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Review Paper

Membrane Fabrication by Solid Waste: Opportunities and Challenges

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ABSTRACT

Solid waste mismanagement is a global issue caused by population growth, industrialization, and daily human activity. Currently, the majority of trash produced is either dumped in landfills in affluent countries or open pits in poor nations. In addition to necessitating a great deal of land area, landfilling and open dumping may cause other environmental difficulties. In fact, solid wastes may provide many chances for reusing as raw materials for the creation of useful, high-value goods in response to the need for a circular economy. Due to their cheap prices, possible high removal efficiency for pollutants, renewable and sustainable qualities, solid waste-derived membranes have gained considerable research attention as a waste-to-resource solution for a variety of water treatment applications. The fabrication and applications of economical membranes manufactured from natural resources have been reported. However, comprehensive reviews that discuss the fabrication, properties and potential applications waste-generated membranes are still limited. The features and material recoverable resources for membrane production are emphasized in this study. Based on biopolymers, plastics, and inorganics recycled materials, a summary of membrane manufacturing and performance using recoverable resources for liquid separation applications is provided. There are many prospects in this fascinating field since waste-derived membrane for water filtration is a new technology. For converting solid wastes into useful membrane products for water treatment, this evaluation offers crucial advice.

KEYWORDS: Recycled Materials; Waste management; Waste-derived membranes; Circular economy; Liquid separation.

GRAPHICAL ABSTRACT

HIGHLIGHTS

- This review discusses recycling solid waste into water-treatment membranes.
- Circular economy solid wastes can be utilized to make membranes.
- Suitable biopolymers, plastics, and inorganics waste for membranes is introduced.
- Membrane fabrication and performance with recycled materials are discussed.
- Future perspectives on waste-derived membranes are suggested.

1. Introduction

A significant population growth and development in industrialization has led to the concurrent expansion in many sectors including agricultural activities and daily consumption (Zhang et al, 2022). Numerous everyday activities and industrial operations create garbage, and the amount of waste generated rises proportionately to the demand for goods (Sebastian and Louis, 2021). As a result, the issues related to resource management and garbage disposal are rapidly increasing. In addition to posing serious environmental risks, poor disposal and handling can have a detrimental effect on human health (Mrozik

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et al, 2021). Due to the tremendous scope of these problems, researchers are forced to look for answers that include the development of cleaner technology and the use of more sustainable resources. More studies and research are needed, and they should concentrate on methods for waste management, circular economy, and product life cycle analysis since trash creation is at an alarming level (Sharma et al, 2022). The circular economy, as shown in Fig. 1a, is a resource-efficient framework that emphasizes getting rid of waste and strengthening the sustainability of the whole economy.

Membrane technology is known as an important instrument for desalination and wastewater treatment, in parallel to the constant development in worldwide clean water demand and the persistently restricted supply and stress on these resources. Due to its high reliability, high efficiency, and simplicity of use, membrane technology has been used in a wide range of industrial and municipal installations and is now popular for both water treatment and reuse as well as water desalination (Issaoui et al, 2022). Especially, wastewater treatment technologies with membranes are widely accepted in many developed regions to offer high-quality and consistent treatment, meet the increasingly stringent discharge requirements, and obtain high-quality discharge that is suitable for beneficial reuse (Obotey Ezugbe and Rathilal, 2020; Ahmad et al, 2021). While researchers are looking for cheap materials to reduce the price of producing membranes, many solid wastes can provide easily accessible and cost-effective sources for membrane manufacture (Mohanty et al, 2021). The recyclable biopolymers, plastics, and inorganics resources for membrane production are shown in Fig. 1b. In addition to lowering the cost of membranes and waste disposal, using wastes as raw materials for membranes provides value to trash that would otherwise be disposed of in the traditional manner.

The goal of this study is to provide an evaluation of current advancements in membranes generated from solid waste for water treatment. There have been several summaries of research into the materials, uses, and manufacture of cheap membranes made from natural substances (Issaoui and Limousy, 2019; Saha et al, 2022). But there is currently a lack of comprehensive analyses of membranes made from waste products. The importance of "waste-to-resource" and the rising demand for solid wastes to be converted into membranes need an up-to-date evaluation of this intriguing subject. This review begins by providing recoverable biopolymers, plastics, and inorganics resources for membrane manufacturing. We also provide a summary and analysis of the production of membranes made from trash. Finally, we examine the probable future of membranes created from garbage and identify future research options. This article offers valuable information on how to convert the garbage into marketable membrane products for water purification.

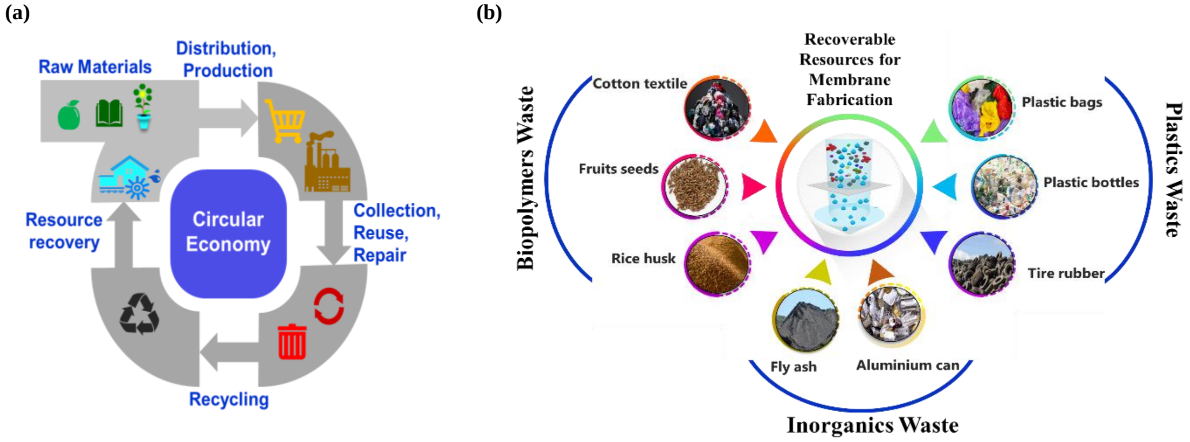

Figure 1. (a) The depiction of the circular economy idea; (b) Biopolymers, plastics, and inorganics recoverable resources for membrane fabrication.

2. Recoverable resources for Membrane Fabrication

The production of biopolymers, plastics, and inorganics trash have increased dramatically as human activity around the globe has expanded. Materials may be chosen for an appropriate purpose based on the kind of restoration, the qualities, and the cost. Any substance that is biodegradable and originates from a plant or animal is referred to as biopolymers waste (Fredi and Dorigato, 2021). Paper, cotton textiles, food scraps, and rice husk are only a few forms of biopolymers waste. The term plastics and inorganics waste refer to the kind of rubbish or the remainder of the material that cannot be broken down quickly and typically does not come from living things like plants or animals (Cherubini et al, 2009). Some common types of plastic waste include tires, food containers, plastic bags, and bottles. Examples of inorganic waste are glass, aluminum cans, and fly ash. Solid wastes from homes and factories both include components that might be useful in making membranes for improving the quality of water. In the next sections, the biopolymers, plastics, and inorganics recoverable resources for membrane fabrication will be explored individually.

2.1 Biopolymers recoverable resources

The most classical example of biopolymers recoverable resourses is cellulose. Cellulose may be obtained from a variety of sources, including plants (rice husk, banana rachis, kinds of cotton, and sugarcane bagasse) (Baruah et al, 2022). Large amounts of investment are being made to convert cellulose from this inexpensive and readily available feedstock into higher-value goods (Goswami et al, 2022). Due to its intricate inter- and intramolecular hydrogen connections, cellulose is a fibrous, strong, and water-insoluble polymer that is vital to preserving the structure of cell walls in plants. Furthermore, since cellulose is a renewable natural polymer, it may be used as an alternative to non-biodegradable polymers derived from fossil fuels. The global focus of many scientific studies has shifted to cellulose and its structure and shape. A linear polysaccharide comprising D-glucopyranose units joined to one another by -(1-4)-glycosidic linkages makes up the biopolymers molecule known as cellulose, having the chemical formula $(C6H10O5)n$ (Srishti et al, 2022). Cellobiose is the name for the glucose dimer that makes up the repeating unit (Lehrhofer, 2022). The cellulose chain has three hydroxyl groups on each monomer. Three hydroxyl groups are present, as shown in Fig. 2a, at locations C2 and C3 (secondary hydroxyl groups), as well as C6 (primary hydroxyl groups). Both intramolecular and intermolecular hydrogen bonds may be formed between these three hydroxyl groups (Fig. 2b) (Stenstad, 2008). While intermolecular hydrogen bonding refers to the linking with other polymer chains, intramolecular hydrogen bonding refers to the bonding between D-glucopyranose rings inside polymer chains. The production of very dense molecular arrangements made possible by these two forms of hydrogen bonding results in the construction of web-like structures in three dimensions.

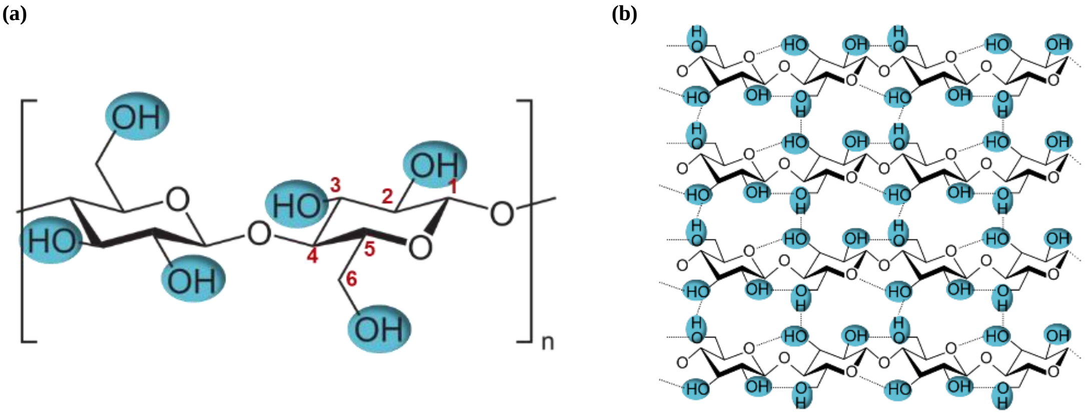

Figure 2. (a) Structure of cellulose unit; (b) Intermolecular and intramolecular hydrogen bonding in cellulose.

Numerous waste sources may be used to extract cellulose. Known key sources of cellulose are agricultural wastes and woody leftovers. High adsorptive potential for the removal of industrial contaminants has been shown for nanocrystalline cellulose, which was isolated from oil palm empty fruit bunch (Septevani et al, 2020). Continuous expansion of the textile industry's chemical and water use has resulted in a substantial increase in waste output. Cotton is the second-most important raw material after synthetic fibers, and as a result, more cotton waste is produced, either during the pre-consumer stage of production, such as when yarn, fabric, and apparel products are made, or during the post-consumer stage, when the waste is disposed of after the product's useful life has expired. Cotton textiles, which are >95% cellulose (Subramanian et al, 2022), may be handled to produce cellulose if the right solvent is found. Paper waste contributes significantly to municipal and industrial garbage, with an estimated 400 million tonnes generated yearly, including cardboard, office documents, and newspapers (Del Rio, 2022). The regeneration of waste newspapers, which are rich in cellulose, lignin, and hemicellulose, has produced a translucent or clear film with superior mechanical properties (Xia et al, 2021). Converting wastepaper into useful cellulose-based goods provides more financially appealing alternatives than recycling wastepaper into undervalued commodities like newspapers and boxboard. One of these products is a cellulose-based membrane, which has been crucial in several applications (Bharathi, 2022). The thermal stability and mechanical strength of polymeric films are significantly improved when cellulosic membranes generated from agricultural waste are included in the matrix of the films (Bascón-Villegas, 2021). Three significant sources of cellulose waste including waste cotton textiles, date fruit seeds, and rice husk waste covered in the section on membrane fabrication and performance using biopolymers recycled materials.

2.2 Plastic recoverable resources

Plastic is the miracle substance of our current industrialized period, fuelling the astounding expansion of our contemporary economy. Polystyrene, poly (ethylene urethane), and poly(ethylene terephthalate) (PET), are the next most commonly used polymers after Poly(vinyl chloride) (PVC), polypropylene (PP) and polyethylene (PE). Over 90% of all plastics created to date are these six types. The thermoplastic nature of the majority of these polymers gives them exceptional resistance to degradation. The yearly global production of plastics is estimated at 380 million tonnes, with only around 20% generally recycled. This has a significant impact on both global waste and environmental contamination. Post-consumer plastic garbage typically contains a variety of polymers of unknown content and often includes organic like food leftovers and inorganic for instance inks impurities, making challenges to plastic recycling. The vast majority of this plastic trash has little value since it is burnt in power plants, dumped in landfills, or washed out to sea (Kumar et al, 2021). The estimated decomposition time for the currently produced plastic garbage is between 250 and 500 years due to the chemical inertness of the substance. The components of plastic garbage may also get into our food supply via animals and crops. Nano plastics with diameters less than 6 nm may easily pass through the cell membrane of plants and accumulate in plant tissues.

Chickens may be exposed to microplastics if they eat earthworms that have consumed microplastics themselves. This presents a significant hazard to health, the amount of which is unclear (Sangkham et al, 2022). Reusing and recycling plastics is the preferred method of waste management since it reduces demand for plastic and other fossil fuel-based commodities (Wiah et al, 2022). Alternative routes of recycling include producing energy, mechanical recycling, and membrane production (Thakur et al, 2018). Over the past decades, membrane fabrication has become increasingly used as a separation medium due to its many advantageous characteristics. These include its simplicity of construction, high mechanical strength, cost-effectiveness, low energy requirement, and superior chemical resistance against organic and inorganic solvents (Dong et al, 2021).

These recyclable polymers are prospective materials for membrane fabrication due to their vast availability as post-consumer waste, simplicity of processing, and capacity for film formation. As with other typical hydrophobic high-efficiency thermoplastics, the hydrophobic property of the majority of waste-derived plastics has become the greatest obstacle to their re-use as raw materials for membranes in water purification (Goh et al, 2021). This constraint may be addressed by the addition of hydrophilic polymers or additives to plastic trash. Poly(ethylene glycol) (PEG) and polyvinylpyrrolidone are two examples of commonly used hydrophilic additives that may be used to increase the hydrophilicity, mechanical strength, and porosity of polymers generated from plastics (Wongchitphimon et al, 2011; Amirilargani et al, 2010). Most plastics are hydrophobic, making them a good choice for membrane distillation, a process which uses a microporous hydrophobic membrane to limit the mass transfer of liquid to form a gas-liquid barrier.

2.3 Inorganic recoverable resources

2.3.1 Ash waste

Fly ash generated by thermal power plants is one of the most dangerous air pollutants and a significant cause of respiratory diseases such as allergies, asthma, and pulmonary fibrosis (Munawer et al, 2018). This is due to the fact that fly ash includes silica, which irritates the mucous membranes of the lungs and may lead to these illnesses as well as more dangerous ailments such as cancer (Zierold et al, 2020). The high metal concentration of fly ash also makes it a potential cause of groundwater pollution. The annual production of fly ash in China is over 600 metric tonnes, making it the first biggest producer in the world before India (Assi et al, 2020). With an ash concentration of close to 30-45%, the coal utilized in thermal power plants in India is of extremely low quality (Debnath et al, 2021). This enormous amount of fly ash is produced, and some of it is utilized in the manufacture of bricks, cement, tiles, filling mines, building flyovers, and roads, along with others. While most of the fly ash produced is put to effective use, as of 2018-2019, 22.41% of it is wasted because it is dumped in improper locations, polluting the air and water (Yousuf et al, 2020). Recent research has concentrated on finding the best possible uses for fly ash, such as in membrane separation technology, to prevent its wasteful disposal (Yusuf et al, 2020; Samadi et al, 2022). Using fly ash in membrane production is helpful since it lowers production costs and eliminates the problem of sloppy waste disposal (Rathoure, 2020). Furthermore, the application of fly ash for membrane fabrication is appealing since it recycles a by-product into a useful substance that may be used for the cleaning of polluted water (Goswami and Pugazhenthi, 2021).

2.3.2 Aluminium can waste

Aluminium dross is a complex oxidic substance that results from the oxidation of aluminium in the presence of air during the melting process. On the surface of molten aluminium, a by-product composed of inorganic compounds with a high concentration of oxides accumulates (Xiao and Reuter, 2002). This solid, dark-grey waste is often a by-product of the aluminium manufacturing process. When aluminium is burned off in a furnace, the material also has an uneven form and contains lumps and grains (Tsakiridis et al, 2013). While fine aluminium dross has a very high concentration of oxides and salts, aluminium dross clumps possess a high concentration of metals and a small concentration of oxides (Zhu et al, 2022). Silicon dioxide, aluminium oxide, and magnesium oxide are the primary elements in aluminium dross, with the alumina percentage ranging from 50-75% (Mahinroosta and Allahverdi, 2018). Aluminium dross has been investigated for possible use in ceramics, nonferrous metals, cement, and potentially nuclear engineering and space technology due to its high alumina content (Shokravi et al, 2021).

Unfortunately, millions of tonnes of this trash are eventually dumped in landfills, where it poses major health and environmental risks (Gupta et al, 2019). Aluminium dross should not be disposed of in landfills since doing so is not sustainable and might lead to environmental degradation. Aluminium dross has been designated as a scheduled waste in Malaysia. This waste requires the careful and secure collection, processing, and disposal. Furthermore, the municipal authorities charge $490 per tonne for the disposal of this material, which is an expensive operation (How et al, 2017). Aluminium production firms may find the high fees connected with this trash to be a hardship, leading to the potential for illegal dumping of aluminium dross waste in a remote place. The production of this schedule waste as an industrial by-product for the creation of a ceramic membrane with prospective uses is ideal. Alumina spinel composite hollow fiber membranes made from aluminium dross waste might be a very competitive alternative for membrane-based treatment due to their cheap cost. Furthermore, it is anticipated that this discovery will make it possible for the development of alternative alumina-spinel-based hollow fiber membranes from aluminium dross waste, the utilization of which will be cost-effective for the aluminium manufacturing industries by lowering disposal expenses and will also result in fewer environmental issues (Verma et al, 2021).

3. Membrane fabrication and performances with biopolymer recycled materials

3.1 Waste cotton textile

Cotton textile has the greatest potential for successful recycling since it is predominantly made of cellulose, which has a wide range of uses, including reinforced composites and other products (Ramamoorthy et al, 2015). Waste cotton, which has outlived its usefulness, maybe upcycled into a variety of value-added goods with customizable characteristics and sustained use potential due to the cellulose in them (Ślusarczyk and Fryczkowska, 2019). After identifying a suitable solvent medium, one alternative is to manufacture cellulose membranes. The dissolution of cellulose in ionic liquids and ionic liquids cosolvent systems is now a topic of extensive discussion (Zhang et al, 2021). For the manufacture of membrane casting solutions, 1-ethyl-3-methylimidazole acetate [EMIM][Ac], a low-corrosive and -toxic ionic liquids, combined with dimethylsulfoxide (DMSO) provides a medium-viscous and inexpensive system (Livazovic et al, 2015). Due to cellulose's biocompatibility, hydrophilicity, and reasonably excellent durability, the resultant membranes have a wide range of potential uses. The hydrophilicity of the cellulose membrane makes it a practical choice for a variety of applications, including the purification of wastewater from the paper and pulp industry and biorefinery streams (Li and Takkellapati, 2018).

Lopatina et al. assessed the viability of using waste cotton textiles in the production of cellulose membranes (Lopatina et al, 2021). The [EMIM][Ac] - DMSO combination was used to dissolve the cotton textile waste. The cellulose content in the casting mixture and casting thickness were two variables tested when creating the membrane. Water permeabilities of 0.51 to 0.67 m3/(m2sPa) were measured for membranes cast at 150 nm with 5%, 6%, and 7% cellulose concentrations, respectively; PEG 35 kDa retention was almost 90%. Streaming potential measurements revealed that all of the membranes had a negative surface charge and were extremely hydrophilic. This research indicates conclusively that the production of membranes from used textiles is a viable upcycling technique.

Study has been performed by using electrospinning utilized nylon (polyamide) stockings to create a thin fibrous membrane and incorporated the safe antibacterial chemical monoacylglycerol (MGL) into the recycled membrane (Opálková Šišková et al, 2021). Hydrophobic neat, recycled polyamide (PAI) fibers were shown to be transformed into hydrophilic fibers by combining varying concentrations of MGL with PAI solution before electrospinning. Fig. 3a illustrates the neat and loaded PAI fibrous membranes. As shown by PAI containing 2% MAG, the fibers had flat cross sections and high substructures incorporating extremely thin strands, producing a continuous web visible in the membrane. The generated PAI / MGL fiber membranes are antibacterial against S. aureus and effective against the two tested bacterial strains, as shown in Fig. 3b, where their filtering efficiency (E100) surpassed 92% and 96%, respectively. Viability tests for live/dead microorganisms were performed using fluorescence microscopy (Fig. 3c). Bacterial cells that are still alive are shown in green, while those that have died are shown in red. Because of its particular surface electro kinetic characteristics and hydrophobic interactions, rPA/2 wt% MAG fibre membrane was found to be free of living cells (green) of SEM images of the neat PAI and PAI/MGL fibers, both *S.* aureus and *E. coli*.

3.2 Date fruits seeds

Date fruit seeds, which are plentiful and inedible by-products, can serve as a source of lignocellulosic biomass. Pre-treatment of lignocellulosic biomass has been suggested as a possible application for ionic liquids. For the dissolving of cellulose, ionic liquids containing butyl cations, such as (1-butyl-3-methylimidazolium) or [Bmim], with various anions, have received extensive research (Lim et al, 2014). It is hypothesized that the chloride in [Bmim]Cl has a major impact on the dissociation of hydrogen bonds in cellulose. Nevertheless, [Bmim]Cl is very poisonous and crystallizes at ambient temperature (Khaw et al, 2019). Alternately, 1-Butyl-3-methylimidazolium acetate ([Bmim][OAc]) has been deemed beneficial in lignocellulosic biomass swelling, and its lignin solubility is not as impacted by water as [Bmim]Cl's (Gogoi and Hazarika, 2019). Nevertheless, [Bmim][OAc] is a costly solvent that generates considerable volumes of effluent during membrane production due to its lengthy demixing time and several washing stages. Therefore, it has been demonstrated that using ionic liquids with the assistance of organic solvents is a practical method for treating lignocellulosic biomass. To create a dope solution for membrane casting, DMSO can be used as a co-solvent with [Bmim][OAc] since it is both cheap and environmentally friendly.

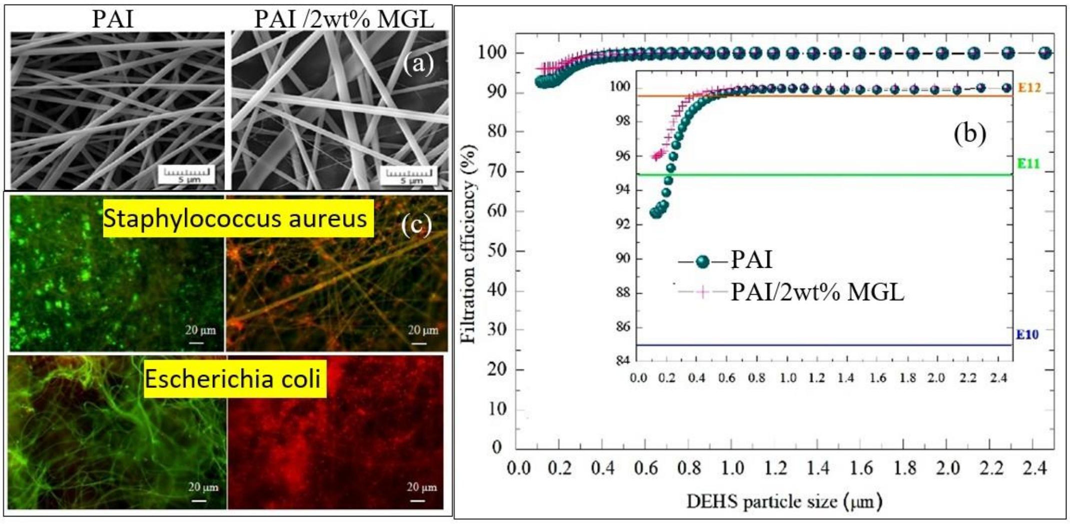

Figure 3. (a) SEM images of the neat PAI and PAI/MGL fibers; (b) membrane filtration efficiencies for pure PAI and PAI/MGL 2 wt%; (c) Bacterial viability test using LIVE/DEAD fluorescence microscopy (Adopted from (Opálková Šišková et al, 2021)).

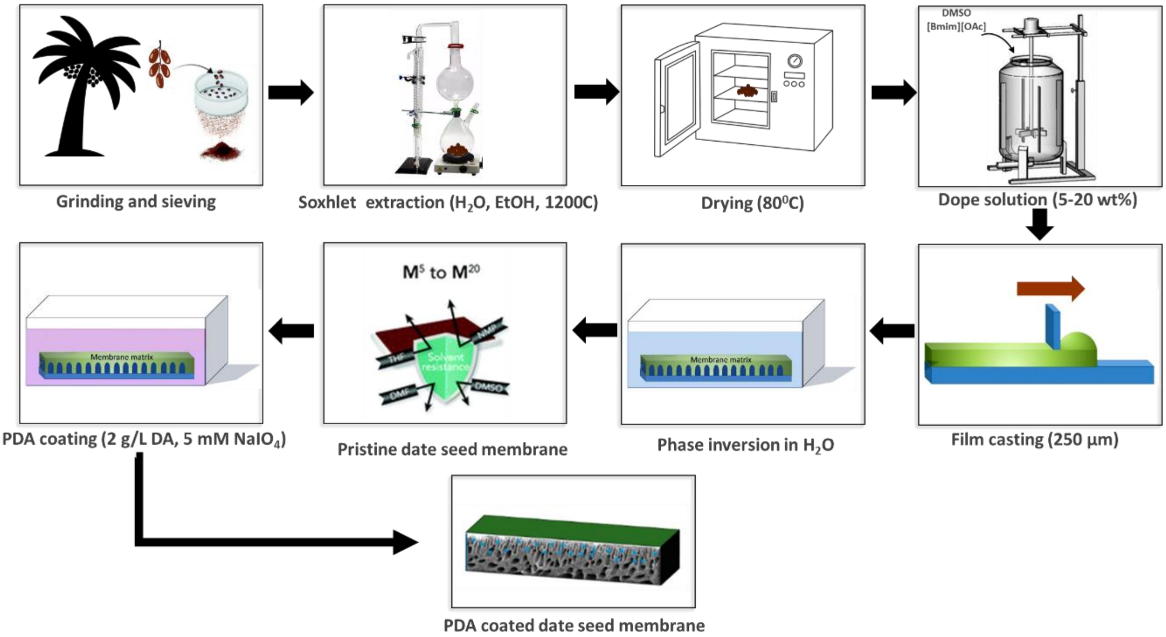

Figure 4. Schematic depicting the production of polydopamine coated date seed membranes (Adopted from (Alammar et al, 2022))

Nanofiltration (NF) membranes were fabricated from waste date seed biomass by Alammar et al., who used ionic liquids and dimethyl sulfoxide (which are more environmentally friendly than conventional organic solvents) as shown in Fig. 4 (Alammar et al, 2022). Oil-in-water separation and organic solvent NF both showed outstanding performance from the produced membranes. The top-performing membrane has a rejection of 96% when tested with acid fuchsin 585 g mol-1 and acetonitrile permeance of 7.8 L m-2 h-1 bar-1. Additionally, with the water permeance of 5.7 L m-2 h-1 bar-1, oil-removal effectiveness of up to 97% was attained. In continuous NF experiments, the produced membranes exhibited remarkable stability for more than seven days. This study reveals that solvent-resistant biodegradable membranes can be fabricated from lignocellulosic biomass using a sustainable, long-term strategy.

3.3 Rice husk waste

One of the primary agricultural solid wastes of the rice manufacturing process is rice husk, which is the outer coating covering the rice grain (Onyelowe et al, 2021). In fact, valuable silica can be derived from either pyrolyzing rice husk (RH) at high temperatures to produce rice husk ash (RHA) or directly extracting sodium silicate from RH (Gebretatios et al, 2022).

Finding ways to completely utilize RHA is crucial because if it is dumped in open areas, it could have negative effects on the environment and human health. The most promising choice for water treatment applications for a long time has been membrane technology, particularly with a porous structure (Ahmad et al, 2020a). From leftover rice husk, both amorphous and crystalline silica can be recovered. Low-cost, an environmentally friendly ceramic hollow-fiber membrane made from waste RH for water filtering using phase inversion and sintering process is reported in detail by Hubadillah et al. Strong mechanical properties (71.2 MPa) and excellent porosity (50.2%) were both attained by the ceramic hollow fiber membrane constructed with 37.5 wt% crystalline silica-based rice husk ash (CRHA) content and sintered at 1200 °C. As shown in Fig. 5a, this resulted in a high pure water flux (PWF) that was steady after 20 minutes and had a value of 300 L/m2. The steady flow of water through the membrane pores over time causes the water flux to decrease. At t = 0 min, since water molecules are so little, it is clear that they are easily able to travel through the membrane openings. Afterward, the water molecules formed a monolayer inside the pores of the membrane by adsorption and condensation (Hubadillah et al, 2018), and the flux of water across the membrane is beginning to stabilize (Fig. 5b). This research shows that the issue of rice husk waste can be applied to the production of a green, low-cost ceramic hollow-fiber membrane for water filtering.

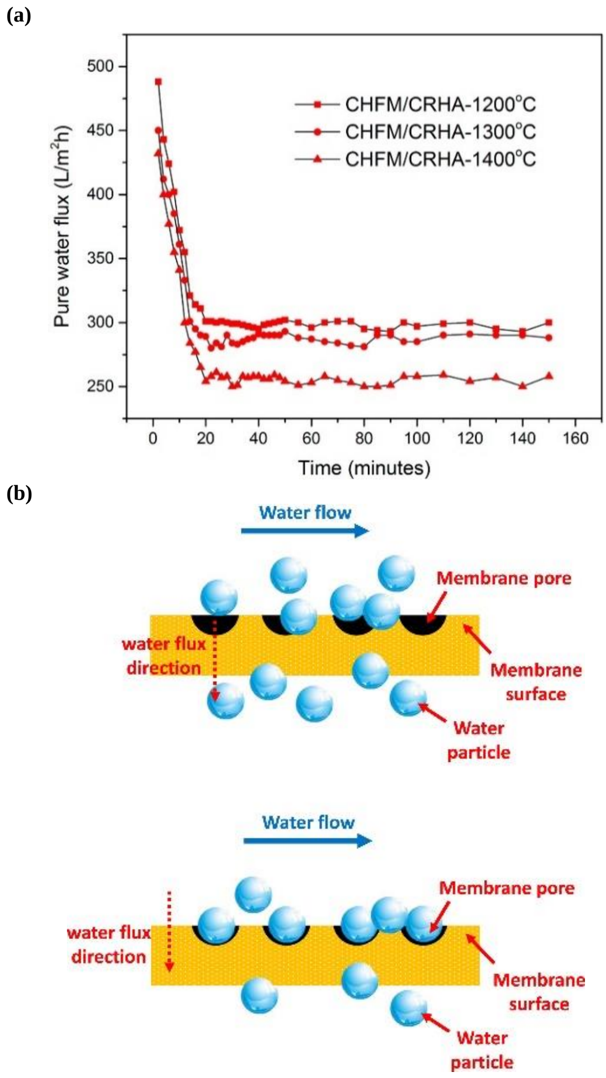

Figure 5. (a) CHFM/CRHA PWF versus sintering temperature and duration; (b) Purified water flow mechanism through the porous ceramic membrane (Adopted from (Hubadillah et al, 2018)).

4. Membrane fabrication and performances with plastic recycled materials

4.1 Waste plastic bags

Plastics have also been used in the production of membranes due to their simplicity of processing, cheap cost, and ability to form films (Lai et al, 2021). Garcia-Ivars et al. (2017) developed membranes using post-consumer polystyrene, Carbon nanotube membranes were made using plastic bags and the process was investigated by Altalhi et al. (2013), and several other researchers have described using waste PET to make membranes (Korolkov et al, 2018). Aji et al. (2020) used recycled PVC as a membrane substrate. To counteract the hydrophobic characteristic of PVC in membrane production, waste PVC was combined with cellulose acetate. The results indicated that the tidy PVC membrane had a bovine serum albumin (BSA) rejection of more than 90% and a PWF of 85 L/m2 h. A 19% increase in equilibrium water content, a 25% reduction in contact angle, and an increase in hydrophilicity were all achieved.

Recycled PET was investigated by Kusumocahyo et al. (2020) as a potential material for ultrafiltration (UF) membranes fabricated by the phase inversion method. They found that combining mixtures of water and polar solvents (like ethanol, n-butanol, and n-propanol) resulted in greater water permeability. Also, in order to increase the water flux across the membrane, it was necessary to increase the molecular weight and quantity of additives in the casting solution. The membranes in the UF experiment revealed rejection rates of up to 91% when BSA was used as the foulant model.

4.2 Waste plastic bottles

In another attempt to make UF membranes from recycled PET bottles, Kusumocahyo et al. (2021) mixed the bottles with PEG (Mwt = 400 KDa) as an additive and water/ethanol as a coagulation non-solvent. PEG has a critical function in determining the membrane's characteristics. The membrane's pore size decreased with increasing PEG content but its porosity and hydrophilicity increased. These modifications increased the flow of pure water and the rejection of BSA solution. Electrospinning was utilised to create nanofiber MF membranes from PET recycled bottles (Kusumocahyo et al, 2021). Using the membrane, latex beads with diameters ranging from 30 to 2000 nm were separated. By using solely gravity filtration, it was discovered that 99% of the beads could be separated by using this membrane. Xu et al. created nanofiber membranes by electrospinning recycled Coca-Cola bottles and then fluorinated them (Xu et al, 2020). For membrane distillation, the produced membranes were utilised. The outcomes demonstrated that the membranes were significantly more hydrophobic than pristine membranes, with a contact angle of about 130°, higher water flux (11-23 LMH), and better rejection (nearly 100%).

Porous UF membranes were made from recycled PET by Pulido et al. (2019) for the filtration of PEG/water and PEG/dimethylformamide at high temperatures and with strong chemicals. At 100 °C in the presence of solvents like dimethylformamide, the PET membranes showed outstanding resistance toward acidic and oxidative chemicals. This is evidence of the effectiveness of recycled PET membrane in environments with high temperatures and corrosive substances. Kiani et al. used PET/ xanthan and two nonsolvent solutions (methanol and water) to fabricate NF membranes (Kiani et al, 2021). Membranes were used to filter diltiazem out of the water. The porosity, thickness, and hydrophilicity of membranes fabricated in water and methanol were improved by adding 0.25 to 0.75 wt% xanthan to the casting solution. These characteristics were diminished as xanthan was increased by more than 1 wt%. Tensile and elongation tests demonstrated that xanthan addition weakened the membrane's structural integrity. Maximum steady-state flux values of 38 and 42 LMH were recorded for membranes made with 0.75 wt% xanthan in water and methanol, respectively. PET membranes containing 0.25 wt% xanthan synthesized in methanol showed the maximum rejection (98%) of diltiazem, while membranes containing 1 wt% xanthan manufactured in water showed the lowest rejection (92%) of diltiazem.

4.3 Waste tire rubber

Similar to other polymeric waste materials, reclaimed rubber can be used in the construction of membranes. Zhuang et al. (2016) suggested that recycled rubber might serve as a raw material for making gas-separation membranes. The scientists used two distinct kinds of recovered ground tire rubber (GTR) produced using mechano-chemical and cryo-mechanical processes. The method of producing membranes from recycled rubber for gas separation is shown in Fig. 6. In the first stage, toluene is used to extract the soluble rubber phase from the recovered rubber, while centrifugation is used to separate the carbon black and other solid impurities. The sol fraction obtained from recovered GTR is combined with the curing system in the next phase. After obtaining a solution, it was spun onto an aluminium oxide substrate to coat a protective layer. The solvent is then allowed to evaporate, and the membrane made from recycled rubber is cross-linked. The membrane made from recycled rubber performed well in tests of durability, separating carbon dioxide from nitrogen and oxygen from nitrogen under high pressure and after extended use. In addition, the gas permeability of the membranes was superior to that of the vast majority of traditional rubber-mix membranes, making them competitive. This research demonstrates the promising use of membranes made from reclaimed tire rubber for gas separation.

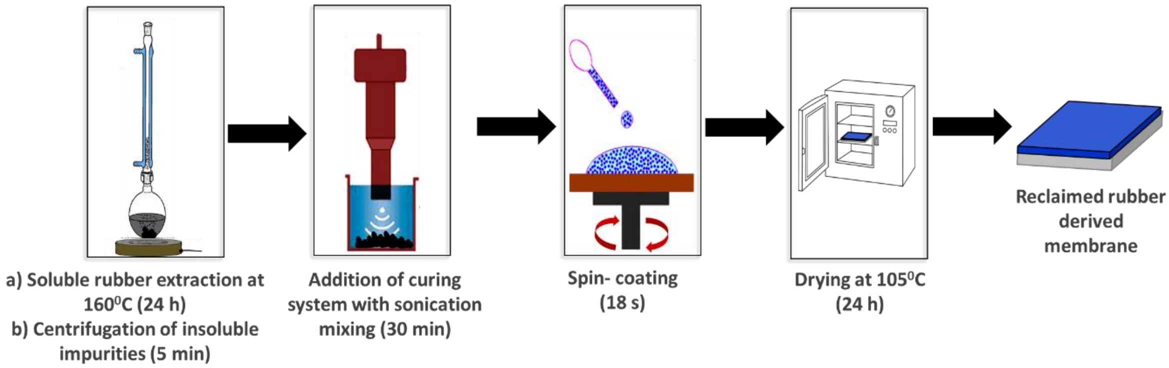

Figure 6. Producing gas-separation membranes from recycled rubber (adopted based on (Zhuang et al, 2016)).

5. Membrane fabrication and performances with inorganic recycled materials

5.1 Waste fly ash

Using membranes made from fly ash would not only cut down on the process's overall cost, but it will also increase the separation's efficiency in several other ways, such as its energy efficiency, environmental friendliness, etc. Nevertheless, employing these membranes in acidic solutions should be avoided since it might lead to the leaching of heavy metals contained in fly ash, posing health risks. While the majority of these membranes rely on the size exclusion principle to work, charge-based membranes for separation are also widely known. Fly ash has promising prospects for cost-effective inorganic membrane manufacturing in wastewater treatment applications due to its composition and quantity of metal oxides (Mushtaq et al, 2019). The fly ash made materials are well-suited to serve as microfiltration membranes and support layers because of their uniform pore size distribution. However, because of its robust mechanical structure, much research on fly ash usage in membrane technology has focused on synthesizing support layers. Membranes produced by fly ash have pores that are 0.18 μm to 7.28 μm in size (Abdullayev et al, 2019). NF membranes can be made using a combination of fly ash and zeolite. Fly ash and zeolite have been mixed in two separate investigations, one by by Dong et al. (2009) and the other Zhu et al. (2015), to create membranes with pore diameters ranging from 0.93 μm to 2.2 μm and from 0.18 μm to 0.26 μm, respectively.

Composite membranes using fly ash as the base can be used in UF processes. Such composite UF membranes, for instance, may be used to treat refinery effluent as the last stage in treating oil-in-water emulsions (Ahmad et al, 2020b). Effective recovery of several heavy metal ions is possible by utilizing the composite membranes, such as was reported by Zou et al. (2019b) for stannic acid wastewater treatment (Vinodhini and Sudha, 2017). Moreover, UF and NF range membranes are needed for virus extraction in polluted water and for treating effluent from paper mills and the silk floss manufacturing sector (Gönder et al, 2012; Wu and Zhang, 2014). Consequently, fly ash supports covered with various precursor materials seem to be excellent for such a broad spectrum of UF and NF applications.

5.2 Waste aluminium can

Incorporating membranes made from recycled aluminium dross residue into purification procedures not only boosts mechanical strength but also decreases sintering temperatures. By combining the phase inversion approach with the sintering process, Aziz and co-workers (2019b) were able to create a ceramic hollow fiber membrane out of aluminium dross, a waste by-product from the aluminium industry. Since the hollow fiber membrane became denser as the sintering temperature rose, the flux decreased. Spinel's inclusion in the hollow fiber's microstructure aided in achieving a lower sintering temperature. This alternative ceramic hollow fiber membrane showed mechanical strength of 78.3-155.1 MPa, which is equivalent to pure alumina membrane counterparts, although having lower sintering temperatures ranging from 1350℃ to 1400℃ at ceramic loading of 40%. The anodization method is another method for creating ultra-thin membranes from aluminium scrap. (2.10) Ultra-thin anodic aluminium oxide (AAO) membranes with uniformly spaced holes were created by Anh et al. using the anodization technique and recycled aluminium cans (Anh et al, 2022). By adjusting the duration of the second anodization step, the AAO thickness was kept within a narrow range of 60-650 nm. The anodic voltage of 40 V and 25 V produced hexagonal AAO membranes with hole densities of 1.121010 and 2.961010 hole/cm2, respectively. The AAO membranes' holes increased in diameter from 30 nm to 95 nm by lengthening the pore-widening period.

Table 1 summarises the recent developments of waste-derived membranes constructed from cellulose, fly ash, aluminium can, plastics, and polymers. The broader use of waste compounds is possible with a greater knowledge of their nature, complicated functional structures, and extraction technologies. To encourage waste re-utilization in the membrane sector, we have highlighted several obstacles and restrictions, along with recommendations for future research in the next part.

Table 1

Summary of membranes prepared from biopolymers, plastics, and inorganics recycled materials.

Recycled Materials		Kind of membrane	Removal/ Separation	Contact angle, ◦	RE, %	OP (bar)	Permeance (L/m^{-2} h^{-1})	Ref.
Biopolymers	Cotton textile	Flat sheet	Testing with pure water	14	-	1	2.39 × 106	(Lopatina et al, 2021)
		Flat sheet	Antimicrobial against S. aureus.	70	96.0	0	NR	(Opálková Šišková et al, 2021)
		Flat sheet	Antibacterial activity against E. coli	36	NR	0	NR	(Vignesh et al, 2021)
	Fruits seeds	Flat sheet	Oil-in-water	66	97.0	30	2.34 × 102	(Alammar et al, 2022)
	Rice husk	Hollow fiber	Testing with pure water	NR	NR	3	3.00 × 102	(Hubadillah et al, 2018)
Plastics	Bags and bottles	Flat sheet	BSA	64	90.0	-	85.00	(Aji et al, 2020)
		Flat sheet	Oil-in-water	90	98.0	-	19.40 × 102	(Gan et al, 2021)
		Flat sheet	Water-In-Oil Emulsion	153	99.7	-	9.92 × 102	(Xiong et al, 2022)
		Flat sheet	Water-in-oil emulsion	125	98.7	1	17.26 × 102	(Gan et al, 2022)
		Flat sheet	Humic acid rejection	86	61.0	3	19.71	(Mulyati et al, 2018)
	Tire rubber	Flat sheet	Dye removal	98	93.1	1	10.64	(Lin et al., 2020)
		Flat sheet	Desalination	160	99.9	4.9	8	(Ray et al., 2018)
Inorganic	Fly ash	Flat sheet	Oily wastewater	NR	99.5	2.5	8.67 × 102	(Agarwal et al, 2020)
		Flat sheet	Oily wastewater	NR	92.0	1	13.00 × 103	(Das et al, 2020)
		Flat sheet	Textile wastewater	NR	99.0	5	57.82	(Ahmad et al, 2022)
		Hollow fiber	Poultry slaughterhouse wastewater	NR	100	2	28.35	(Goswami and Pugazhenthi, 2020)
		Flat sheet	Oily wastewater	NR	98.5	1	5.30 × 102	(Zou et al, 2021)
		Hollow fiber	Pb(II)	NR	99.9	1	8.33 × 102	(Zhu et al, 2018)
		Flat sheet	Tin wastewater	NR	99.0	0.5	17.50 × 103	(Zou et al, 2019a)
	Aluminium can	Hollow fiber	Testing with pure water	NR	NR	1	129.00	(Abd Aziz et al, 2019b)
		Hollow fiber	Oily wastewater	NR	92.4	1	200.00	(Abd Aziz et al, 2019a)

6. Conclusion and Future Perspective

Membranes made from recycled materials are a possible replacement for more costly ceramic and polymeric membranes. This is a result of their inexpensive prices, outstanding separation performance, and durability. The next point is, as a waste-to-resource approach, they provide hopeful answers to the issues of waste management. Another advantage of recycling membrane material is that it decreases the need for rare and costly materials. Moreover, the synergistic combination of adsorption, filtration, and catalytic characteristics in membranes formed from waste might provide superior performance in pollutant removal. Thus, to ensure long-term viability and promote a circular economy, additional study of this promising field is required.

However, making and using membranes made from waste materials has several difficulties. First of all, there may be quality control concerns with the manufactured membranes because of the wide range of compositions and contaminants present in the waste materials from various sources and processes. Secondly, due to the stringent restrictions and standards in the biotechnological, pharmaceutical, food, and beverage sectors membranes generated from waste may not be employed. Furthermore, the membrane's mechanical strength and its ability to remove tiny molecules or ions may be compromised by volatile or biodegradable stuff in the waste materials, which may result in significant high porosity, weight loss, and big hole size for the manufactured membrane.

Waste-derived membranes have been manufactured from a variety of solid wastes, including fly ash, rice husk ash, Cotton textile plastic, tire rubber, and aluminium cans. These solid wastes may function as a selective layer, support layer, pore-forming agents, or binders during membrane construction. Membranes made from recycled materials show great promise in a variety of water purification contexts, including size-exclusion-based industrial wastewater treatment, desalination, oil-water separation, pollutant adsorption like heavy metals, virus extraction, gas separation, and catalytic degradation of organic contaminants. Waste-derived membranes are becoming more popular for use in water purification due to the increasing awareness of the importance of the "waste-to-resource" approach and the circular economy. The field of waste-derived membranes is still in its infancy; thus, many questions need answering. Future research that should be prioritized includes but is not limited to the following: (i) It is important to research the appropriateness of various casting methods for waste-based additives in order to choose the optimal production practices for the optimum compatibility of the additives with the continuous phase. To construct a convincing evaluation of the efficacy of these Waste-derived membranes, various study paths must be followed. (ii) Examining the similarities and differences between conventional and waste-derived membranes in terms of their properties (like pore size, porosity, and mechanical strength), separation performance (such as selectivity and permeability), and long-term stabilities. (iii) determining if any dangerous substances leak from the waste-derived membrane throughout the course of its prolonged use.

This will provide insights into the suitability of membranes made from waste for biotechnology, pharmaceutical, food, and beverage-related sectors. (iv) Evaluate the cost-effectiveness and sustainability of membranes derived from municipal solid waste. Thus, the advancement of waste-based membranes and their effective application in different wastewater treatment processes is a key step toward reaching sustainable development objectives, and it also provides an enormous opportunity for further research and improvement in the field of membrane technology for water purification.

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References

Abd Aziz, M.H., Othman, M.H.D., Hashim, N.A., Rahman, M.A., Jaafar, J., Hubadillah, S.K., Tai, Z.S., 2019a. Pretreated aluminium dross waste as a source of inexpensive alumina-spinel composite ceramic hollow fibre membrane for pretreatment of oily saline produced water. Ceram Int. 45(2), 2069-2078.

Abd Aziz, M.H., Othman, M.H.D., Ismail, A.F., Abdul, M., Rahman, J.J., Hubadillah, S.K., Cheng, T.Z., 2019b. Fabrication of ceramic hollow fibre membranes from aluminium dross waste for water purification. Mal. J. Fund. Appl. Sci. 15(4), 483-488.

Abdullayev, A., Bekheet, M.F., Hanaor, D.A., Gurlo, A., 2019. Materials and applications for low-cost ceramic membranes. Membranes. 9(9), 105.

Agarwal, A., Samanta, A., Nandi, B.K. and Mandal, A., 2020. Synthesis, characterization and performance studies of kaolin-fly ash-based membranes for microfiltration of oily waste water. J. Pet. Sci. Eng. 194, 107475.

Ahmad, B., Dilshad, M.R., Haider, B., Anwar, M.M., Ali, H., Gilani, S.M.A., Ahmad, H.B., Farooq, M., 2022. Synthesis of novel fly ash based geo-polymeric membranes for the treatment of textile waste water. Int. J. Environ. Sci. Technol. 19(7), 6117-6126.

Ahmad, N.A., Goh, P.S., Yogarathinam, L.T., Zulhairun, A.K., Ismail, A.F., 2020a. Current advances in membrane technologies for produced water desalination. Desalination. 493, 114643.

Ahmad, N.N.R., Ang, W.L., Leo, C.P., Mohammad, A.W., Hilal, N., 2021. Current advances in membrane technologies for saline wastewater treatment: A comprehensive review. Desalination. 517, 115170.

Ahmad, T., Guria, C., Mandal, A., 2020b. A review of oily wastewater treatment using ultrafiltration membrane: A parametric study to enhance the membrane performance. J. Water Process Eng. 36, 101289.

Aji, M.M., Narendren, S., Purkait, M.K., Katiyar, V., 2020. Utilization of waste polyvinyl chloride (PVC) for ultrafiltration membrane fabrication and its characterization. J. Environ. Chem. Eng. 8(2), 103650.

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

Altalhi, T., Kumeria, T., Santos, A., Losic, D., 2013. Synthesis of well-organised carbon nanotube membranes from non-degradable plastic bags with tuneable molecular transport: Towards nanotechnological recycling. Carbon. 63, 423-433.

Amirilargani, M., Saljoughi, E., Mohammadi, T., Moghbeli, M.R., 2010. Effects of coagulation bath temperature and polyvinylpyrrolidone content on flat sheet asymmetric polyethersulfone membranes. Polymer Eng. Sci. 50(5), 885-893.

Anh, D.H., Toan, N.Q., Tung, P.C.T., Son, C.T., Nguyen, H.P.T., Nguyen, H.D., 2022. Fabrication of ultra-thin alumina membranes utilizing waste aluminum cans. Vietnam J. Chem. 60(1), 84-91.

Assi, L.N., Carter, K., Deaver, E., Ziehl, P., 2020. Review of availability of source materials for geopolymer/sustainable concrete. J. Clean. Prod. 263, 121477.

Baruah, J., Bardhan, P., Mukherjee, A.K., Deka, R.C., Mandal, M., Kalita, E., 2022. Integrated pretreatment of banana agrowastes: Structural characterization and enhancement of enzymatic hydrolysis of cellulose obtained from banana peduncle. Int. J. Biol. Macromol. 201, 298-307.

Bascón-Villegas, I., Sánchez-Gutiérrez, M., Pérez-Rodríguez, F., Espinosa, E., Rodríguez, A., 2021. Lignocellulose Nanofibre Obtained from Agricultural Wastes of Tomato, Pepper and Eggplants Improves the Performance of Films of Polyvinyl Alcohol (PVA) for Food Packaging. Foods. 10(12), 3043.

Bharathi, S.S.K.N., Adiga, V., Khasnabis, S., Nath, B., Khan, N.A., Ramamurthy, P.C., 2022. Study of nano cellulose-based membrane tailorable biodegradability for use in the packaging application of electronic devices. Chemosphere. 309, 136683.

Cherubini, F., Bargigli, S., Ulgiati, S., 2009. Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. Energy. 34(12), 2116-2123.

Das, D., Nijhuma, K., Gabriel, A.M., Daniel, G.P.F., Murilo, D.D.M.I., 2020. Recycling of coal fly ash for fabrication of elongated mullite rod bonded porous SiC ceramic membrane and its application in filtration. J. Eur. Ceram. Soc. 40(5), 2163-2172.

Debnath, N.K., Acharya, V., Jangu, S., Singh, P., Majhi, M.R., Singh, V.K., 2021. Characterization of fly ash solid-waste for low-cost insulation refractory bricks. Mater. Today: Proc. 47, 1598-1600.

Del Rio, D.D.F., Sovacool, B.K., Griffiths, S., Bazilian, M., Kim, J., Foley, A.M., Rooney, D., 2022. Decarbonizing the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options. Renewable Sustainable Energy Rev. 167, 112706.

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

Dong, Y., Zhou, J.E., Lin, B., Wang, Y., Wang, S., Miao, L., Lang, Y., Liu, X., Meng, G., 2009. Reaction-sintered porous mineral-based mullite ceramic membrane supports made from recycled materials. J. Hazard. Mater. 172(1). 180-186.

Fredi, G., Dorigato, A., 2021. Recycling of bioplastic waste: A review. Adv. Ind. Eng. Polym. Res. 4(3), 159-177.

Gan, L., Qiu, F., Yue, X., Chen, Y., Xu, J., Zhang, T., 2021. Aramid nanofiber aerogel membrane extract from waste plastic for efficient separation of surfactant-stabilized oil-in-water emulsions. J. Environ. Chem. Eng. 9(5), 106137.

Gan, L., Zhang, D., Yue, X., Xu, J., Qiu, F., Zhang, T., 2022. A recyclable and regenerated aerogel membrane derived from waste plastic for emulsion separation. J. Environ. Chem. Eng. 10(5), 108221.

Garcia-Ivars, J., Wang-Xu, X., Iborra-Clar, M.I., 2017. Application of post-consumer recycled high-impact polystyrene in the preparation of phase-inversion membranes for low-pressure membrane processes. Sep. Purif. Technol. 175, 340-351.

Gebretatios, A.G., Pillantakath, A.R.K.K., Witoon, T., Lim, J.W., Banat, F., Cheng, C.K., 2022. Rice husk waste into various template-engineered mesoporous silica materials for different applications: A comprehensive review on recent developments. Chemosphere, 136843.

Gogoi, G., Hazarika, S., 2019. Dissolution of lignocellulosic biomass in ionic liquid-water media: Interpretation from solubility parameter concept. Korean J. Chem. Eng. 36(10), 1626-1636.

Goh, P.S., Othman, M.H.D., Matsuura, T., 2021. Waste Reutilization in Polymeric Membrane Fabrication: A New Direction in Membranes for Separation. Membranes. 11(10), 782.

Gönder, Z.B., Arayici, S., Barlas, H., 2012. Treatment of pulp and paper mill wastewater using utrafiltration process: Optimization of the fouling and rejections. Ind. Eng. Chem. Res. 51(17), 6184-6195.

Goswami, K.P., Pugazhenthi, G., 2020. Treatment of poultry slaughterhouse wastewater using tubular microfiltration membrane with fly ash as key precursor. J. Water Process Eng. 37, 101361.

Goswami, K.P., Pugazhenthi, G., 2021. Effect of binder concentration on properties of low-cost fly ash-based tubular ceramic membrane and its application in separation of glycerol from biodiesel. J. Cleaner Prod. 319, 128679.

Goswami, L., Kayalvizhi, R., Dikshit, P.K., Sherpa, K.C., Roy, S., Kushwaha, A., Kim, B.S., Banerjee, R., Jacob, S., Rajak, R.C., 2022. A critical review on prospects of bio-refinery products from second and third generation biomasses. Chem. Eng. J. 448, 137677.

Gupta, G.K., Liu, H., Shukla, P., 2019. Pulp and paper industry–based pollutants, their health hazards and environmental risks. Curr. Opin. Environ. Sci. Health. 12, 48-56.

How, L.F., Islam, A., Jaafar, M.S., Taufiq-Yap, Y.H., 2017. Extraction and characterization of γ-alumina from waste aluminium dross. Waste Biomass Valorization. 8(2), 321-327.

Hubadillah, S.K., Othman, M.H.D., Ismail, A.F., Rahman, M.A., Jaafar, J., Iwamoto, Y., Honda, S., Dzahir, M.I.H.M., Yusop, M.Z.M., 2018. Fabrication of low cost, green silica based ceramic hollow fibre membrane prepared from waste rice husk for water filtration application. Ceram. Int. 44(9), 10498-10509.

Issaoui, M., Jellali, S., Zorpas, A.A., Dutournie, P., 2022. Membrane technology for sustainable water resources management: Challenges and future projections. Sustainable Chem. Pharm. 25, 100590.

Issaoui, M., Limousy, L., 2019. Low-cost ceramic membranes: Synthesis, classifications, and applications. C.R. Chim. 22(2-3), 175-187.

Khaw, Y.Y., Chee, C.Y., Gan, S.N., Singh, R., Ghazali, N.N.N., Liu, N.S., 2019. Poly (lactic acid) composite films reinforced with microcrystalline cellulose and keratin from chicken feather fiber in 1-butyl-3-methylimidazolium chloride. J. Appl. Polym. Sci. 136(24), 47642.

Kiani, S., Mousavi, S.M., Bidaki, A., 2021. Preparation of polyethylene terephthalate/xanthan nanofiltration membranes using recycled bottles for removal of diltiazem from aqueous solution. J. Cleaner Prod. 314, 128082.

Korolkov, I.V., Gorin, Y.G., Yeszhanov, A.B., Kozlovskiy, A.L., Zdorovets, M.V., 2018. Preparation of PET track-etched membranes for membrane distillation by photo-induced graft polymerization. Mater. Chem. Phys. 205, 55-63.

Kumar, S., Singh, E., Mishra, R., Kumar, A., Caucci, S., 2021. Utilization of plastic wastes for sustainable environmental management: a review. ChemSusChem. 14(19), 3985-4006.

Kusumocahyo, S.P., Ambani, S.K., Kusumadewi, S., Sutanto, H., Widiputri, D.I., Kartawiria, I.S., 2020. Utilization of used polyethylene terephthalate (PET) bottles for the development of ultrafiltration membrane. J. Environ. Chem. Eng. 8(6), 104381.

Kusumocahyo, S.P., Ambani, S.K., Marceline, S., 2021. Improved permeate flux and rejection of ultrafiltration membranes prepared from polyethylene terephthalate (PET) bottle waste. Sustainable Environ. Res. 31(1), 1-11.

Lai, W.H., Hong, C.Y., Tseng, H.H., Wey, M.Y., 2021. Fabrication of waterproof gas separation membrane from plastic waste for CO2 separation. Environ. Res. 195, 110760.

Lehrhofer, A.F., Goto, T., Kawada, T., Rosenau, T., Hettegger, H., 2022. In vitro synthesis of cellulose–A mini-review. Carbohydr. Polym. 285, 119222.

Li, T., Takkellapati, S., 2018. The current and emerging sources of technical lignins and their applications. Biofuels, Bioprod. Biorefin. 12(5), 756-787.

Lin, Y.T., Kao, F.Y., Chen, S.H., Wey, M.Y., Tseng, H.H., 2020. A facile approach from waste to resource: Reclaimed rubber-derived membrane for dye removal. J. Taiwan Inst. Chem. Eng. 112, 286-295.

Lim, H.K., Song, H.Y., Ko, J.H., Lee, S.A., Lee, K.I., Hwang, I.T., 2014. An alternative path for the preparation of triacetylcellulose from unrefined biomass. Adv. Chem. Eng. Sci. 5(01), 33.

Livazovic, S., Li, Z., Behzad, A.R., Peinemann, K.V., Nunes, S.P., 2015. Cellulose multilayer membranes manufacture with ionic liquid. J. Membr. Sci. 490, 282-293.

Lopatina, A., Anugwom, I., Blot, H., Conde, Á.S., Mänttäri, M., Kallioinen, M., 2021. Re-use of waste cotton textile as an ultrafiltration membrane. J. Environ. Chem. Eng. 9(4), 105705.

Mahinroosta, M., Allahverdi, A., 2018. Hazardous aluminum dross characterization and recycling strategies: A critical review. J. Environ. Manage. 223, 452-468.

Mohanty, S.S., Koul, Y., Varjani, S., Pandey, A., Ngo, H.H., Chang, J.S., Wong, J.W., Bui, X.T., 2021. A critical review on various feedstocks as sustainable substrates for biosurfactants production: a way towards cleaner production. Microb. Cell Fact. 20(1), 1-13.

Mrozik, W., Rajaeifar, M.A., Heidrich, O., Christensen, P., 2021. Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy Environ. Sci. 14(12), 6099-6121.

Mulyati, S., Armando, M.A., Mawardi, H., Fahrina, A., Malahayati, N., Syawaliah, S., 2018. Fabrication of hydrophilic and strong pet-based membrane from wasted plastic bottle. Rasayan J. Chem. 11, 1609-1617.

Munawer, M.E., 2018. Human health and environmental impacts of coal combustion and post-combustion wastes. J. Sustainable Min. 17(2), 87-96.

Mushtaq, F., Zahid, M., Bhatti, I.A., Nasir, S., Hussain, T., 2019. Possible applications of coal fly ash in wastewater treatment. J. Environ. Manage. 240, 27-46.

Obotey Ezugbe, E., Rathilal, S., 2020. Membrane technologies in wastewater treatment: a review. Membrane. 10(5), 89.

Onyelowe, K.C., Obianyo, I.I., Onwualu, A.P., Onyia, M.E., Moses, C., 2021. Morphology and mineralogy of rice husk ash treated soil for green and sustainable landfill liner construction. Cleaner Mater. 1, 100007.

Opálková Šišková, A., Pleva, P., Hrůza, J., Frajová, J., Sedlaříková, J., Peer, P., Kleinová, A., Janalíková, M., 2021. Reuse of Textile Waste to Production of the Fibrous Antibacterial Membrane with Filtration Potential. Nanomaterials. 12(1), 50.

Pulido, B.A., Habboub, O.S., Aristizabal, S.L., Szekely, G., Nunes, S.P., 2019. Recycled poly (ethylene terephthalate) for high temperature solvent resistant membranes. ACS Appl. Polym. Mater. 1(9), 2379-2387.

Ramamoorthy, S.K., Skrifvars, M., Persson, A., 2015. A review of natural fibers used in biocomposites: Plant, animal and regenerated cellulose fibers. Polym. Rev. 55(1), 107-162.

Rathoure, A.K., 2020. Heavy metal pollution and its management: Bioremediation of heavy metal. In Waste Management: Concepts, Methodologies, Tools, and Applications (pp. 1013-1036). IGI Global.

Ray, S.S., Gandhi, M., Chen, S.S., Chang, H.M., Dan, C.T.N., Le, H.Q., 2018. Anti-wetting behaviour of a superhydrophobic octadecyltrimethoxysilane blended PVDF/recycled carbon black composite membrane for enhanced desalination. Environ. Sci. Water Res. Technol. 4(10), 1612-1623.

Saha, K., Deka, J., Gogoi, R.K., Datta, K.K.R. and Raidongia, K., 2022. Applications of Lamellar Membranes Reconstructed from Clay Mineral-Based Nanosheets: A Review. ACS Appl. Nano Mater. 5 (11), 15972–15999

Samadi, A., Gao, L., Kong, L., Orooji, Y., Zhao, S., 2022. Waste-derived low-cost ceramic membranes for water treatment: Opportunities, challenges and future directions. Resour. Conserv. Recycl. 185, 106497.

Sangkham, S., Faikhaw, O., Munkong, N., Sakunkoo, P., Arunlertaree, C., Chavali, M., Mousazadeh, M., Tiwari, A., 2022. A review on microplastics and nanoplastics in the environment: Their occurrence, exposure routes, toxic studies, and potential effects on human health. Mar. Pollut. Bull. 181, 113832.

Sebastian, R.M., Louis, J., 2021. Understanding waste management at airports: A study on current practices and challenges based on literature review. Renewable Sustainable Energy Rev. 147, 111229.

Septevani, A.A., Rifathin, A., Sari, A.A., Sampora, Y., Ariani, G.N., Sondari, D., 2020. Oil palm empty fruit bunch-based nanocellulose as a super-adsorbent for water remediation. Carbohydr. Polym. 229, 115433.

Sharma, N., Kalbar, P.P., Muhammad, S., 2022. Global review of circular economy and life cycle thinking in building Demolition Waste Management: A way ahead for India. Build. Environ. 222, 109413.

Shokravi, H., Mohammadyan-Yasouj, S.E., Koloor, S.S.R., Petrů, M., Heidarrezaei, M., 2021. Effect of alumina additives on mechanical and fresh properties of self-compacting concrete: A review. Processes. 9(3), 554.

Ślusarczyk, C., Fryczkowska, B., 2019. Structure–property relationships of pure cellulose and GO/CEL membranes regenerated from ionic liquid solutions. Polymers. 11(7), 1178.

Srishti, K., Rohit, R., Rashmi, K., 2022. Microbial Production of Amylase using Lignocellulosic Biomass: Recent developments and prospects. Res. J. Biotechnol. 17, 5.

Stenstad, P., Andresen, M., Tanem, B.S., Stenius, P., 2008. Chemical surface modifications of microfibrillated cellulose. Cellulose. 15(1), 35-45.

Subramanian, K., Sarkar, M.K., Wang, H., Qin, Z.H., Chopra, S.S., Jin, M., Kumar, V., Chen, C., Tsang, C.W., Lin, C.S.K., 2022. An overview of cotton and polyester, and their blended waste textile valorisation to value-added products: A circular economy approach–research trends, opportunities and challenges. Crit. Rev. Environ. Sci. Technol. 52(21), 3921-3942.

Thakur, S., Verma, A., Sharma, B., Chaudhary, J., Tamulevicius, S., Thakur, V.K., 2018. Recent developments in recycling of polystyrene based plastics. Curr. Opin. Green Sustainable Chem. 13, 32-38.

Tsakiridis, P.E., Oustadakis, P., Agatzini-Leonardou, S., 2013. Aluminium recovery during black dross hydrothermal treatment. J. Environ. Chem. Eng. 1(1-2), pp.23-32.

Verma, S.K., Dwivedi, V.K., Dwivedi, S.P., 2021. Utilization of aluminium dross for the development of valuable product–A review. Mater. Today:. Proc. 43, 547-550.

Vignesh, N., Suriyaraj, S.P., Selvakumar, R., Chandraraj, K., 2021. Facile fabrication and characterization of zn loaded cellulose membrane from cotton microdust waste and its antibacterial properties—a waste to value approach. J. Polym. Environ. 29(5), 1651-1662.

Vinodhini, P.A., Sudha, P.N., 2017. Removal of heavy metal chromium from tannery effluent using ultrafiltration membrane. Text. Clothing Sustainability. 2(1), 1-15.

Wiah, E.N., Addor, J.A., Alao, F.I., 2022. Transitional probabilities for plastic waste management and implication on sustainability. Sustainable Environment. 8(1), 2118654.

Wongchitphimon, S., Wang, R., Jiraratananon, R., Shi, L., Loh, C.H., 2011. Effect of polyethylene glycol (PEG) as an additive on the fabrication of polyvinylidene fluoride-co-hexafluropropylene (PVDF-HFP) asymmetric microporous hollow fiber membranes. J. Membr. Sci. 369(1-2), 329-338.

Wu, M.H., Zhang, Y.Q., 2014. Nanofiltration recovery of sericin from silk processing waste and synthesis of a lauroyl sericin-based surfactant and its characteristics. RSC Adv. 4(8), 4140-4145.

Xia, G., Zhou, Q., Xu, Z., Zhang, J., Ji, X., Zhang, J., Nawaz, H., Wang, J., Peng, J., 2021. Cellulose-based films with ultraviolet shielding performance prepared directly from waste corrugated pulp. Polymers. 13(19), 3359.

Xiao, Y., Reuter, M.A., 2002. Recycling of distributed aluminium turning scrap. Miner. Eng. 15(11), 963-970.

Xiong, Q., Tian, Q., Yue, X., Xu, J., He, X., Qiu, F., Zhang, T., 2022. Superhydrophobic PET@ ZnO Nanofibrous Membrane Extract from Waste Plastic for Efficient Water-In-Oil Emulsion Separation. Ind. Eng. Chem. Res. 61(32), 11804-11814.

Xu, G.R., An, X.C., Das, R., Xu, K., Xing, Y.L., Hu, Y.X., 2020. Application of electrospun nanofibrous amphiphobic membrane using low-cost poly (ethylene terephthalate) for robust membrane distillation. J. Water Process Eng. 36, 101351.

Yousuf, A., Manzoor, S.O., Youssouf, M., Malik, Z.A., Khawaja, K.S., 2020. Fly ash: production and utilization in India-an overview. J. Mater. Environ. Sci. 11(6), 911-921.

Yusuf, A., Sodiq, A., Giwa, A., Eke, J., Pikuda, O., De Luca, G., Di Salvo, J.L., Chakraborty, S., 2020. A review of emerging trends in membrane science and technology for sustainable water treatment. J. Clean. Prod. 266, 121867.

Zhang, L., Huang, C., Zhang, C., Pan, H., 2021. Swelling and dissolution of cellulose in binary systems of three ionic liquids and three co-solvents. Cellulose. 28(8), 4643-4653.

Zhang, X., Han, L., Wei, H., Tan, X., Zhou, W., Li, W., Qian, Y., 2022. Linking urbanization and air quality together: A review and a perspective on the future sustainable urban development. J. Cleaner Prod. 346, 130988.

Zhu, L., Dong, Y., Li, L., Liu, J., You, S.J., 2015. Coal fly ash industrial waste recycling for fabrication of mullite-whisker-structured porous ceramic membrane supports. RSC Adv. 5(15), 11163-11174.

Zhu, L., Ji, J., Wang, S., Xu, C., Yang, K., Xu, M., 2018. Removal of Pb (II) from wastewater using Al2O3-NaA zeolite composite hollow fiber membranes synthesized from solid waste coal fly ash. Chemosphere. 206, 278-284.

Zhu, X., Yang, J., Yang, Y., Huang, Q., Liu, T., 2022. Pyrometallurgical process and multipollutant co-conversion for secondary aluminum dross: A review. J. Mater. Res. Technol. 21, 1196.

Zhuang, G.L., Wey, M.Y., Tseng, H.H., 2016. A novel technique using reclaimed tire rubber for gas separation membranes. J. Membr. Sci. 520, 314-325.

Zierold, K.M., Odoh, C., 2020. A review on fly ash from coal-fired power plants: chemical composition, regulations, and health evidence. Rev. Environ. Health. 35(4), 401-418.

Zou, D., Chen, X., Drioli, E., Qiu, M., Fan, Y., 2019a. Facile mixing process to fabricate fly-ash-enhanced alumina-based membrane supports for industrial microfiltration applications. Ind. Eng. Chem. Res. 58(20), 8712-8723.

Zou, D., Fan, W., Xu, J., Drioli, E., Chen, X., Qiu, M., Fan, Y., 2021. One-step engineering of low-cost kaolin/fly ash ceramic membranes for efficient separation of oil-water emulsions. J. Membr. Sci. 621, 118954.

Zou, D., Xu, J., Chen, X., Drioli, E., Qiu, M., Fan, Y., 2019b. A novel thermal spraying technique to fabricate fly ash/alumina composite membranes for oily emulsion and spent tin wastewater treatment. Sep. Purif. Technol. 219, 127-136.