Chapter 2

Commonly used Polymers for Separation Science

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Abstract

Many synthetic and organic (bio-based) polymers have been used for membrane fabrications. In this chapter, we discuss the structure and properties of some commonly used polymers, which have been used for water purification and gas separation applications. To supplement that, we discuss some characterization tools and membrane module testing conditions for performance checks.

Keywords

Polymers, Membrane Separation, Water Purification, Filtration, Membrane Modules

Contents

Commonly used Polymers for Separation Science	9
1. Introduction.....	10
2. Polymers structure and properties	12
3. Classification of polymers	12
4. Uses of polymers	13
5. Polymeric membrane fabrication	17
5.1 Types of polymeric membranes	18
6. Membranes characterization tools.....	19

6.1	Scanning electron microscopy (SEM).....	19
6.2	Transmission electron Microscopy (TEM)	20
6.3	X-ray diffraction (XRD).....	21
6.4	Fourier-transform infrared spectroscopy (FTIR)	21
7.	Modules for polymeric membrane testing	21
7.1	Spiral wound modules	22
7.2	Hollow fibre module.....	23
7.3	Capillary module	23
7.4	Plate and frame module	23
7.5	Tubular module.....	24
	Conclusion.....	24
	Acknowledgement	24
	References	25

1. Introduction

One of the 21st century challenges is lack of freshwater due to increased world population, which is expected to reach 10 billion by 2050. Availability of pure drinking water in the developing world is another area of major concern. The innovation in the existing technologies, used for water purification, is very limited. In various separation processes, membranes are used as barriers which are semipermeable and can be used in separation and restriction of the transportation of substances. Thus, it involves concentration of components both in the retentate and permeate fractions. As of now, different types of membrane methods like membrane distillation (MD), microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been used for this purpose. MF and UF techniques are used for water treatment, whereas NF and RO technique is mainly used for water softening and desalination purposes. Among this technique, MD is currently developing fast and it is an efficient technique for desalination. The membranes used in these techniques play a vital role in determining the economic and technological efficiency of the technique employed. The nature of material used and pore size of the membranes determine its application [1]. Membranes used for various applications can be varied depending on sectors such as biotechnological, chemical, and pharmaceutical and food industries. In majority of these cases, energy

efficiency, better separation efficiency, reduction in steps of processing and improvement in product quality are the major lookouts for adopting a suitable technology [2].

In conventional filtration technologies whatever may be the fluid flow (gas or liquid), it is always perpendicular to the membrane surface so that the solutes get deposited on it and that requires a periodic interruption processing system for cleaning or replacing the filter. Alternatively, when the membrane filtration is tangential, the fluid flows parallel to the surface of the membrane. The solutes accumulated onto the surface are stripped away from the surface owing to high velocity. This increases the efficiency of the process. The application of hydraulic pressure for driving mass transport distinguishes the common separation processes like MF, UF, NF and RO [3]. The nature and properties of these membranes control the permeation of each component and their selective retention as they are separated with accordance to their molar masses and particle size. MF generally uses pressures lower than 0.2 MPa which is able to separate molecules in the range of 0.025 and 10 μm . Secondly, UF uses pressures which is greater than 1 MPa and is able to separate particles with molar masses in the range of 1 and 300 kDa. Thirdly, NF pressure ranges between 1 to 4 MPa and has a capability to separate particles in the range of 350 to 1000 Da. Finally, RO needs a pressure in the range of 4 to 10 MPa can accumulate particles below 350 Da and separate it. The membrane pore size is a crucial factor and is designated as molecular weight cut-off (MWCO). This indicates the molar mass of the component which is smallest that could be retained with an efficiency of around 95% [2, 4-8].

The solute's selectivity is determined by the dimension of the molecule to be separated and the pore size of the membrane. Solute diffusivity and the electric charges associated with it are also responsible. The separation properties of any membrane is also influenced by the material chemical composition and other factors like temperature, feed flow, pressure of flow and interaction between the molecules and also the surface morphology of the membrane. On the basis of the structure of a membrane, it can be asymmetrical or symmetrical having larger pore size and uniform pore size as respective characteristics. It can also be dense and porous. However, various materials are involved in fabricating these membranes for water purification and gas separations.

In this chapter, we highlight the materials, especially the polymers, which have been utilized for membranes fabrications. These polymeric membranes are fabricated from a wide array of polymers. There are various characterization tools for assessing their structures and also testing modules for their performance checks. Therefore, we also cover these aspects. They are required for various applications mainly discussed here in the purview of water purification [8].

2. Polymers structure and properties

A substance which comprises of very large molecules each of which have many repeating subunits is known as a polymer. The definition of polymer says it is ‘chemically made up of many repeating units’. The unit may be a single atom or a small group of atoms. The word “polymer” comes from the Greek word meaning many parts/multiple repeating units, and the repeating unit made up with carbon and hydrogen are called hydrocarbons. In some cases, the repeating unit made up with oxygen, nitrogen, sulfur, chlorine, fluorine, phosphorous and silicon. These larger molecules bring about some unique properties, which are not present in the smaller ones. They bring properties like viscoelasticity, formation of crystalline and semi-crystalline structures, enhanced mechanical properties like elasticity, toughness etc. Polymers may have natural origins or may be synthetically manufactured. The examples for naturally occurring polymers are Silk, Wool, DNA, Cellulose, Protein etc. Historically polymer was first coined by Jöns Jacob Berzelius in the year 1833. In 1920, the modern concept of polymers describes as “covalently bonded macromolecular structure” was proposed by Hermann Staudinger. In 1909, Bakelite which was created for manufacturing telephone components was the first synthetic polymer. In 1910, rayon was manufactured from cellulose and nylon was discovered in 1935.

There are different types in the synthetic polymers named as homopolymers, copolymers, thermoplastics, thermosets etc. Homopolymer is defined as polymer that has the same monomeric unit in the chain. Examples are likely polyvinylchloride (PVC) having vinyl chloride units and polypropylene with propylene units. Again, polymerization of more than one type of monomer results in formation of copolymers and the process is called copolymerization. Acrylonitrile butadiene styrene (ABS) and styrene-isoprene-styrene (SIS) are the common examples for the copolymers [9,10]. Depending upon the behaviour of a polymer on application of heat, it can be classified as thermoplastic and thermosetting polymers. A thermoplastic material become pliable and mouldable at certain elevated temperatures and consequently solidifies upon cooling. On the other hand, thermosetting polymers become irreversibly rigid when heated. Heat increases the cross linking between the chains and cures the polymer. Polyvinylchloride, polypropylene etc. are common examples of thermoplastics; whereas vulcanized rubber, polyester etc. are examples of thermosets [11].

3. Classification of polymers

Polymers can be classified on the basis of various factors. Of them, classifications based on source, structure, mode of polymerization and molecular forces are of importance. As discussed earlier, depending upon sources the polymers can be classified as natural and

synthetic polymers. Semi-synthetic ones are those which have origins from a natural source but have been modified artificially in a lab (e.g., cellulose acetate). Depending upon the structure, polymers can be of three types, such as linear, branch chained and crosslinked. Based on process through which they have been polymerized, it is possible to yield various types like addition polymers (e.g., polyethylene) and condensation (e.g., Nylon 66) polymers. Again, depending upon the molecular forces, polymers can be of different types like fibres and elastomers. Elastomers are solid rubber like polymers which can be easily stretched (e.g., rubber bands). The polymer chains can be easily stretched depending upon the application of forces. Fibres pose strong inter-molecular forces between its chains which result in less elasticity and high tensile properties. Nylon-66 is an example of this group of polymer [10].

4. Uses of polymers

Polymers can be used in a wide variety of fields. Both synthetic and natural polymers have usage in our daily lives [9, 10]. They are used in manufacturing in the textile sector. For example, polyvinyl chloride is utilized in clothing; shoes, wetsuits, and spandex are produced from polymeric substances. Electronics like light emitting diodes, television parts, transistors etc. are polymeric products. Apart from these consumer goods, polymers are used widely in packaging, insulating and construction materials. They are also used for making automobile parts like rubber tires. Others have applications in paint, pharmaceutical, cosmetic and medical appliance industry. There are nowadays required in making polymeric currencies, bank cards, 3D printing and most importantly membrane separation techniques for water purification. This brief discussion on polymers and its properties in general is given in order to provide an impetus towards understanding the use of polymers as membranes for separation purposes [10]. Several polymers are used for membrane fabrication processes used for solutes separation. The chemical structures of some of these polymers are illustrated in Fig. 1.

Commercial membranes are composed of perfluorinated sulfonic acid polymers such as Nafion. It has good chemical, thermo-chemical and electrochemical properties [12]. Polyether ether ketone (PEEK) based membranes are widely being investigated as they have very high chemical and physical stability, and can be produced by simple economical methods [12]. Polyether sulfone (PES) is a hydrophilic membrane, which is easy to wet and has a fast filtration rate along with a low protein binding affinity that could minimise the membrane biofouling [13]. Polysulfone can be manufactured easily having reproducibility with pore sizes as small as 40 nm. These membranes have potential to be used in processes like waste water treatment, haemodialysis, food products processing and gas separation [13]. Polyvinylidene difluoride (PVDF) based flat

membrane is commercially available which has been extensively used for water and gas purification. Polytetrafluoroethylene (PTFE) membrane is the best for its hydrophobicity, chemical and thermal stability. Moreover, its good chemical resistance and excellent mechanical strength have attracted researchers' attention [14]. PTFE based membranes are popularly used for membrane distillation application because of its hydrophobicity. This type of polymers have various properties ranging from high chemical and temperature resistance to good electrical insulation capacity along with superior resistance to environmental factors such as UV, weathering etc. It also possess flexibility, resistance to fatigue, low moisture absorption coupled with its availability in purified food and medical grades [15]. Again, linear polymers like polycarboxylates having high molecular mass, polymers of acrylic acid or copolymers of acrylic and maleic acid, biodegradable, non-conventional polymers like poly lactic acid are also used for making polymeric membranes nowadays [16].

Figure 1. Chemical structures of commonly used polymers for membrane fabrication: a) Polyvinyl chloride, b) Polypropylene, c) Polystyrene, d) Polyester, e) Polyether sulfone, g) Polyvinylidene difluoride, h) Polyamide, i) Polyacrylonitrile, j) Nafion, and k) Polysulfone.

Table 1. Commonly used polymers used in separation science and their properties (Reproduced with permission from [20]).

Material	Technique Used in	Advantages	Disadvantages	Mechanical Strength durability	Hydrophilicity and Contact Angle	pH range	Chlorine resistance
Polysulfone	Microfiltration/Ultrafiltration	Good Mechanical Strength, Chemically resistant		√√	√ ~75	1–13 ^a	√√
Polyethersulfone	Microfiltration/Ultrafiltration	Rigid, compaction resistant, very permeable		√√	√ ~70	1–13 ^a	√√
Polyacrylonitrile	Microfiltration/Ultrafiltration	Oxidant tolerant, narrow pore size distribution		√	√√ ~60		
Polyvinylidene fluoride	Microfiltration/Ultrafiltration	Very oxidant tolerant, Chlorine resistant	Broader pore size distribution	√√	× 100	2–11 ^a	√
Polyethylene	Microfiltration/Ultrafiltration (uncommon)	High resistant to organic solvents, low cost, oxidant tolerant	Poor thermal properties, Weaker fouling resistance	√	×		×
Polypropylene	Microfiltration/Ultrafiltration (uncommon)	High resistance to organic solvents, decent mechanical strength	Low fouling resistance, not oxidant tolerant	√	√	2–13	×
Polyvinyl chloride	Microfiltration/Ultrafiltration		Poor thermal stability, not	×	×		

	ltrafiltration (occasionally)			oxidant tolerant				
Cellulose acetate	Reverse Osmosis, Microfiltration/U ltrafiltration	Renewable resource		Low permeability (RO)	×	√√√	5–8.5	√√
Polyamide	Reverse Osmosis (TFC active layer), Nanofiltration, Microfiltration/U ltrafiltration (occasionally)	Small pores, excellent retention, selectivity		Relatively impermeable/dense	√	√√ ~55	1–13 ^b	×

Symbols are used as follows: √√√= excellent, √√= good √= fair, and X = poor. ^aPoor long-term stability in basic conditions. ^bPoor long-term stability in acidic or basic conditions.

5. Polymeric membrane fabrication

In recent times, different techniques are available for membrane fabrication. The selection of the process depends on the polymer and the structure required. Phase inversion, stretching, interfacial polymerization and electrospinning are the commonly used techniques. In phase inversion, a homogeneous polymeric solution in a controlled manner is converted towards solid state by immersion-precipitation, thermally induced phase separation, evaporation-induced phase separation and vapour induced phase separation processes. Interfacial polymerization (IP) is a commercial method of fabrication of thin film composites for RO and nanofiltration (NF) membranes. In the basic IP method, a microporous PSf support is usually immersed in a polymeric amine solution and then the amine-incorporated membrane is again immersed in di-isocyanate in hexane. The membranes are then cross-linked by applying heat (sometimes not necessary) to form the porous membrane. Stretching is also a technique applied for microporous membranes used for MF, and UF processes. In this process, the polymer is melt-extruded and then stretched to get the porous structure. In track-etching, non-porous membranes are irradiated with heavy ions to form damage tracks across irradiated polymeric films. In recent times, electrospinning also emerges as a one of sophisticated techniques to fabricate porous membranes [1] In the following Table 2, some commonly used polymers for separation processes and their fabrication techniques are given.

*Table 2: Commonly used polymers and their membrane fabrication techniques
(Reproduced with permissions from [1]).*

Water treatment Process	Polymers used for membrane fabrication	Fabrication techniques	Average pore size of the membrane
Reverse Osmosis	Cellulose acetate/triacetate Aromatic polyamide Polypiperzine Polybenzimidazole	Phase inversion, Solution casting	3–5 Å 3–5 Å
Nanofiltration	Polyamides Polysulfones Polyols Polyphenols	Interfacial polymerization Layer-by-layer deposition Phase inversion	0.001–0.01 µm
Ultrafiltration	Polyacrylonitrile (PAN)	Phase inversion Solution wet-spinning	0.001 – 0.1 µm

	Polyethersulfone (PES)			
	Polysulfone (PS)			
	Polyethersulfone (PES)			
	Poly(phthazine ether sulfone ketone) (PPESK)			
	Poly(vinyl butyral)			
Microfiltration	Polyvinylidene fluoride (PVDF)	Phase inversion	Stretching	0.1–10 μm
	Poly(tetrafluorethylene) (PTFE)	Track-etching		
		Phase inversion	Stretching	
		Track-etching		
	Polypropylene (PP)	Phase inversion	Stretching	
		Track-etching		
	Polyethylene (PE)	Phase inversion	Stretching	
		Track-etching		
Membrane distillation	PTFE	Phase inversion	Stretching	0.1–1 μm
	PVDF	Electrospinning		

5.1 Types of polymeric membranes

Membranes are semi permeable which can separate two phases of matter and can selectively allow certain materials to pass while others to retain. Few controlling factors of membrane efficiency are its chemical composition, pressure, temperature, internal reactions etc. [19]. Selectivity of the membrane depends upon particle dimension, pore size, the diffusivity of solute in the matrix and electric charges associated [21]. Separation performance of the membrane depends upon pressure, temperature, feed flow, chemical composition of the membrane and its surface [22]. Most important membrane characteristics include thickness, porosity, pore diameter, solvent permeability, density, symmetry or asymmetry, mechanical and chemical resistance etc. [23]. Symmetrical membranes have uniform cross sectional pore sizes unlike asymmetric membranes which have larger pores [24, 25]. Morphologically, membranes can be of two categories i.e. dense and porous. In case of the dense membranes, the components undergo both dissolution and diffusion across the membrane while in porous membranes, the permeate transport in continuous fluid phase filling the pores of the membrane [26]. The other membranes are of two types: organic (e.g., cellulose acetate, polyamide etc.) or inorganic, like the metallic or ceramic membranes [25].

Membranes are of several generations:

- Membranes derived from cellulose acetate belong to first generation. These are pH, heat, microbe and disinfectant sensitive [21].

- Membranes derived from synthetic polymers belong to second generation. Such membranes are resistant to strong acids and bases, high temperatures and hydrolysis [21]. However, they are susceptible to mechanical compacting.
- Membranes of ceramic materials deposited on graphite surfaces belong to third generation. They are tolerant to high temperature, total pH range, high pressure and mechanical compacting [21].
- A hybrid of conventional electrodialysis and membranes with different pore sizes belong to fourth generation [21]. The process is termed as continuous electrophoresis with porous membranes (CEPM), and the driving force in here is a directly applied electric field [21, 27-28].

6. Membranes characterization tools

Nowadays, polymeric membranes are widely used technologies in gas separation, recovery, water purification and wastewater treatment. In order to ensure better and desirable membrane performances, these membranes need extensive characterization using various techniques. This help to understand their structure and chemical properties of membranes and confirm the quality and purity of the prepared membranes [29]. There are a lot of important techniques to understand the physical structure of polymeric membranes which are hereby discussed.

6.1 Scanning electron microscopy (SEM)

SEM is a technique almost similar to an optical microscope but only consists of electrons instead of light [30]. Prepared membranes are morphologically and topographically characterized by SEM. This technique is capable of determining the pore size of the porous polymeric membranes as well as measuring the thickness of layers in dense membranes [31]. In order to protect the polymers from burning, generally, polymeric membranes are thin-coated by gold or platinum which makes the membrane conductive. In SEM, data are presented as surface image which is expected to be free of cracks and holes. It is a surface of uniform structure having small holes in case of porous membranes. Average pore size is calculated with MATLAB software. Composite membranes made of two or more than two polymers can also be analyzed by SEM [32]. A porous support holds a thin layer of selective polymer and cross-section surface examination gives structural information of two polymers. In case of polymeric gas separation membrane, the transport mechanism is based on solution-diffusion model. In this case, the fully dense surface is free from fully penetrating holes and cross-section analysis is done in several reports [33]. SEM detects the thickness of the dense layer to

calculate gas permeability. For undergoing SEM technique, the sample must be solid in form and free of moisture as SEM is operated at vacuum and it can cause sample loss by evaporation [34, 35]. The samples are either to be electrically conductive or they must be coated. SEM does not measure membrane pore size in gas operation membrane. It measures the films of thickness more than 10 nm [36]. A SEM micrograph is given in Fig. 2 which shows a porous membrane structure.

Figure 2. SEM of polypropylene MF membrane where porous membrane structure is visible. Reproduced with permission from [20].

6.2 Transmission electron Microscopy (TEM)

TEM is another technique with magnification reaching 50 million and making it suitable for nano scale measurements [37]. In TEM, electrons are shot from an electron gun pointed at the sample. Electrons pass through the sample and these transmitted electrons create an image in a fluorescent screen that could give the details of internal membrane structure [37]. TEM is extremely useful in analysis of mixed-matrix membranes [38]. The nanoparticles to be uniformly distributed through the membrane can also be characterized. Agglomeration of particles as a result of molecular electrostatic forces could be analysed by TEM [39]. TEM requires special preparation of sample unlike SEM. Sample should be within 2.5 mm in diameter and up to 100 micron thick. Volatile samples cannot be used as it too causes sample evaporation and damage to the instrument. TEM only provides 2D image and does not give topographical data of the sample surface.

6.3 X-ray diffraction (XRD)

XRD is a unique technique which helps in the study of crystal structure of the polymeric membrane and the distance between the polymeric chains [39]. Mechanical properties can also be elicited by XRD. Besides, XRD identifies the chemical compounds, which help to confirm the sample purity [40]. In this technique, a tungsten filament generates X-ray beams, which is directed to the sample and the scattered X-ray is thereafter detected and analysed [40]. Bragg's law is used to calculate the diffraction angle [41, 42]. XRD represents data by intensity versus diffraction peak angle. Membranes having filler content can be analysed for their structural properties through XRD [43]. These structural properties are important to characterize in determining gas permeation through these membranes [44, 45]. XRD accurately measures large crystalline structures as compared with small structures [46] and does not strongly interact with lighter elements [47].

6.4 Fourier-transform infrared spectroscopy (FTIR)

This is a unique technique which helps to determine the functional groups of polymers. This method is applicable on gases, liquids and solids [48] and it is a quantitative method. In FTIR, an infrared radiation is sent to the sample using a reference solvent and some of the radiation from the sample will absorb while passing through or transmitting the rests. The Fourier transform function is a mathematical model which converts the data into spectrum. Another method to generate FTIR spectrum without using reference material is attenuated total reflection (ATR) [49]. FTIR gives data as the transmittance versus the wavelength. When the sample absorbs the entire radiation, the transmittance is zero and consequently 100% transmittance represents that the sample and the reference absorbed equal amounts of radiation. FTIR is very unique for tracing the hydroxyl, carboxylic acids and others. FTIR is capable of differentiating such chemical groups based on their wavelength [49]. This technique also determines the compatibility between the polymer and the solvent [50]. For mixed matrix membranes, FTIR determines the interaction of polymer and fillers and it is studied by the detection of functional groups of the fillers within the FTIR spectrum [51-53].

7. Modules for polymeric membrane testing

The arrangement of a membrane into devices and hardware is called “membrane module”, and it is used for the separation of the feed stream into retentate and permeate stream. The retentate means the remaining product after the filtration and the solution or compound which passes through the membrane in the process of filtration is called permeate. Module design is an important operation in the membrane separation process. Two types of membranes will be used for the design of a module: a) flat sheet membrane

and b) tubular membrane. There are two important things which will affect or lead to the range of the module, one will be the size of the membrane and second one is the method which is used for the packaging of a membrane into device. Nowadays, the membrane separation has been installed from small laboratories to big scale industries also. Here some of the separation techniques use e.g. membrane modules (RO), pervaporation (PV), (MF), (UF) and electrodialysis (ED) [54]. There are five basic designs that will be available in the membrane modules namely a) spiral wound, b) hollow fiber, c) capillary, d) plate and frame and e) tubular membrane.

Every membrane module has its own applications. For example, in RO separation and (PV) techniques; spiral wound, hollow fiber and plate and frame membrane modules are used. In UF and MF separation process, plate and frame, tubular, capillary membrane modules are used. Particularly in ED separation process, the plate and frame membrane modules are used. Even if the same membrane module design is using for different separation process, which means the design for the both separation processes is not same. For example, the plate and frame module designed for (ED) is quite different to the design make for pervaporation. The details of different membrane modules uses are highlighted in Table 3 and a schematic representation is given in Fig. 3.

Table 3. Membrane module testing for separation processes.

Types	Spiral Wound	Hollow fiber	Plate and Frame	Tubular	Capillary
RO	Yes	Yes	Yes	Yes	No
PV	Yes	Yes	Yes	No	No
ED	No	No	Yes	No	No
UF	Yes	No	Yes	Yes	Yes
MF	No	No	Yes	Yes	Yes

7.1 Spiral wound modules

The spiral wound module is manufactured by winding the permeate spacers and feed spacers along with the flat sheet membranes around a perforated central pipe. As mentioned earlier that this module is mainly used for RO, pervaporation and UF operations. The replacement of module elements is easily possible and further scaled up for bulk scale operations which are the major advantages in spiral wound module. Spiral wound module cannot be mechanically cleaned as hollow fibre module and because of that the particular material has a low tolerance. The spiral wound modules has limited

applications in UF because of low tolerance by increasing the width space between the membranes and the tolerance will be high for the UF [54].

7.2 Hollow fibre module

The hollow fibre module is manufactured by packing the many membranes in cylindrical shape. It is of two types either out-side (shell side) feed types or in-side (Bore side) feed types as shown in Fig. 3. The out-side-feed-type is used in case of high-pressure conditions and in-side-feed-type is used in case of low and medium pressure conditions [55]. Hollow fibre module consists of two layers, one is an active layer having the thickness of greater than 40 nm and another one is a porous non-selective support layer with thickness of 200 micro meters [56]. Hollow fiber modules have largest applications in membrane science. The main and important thing about hollow fiber module is that the feed stream needs to be very clean.

7.3 Capillary module

The capillary module is also like hollow fibre module. In capillary module, the fiber has larger diameter than for the RO. In this modular design, the feed flow will be arranged inside the feed flow as like active layer skin, which gives good control of concentration polarisation. Modules are fixed in shells with 0.8-1.0 meter in diameter and approximately 1.0 meter length. The packing densities are lower than RO unit because of its high diameter size. The capillary modules are mainly used in UF method. The capillary membranes for UF utilize polymers including polyacrylonitrile, polysulphone, chlorinated poly olefins etc. [54]. In certain cases, capillary membrane modules are also used in MF and UF. The fiber size (approximately 600 micron) is greater than the fiber size used in UF.

7.4 Plate and frame module

The plate and frame module is one of the earliest modules in membrane science. This module contains the membranes, feed and product spacers that are combined together in a metallic frame [57]. The main applications of plate and frame module are ED and UF, and the membrane arranged in flat sheet form. The spacers will not stick together with the membrane and they provide channels for the free flow of feed and product. But this is not using regularly in the present cases; this will specially be employed for the purposes of waste water treatment with higher levels of suspended solids like landfill leachate [55].

7.5 Tubular module

The tubular module consists of a straight and long membrane tube surrounded by a support tube and a porous support layer. The flow of feed is from internally along with the tube and the permeate passes through the membrane then into the porous layer and through appropriate holes in the support tube [54]. The main applications of the tubular module are UF and MF. The development of inorganic membrane materials in tubular form module is a particular significance in UF applications [54, 58].

*Figure 3. A schematic representation of some polymeric membrane module structures.
(Reproduced with permission from [20].*

Conclusion

Membrane technologies are used worldwide for purification purposes. These membranes are processed from varied types of polymeric materials. Among the materials used, polymers are groups of widely sought materials for membrane fabrications [59-67]. These membrane structures are determined by various morphological techniques. The applications of these membranes are determined by various membrane testing modules. Thus, these polymeric membranes have a huge potential for membrane separation processes especially in reclaiming wastewater and purification of drinking water [68-74]. In order to achieve sustainability in our technologies application of such novel processes is required worldwide.

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