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Review

Sustainable Membrane Technologies for By-Product Separation of Non-Pharmaceutical Common Compounds

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Abstract: The Chinese pharmaceutical industry and traditional Chinese medicine (TCM) are both vital components of Chinese culture. Some traditional methods used to prepare TCMs have lost their conformity, and as a result, are producing lower-quality medicines. In this regard, the TCM sector has been looking for new ways to boost productivity and product quality. Membrane technology is environmentally-friendly, energy-saving technology, and more efficient than traditional technologies. Membrane separation is the most effective method for separating and cleaning the ingredients of the non-pharmaceutical common compounds from traditional Chinese medicine (TCM). Membrane technology is currently being employed for the concentration, purification, and separation of TCMs. This review paper discusses how membranes are fabricated and their role in non-pharmaceutical common compound separation and TCM purification. Accordingly, the membrane applicability and the technological advantage were also analyzed in non-pharmaceutical common compound separation. Researchers pay attention to the choice of membrane pore size when selecting membranes but often ignore the influence of membrane materials and membrane structure on separation, resulting in certain blindness in the membrane selection process.

Keywords: membrane; membrane filtration; macromolecules; TCM; purification

1. Introduction

Pharmaceutical common compounds in traditional Chinese medicine (TCM) are the components most vital to and essential for human life. TCM has been the treasure of human existence for thousands of years. TCM has a different way of thinking about and treating illness that has been built up over this time. Herbal medicines, acupuncture, acupressure, massage, and moxibustion are all examples of traditional treatments. They are responsible for about 40% of all health care in the far East and especially in China [1]. According to the World Health Organization (WHO) definition, traditional medicine is a wide range of health practices, ways of thinking, knowledge, and beliefs. In recent times, more than 140 countries' health ministries have added TCM to their medication systems. So, it is known all over the world that the WHO has proven the medication activity of TCM for common diseases.

Evaluating the TCM administrative system, clinical technology, service monitoring, and other concerns supports TCM's development and improves its quality and level of service [2]. The clinical evaluation of TCM has mainly focused on evaluating its therapeutic effect, while research on its management systems and service supervision has mostly evaluated its community service competence. TCM includes medicines made from plants, animals, or minerals, spiritual therapies, manual techniques, and exercises, which can be used alone or together to keep people healthy and treat or prevent illness [3], whereas Western medicine is based on chemical compounds made in labs. TCM is made by extracting, separating, purifying, concentrating, and drying the ingredients [4]. As pharmaceutical technology has progressed, it has become evident that several traditional TCM preparation methods no longer meet industry standards, although TCM has unique effects and occupies a significant position in the field of medicine in the world. TCM water extracts have low active component concentrations and many contaminants. Unfortunately, the resources of TCM quality deteriorate continuously due to a lack of separation and purification levels. Generally, TCM decoctions based on decoction in water have been the main method of clinical use in Chinese medicine. At present, most Chinese medicine manufacturers still use water decocting as the basic extraction process [5–7].

The composition of the water extract in Chinese medicine is too complex, and the content of medicinal ingredients is generally low. It often contains non-medicinal ingredients such as starch, protein, mucilage, pigment, gum, and pectin [8,9]. It also contains toxic ingredients, which results in large amounts of TCM preparations, strong hygroscopicity, and difficulty in preparing quick-acting dosage forms [4,10]. There have been about 7000 kinds of TCM products on the market in China in the past few years. TCM products often have the appearance of being "big, black, and coarse". In particular, more than 80–95% of solid preparation products have invalid impurities and excipients, and the effective ingredients account for about 3–20% of product quality [4,11,12]. Traditional refining methods mainly include chemical treatment, general mechanical filtration (such as plate and frame, adsorption, and high-speed centrifugation), water extraction and alcohol precipitation or alcohol extraction, water precipitation, solvent extraction, etc. [13,14]. There are many problems, such as high solvent consumption, long production cycle, unstable product quality, high energy consumption during high-temperature concentration, a large amount of extraction wastewater, and environmental burden, which make it challenging to meet the needs of modernization and internationalization of TCM. In order to realize the modernization of TCM [15], high-tech membrane technology can be applied to raise the separation quality of TCM and shorten the dosing percentage of TCM and obtain the effect of "discarding the dross and selecting the essential" parts of TCM [12,16,17].

Naturally, high-molecular materials from plants (such as starch, polysaccharides, proteins, etc.) have been widely used in traditional pharmaceutical preparations as indispensable binders, excipients, emulsifiers, and so on [18]. Modified natural polymer materials or synthetic polymer materials have better permeability, film-forming properties, and adhesive properties [5,19]. When used as excipients in pharmaceutical preparations, they can not only improve the stability and moldability of the drug but also create a new type of pharmaceutical that provides specific intelligence (such as sensitivity to pH, temperature, and enzymes) or improve or enhance the biocompatibility and biodegradability of drugs, and increasingly show their potential in the field of medicine [20]. At present, modified natural high-molecular materials and synthetic high-molecular materials, especially synthetic high-molecular materials, have gradually shifted from subordination and an auxiliary role to a dominant position, forming characteristic polymer drugs, especially as drug delivery carriers. Since the 1960s [13], the continuous emergence of various new high-molecular materials has enabled sustained-release, controlled-release, and targeted drug formulations to develop rapidly in theory and practical applications [21].

The relative molecular mass of the active ingredients of traditional Chinese medicine is usually less than 1000, while the relative molecular mass of the ineffective ingredients (such as starch, pectin, protein, etc.) is generally more than 50,000, which can be called "non-pharmaceutical common polymer substances". Membrane separation technology based on a sieving mechanism can remove non-pharmaceutical macromolecules, so that small molecular components in traditional Chinese medicine and its compound can be screened in clusters. However, in the actual membrane application process, it is often found that high-molecular substances such as starch, pectin, and protein appear in the membrane and permeate with low-molecular-weight, which severely restricts the use of membrane technology advantages. At the same time, non-medicinal macromolecules are also the main factors causing membrane fouling [12].

Therefore, in response to the major demand for obtaining the essential medicinal substances of traditional Chinese medicine, based on the analysis of the molecular structure of non-medicinal polymer substances, we will focus on the study of the correlation between membrane materials, membrane processes, and polymers in the aqueous extracts of traditional Chinese medicines, and explore the optimization and optimization of traditional Chinese medicine membranes and membrane material design mechanisms and methods, to overcome the technical bottleneck of removing non-pharmaceutical macromolecule substances, and to break through to the key technology of obtaining small-molecular medicinal components of Chinese medicine compounds below 1000 by the membrane method [22].

Membrane separation technology has attracted wide interest from researchers in non-pharmaceutical common compound production because of its energy savings, high efficiency, and green characteristics. Membranes have proven to be one of the most effective technologies globally for filtration and separation of by-products from TCM [23–26], as shown in Figure 1. This technology has been recognized internationally as a significant high-tech with the most promising development in this century [26,27], and has been widely applied in food, medicine, the chemical industry, water treatment, and environmental protection. It is also regarded as one of the high and new technologies urgently needed to be promoted in Chinese traditional medicine in the pharmaceutical industry. In recent years, a number of enterprises in China's TCM industry have also taken the lead in adopting membrane separation technology, which has obtained enormous economic and social benefits [5,28]. In addition, the absorption method of TCM is realized through the biomembrane transport process, and the absorption rate is directly related to the particle size of the active ingredient of the medicine, which coincides with the separation principle of membrane separation technology; namely, the pore size screening effect [18,24,29,30]. A more effective and sustainable refining technology for non-pharmaceutical common compounds with membrane separation as the core is established to form a breakthrough in the traditional hydro-alcohol method; the production process of solid–liquid separation, purification, and concentration in the non-pharmaceutical common compound industry is transformed by integrated membrane integration technology, so as to realize the high efficiency, environmental protection, stability and intelligent control of non-pharmaceutical common compounds such as in TCM production [31–33].

Food processing [28,34,35], desalination [36,37], wastewater treatment [38–41], and the pharmaceutical sector [42], etc., all use membrane technology. It is incredibly efficient, requires a modest investment, consumes little energy, and is easy to use. Membrane technology is a TCM pharmaceutical industry alternative to several standard procedures. This review paper covers membrane technology's current use and future possibilities in non-pharmaceutical common compounds such as TCMs, including suggestions for ideal membrane applications and developments.

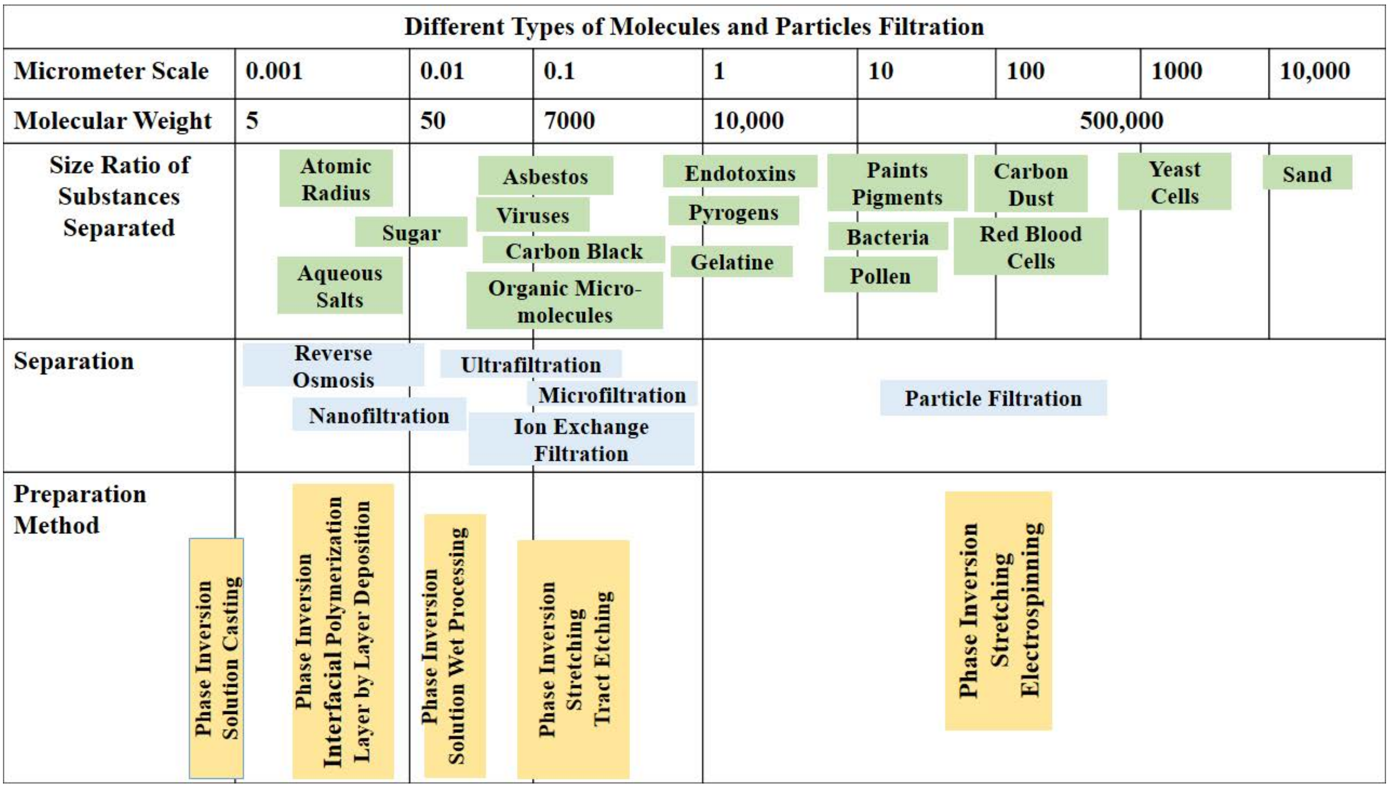

Figure 1. Different types of molecule and particle filtration.

2. Membrane Filtration

Semi-permeable membranes are formed as soon as a motive force is utilized in a membrane [43]. Many different types of filters with various pore sizes are available [25,43]. The vast range of membrane filtration applications, from removing large particulates to removing dissolved compounds, makes membranes an excellent choice for various industries. In recent years, membrane methods have become increasingly popular for eliminating bacteria, germs, and particles, along with organic matter from nature, and can change water's color, taste, and odor. In addition, they react with disinfectants to produce disinfection by-products [27,43–45]. Capital and operational costs are continuing to fall as advances in membrane manufacturing and upscaling are realized. The membrane processes discussed here include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) [46], and reverse osmosis (RO) [47,48].

2.1. *Microfiltration (MF)*

Membrane separation using membranes with different pore diameters of between 0.1 and 10 µm (1 micrometer = 0.0001 mm) and a molecular weight cutoff (MWCO) of more than 1,000,000 daltons is known as microfiltration (0.02 MPa and 0.5 MPa). In addition to removing sand and clay from water, MF is also effective at removing cysts from Giardia lamblia and cryptosporidium, algal growths, and a wide variety of bacteria [24,49]. However, MF does not provide an impenetrable barrier against viruses or bacteria. MF appears to suppress harmful bacteria in water when applied in conjunction with disinfection [50,51]. It is becoming increasingly important to control the quantities and types of chemicals used in water treatment. Membrane filtering can considerably decrease the addition of chemicals, such as chlorine, by physically eliminating microorganisms. The process can also remove synthetic and natural organic compounds to minimize fouling [26,34]. MF eliminates little or no organic matter in its regular operation; pretreatment, on the other hand, may increase the amount of organic material removed. In order to prevent fouling, MF can be applied prior to RO or NF. Groundwater desalination or hardness removal is required, for which RO and NF have historically been used [28,52].

2.2. Ultrafiltration (UF)

There is a wide range of MWCOs, operating pressures, and pore sizes for ultrafiltration, ranging from 0.02 to 0.1 μm. UF will eliminate bacteria and microorganisms that are not removed by MF, as well as certain viruses [29,53]. UF employs a membrane filter to remove dangerous micro-size bacteria, viruses, and micro-size other impurities from wastewater and drinking water [54,55]. The major advantages of UF membrane processes over traditional methods and disinfection procedures are size-exclusion filtrations rather than media depth filtration, the elimination of the need for chemical processes, and consistent elimination of particles and microorganisms in high-quality fouling treatment of water [56]. Furthermore, the UF membrane process for pharmaceutical and water treatment has a few drawbacks [25,57].

An ultrafiltration processing system employs 3.4 to 8.3 bar pressure. In suspension, larger particles stick to the membrane's outer surface because they are too large to flow through the membrane. The filtration system only accepts fresh water and minerals dissolved in water [15,55]. The UF membrane, a superfine filter, reduces particles to 5000 times smaller than a human hair in size. UF can eliminate these pollutants with a 90% to 100% success rate [58]. This membrane can last for up to two years [59]. Because of the differences in pore size and the different sorts of particles removed, each type of filtration has a specific function. For persons who desire to keep minerals in their water while yet removing minute impurities, UF is the filtration method of choice [60]. A UF system may be preferable to a RO system since it wastes less water in the drain than a RO system. In California, where water use is strictly regulated, UF may be a preferred choice. Someone living in South Carolina, where the water contains few dissolved minerals, may choose UF rather than RO because RO would not be required. UF is sometimes used to recycle effluent water after it has been filtered, allowing the water to be used for agricultural purposes [52,61].

2.3. Nanofiltration (NF)

Nanofiltration membranes have a MW range of 1000–100,000 daltons and a nominal membrane pore size of 0.001 μm. Higher operating pressure is required to push water through these narrower membrane cavities. Typical operating pressures range from 600 kPa (4.134 bar) to 16.00 bar. Almost all kinds of cysts, bacteria, viruses, and humic particulates may be removed with NF [62,63]. The addition of a disinfectant residual after the membrane filtering process provides excellent protection against the production of disinfection by-products (DBPs). Because NF membranes remove alkalinity, the resulting product water is corrosive, necessitating procedures like those used to treat fresh water. NF membranes also remove hardness from water, which is why they are also referred to as "softening membranes". Pretreatment of hard water treated by NFs is required to prevent hardness ions from precipitating in the membrane process. NF, on the other hand, requires more energy than MF or UF [22].

2.4. Reverse Osmosis (RO)

Nearly all inorganic pollutants may be successfully removed from water using reverse osmosis. Radium, natural organic compounds, pesticides, cysts, germs, and viruses may all be successfully removed with RO. When used in series with numerous units, RO is especially effective. Water should also be disinfected to guarantee its safety. Nearly all contaminants and non-ions can be removed using RO, which also removes most dissolved ions. It is useful for removing systems with seasonal demand variations because it is insensitive to flow and TDS levels [64]. RO has a number of downsides, such as high capital and operating costs; there is also concern about dealing with wastewater (brine treatment). In some circumstances, a high amount of pretreatment is required, fouling is a problem with membranes, and it produces the greatest effluent, accounting for between 25% and 50% of the feed [65,66].

3. Membrane Fabrication Method

Fabricating polymer membranes uses a variety of techniques, each of which has its own advantages and disadvantages [67,68]. Phase inversion, interfacial polymerization, electrospinning, melt spinning and stretching, and track etching are some of the most popular ways to produce polymeric membranes. By all these methods, two types of membranes can be fabricated: (a) flat membranes and (b) hollow-fiber membranes. These two membranes could be used to separate different types of ingredients from substances in the separation process, as shown in Figure 2.

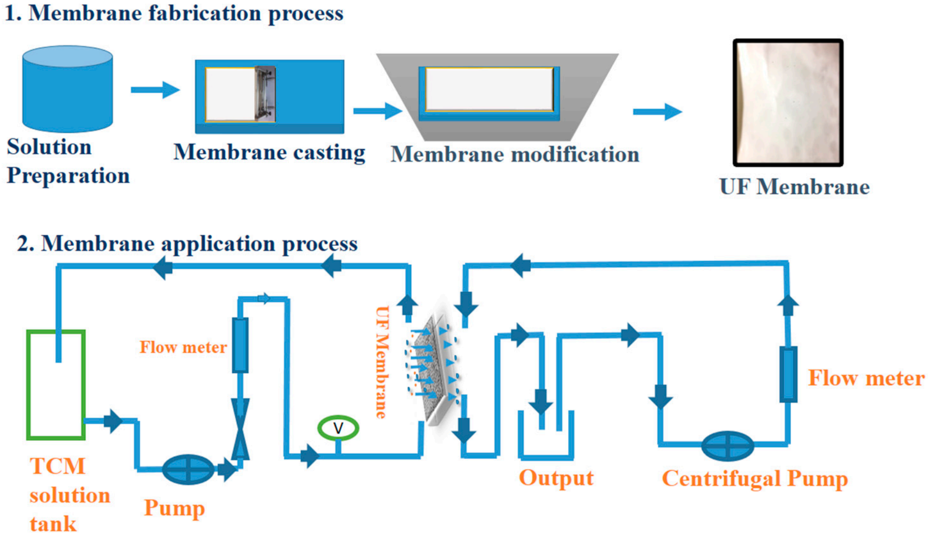

Figure 2. Flow chart membrane fabrication method (**1**) and application process (**2**).

3.1. Flat Membrane

3.1.1. Phase Inversion Membrane

Phase inversion occurs when a homogenous polymer solution is changed from a liquid to a solid phase after being homogeneous. Four fundamental forms are used in the fabrication of phase inversion membranes: (1) immersion precipitation, (2) vapor-induced phase separation, (3) evaporation-induced phase separation, and (4) thermally induced phase separation. Most polymeric membranes are prepared by immersion precipitation.

3.1.2. Immersion Precipitation

The immersion precipitation method is the most frequent method for fabricating flat membranes. The polymer solution (polymer solution) is cast and then immersed in distilled water containing a coagulation bath (CB) on an appropriate support layer. The interchange of solvents and non-solvents results in precipitation. Solubility in the solvent mixture is dependent on polymer solubility. Phase separation and mass transfer influence membrane structure. The shape and properties of the membranes are determined by the casting solution's temperature, viscosity, and velocity. Immersion precipitation refers to a method in which a concentrated polymeric casting solution is immersed in a non-aqueous solution (Figure 3) for the purpose of precipitation [69].

Here, both Q_1 and Q_2 represent the non-solvent flow, respectively, where X(t) is the position coordinate of the membrane in the CB interface, x is a spatial position coordinate normal to the membrane surface, and m is a coordinate indicating a location in the polymer-fixed frame of reference [70]. Figure 4 depicts the processes that take place when a polymeric casting solution is immersed in a non-solvent CB. Flux is a solvent/non-solvent that diffuses into the cast film, while flux Q_2 is a solvent that goes to CB. As the solution becomes thermodynamically unstable, the solvent and the non-solvent exchange continue until demixing happens. A solid polymer film with an asymmetric structure is formed as a result.

Membranes with pores between 10 and 300 µm wide are frequently formed at $Q_2 = Q_1$, and those with pores between 2 and 5 µm wide at $Q_2 = Q_1$.

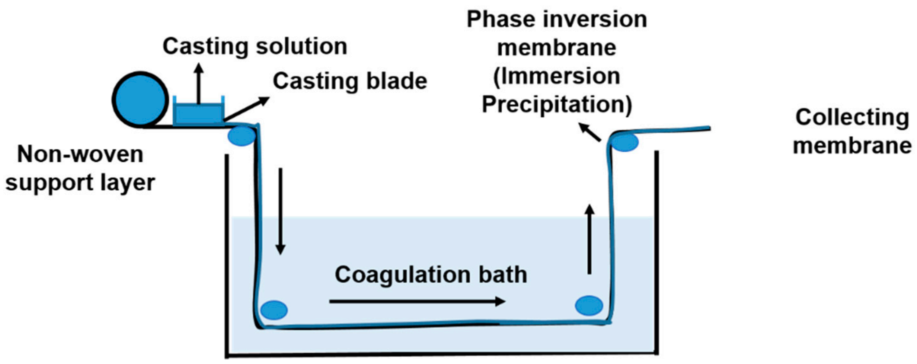

Figure 3. Phase inversion immersion precipitation.

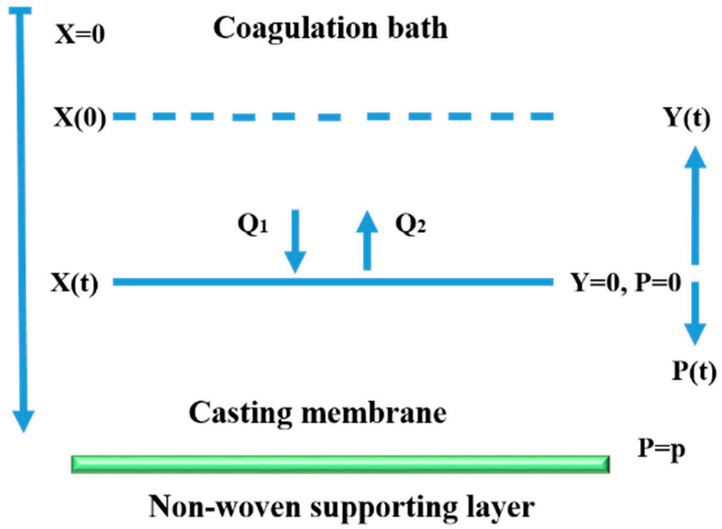

Figure 4. Visual representation of how a membrane and a bath interact.

3.1.3. Vapor Phase Precipitation

After the membrane formation has been cast with a solvent–polymer mixture, the casted membrane is placed into a non-solvent saturated vapor environment that contains the solvent. The high concentration of solvent in the vapor atmosphere prevents the cast film's solvent from evaporating into the environment. When a non-solvent is absorbed into the cast film, the membrane is formed. The formation of a porous flat sheet membrane is achieved by the use of this technique.

3.1.4. Precipitation by Controlled Evaporation

The mixture of solvent/non-solvents is used to dissolve the polymer in such a case. It is because of the solvent's fast vaporization rate that it evaporates, leaving behind a more polymer-rich makeup. Over time, the polymer precipitates, and a thin membrane is formed on top of it.

3.1.5. Thermally-Induced Phase Separation

A chilled polymer solution containing a mixed or a single solvent is used to achieve phase separation. Membrane formation is induced by solvent evaporation. Microfiltration membranes are frequently prepared using this approach.

3.2. Hollow Membrane Fabrication

The manufacture of hollow-fiber membranes is done in a variety of ways. The development of commercial reverse osmosis saltwater desalination membranes has had a significant impact on the development of hollow-fiber desalination membranes. Hollow-fiber membranes are being employed in a variety of filtration applications. The high surface area to volume ratio of hollow fibers is a significant benefit over other types. Melt spinning, dry spinning, and wet spinning are the three major methods [71]. For the production of HFM, an artificial polymer is utilized as the base ingredient prior to spinning. The three manufacturing processes are listed below.

3.2.1. Melt Spinning

Extruding polymer through a spinneret after heating it to its melting point in an inert environment is called melt spinning. During a phase transition, the polymer solidifies as it cools rapidly. This method creates a capillary or hollow fiber with a homogenous structure. With a wall thickness of N 5 pm, it is possible to stretch thin fibers with diameters smaller than 50 pm. The wheel's rotational speed can reach more than 1000 m s^{-1}.

3.2.2. Dry Spinning

Dry spinning involves dissolving the polymer in a highly volatile solvent. Extrusion is followed by heating, and the polymer solution hardens as the solvent is evaporated. This method can also be used to create ultra-thin fibers.

3.2.3. Wet Spinning

A wet spinning technique is used to spin the bulk of the hollow fibers used in technical membrane operations. This approach may be used to create any sort of membrane shape since many of the factors involved can be changed. Depending on the polymer used and its molecular weight, HFM production can be affected. During the extrusion process, the polymer solution is mixed with a non-solvent bath, resulting in demixing. The membrane begins to form in air spaces between the spinneret and the non-solvent water. Having a thorough understanding of this phase is a prerequisite for changing the morphology of the membrane [72].

In order to effectively separate and evaporate gases, the integrally skinned hollow fibers' uppermost layer must be defect-free at all times. Tube-in-orifice spinnerets are commonly used for this wet spinning technique, but they have a downside in that it is difficult to control the air gap conditions in the tube. An innovative three-orifice spinneret has been developed which can provide more control over spinning conditions applicable to a wide range of hollow fibers [73]. The following is a comprehensive breakdown of the various aspects that go into wet spinning.

4. Membrane Characterization

There are many types of membrane materials for the separation of active ingredients and effective parts of materials and substances. For example, traditional Chinese medicine, which includes different materials and particle sizes, requires different types of porous membranes. Once the separation system is selected, the membrane's pore size and pattern are easy to determine, but the choice of membrane material is not so simple [12].

4.1. Mechanism of Designing and Modifying Membrane Materials to Improve the Removal Rate of Non-Pharmaceutical Common Compounds

4.1.1. Improvement of Anti-Pollution Performance of Film Surface

In the process of membrane separation o, membrane fouling is the first problem to be considered. In this review, PES with better hydrophilicity can be selected as the membrane material, and the polymeric membrane separation process under different surface morphologies can be evaluated for the pollution resistance of non-pharmaceutical common compounds [12].

4.1.2. Optimum Design of the Membrane Surface

The spatial structure of the membrane surface affects the deposition and adsorption of non-pharmacologically common polymeric substances on the membrane surface to some extent. The polymeric membrane's surface-active group is used to carry out the graft reaction in the active center. By adjusting the reaction conditions and the concentration and type of the reactive monomer, a loose composite layer with different spatial morphology is constructed on the surface of the membrane [12].

4.2. Mechanism of the Membrane Preparation Process for Improving the Removal Rate of Non-Pharmaceutical Common Compounds

4.2.1. Distribution and Regulation of Membrane Pore Size

A cellulose membrane has to have an excellent homogeneous sponge membrane pore structure, optimum membrane pore size, and distribution regulation mechanisms, all of which are explored to improve the filtration precision of the non-pharmaceutical common polymer material [43].

4.2.2. Microscopic Regulation of Membrane Pore Structure

Aiming at the microscopic regulation of the special morphological structure of the membrane pores, a new asymmetric gradient was developed by changing the type and content of the solvent in the membrane casting solution, the composition of the non-solvent system, and the regulation of temperature and humidity during membrane formation [43].

5. Non-Pharmaceutical Common Polymer Material Characterization

The chemical composition of non-pharmaceutical common compounds such as TCMs is very complicated; they usually contain inorganic salts, alkaloids, amino acids, organic acids, phenols, ketones, saponins, steroids, terpenoids, tannins, protein, starch, and cellulose. Generally speaking, the relative molecular mass of the active ingredients such as alkaloids, flavonoids, glycosides, etc., is small and mostly not more than 1000; the relatively high-molecular-weight substances are mainly non-medicinal ingredients or drugs and can include protein, starch, and cellulose. Poorly used ingredients, of course, include some high-molecular-weight compounds such as certain polysaccharides and trichosanthin, which have certain physiological effects, and can be considered special cases. It can be seen that due to the diversification of botanical ingredients, suitable deep-processing separation techniques should give these products a certain molecular mass segment. Impurities in the inactive ingredients can cause major problems for non-pharmaceutical common compound formulations, such as the necessity for poor stability, large doses, and strong hygroscopicity. This is better illustrated in Table 1, which lists some of the active components found in various types of TCMs.

Table 1. Some TCM relative molecular masses (M.m.) [7].

Saponins		Alkaloids		Flavonoids		Phenolic Acids	
Ingredients	**M. m. (kDa)**	**Ingredients**	**M. m. (kDa)**	**Ingredients**	**M. m. (kDa)**	**Ingredients**	**M. m. (kDa)**
Timosaponin-A-III	0.74093	Aconitum	0.64574	Catechin Hydrate-98	0.29027	Salvianolic acid-I	0.49445
Timosaponin-Bii	0.92108	Rhynchophy-lline	0.38446	Kaempferi-de (KF)	0.30027	Salvianolic acid-II	0.71862
E SCUlentOSide A	0.82696	Crotaline	0.32536	Isoginkgeti-n	0.56652	Salvianolic acid-III	0.49244
Glycyrrhizinic acid	0.82293	Nuciferine-98	0.29538	Puerarin	0.41638	Salvianolic acid-IV	0.41835
Gypenoside-A	0.89907	Hyoscyamine or Levsin	0.28938	Edgar Morin	0.30224	Tanshinone-iiA	0.29435
Saikosaponin-C	0.92712	Arecoline	0.15519	Hesperidin	0.61057	Tanshinone-I	0.27629
Saikosaponin-A	0.78098	Matrine alkaloid	0.24837	Liquiritin	0.41840	Cryptotanshinone (CT)	0.29637

5.1. Ingredients (Effective Component or Effective Site)

Modern membrane separation technologies (such as microfiltration and ultrafiltration) use the "sieving" mechanism; that is, they use the membrane's pore size characteristics to separate and purify the material, and thus are increasingly favored in the production of non-pharmaceutical common compounds such as in the case of TCM.

The interaction can be roughly divided into three types. When the pore sizes of the membrane are smaller than the actual size of the suspended particles or macromolecules, the particles or macromolecules are blocked by their geometry and cannot enter and pass through the membrane but separate from the permeate, which is called extra-hole retention or surface entrapment. The pores of the membrane are more significant than the size of the particles or macromolecules, and they are able to enter the interior of the membrane pores while being trapped by the network within the membrane, which is referred to as pore retention. The "bridge" phenomenon occurs at the entrance of the membrane pore due to the accumulation of particles, so particles smaller than the membrane pore can also be trapped, which may cause "microfiltration" to become "ultrafiltration". The solute's adsorption on the membrane results from the interaction between the membrane, solvent, and solute. Most important is the interaction between the membrane surface and the solute, including the dual electron layer [3], van der Waals force [4], and the three-dimensional space. Role [4] and interaction forces are generated by Brownian motion [5].

5.2. Characteristic Methods of Non-Pharmaceutical Common Compounds

When preparing non-pharmaceutical common compounds, such as in the case of traditional Chinese medicines with the traditional separation method, membrane separation has unique advantages. (1) There is no phase change when separating, and specifically, it is well suited to the separation and concentration of heat-sensitive substances in TCM applications. (2) Separation does not consume organic solvents (especially ethanol), which can shorten the production cycle, reduce the loss of active ingredients, and help reduce environmental pollution. (3) The separation selectivity is high. Selecting the appropriate membrane material for filtration can retain the enamel, starch, resin, and some proteins without pharmacological effects in the Chinese herbal extracts without losing the active ingredients and improving the quality of the preparation. (4) Membrane separations have many applications, from removing solid particles such as pyrogens and bacteria to separating organic and inorganic substances in solution. (5) It can realize continuous and automatic operation, and is easy to couple with other processes to fulfill the requirements of advanced production of TCM. Recently, membrane separation technologies have been applied in the production of Kampo medicine in Japan, and there are products on the market made this way.

However, the promotion and application of advanced membrane technology in TCM are still in their infancy. The main reasons are: (1) The membrane pores are easily blocked, and the flux is rapidly attenuated, resulting in a decrease in production efficiency and a shortened membrane life. (2) Traditional Chinese medicine, especially compound preparation, has complex composition. Its active ingredients have not been fully clarified, limiting the application of membrane technology. (3) The research on the application of membrane technology in TCM systems is not systematic and in-depth. These shortcomings point the way to further research work; at the same time, some successful examples also prove that the application of advanced membrane separation technologies in the separation of active ingredients and effective parts of the non-pharmaceutical common compound such as TCM will increase and become broader.

6. Membrane Separation Process

6.1. Mechanism of Chinese Medicine Membrane Separation Process Based on Molecular Structure Analysis

By adjusting the concentration of macromolecular solute in the separation system, pH value of the solution, ionic strength, and charge composition, the interaction force between the non-pharmaceutical common polymer substance and the medicinal ingredient is changed; by computer simulation and by means of laser, the particle size analyzer was used to study the content and composition distribution of each component in the separation process, and explore the influence mechanism of the solution environment on the separation system.

6.2. Mechanism of Membrane Pore Size Distribution and Its Structural Regulation of the Separation Process

The corresponding relationship between membrane pore size, pore size distribution, and non-pharmaceutical polymer material removal rate under different solution environment systems were constructed. The filtration performance analysis of membrane separation with various gradient structure changes was carried out.

6.3. Mechanism of Influence of Process Operating Conditions on Separation Process

The flow rate can regulate the shearing force of the membrane surface and change the spatial structure of the common polymer; the trans-membrane pressure difference mainly affects the deposition rate and transmittance of the polymer on the membrane surface. By examining the removal effect of cellulose separation membrane on the non-pharmaceutical common compound under different flow rates and pressure conditions, the mechanism of the influence of process operation conditions on the separation process of TCM was studied.

7. Application of Membrane Integration Technology in Preparation of Non-Pharmaceutical Common Compounds

A preparation membrane integration technology is formed through a variety of membrane combination methods such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. The most widely used membrane integration technologies involve the extraction, oral liquids, and injection. The application of membrane separation technologies in the field of non-pharmaceutical common compounds such as in TCM can improve the product yield by 5–10% and the purity by 20–50%, or even higher; the production cycle is shortened by about half, the floor area is smaller, and the energy consumption is reduced by 30–80%.

7.1. Preparation of Non-Pharmaceutical Common Compound Liquor

Membrane separation technology is used to prepare common non-pharmaceutical polymer materials, especially in traditional Chinese medicinal liquor, which has a good effect on improving the stability and clarity of the medicinal liquor. A company (Jiangsu Jiuwu Hi-Tech Co., Ltd., Nanjing, China [47]) broke through with a TCM purification and separation method, building the first Chinese medicine extraction refining and concentration production line with membrane integration technology, and hence has reformed the traditional method of solid–liquid separation, purification, and concentration". Using ceramic ultrafiltration membrane to treat TCM, the transfer rate of effective components was 20% higher than that of the traditional alcohol precipitation process; the transfer rate of further purification by an organic membrane was 80–97%; 80–90% of the solvent was removed by nanofiltration membrane; the production cycle was reduced from 12 to 2 days, energy consumption was 10% lower, resource utilization was 15% higher, and labor productivity was 30% higher [47,74].

7.2. Pure Water Preparation

Since 1975, *The United States Pharmacopoeia* (USP) has specified reverse osmosis as the traditional method for the preparation of water for injection in seven consecutive editions. *The Chinese Pharmacopoeia* (2005 Edition) began to use reverse osmosis to prepare purified water. Through coarse filtration, ultrafiltration, electrodialysis, reverse osmosis, etc., impurities and harmful substances such as particulates, pyrogens, and inorganic salts in tap water can be removed effectively, stably, and with low energy consumption.

7.3. Comprehensive Utilization of Waste Resources of Non-Pharmaceutical Common Compounds

In the production of non-pharmaceutical common compounds such as TCM, the washing liquid of raw materials and the washing liquid or extraction liquid of medicine residue after extraction contain the target product or other effective ingredients. Due to their low concentration and difficulty in recovery, they are generally discharged directly as wastewater. As an economic purification method, membrane separation technology can be used to recycle these useful components.

In China, for instance, the framework of strategic planning for the development of TCM was recently released by the State Council (2016–2030), which regards the inheritance and innovation of TCM as an important aspect of the national science and technology strategy. It is clearly pointed out that TCM is one of the few science and technology fields with original advantages in China and an important embodiment of scientific and technological competitiveness in the field of medicine and health. Primary responsibilities include promoting the reform and upgrading of the Chinese medicine business, as well as implementing green manufacturing projects in the TCM industry. Because membrane technology has energy-saving, environmental protection, and high-efficiency attributes, it is recognized internationally as a key technology for green manufacturing. It is believed that membrane technology will inevitably play an increasingly important role in the Chinese medicine pharmaceutical industry [12,24].

8. Membrane Technology Applications in the TCM Industry

The general technological procedure of TCM preparation is shown in Figure 5. The conventional methods of separating and purifying TCMs—sedimentation, centrifugation, ethanol precipitation, salting out, clarifying agents, and macroporous resin adsorption—can be supplemented or even replaced by MF and UF. Figure 5 depicts the concentration process of TCMs, which can be accomplished via NF, RO, or MD.

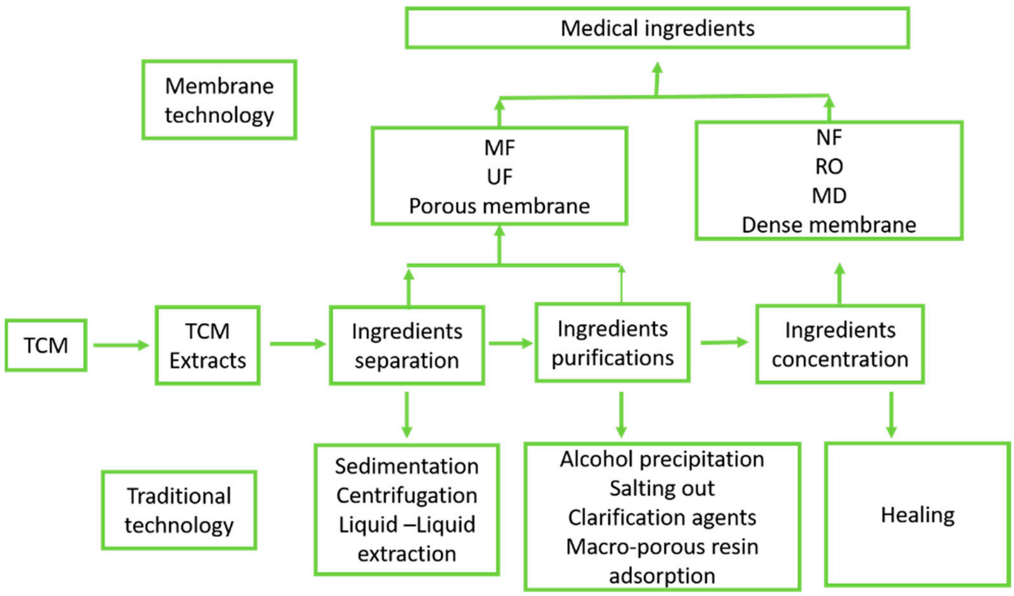

Figure 5. General technological procedure of TCM preparation.

8.1. TCM Extraction Process

The sieving effect of the membrane can separate the substances by the characteristics of the pore size of the membrane, which means that the separation product of the membrane can be multiple components of a certain relative molecular mass section, which is exactly the same as the relative molecular mass distribution characteristics of the medicinal substances of traditional Chinese medicine. Therefore, the most important advantages and characteristics of membrane technology for the traditional Chinese medicine system are: basically maintaining the traditional process of water extraction, and according to the relative molecular mass characteristics of the effective ingredients of traditional Chinese medicine, it will accurately remove starch, pectin, protein, and other polymer substances. At the same time, the small molecule components in traditional Chinese medicine and their compound prescriptions are used as a group of special chemical drugs for cluster screening.

8.1.1. Separation Process

Pretreatment technology is a key factor that prevents and controls membrane pollution and affects the effectiveness and economy of membrane separation technology. Advanced pretreatment technology and its optimized combination can ensure the long-term stable operation of the subsequent membrane system and reduce its operating costs and expand the application field of membrane separation technology. By understanding the characteristics of the materials to be separated, the targeted pretreatment process to ensure the long-term stable operation of the subsequent membrane system has become an advanced membrane technology concept. At present, the research on the pretreatment of the Traditional Chinese medicine liquid before the membrane mainly focuses on the macroscopic performance of the membrane flux attenuation and the retention rate of certain 1 to 2 index components by the relevant methods. However, the understanding of the pretreatment technology to improve the mechanism of membrane separation is unclear, making it difficult for the pretreatment technology to achieve the expected purpose, and we lack a scientific evaluation system for its effect. It is often necessary to make a large number of experiments with different traditional Chinese medicine systems to find a suitable pretreatment method, which requires a lot of work and a narrow range of applications.

Gao et al. discovered that purifying sophorae flavescent radix extract with 0.2 m Al_2O_3 ceramic filters reduced active ingredient loss compared to ethanol precipitation [75]. The turbid extract was filtered to produce a clear solution with a 39.5% decrease in solids and 79.7% retention of the oxymatrine, and 77.2% retention of the active flavonoid ingredients. The solid content of the flavescent radix extract was reduced by 39.9% after precipitation in 70% ethanol, and the retention rates of oxymatrine and total flavonoids were 66.0% and 54.8%, respectively. This demonstrated that membrane technology outperformed ethanol precipitation in terms of reducing active ingredient loss. Wang et al. [26] found that processing a 0.374 mg mL^{-1} chinaberry tree extract at 35 °C using a 0.45 m polyethersulfone (PES) membrane at a pressure of 0.08 MPa and a cross-flow of 0.15 L h^{-1} were optimal conditions. The membrane flux reached 147 L m^{-2} h^{-1} under optimal conditions, toosendanin retention was 99.4%, solid removal was 8.3%, and toosendanin purity increased from 0.89% to 8.8%.

8.1.2. Purification Process of TCM

Polysaccharides have been purified using fractional precipitation by organic solvents [76] salting out [77], quaternary ammonium salt precipitation [78], column chromatography including gel permeation chromatography [79], ion exchange chromatography [80], and membrane filtration [81,82]. Table 2 shows a comparison of different purification methods. Membrane filtration does not require heating or chemical reagent treatment; it is efficient, energy efficient, and environmentally friendly. Filtration also effectively retains polysaccharide biological activity. 9.4 section shows examples of using membrane filtration to purify TCM polysaccharides and other natural polysaccharides.

8.1.3. Concentration Process

The separations attained by NF fall in the middle of those attained by RO and UF [83]. Aqueous solutions of organic solutes with molecular weights of more than 300 Da can be concentrated and purified using NF membranes with pores of 0.5–2 nm in size [84]. The benefits of NF include lower costs than RO and a higher retention capacity than UF. NF is a viable substitute for heat treatment to concentrate TCM extracts since the molecular weight of TCM active components, with the exception of polysaccharides and proteins, varies from 100 to 1000 Da. Table 2 provides examples of the application of membrane filtration to concentrate TCM extracts.

Table 2. Examples of applications of membrane technology on the concentration of TCM extracts.

TCM Names	Membranes Type	Pore Size (μm)	Concentration (%)	Ref
Glycyrrhizae radix et rhizoma	NF and RO	0.02	90.7	[85]
Leonuri herba	VMD: Hollow-fiber membrane	0.2	10	[86]
Scutellariae radix	VMD: PVDF hollow-fiber membrane	0.18	100	[87]
Roselle	NF and RO	0.016	99.6	[88]
Salvia officinalis	MF, UF, and NF	0.45	100	[89]

Since the molecular weight of active ingredients in traditional Chinese medicine is generally below 1000, it is more suitable for concentration by nanofiltration. Traditional Chinese medicine concentration methods, such as multi-effect distillation, have many disadvantages, such as high energy consumption, serious loss of organic solvents, serious pollution of water resources and air, and high loss of active ingredients. The application of nanofiltration to the concentration and separation of traditional Chinese medicine can effectively solve the above problems. Since the nanofiltration membrane operates at room temperature without phase change, it is more suitable for the separation and concentration of some heat-sensitive drugs such as saponins, steroids, and terpenes in traditional Chinese medicine.

8.2. Electrodialysis (ED) Method for Traditional Chinese Medicine Recovery

Many studies have been done on the use of electrodialysis in TCM separation to recover valuable TCM compounds. Due to its complex TCM quality and high content of various macromolecules and impurities, electroplating macromolecules has always been a difficult point in the membrane concentration process (Figure 6). The use of a homogeneous membrane electrodialysis device effectively solves this problem. After this, the raw water is pretreated by sedimentation, oxidation, and ultrafiltration. It enters the electrodialysis concentration, and after reaching 12%, it enters the MVR evaporation, the fresh water is reused after reverse osmosis treatment, and the electroplating wastewater is effectively treated to achieve near zero discharge. The reverse osmosis concentrated water of the thermal power plant is treated by electrodialysis to meet the boiler water standard. The conductivity of reverse osmosis concentrated water is 3700 $\mu S\ cm^{-1}$, and the water volume is 150 $m^3\ h^{-1}$. After electrodialysis treatment, the effluent of electrodialysis concentrated water is 26 $m^3\ h^{-1}$, with a salt content of 11118 $mg\ L^{-1}$. Further, the electrodialysis fresh water enters the reverse osmosis system, and the reverse osmosis fresh water is further processed into boiler water by EDI. The conductivity of EDI water is $\leq$0.2 $\mu S\ cm^{-1}$, and the pH value is 7 ± 1.

Electrochemical oxidation in the electrodialysis process has been used for antibiotics removal during nutrient recovery from pig manure digestate. Lin Shi et al. found that antibiotics in the anode-ED were removed much more efficiently, with SD and TC removed in 30 and 60 min [90]. The electrodialysis process might improve the efficiency of traditional CMM production when it is used in the pharmaceutical industry of CMM. The diffusion dialysis flow process has been employed here. The process describes the wastewater/non-ingredients from traditional Chinese medicine extracts as filtered by a ceramic membrane, which then enters a diffusion dialysis device for treatment, and the residual liquid of diffusion dialysis is discharged to a biochemical treatment system for biochemical treatment. In the homogeneous membrane electrodialysis for concentration and desalination, the freshwater can be reused as a diffusion dialysis receiving solution, and the concentrated water is concentrated to a sulfuric acid content of more than 9% and reused in the production process of traditional Chinese medicine extrication. Through the combination of membrane integration technology and traditional biochemical process, the wastewater/non-ingredients of the traditional Chinese medicine extract can be utilized as a resource.

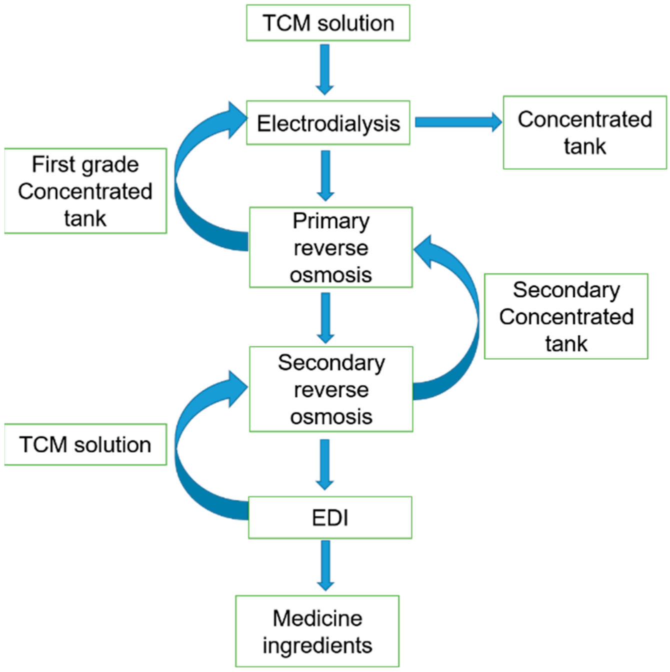

Figure 6. Electrodialysis process for TCM concentration process.

9. By-Products Separation Process

The effective components of TCM have a molecular weight lower than 1000. However, non-effective macromolecules (starch, pectin, and other macromolecules) have no physiological activity, limiting the overall benefits of membrane separation technologies in obtaining small molecular pharmacodynamics substances such as macromolecules, which are the primary cause of membrane fouling. As a result, in order to determine non-pharmaceutical common compounds' total pharmacological efficacy, molecular structure analysis of non-effective common macromolecules, aimed at the key scientific problems in the correlation between the molecular structure of non-effective common macromolecules and the pore structure of membrane material, and using material science theory and molecular simulation method, multidisciplinary approaches could be used to (a) Optimize the spatial form of the membrane surface and improve the membrane's antifouling ability; (b) Precisely control the pore sizes structure of the membrane and equal pore size distribution of the membranes, aiming at the innovative preparation technology of special membranes used; (c) Adjust the solution environment based on molecular structure analysis, and establish the optimum solution environment. Furthermore, the technological bottleneck of successfully obtaining pharmacodynamics macromolecules could be overcome, and non-pharmaceutical common compound engineering theory and technology could be created using multivariate and integrative concepts [24,81].

9.1. Active Ingredients and Effective Parts Separation Process by Different Membrane Filtration Processes

There are many types of membrane materials for separating active ingredients and effective parts of the non-pharmaceutical common compounds such as TCMs, including different materials, pore sizes, and membranes. Once the separation system is selected, the pore size and pattern of the membrane are easy to determine, but the choice of membrane material is not so simple. TCM extracts have historically been purified using ethanol precipitation. Even though it is a basic approach that provides excellent separation, it uses an organic solvent, consumes a substantial amount of energy, and significantly loses active components [91]. MF and UF are used to replace ethanol precipitation when separating TCM extracts. Table 3 shows several examples of membrane filtration separating TCM extracts [7,52].

Table 3. Some examples of membrane technology of TCM extracts [7].

TCM Names	Membranes Type	Pore Size	Filtration (%)	Ref
Sophora flavescens	Al_2O_3 ceramic MF membrane	0.2 µm	77.2	[75]
Toosendanin	PES MF membrane	0.45 µm	99.4	[26]
Cornus Officinalis	Al_2O_3 ceramic MF membrane	0.05 µm	80–90	[23]
Hawthorn	Ceramic MF membrane	0.2 µm	82.9	[90]
Ginkgo leaves	UF membrane 20 kDa	-	96	[27]
Glycyrrhizae radix et rhizoma	PS UF membrane	10 nm	98.9 to 99.3	[92]

9.2. Separation of Inorganic by-Products

With the establishment of modern pharmaceutical medicine and the hazardous effects acknowledged, science now considers TCMs containing HgS or Hg_2Cl_2 inferior to antibiotics and sedatives accessible in contemporary medicine.

9.3. Separation of Biological by-Products

The membrane filtration process is the most environmentally eco-friendly technique for future generation virus and bacteria filtration from TCM and wastewater. Its nano and ultra-size sponge and honeycomb-like pore structures easily filter micro and nanosized viruses and bacteria from TCM solutions, wastewater, and air. Talukder, M.E et al. have fabricated a micro-size (less than 1 µm) flat sheet UF membrane that can provide filtration 99% of viruses and bacteria from the air and water [25,93]. ETH Zurich researchers are working on a new filter membrane that is particularly effective at filtering and inactivating a wide range of airborne and waterborne viruses [25,91,94].

9.4. Active Polysaccharides Purification from Non-Pharmaceutical Common Compounds by Membrane

Polysaccharide biological activity is also successfully preserved by filtration [93,95,96]. Table 4 illustrates how to filter TCM polysaccharides and other natural polysaccharides using membrane filtration [97]. The complexity of polysaccharide extracts makes it challenging to produce high-purity polysaccharides with just one purifying technique. To separate polysaccharides as desired, it is required to combine two or more techniques. Ye et al. [98] started with 0.45 m membranes in their exploration of the combined use of MF, UF, and ion exchange chromatography to extract Sargassum pallidum polysaccharides in order to prevent fouling of the UF membranes. To separate the primary polysaccharide fractions, the filtrate was fractionated using MF membranes with 0.1 m pore size and UF membranes with 100, 50, 10, and 3 kDa MWCO [99].

Table 4. Examples of polysaccharides filtration by membrane technology [7].

Polysaccharides	**Membranes**	**Pressure**	**Membrane Separation (%)**	**Ethanol Extraction (%)**	**Water Flux**	**Feed Solid Concentration**	**Rejection Rate (%)**	**Feed Temperature (°C)**	**pH**	**Ref**
Rapeseed	PVDF UF membrane	1 bar	53.4				95.1	30 and 40	9	[79]
Porphyridium Cruentum	PES flat sheet UF membrane		80	48		0.35 g L^{-1}				[80]
Fructus Lycii	MF and UF flat sheet membrane with 0.2 µm pore size		90.4							[99]
Rhei Radix	PVDF UF flat sheet membrane	0.08–0.12 MPa	53.7			2.04–4.11 g L^{-1}		35–40	6–8	[100]
Poria	PS MF and UF membrane with 0.2 µm pore size	0.225 MPa	88.4	42.9	34.7 L m-^{2} h^{-1}	2 g/L	77.3	25		[32]
Cyclocarya	PS UF flat sheet membrane	0.05 Mpa	69.5			1 mg mL^{-1}			8.5	[101]
Ganoderma	UF flat membrane		Ultrasonic extraction							[102]
Radix Panacis	MF and UF flat membrane (5 µm, 1.2 µm and 0.45 µm pore size)	0.05 MPa	37.98–46.61						6–8	[103]
Concha Ostreae	PS UF flat membrane	0. 04 MPa	59.0%					30	7	[104]
Portulacae Herba	Al_2O_3 ceramic MF and PES UF flat membrane (5 µm, 1.2 µm and 0.45 µm pore size)	0.05 MPa	58.89%-38.89					100		[105]
Alga *Chlorella Pyrenoidosa*	MF and UF flat membrane (pore size of 0.1 µm)	1.0 bar	87.9		96 L m^{-2} h^{-1}			40		[106]
Camellia Oleifera Seed	UF membrane	0.05 MPa	78.55			1 mL min^{-1}		50	10	[107]
Sargassum Pallidum (Turner-c)	MF membrane (pore size of 0.1 µm)	45 MPa	86.6			20 L h^{-1}		55	7	[97]
Agaricus Subrufescens	CA MF flat membrane (pore size of 0.22 µm); PVDF UF flat membrane	0.5 bar	98.3				98		5.6	[81]
Ligusticum Chuanxiong Hort (LC)	ultrafiltration flux of TCM	0.1 MPa	78			10 mL h^{-1}		45 ± 1	1.2	[108]

10. Regeneration of Membrane

The membrane regeneration process for a non-pharmaceutical common compound such as a TCM is crucial. Separation is the most vital aspect of ingredient separation. Reverse osmosis and ultrafiltration membranes were cleaned and regenerated using physical and chemical methods. Several physical techniques were utilized in the cleaning process, such as foam-ball swabbing, water washing, gas–liquid cleaning, ultrasonic treatment, and electric vibration. Inorganic or organic cleaning agents, such as detergents and complex chemicals capable of removing scale from the membrane, were the primary focus of chemical therapy [81,109,110].

11. Nanotoxicology

Nanotoxicology describes the toxicity of membranes. It is concerned with the dangers posed to both humans and the environment. A lot of serious and light toxic polymers (chemical composition, surface structure, solubility, and functional groups) and solvents have been used to fabricate membranes, such as N-methyl-2-pyrrolidone (NMP), dimethylacetamide (DMAc), dimethylformamide (DMF), benzene, carbon tetrachloride, and trichloroethylene, 2-ethoxyethanol, 2-methoxyethanol, and methyl chloride, neurotoxins include n-hexane, tetrachloroethylene, and toluene. For example, the side effects of DMAc include that dimethyl acetamide can irritate the nose and throat when inhaled and contact can irritate the skin and eyes. Brain effects, such as depression, sluggishness, hallucinations, and other personality changes can be brought on by high or repetitive exposure. Dimethyl acetamide may cause nausea and/or jaundice [111]. Due to their effects on both human health and the environment, greener/low-toxicity solvents are beginning to gain attention [112,113]. Opportunities for novel and bio-derived, less hazardous solvents are only anticipated to grow globally as the globe transitions to a more bio-derived manufacturing base. Recently, green solvents such as methyl lactate, triethylphosphate, ionic liquids, organic carbonates, PolarClean, -valerolactone, and others have been researched for membrane manufacturing. Many green solvents are used to fabricate a flat or hollow-fiber membrane, such as ethyl-lactate, Cyrene, dimethyl isosorbide (DMI), tamisolve, and deep eutectic solvents [114].

12. Membrane Fouling

Membrane fouling is the primary impediment to the widespread use of membrane separation in industry. Membrane fouling is caused by the interaction of organic and inorganic components, microbial metabolites, and microorganisms; membrane pores are reduced in size and become blocked, causing a cake layer to form on the membrane's surface. Membrane fouling caused by polymer compounds during extraction of non-pharmaceutical common compounds such as TCMs can affect the permeability of small-molecule medicinal components to a certain extent. Membrane fouling is caused by the physicochemical interaction of particles, colloidal ions, or solute molecules in the filtered liquid with the membrane. Various particles are adsorbed/deposited on the membrane surface or in the membrane pore size, causing the membrane pores to block or become smaller. This affects the membrane's permeation flow rate and separation characteristics [115].

TCM extracts have a high viscosity and high content of macromolecular impurities. It is simple to create an adhesion layer on the membrane's surface, blocking the membrane pores and causing a sharp decrease in membrane flux, which significantly affects the membrane's leaning cycle and service life. Starch, pectin, protein, and tannins are the main pollutants in the membrane process of TCM and food industrial wastewater effluents. According to Bouchareb et al., food industry wastewater effluents are frequently associated with fouling phenomena that cannot be undone, with treatment facilities for potato processing wastewater being plagued by reversible fouling [116]. The main factors affecting membrane fouling are the internal resistance of the membrane, the resistance of membrane adsorption, the resistance of membrane surface deposition, and the resistance of concentration polarization [117,118], of which polarized concentration is an essential factor that causes the membrane flux to decrease in the process of membrane separation of TCM. The static adsorption of polymer substances such as starch and pectin on the membrane conforms to the Langmuir adsorption model; the content of pectin has the most significant correlation with viscosity; the solution structure of protein and its concentration, electrical properties, and solvency is important. When the protein is in a local instantaneous high concentration or high-density condition, it easily aggregates and causes membrane fouling. Although the choice of membrane pore size or intercepted relative molecular mass is mainly based on the relative molecular mass of the separated substance, the hydraulic size of the molecule is not only related to its configuration and aggregation state but also related to the concentration of the drug solution. Therefore, in view of the high viscosity and high membrane fouling characteristics of the Chinese medicine system, the relative molecular weight of the membrane should be appropriately increased when selecting the membrane [115].

13. Challenges

Nano and ultrafiltration membranes are used to separate micromolecules from a non-pharmaceutical common compound such as TCM and treat wastewater sustainably. Undoubtedly, some problems still severely restrict the development of non-pharmaceutical common compound membrane technology. For example, in theory, polymer materials cannot pass through membranes whose pore size is much smaller than their relative molecular mass. However, tens of thousands or even hundreds of thousands of polymer components with relative molecular mass, such as starch, pectin, and protein, are often found in the actual membrane process. They appear in the permeate of ultrafiltration membranes with a relative molecular mass of 10,000 or even 1000, which severely limits the technical advantages of the membrane to obtain overall medicinal substances. Membrane fouling is also a key obstacle to obtaining the desired filtration and separation result during the filtration process. A super-hydrophilic membrane can reduce fouling percentage problems during the filtration and separation process.

For another example, related studies have found that starch, pectin, protein, and tannins in the water extract samples account for a large proportion of TCMs (especially starch, pectin, and other carbohydrates). This is the main factor that affects the water extract's process, and chemical characteristics of TCM and causes the attenuation of the membrane flux, so it is the main factor leading to membrane fouling. However, it is difficult to predict, optimize, and monitor the membrane process with conventional mathematical models for TCM membrane separation's high-dimensional and multi-dimensional target products. Due to the lack of systematic theoretical guidance, especially on membrane fouling mechanisms, there is still no ideal method for membrane fouling control.

14. Future Perspectives

For the separation technology that relies on polymer materials, many studies have shown that it can be used to remove macromolecular impurities such as tannins and polysaccharides in the extract of TCM, and the effect is better than the previous separation technology, such as alcohol precipitation, and it consumes less energy. Less pollution is more conducive to the retention of active ingredients. However, because these new advanced technologies have just been applied to the field of non-pharmaceutical common compounds such as TCMs, there are still many problems that need to be solved, such as the high cost of membrane separation, the contamination of the membrane by chemical liquids, the unstable flocculants, and the specifications of the basic materials of various separation technologies. These technologies are used in the production of the non-pharmaceutical common compounds, and there is still a lack of corresponding equipment and processes, so there is still a way to go before they are promoted to industry. While conducting basic research, applied research should be strengthened simultaneously so that these new technologies can be used to produce non-pharmaceutical common compounds such as TCM preparations as soon as possible, and the quality of these products should be improved.

Due to the complexity and uncertainty of the active ingredients and the mechanism of action of TCMs (especially compound prescriptions), it is still difficult to apply new drug delivery systems with new polymer materials as carriers in TCM. However, it is currently possible to study the mechanism of ingredients. Relatively mature TCMs or natural medicines whose dosage forms need to be improved apply these technologies to improve the efficacy and bioavailability of Chinese medicines. Several new dosage forms of Chinese medicines with reliable efficacy have been introduced.

When using biocompatible and degradable polymer materials to prepare slow-release and controlled-release preparations such as TCM nanocapsules and microspheres, some still lack a reliable drug release measurement and efficacy evaluation system. There is still a long way to go to the genuinely controllable release of drugs, which requires the joint efforts of materials science and TCM researchers.

15. Conclusions

The high-efficiency removal of "non-pharmaceutical common polymer substances" in cases such as TCM is described and discussed, and the application prospects of membrane filtration technology that can achieve precise separation without phase change have been investigated. However, the membrane separation effect is not ideal due to the substances' complex molecular space structure. In future research, on the one hand, it is necessary to carry out an in-depth analysis of molecular spatial structures; on the other hand, it is essential to select membrane materials according to specific conditions and micro-control the internal structure of membrane pores; in addition to the basic pore-size sieving principle. It is necessary to pay attention to the modification methods of the membrane surface and to study the mechanism of action between the membrane surface and the polymer substance; at the same time, the influence of the solution environment on the spatial structure of the polymer and the separation process should be investigated. Therefore, only by carefully considering the above factors can the technical advantages of membrane separation be fully utilized. The technical bottleneck of removing "non-pharmaceutical common polymer substances" widely existing in medicines can be realized in this way.

In short, the modernization of Chinese medicine is a huge system of engineering, which requires cooperation among multiple disciplines, and polymer materials have a broad application prospect in Chinese medicine. To fully integrate polymer materials science and traditional Chinese medicine require both the efforts of materials science and the efforts of traditional Chinese medicine and pharmacy. The popularization and application of new materials and new technologies in traditional Chinese medicine rely more on the basic research of traditional Chinese medicine, such as chemistry, analysis, and pharmacology.

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