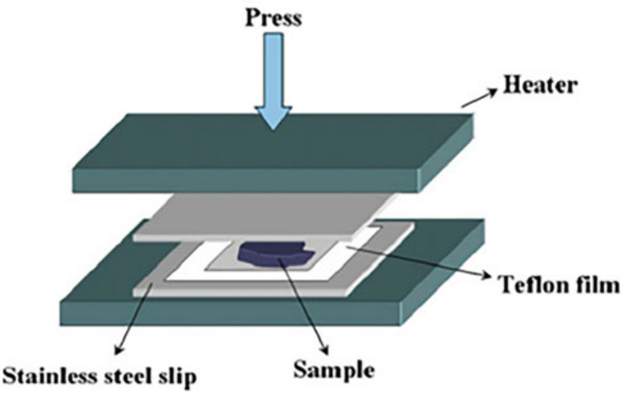
Alternative nontoxic solvents suitable for NIPS include sulfonylbismethane (DMSO), ionic liquids, ethyl lactate, and methyl lactate.

Temperature-Induced Phase Separation (TIPS)

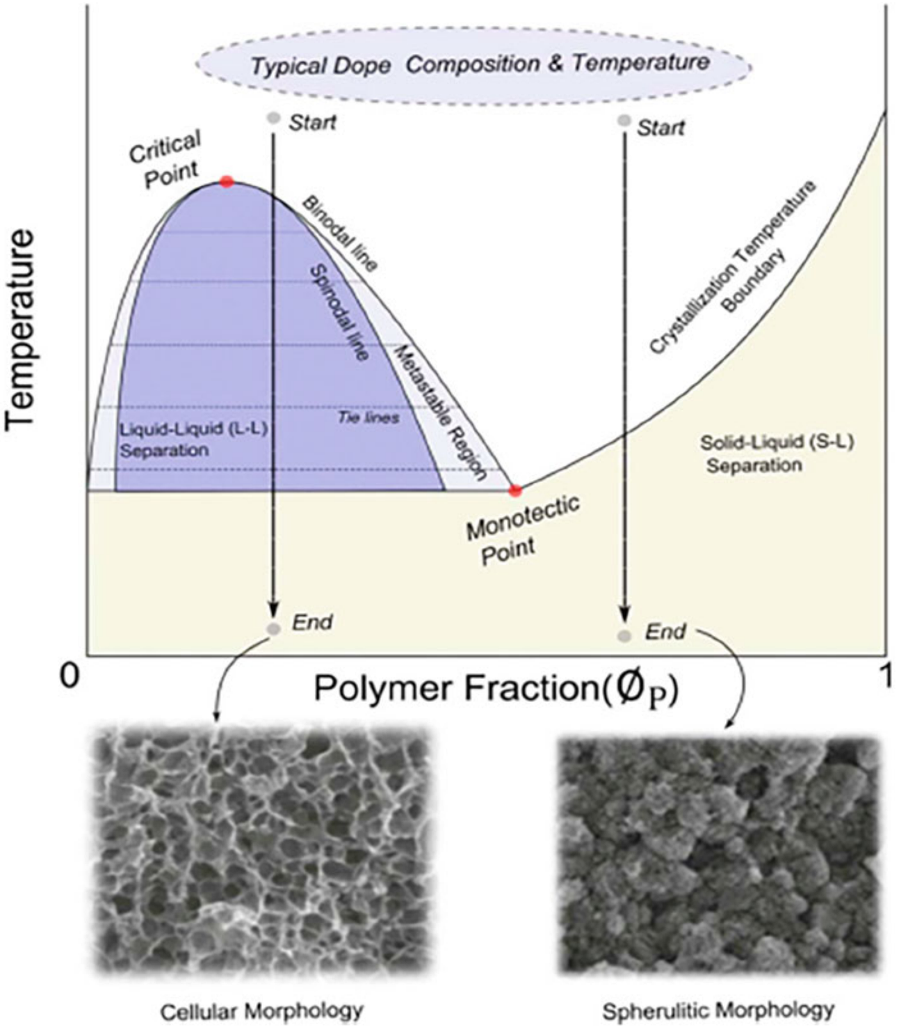
The general TIPS process consists of the following. To begin, that certain portion of polymer containing strong melting point and lower molecular mass diluent (solid or liquid) combination is located among the two metal sheet plates to obtain a uniform mixture. As shown in Fig. 4, Teflon film with planning tetragon opening within central core is embedded among them to alter the membrane texture. The specimen is disintegrated by heating it at a high temperature under pressure. It should always be noted that throughout the stage, the initial temperature has to be smaller than the diluent's boiling point and is traditionally 25–100 °C higher than with the melting temperature of clean polymers or transition temperature of glass.

Following that, an uniform blend is established keenly on the required shape, which really is customarily a tube, flat pane, or hollow fiber. Consequently, a constrained rate of cooling causes a phase mass transfer (thermal quenching). The solvent then is usually extracted using solvent extraction. Ultimately, the extractant is removed (customarily by evaporation) to yield a microporous arrangement (Lloyd et al. 1991). The science's crucial point is to stimulate phase separation in membrane preparation by expelling heat energy from a relatively homogeneous dope solution. TIPS are thus a sense of balance of phase segregation route, polymer, and solvent interaction (thermodynamics), drying condition, selection of extractant, and cooling kinetics.

Phase diagram for a temperature–composition can be used to depict the TIPS operation for membrane preparation. As shown in Fig. 5, TIPS



Green Membrane Preparation and Manufacturing Practices, Fig. 4 Schematic diagram of TIPS membrane process. (Reprinted from Zhang et al. (2010))



Green Membrane Preparation and Manufacturing Practices, Fig. 5 Phase diagram of the TIPS process. (Reprinted from Kim et al. (2016))

membranes frequently follow one of two routes: solid–liquid (S-L) isolation to resulting crystallization or liquid–liquid (L-L) isolation to resulting crystal growth (Kim and Lloyd 1991). Several studies have also shown that phase inversion technique enhances the resulting membrane integrity dramatically (Matsuyama et al. 1998). Simultaneously, membrane performance is greatly influenced by membrane pore diameter and pore size distribution. As a result, strong control of something like the microporous configuration is critical in membrane preparation (Park and Kim 2014).

Once the polymer concentration is greater the monotectic argument (usually greater than 30%), the meth solution passes through the entire phase transition temperature boundary and emerges in the solid–liquid (S-L) segregation territory. In contrast, phase segregation occurs by means of liquid-liquid splitting, followed by crystallization at relatively low polymer percentages. It should be noted that when primary polymer composition of casting resolution is much less than the vital point, an uninterrupted rich-solvent phase and a non-continuous rich-polymer phase may develop. Therefore, rather than a solid membrane, the finished product seems to be powders. The separation method has a significant effect on the membrane's shape when a partly dependent concentration is selected.

Solid-liquid phase segregation (S-L) are generally triggered by means of the configuration of crystal nuclei through the use of principal heterogeneous nucleation, which is followed by the accumulation of nuclei through the use of secondary nucleation. The porous polymer and solvent are rebuffed by the crystal formation during the crystallization procedure. The solvent among the spherulites or lamellae is then removed to form the microporous frameworks. As previously discussed, the motivating factor is the divergence in polymer chemical prospective between the solution phases and crystalline, but crystallization thermochemistry and equilibria also engage in recreation role in phase inversion.

The high temperature-dependent destabilization of such polymer-diluent process creates liquid-liquid phase isolation (L-L). Relatively polymer–diluent homogeneous combination could be formed at sufficiently high temperature and afterward exhibits specified threshold temperature of the solution type phase behavior as the system cools and enters an unstable situation. Early on in phase segregation and the two-phase scheme, before the densification operation crosses the threshold, the crystalline microstructure may be found.

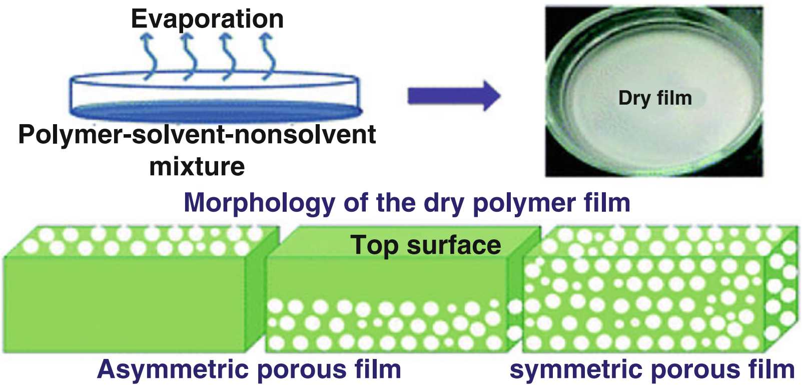
The kinetic studies are still evolving as a result of the potential to decrease the exterior energy associated well with specific surface vicinity. This results in a diminution in quantity of diluent raindrops because of increasing droplet size. When the solution of polymer is hardened by means of more cooling, which is below crystallization temperature, the advancement of diluent raindrop stops. This implies that, in the case of semicrystalline, phase segregation (L-L) is linked to polymer crystallization, whether concurrently or later. To identify the relationship among the membrane porosity and final diluent droplets, two significant factors were primarily considered: the coarsening method and phase partition temperature.

As previously stated, the formation of porous structures is related to multiple separation processes. Whenever a best possible way is chosen, the ultimate membrane pore structure and pore size are heavily influenced by the operating temperatures; convective cooling does provide numerous nuclei and consume less time for crystallization process, whereas slow cooling would provide more time for crystallization process, tends to result in membranes primed through the use of L-L segregation that typically have a porous, cellular-like, two-phase structure arrangement. Membranes created by S-L splitting, on the other hand, have fuzzified microstructure (sphere-like) frameworks. Acetyltriethylcitrate (ATEC), acetyltributylcitrate (ATBC), soybean oil, and triacetin are some good alternative nontoxic green solvents for TIPS process.

Evaporation-Induced Phase Inversion (EIPS)

This is perhaps the most basic method of phase inversion. To prevent the existence of water vapor, the casting polymer liquid solution is applied to

Green Membrane Preparation and Manufacturing Practices, Fig. 6 Evaporation of solvent-induced phase segregation (EIPS). (Reprinted from Pervin et al. (2019))



endorse and allowed to evaporate in an inert environment. Throughout this case, the high speed evaporation of the solvent results in a dense homogeneous membrane. The evaporation of solvent-induced phase segregation technique, depicted in Fig. 6, involves disintegrating a polymer inside a blend of solvent/nonsolvent, in which the solvents have higher volatile when compared with nonsolvents. Phase transition and demixing of the solvent, polymer, and nonsolvent scheme occur as a consequence of solvent evaporation, resulting in a permeable porous film. Components of polymer, solvent, and nonsolvent solutions could be changed to influence the porous structure (Pervin et al. 2019).

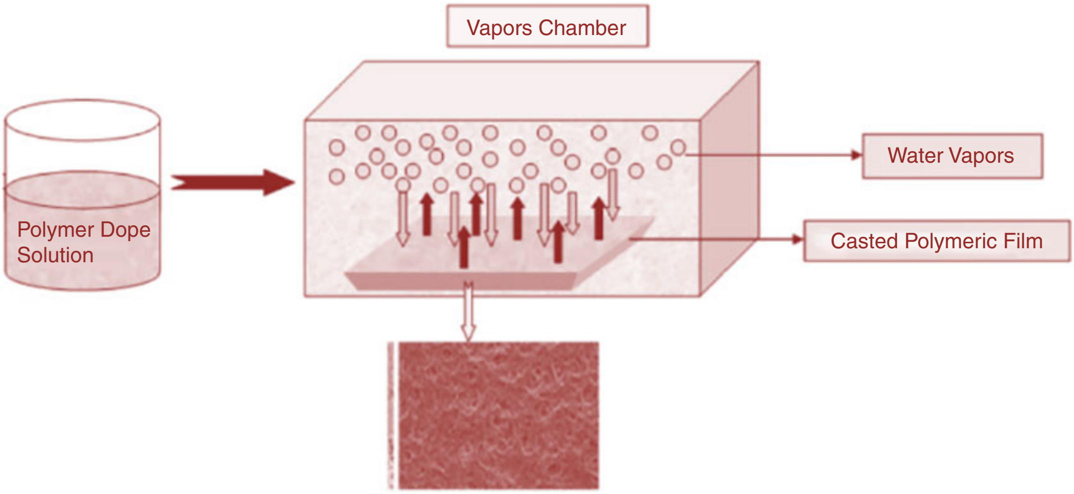
Samuel et al. (2011) examined the application of EIPS mostly in casting of polymethylmethacrylate membranes (PMMA) in a solvent of tetrahydrofuran (THF) with nonsolvent of water. Condensation of water raindrops ensued throughout fast solvent evaporation, resulting in the formation of highly permeable polymer films. As a result, the water content influenced the porous structure morphological characteristics on the surface of the membrane; the regular pore diameter of procured membranes amplified in tandem with the help of water activity.

Vapor-Induced Phase Inversion (VIPS)

An alternative process for creating permeable membranes is vapor-induced phase separation (VIPS). A dope solution would be able to prepare and cast it into a fluid layer, which could then be out to an environment of nonsolvent volatiles in a vapor chamber, as shown in Fig. 7. While the operation is related to NIPS, phase inversion transpire well with transport of water vapor further keen on film whereas solvent propagates further keen on vapor to build a rigid membrane film. Zhao et al. (2018) inspects the use of VIPS for preparation of permeable porous polyvinylidene fluoride membrane. While the vapor temperature was 65 °C, the contact period was 20 min, and the comparative humidity was 70%, the membrane urbanized a cellular arrangement. Unlike NIPS, which immerses the dope liquid film in a nonsolvent tub, the dope fluid film was uncovered to a vapor phase nonsolvent for the period of VIPS, which hinders the phase segregation route and results in a cellular membrane arrangement. Because the cellular structures were bi-continuous, mechanical strength was increased. The merits and demerits of NIPS, TIPS, and VIPS process is presented in Table 1.

Green Solvents Utilized for Membrane Practices

Solvents have a significant impact on the morphology of films, as well as their characteristics and performance. The most common vital layer production methods rely on the use of conventional solvents such as DMF (dimethylformamide), DMSO (dimethyl sulfoxide), NMP (N-methyl-2-pyrrolidone), DMAC (dimethylacetamide), and THF (tetrahydrofuran), all of which pose potential health and environmental hazards due to their flammability and poisonous quality. When these classic solvents come into touch with the skin or are



Green Membrane Preparation and Manufacturing Practices, Fig. 7 Vapor-induced phase separation process (VIPS). (Reprinted from Zahid et al. (2018))

Green Membrane Preparation and Manufacturing Practices, Table 1 Merits and demerits of NIPS, TIPS, and VIPS process

S. no.	Process	Merits	Demerits
1.	NIPS	Well with support of admixtures, NIPS can totally manage the pore size as well as other surface properties of membranes	Controlling the phase inversion operation pretty much exactly is difficult
2.	TIPS	1. Suitable for an extensive array of polymers, particularly semicrystalline that are difficult to dissolve with solvent 2. Membranes are intrinsically realistic and a smaller amount prone to mistakes than some other methods of phase segregation	1. Low optical attraction among the diluents and the nondiluent actually results in little tuning of the exterior porosity 2. Expensive, as well as the use of organic solvents are somewhat typically unfriendly to the environment
3.	EIPS	Excellent reproducibility	Solvent selection and nonsolvent selection are very complicated
4.	VIPS	VIPS allows for the modification and customization of both hollow-fiber and flat-sheet polymer membrane morphological features, gentle formation process, and form good crystalline structure	Infomercial polymer membrane advancement is still limited, have many operation parameters, have consumed more energy

inhaled, they are hazardous (Kim and Nunes 2021). They irritate the eyes, damage the unborn infant, and cause alterations in germ cells and mammalian somatic cells.

The pollution of wastewater by these solvents accounts for 95% of the total waste created during the production of industrial membranes. In order to increase sustainability and lengthen the membrane fabrication process, green solvents have recently been studied (Madhura et al. 2018). Green solvents are nontoxic, low-volatile, and/or made from renewable resources. Solvent parameters such as polarity, dielectric constant, boiling point, and viscosity must be considered during the membrane production process (Wang et al. 2019). The world is going toward more bio-derived manufacturing greener/lower toxicity solvents for membrane fabrication because of the reduced implications on human health and the environment. Membrane construction has lately been researched using dimethyl sulfoxide (DMSO), dimethyl carbonate, methyl lactate,

Green Membrane Preparation and Manufacturing Practices, Table 2 Potential characteristics of green solvent in membrane fabrication

S. no.	Solvents	Fabrication technique	Boiling point in (°C)	Green characteristics
1.	DMSO ($(CH_3)_2SO$)	NIPS	189	Higher boiling point, lower vapor pressure, water miscible
2.	Methyl lactate ($C_4H_8O_3$)	NIPS	144	Biologically degradable water miscible, slower volatility rate with biodegradability
3.	Triethylphosphate	NIPS	215	Higher boiling point, bio-accumulation, high persistence in the environment
4.	TamiSolveNxG	NIPS	108	High boiling points,low vapor pressure, water miscible
5.	γ-Butyrolactone (γ-BL)	NIPS TIPS	204	Higher boiling points, lower vapor pressure, biomass derivation, biodegradable
6.	Soybean oil	NIPS TIPS	300	Higher boiling points, biomass derivation, biodegradable
7.	Ionic liquids	NIPS	164	Low vapor pressure, high boiling points, complete reduction under mild condition, high thermal stability

Lee et al. (2021) and Winterton (2021)

TamiSolveNxG, butyrolactone, triethylphosphate, ionic liquids, organic carbonates, Polar Clean, −valerolactone, and other green solvents (Lee et al. 2021). Potential characteristics of green solvents in membrane fabrication are presented in Table 2.

DMSO

DMSO is a synthetic organic solvent with a near the ground vapor pressure of 0.6 mm of Hg at 25 °C, elevated boiling point of 189 °C at 1 atm, and stumpy toxicity (Madhura et al. 2018). Due to its vastly polar, clear, water miscible solvent (organic), DMSO has been reported to be a green candidate for toxic solvent replacement due to its ability to successfully disband countless varieties of polymers, for instance, PVDF (polyvinylidene fluoride) and PSU (polysulfone) while having no negative environmental impact (Lee et al. 2021). Lignin is a chemical (natural) that works as an adhesive for tree cells and gives shrubbery their structural reliability, it is the source of DMSO. "Safer solvents and auxiliaries" appear to be a high-quality alternate for higher toxic solvents, in accordance with the green chemistry principle. DMSO can be straight surrogate for perilous solvents with analogous properties, such as DMA, DMF, and NMP, when preparing membranes through NIPS (Figoli et al. 2014). The only flaw is that it has a terrible odor. However, with the current version of DMSO EVOLTM, it has been greatly enhanced (Kim and Nunes 2021).

Through a uniform supply of CNCs on the membrane exterior and acceptable practice, the DMSO-based membrane triumphed. It's also a superb solvent for dissolving Kevlar aramid nanofiber (ANF) in a homogeneous manner, resulting in an ANF hydrogel dope that can subsequently be formed into a membrane using NIPS. The polarity of the membranes made with DMSO as a solvent was very high. The membrane's surface zeta potential was lower, resulting in a thinner active surface layer and higher water permeability. They also had larger cellular pores and macrovoids in their arrangement, indicating increased porosity (Lee et al. 2021).

Methyl Lactate

Naturally occurring lactic acid ester is known as Methyl lactate. For the reason that it is ecological, water miscible, and versatile, this is monochrome liquid with outstanding chemical capabilities of nontoxic solvent for cellulose acetate (CA) membrane fabrication (Lee et al. 2021). It can dissolve chlorine salts and CA powder, yielding a castable homogeneous dope solution (Nguyen Thi et al. 2020). The use of methyl lactate instead of standard solvents for membrane preparation has resulted in a number of faults and quality difficulties, including reduced ecotoxicity, inhomogeneity, the appearance of microvoids resting on the exterior, and varied permeability of water (Lee et al. 2021).

Soybean Oil

Soybean oil is a popular choice for agricultural and vegetable oils around the world. Soybean oil is readily available, with over 96% of it being manufactured commercially for usage in margarine, salad oil, cooking oil, and shortening (Lee et al. 2021). It is now employed as an alternate solvent for membrane fabrication applications due to its chemical characteristics, lack of toxicity, and convenience of usage. Soybean oil can be used as a solvent to maintain things consistent over a wide range of quenching temperatures, with no effect on membrane porosity and no effect on membrane formation (Lee et al. 2021).

Ionic Liquids

Ionic liquids, which are made up of organic cations and polyatomic inorganic anions, are a great alternative to environmentally toxic solvents and organic salts. Halogens, triflates, and trifluorobates are examples of anions, while imidazolium and pyridinium are examples of cations (Kim and Nunes 2021). Ionic liquids have a very low vapor pressure as compared to volatile solvents. Ionic liquids' physiochemical properties can be changed by modifying the cations and anions to fit the needs of future applications such as catalysis, polymer synthesis, and batteries. Due to their environmental benefits, such as minimal vapor pressure, full reduction under mild temperatures, high boiling point, and outstanding adaptability, ionic liquids are increasingly being employed to swap conventional solvents in membrane preparation technologies (Lee et al. 2021). By spinning the dope solutions, ionic liquids like EMIM-Ac (1-ethyl-3-methylimidazolium acetate), EMIM-Cl (1,3-dimethylimidazolium chloride), and EMIM-DEP (1-ethyl-3-ethylimidazolium diethyl phosphate) can be utilized to create cellulose hollow fibers (Nguyen Thi et al. 2020). In general, researchers argue that an ionic liquids-fabricated membrane has a denser structure and can be recycled and reused to create another membrane.

Other Green Solvent

Many green solvents, for instance, glycerol triacetate (GTA), triethylphosphate (TEP), triethylene glycol diacetate (TEGDA), γ-butyrolactone (γ-BL), ATBC, ATEC, and methyl-5 (dimethylamino)-2-methyl-5-oxopentanoate (Rhodiasolv® Polar-Clean), TamiSolveNxG, CyreneTM, are still employed in membrane manufacturing, although their usage in desalination is uncommon (Lee et al. 2021). However, as the scientific community as a whole strives to reach a long-term green aim, more research and investigations into the widespread exercise of green natural solvents in membrane desalination are predicted in the future.

Characterization of Green Membrane Materials

Morphological Characterization

Porosity, tortuosity, pore size distribution, pore size, molecular weight cutoff, surface irregularity, and thickness are the most significant morphological parameters for a membrane. Forward osmosis (0.3–0.6 nm), Microfiltration (50–500 nm), nanofiltration (less than 2 nm), ultrafiltration (2–50 nm), and reverse osmosis (0.3–0.6 nm) are examples of membrane classifications. Furthermore, because membrane performance is honestly related to morphology of membrane, morphology control is an imperative factor in membrane production.

Performance Evaluation

In general, the effectiveness rate and separation capacity of membranes can be used to assess their performance. Permeability (P), flux (J), and permeance (P′) are important parameters in determining membrane productivity, because when effectiveness (segregation performance) is determined by the separation factors (β) and selectivity (α). When divergent special effects are present, however, the observed practical retention coefficient (Robs) and factual retention coefficient (R) have to be measured. The first section of this work contains more information on membrane performance and characterization.

Conclusion

Utilization of green materials as a renewable source for membrane preparation is successful and depends on the economic perspective. A complete overview of current advances in common green membrane preparation procedures was discussed in terms of environmental conservation, health safety, and sustainability. Furthermore, green materials for membrane technology, green techniques for membrane production and characterization of green materials, membrane functionalities and also the green solvent and its synthesis technique, as well as the merits and demerits of various membrane production practices were discussed. From this it was concluded that the green membranes derived from natural sources and green synthesis process has a high potential application for the separation and purification of heavy toxic metals from various industrial activities.

Cross-References

- ▶ Green Membrane
- ▶ Green Solvents
- ▶ Membrane Synthesis Practice

References

Abdelrasoul A, Doan H, Lohi A, Cheng CH (2015) Morphology control of polysulfone membranes in filtration processes: a critical review. ChemBioEng Rev 2:22–43

Alammar A, Hardian R, Szekely G (2022) Upcycling agricultural waste into membranes: from date seed biomass to oil and solvent-resistant nanofiltration. Green Chem 24(1):365–374

Baker RW (2004) Membrane technology and applications, 2nd edn. Wiley, Chichester

Dong X, Lu D, Harris TA, Escobar IC (2021) Polymers and solvents used in membrane fabrication: a review focusing on sustainable membrane development. Membranes 11(5):309

Figoli A, Marino T, Simone S, Di Nicolò E, Li XM, He T, Tornaghi S, Drioli E (2014) Towards non-toxic solvents for membrane preparation: a review. Green Chem 16(9):4034–4059. https://doi.org/10.1039/c4gc00613e

Kim SS, Lloyd DR (1991) Microporous membrane formation via thermally-induced phase separation. III. Effect of thermodynamic interactions on the structure of isotactic polypropylene membranes. J Membr Sci 64: 13–29

Kim D, Nunes SP (2021) Green solvents for membrane manufacture: recent trends and perspectives. Curr Opin Green Sustain Chem 28:100427. https://doi.org/10.1016/j.cogsc.2020.100427

Kim JF, Kim JH, Lee YM, Drioli E (2016) Thermally induced phase separation and electrospinning methods for emerging membrane applications: a review. Adv Mater Sep Mater Devices Process 62:461–490

Lee WJ, Goh PS, Lau WJ, Ismail AF, Hilal N (2021) Green approaches for sustainable development of liquid separation membrane. Membranes 11(4):1–35. https://doi.org/10.3390/membranes11040235

Lloyd DR, Kim SS, Kinzer KE (1991) Microporous membrane formation via thermally-induced phase separation. II. Liquid–liquid phase separation. J Membr Sci 64:1–11

Madhura L, Kanchi S, Sabela MI, Singh S, Bisetty K (2018) Membrane technology for water purification. Environ Chem Lett 16(2):343–365. https://doi.org/10.1007/s10311-017-0699-y

Matsuyama H, Berghmans S, Lloyd DR (1998) Formation of hydrophilic microporous membranes via thermally induced phase separation. J Membr Sci 142:213–224

Mulder M (1996) Basic principles of membrane technology. Kluwer, Dordrecht

Nguyen Thi HY, Nguyen BTD, Kim JF (2020) Sustainable fabrication of organic solvent nanofiltration membranes. Membranes 11(1):19

Park MJ, Kim C (2014) Fabrication of polyethylene microporous membranes using triethylolpropane tris (2-ethylhexanoate) as a novel diluent by a thermally induced phase separation process. J Membr Sci 449: 127–135

Pervin R, Ghosh P, Basavaraj MG (2019) Tailoring pore distribution in polymer films via evaporation induced phase separation. RSC Adv 9:15593–15605

Ren J, Wang R (2011) Preparation of polymeric membranes. In: Wang LK, Chen JP, Hung YT, Shammas NK (eds) Membrane and desalination technologies, Handbook of environmental engineering. Humana Press, Totowa

Samuel AZ, Umapathy S, Ramakrishnan S (2011) Functionalized and postfunctionalizable porous polymeric films through evaporation-induced phase separation using mixed solvents. ACS Appl Mater Interfaces 3:3293–3299

Wang HH, Jung JT, Kim JF, Kim S, Drioli E, Lee YM (2019) A novel green solvent alternative for polymeric membrane preparation via nonsolvent-induced phase separation (NIPS). J Membr Sci 574:44–54. https://doi.org/10.1016/j.memsci.2018.12.051

Winterton N (2021) The green solvent: a critical perspective. Clean Technol Environ Policy 23(9):2499–2522. https://doi.org/10.1007/s10098-021-02188-8

Xie W, Li T, Tiraferri A, Drioli E, Figoli A, Crittenden JC, Liu B (2020) Toward the next generation of sustainable membranes from green chemistry principles. ACS Sustain Chem Eng 9(1):50–75

Zahid M, Rashid A, Akram S, Rehan ZA, Razzaq W (2018) A comprehensive review on polymeric nano-composite membranes for water treatment. J Membr Sci Technol 8:1–20

Zhang C, Bai Y, Sun Y, Gu J, Xu Y (2010) Preparation of hydrophilic HDPE porous membranes via thermally induced phase separation by blending of amphiphilic PE-b-PEG copolymer. J Membr Sci 365:216–224

Zhao Q, Xie R, Luo F, Faraj Y, Liu Z, Ju XJ, Wang W, Chu LY (2018) Preparation of high strength poly(vinylidene fluoride) porous membranes with cellular structure via vapor-induced phase separation. J Membr Sci 549: 151–164