Chapter

Recycled Synthetic Polymer-Based Electrospun Membranes for Filtering Applications

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Abstract

Synthetic polymers have been widely applied in various commercial and household applications owing to their fascinating properties of low-cost, lightweight, and processability. However, increasing population and living standards and rising demand for non-biodegradable polymers have led to the accumulation of plastic pollution resulting in the current environmental crisis. Current waste management methods such as landfilling or incineration do not solve these environmental issues. On the other hand, recycling plastic waste is the most valuable strategy for dealing with waste as raw material for high-value products. One of such products is filter membranes. Polymer fiber membranes as masks in pandemics have been one of the most sought-after products in recent years. Some types of plastic waste became a material source for the development of filter materials, which could contribute to the protection of human health. Utilizing the simple, cheap, and industrially available technological solution is also needed. Given the number of advantages, electrospinning is such a beneficial solution. The electrospun polymer waste-based membranes show excellent filtration performance and can carry many other functionalities. Therefore, this review article presents a brief overview of electrospun nanofibrous membranes based on synthetic plastic waste and summarizes the filtration performance of such membranes. This review will discuss the future perspectives of electrospun membranes as well.

Keywords: plastic waste, recycling, nanofibers, filtration, waste management

1. Introduction

A linear economy system based on taking, making, using, disposing, and polluting is responsible for millions of tons of waste that threaten people's lives, while its littering and leakage in the environment cause negative impacts on land and sea life and also affect air quality [1, 2]. In 2018, an estimated 359 million tons of plastic (synthetic polymers) were produced globally. Production is still increasing due to rising living standards and the growth of the population on the Earth. The problems of a linear, resource-to-waste economy and environmental issues are becoming more acute. More than 29 million tons/annually of plastics are collected in Europe. Due to the low biodegradability of synthetic plastic waste, they need to be disposed of at the end of its service life.

Only 32.5% of plastics are recycled, 24.9% are landfilled, and 42.6% are incinerated. The traditional recycling methods aim to eliminate plastic waste rather than encourage its beneficial, value-added reuse. Landfilled plastics create an environmental burden. For example, all types of synthetic plastics, including polyester, polyamides, acrylic, and olefins, have been found in oceans, rivers, and even water treatment plants [3, 4]. When incinerated, the released toxic gasses create more environmental issues [5]. Air pollution has consistently been one of the most substantial ecological issues with serious consequences for human health regarding industrial growth.

On the contrary, reusing or recycling plastic waste into valuable products aligns well with the circular economy concept; plastics are recirculated by extending product life beyond one cycle.

The pandemic situation since 2019 caused the polymer fibrous membranes as masks against COVID 19 to be the most demanded products ever. Persistence of the dire situation and occurrence of other coronavirus mutations or other respiratory diseases have apparently started a new wave of filter media development. At a time when energy costs are rising, and materials, oil, and gas fields are being emptied or become unavailable, current plastic waste needs to be considered as a possible source of material in the production of high value-added products and filter media to protect human health, and the environment has almost priceless value.

In this respect, electrospinning is simple and industrially available technology for the production of randomly placed nanofibers into the nonwoven membrane suitable for filtration. The principle of electrospinning is based on the electrical discharge from liquid surfaces. The electrostatic attraction of liquid was observed in 1600 by Wiliam Gilbert. However, the first electrospinning patent was filled by J. F. Cooley in 1900. For over 120 years, electrospinning has evolved so much that it has become attractive to thousands of scientists around the world, and electrospinning devices are known in various designs. Since 1995, the number of publications about electrospinning has been increasing exponentially every year [6]. Semi-industrial and industrial equipment is being developed and sold in many countries. However, electrospinning enters the industry only very slowly, and to the best of the authors' knowledge, there is no industrial processing of plastic waste using electrospinning on an industrial scale. Electrospinning deserves a broader discussion, and therefore, Section 2 is addressed in this review.

One of the many advantages of electrospinning is that more than 200 polymers can be processed. Several authors in their studies have demonstrated the suitability of electrospinning in the processing of waste plastics. These are mainly wastes such as poly(ethylene terephthalate) (PET), polystyrene (PS) or expanded polystyrene (EPS), polyamides (PA), and polyurethanes (PUR), or thermoplastic polyurethane (TPU), but also waste natural polymers such as lignin and their mixtures. These membranes have already been studied for air or water filtration, water treatment, and cleaning from pharmaceutical, textile dyes, or oil. Such membranes show the filtration efficiency closed to 100%. The filtration efficiency depends on many factors, including the basis weight and thickness of the membrane or fiber diameters. Other functionalities such as antibacterial activity or wettability could be given to the membranes by additives, e.g., drugs, agents, nanoparticles, other polymers, etc. Despite the exciting possibilities in the field of filtration offered by recycling plastic waste by employing electrospinning, there are still not many articles dealing with this topic. There are still possibilities and perspectives that need to be further explored for expanded exploration of potential industrial applications.

This review article presents a brief overview of synthetic plastic waste-based electrospun nanofibrous membranes for filtration. The filtration performance of such membranes is summarized. The review also consists of the future perspectives of such electrospun membranes, given the composition of the plastics coming into the recycling process.

2. Electrospinning

Electrospinning is a versatile and straightforward technique to produce fine fibers on the scale of 20–1000 nm from polymer solutions or melts. The fibers are spun in a high electric field. Under a powerful electric field force, the polymer solution or melt overcomes its surface tension and viscoelastic force to generate a charge, the mutual exclusion between charges, and the opposite charge electrode's compression to the surface charge, directly creating a force that is opposite to the surface tension. When the electric field strength exceeds a specific critical value, the polymer solution or melt will overcome the droplet's surface tension and form a jet. The apex (Taylor cone) is formed at the spinneret (syringe, pipette, wire, rotating cylinder) from polymer drop due to the high electric field. The polymer jet is drawn, elongated, and stretched from the apex into a straight line to a certain distance; it is sprayed along a spiral path. As the solvent volatilizes, fibers solidify and are finally deposited on the grounded collector [1, 2, 7]. The principle of the electrospinning process is displayed in **Figure 1**.

The fiber morphology depends on parameters that can be divided roughly into several basic groups: polymer properties (molar mass, solubility) [8], solvent properties (boiling point, volatility, dielectric constant) [9], polymer solution properties (concentration, viscosity, conductivity) [10], the process parameters (applied voltage, top of the needle to collector distance, flow rate, needle diameter or cylinder rate) [11], and environmental parameters (humidity and temperature) [12] or properties of additives as plasticizers, drugs, dyes, etc. [13–15]. The effects of some

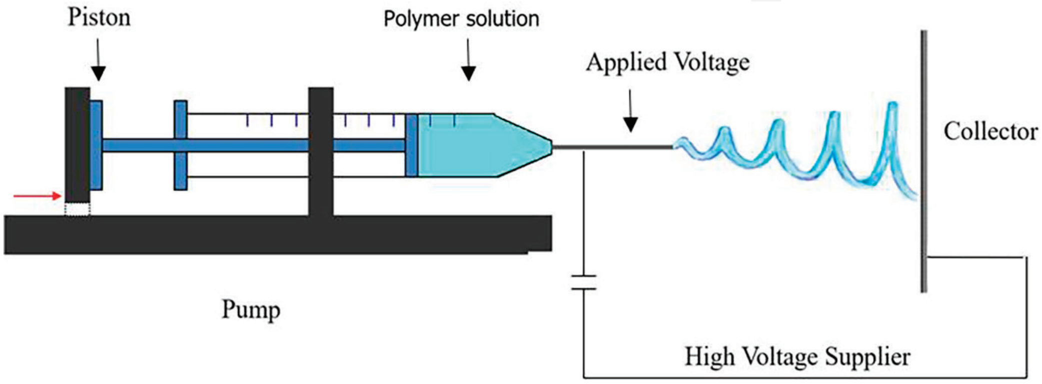

Figure 1.
Schematic representation of electrospinning principle. From archive of authors.

parameters are shown in **Figure 2**. Recently, various electrospinning technique modifications have been developed, such as needless electrospinning, multiple-jet electrospinning, coaxial electrospinning, bubble electrospinning, cylindrical porous hollow tube electrospinning, electro-blowing, magnetic-field-assisted electrospinning, and charge injection electrospinning [16]. Electrospinning has several advantages: it is a low-cost and commercially available technique for industrial production; it is a controllable process with high production efficiency [17]; electrospinning can be used for more than 200 different polymers, including synthetic as well as natural polymers [18, 19]; fibrous layers can be deposited onto a variety of collectors including metal plates, parallel electrodes, rotating-type disks or mandrels, knife-edge collectors, etc. [20]; fibers can be functionalized before, during, and after spinning [2, 21]. Electrospun materials could be used in wide application range such as packaging [22], wound healing [23], tissue engineering [24], drug-releasing systems [25], membranes [26], sensors [27], batteries [28], solar cells [29], supercapacitors [30], catalysts [31], environmental remediation [32], protecting clothing [33], and in many others. Due to all the mentioned advantages, electrospinning is the primary choice for fabricating nanomaterials.

Electrospinning offers the opportunity to reuse polymeric waste, turning plastic waste into higher-value fibrous polymer products from virgin as well as post-industrial or post-consumer polymers. The randomly placed ultrafine fibers in the electrospun membranes are attractive as filtration materials. The high surface area to volume ratios, nanoporosity, vapor permeability, and good mechanical properties of nanofibrous membranes predestined them for air or water filtration or even personal protection against fine dirt and microbes with smaller dimensions than 100 nm or volatile organic compounds [14].

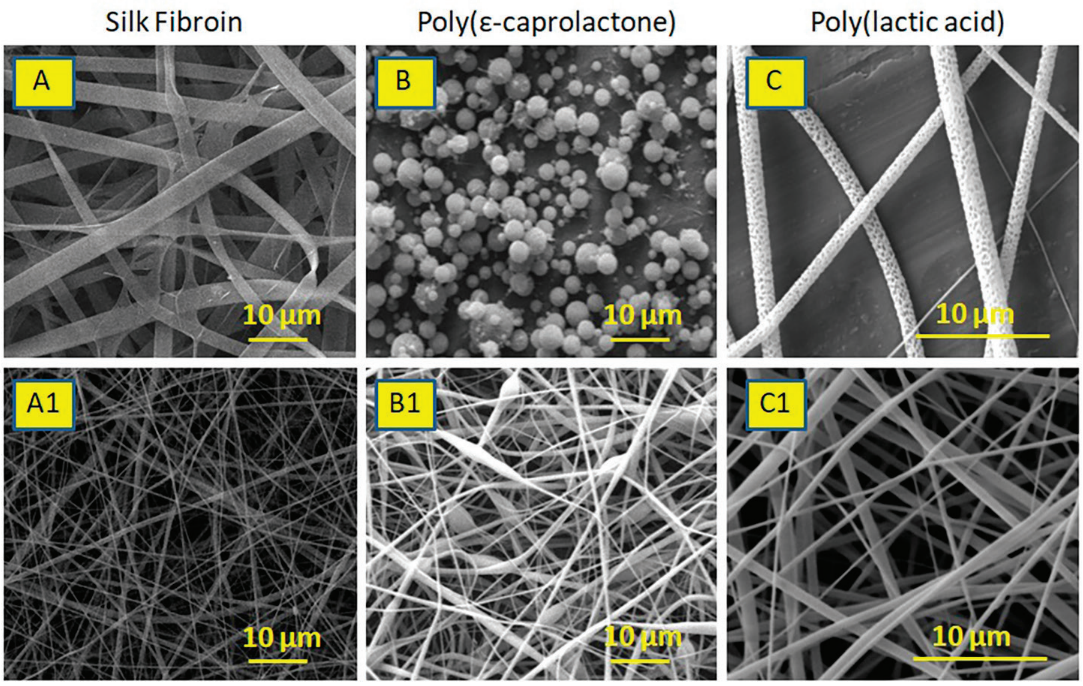

Figure 2.
Effect of some electrospinning parameters on fibrous morphology. Here are represented: (A) silk fibroin (SF) with concentration solution 9 wt.%, (A1) with concentration 7 wt.%, other parameters were kept constant; (B) poly (ε-caprolactone) (PCL) with applied voltage 8 kV, (B1) with applied voltage 12 kV, other parameters were kept constant; (C) poly(lactic acid)(PLA) heated collector on 60°C, (C1) PLA ambient temperature of the collector, other parameters were kept constant. Images are from the archive of authors.

3. Polymeric waste for filtration

Polymeric materials are inexpensive, lightweight, and durable materials processed into various products that are used in a wide range of consumer and industrial applications. Due to their benefits to our society and economy, their production has increased significantly [14].

Especially synthetic polymers such as polyethylene terephthalate (PET), polystyrene (PS), and polyamide (PA) have been widely applied in various applications since the 1940s thanks to the properties related to the processability and corrosion resistance [1].

PET is a low-cost, thermoplastic polyester with 18.3 MT, about 5% of global plastic production. Roughly 30% of that amount of PET is used in the food industry, including single-use plastic, automotive, electrical, electronics, and textile. PS or EPS, known as styrofoam, is used for insulation or packaging materials and accounts for another 5% of total annual plastics production. Polyamides (PAs) are semicrystalline polymers with high chemical resistance and good thermal and mechanical properties [2]. They are usually produced in the form of fibers for use in fashion, automotive, electrical, electronic, construction, packaging, and other industries. Currently, PAs are made on an annual worldwide multimillion-ton scale, and the production is estimated to be continuously growing [34]. Polyamides represent about 2% of total plastic production.

All the mentioned polymers represent an important proportion of plastic waste. Due to the low biodegradation of such plastic waste and increasing consumption created by a rising living standard and a growing world population, the problems with plastic waste and environmental issues are becoming more acute. Moreover, the increased use of mentioned plastics, primarily for packaging and textile, has heightened the importance of managing this material's end of life.

Due to the good processability of PET, PA, as well as PS, was processed by electrospinning and the conditions of production electrospun membranes have been already extensively described in the literature [35–39]. The randomly arranged ultrafine fibers in the electrospun membranes, the high surface area to volume ratios, nanoporosity, good mechanical properties, and vapor permeability of such membranes predestined them for filtration membranes and especially for personal protection as face masks against very fine dirt and bacteria, but also viruses with dimensions of about 100 nm [40, 41]. In the following subsections, the filtration performances of polymer waste-based electrospun membranes in air filtration and water treatment will be discussed.

3.1 Air filtration

The pandemic situation since 2019 caused the polymer fibrous membranes as masks against COVID 19 to be the most demanded products ever. Persistence of the dire situation and occurrence of other coronavirus mutations or other respiratory diseases have apparently started a new wave of filter media development. The new technologies are considered, but it is also necessary to consider the sources of materials. In this respect, every alternative source of materials should be seriously considered, and waste is perceived as a significant and low-cost source of the material.

Rajak et al. developed an air filter by electrospinning EPS waste of electronic appliances packaging [42]. The filtration efficiency for fibers with a diameter of about 3500 nm was 70.4%; however, the lower the fiber diameter, the higher the filtration efficiency. The fibers with a diameter of about 314 nm achieved an efficiency of almost 100%.

Most electrospun recycled PET fibrous membranes were applied for filtration [1]. Tough fibrous membranes for smoke filtration were developed from recycled PET bottles by Strain et al. The diameter of the fibers is about 410 nm, the large surface specific area of 7.07 $m^2.g^{-1}$ and affinity of the rPET mats for airborne hydrocarbons open the way for the applied use in a range of industrial filters [43]. Nosko et al. found that the electrospun recycled PET fibers from the bottle, with an average diameter of around 95 nm, show the highest filtration efficiency of 99.95%, compared with the cotton fabric and melt blown polypropylene nonwoven, of particles with a size of 120 nm. The membrane exhibits good vapor permeability but low breathability [44].

Bonfim et al. investigated the PET bottles waste membrane with average diameter fibers of about 1290 nm. It was shown that the filtration efficiency was 98.4%, with a pressure drop of 212 Pa [45]. Breathing comfort is generally correlated with a pressure drop [46]. Then, by investigating the effect of morphological characteristics on filtration performance, Bonfim et al. obtained a filter with an average diameter of the fibers of about 650 nm that showed a capture of 99% of nanoparticles, the low pressure drop of 19.4 Pa with outstanding mechanical properties [47].

Unlike PET, silk fibroin is a biopolymer obtained from natural silk cocoons. It is favorable due to its biocompatibility, minimal inflammatory reactions, water vapor, and oxygen permeability. Šišková et al. [48] recycled PET from domestic plastic waste and blended it with silk fibroin. In this study, the basis weight of the membrane plays a key role. With the increasing basis weight, the filtration efficiency increases, and the most effective membranes are comparable to the efficiency of HEPA filters according to the European Standard EN1822. Due to the high pressure drop, the membranes were not suitable for personal protection as filtration masks or respirators. However, with the decrease of the basis weight, the pressure drop decreased. Such membrane efficiency was comparable to the FFP1 class facial mask according to the European standard EN149. The tested membranes rPET/SF has been antibacterial against *Escherichia coli* (*E. coli*) and *Staphylococcus aureus* (*S. aureus*) and biocompatible with HaCaT cells spontaneously transformed aneuploid immortal keratinocyte from adult human skin.

Pleva et al. investigated the electrospun recycled polyamide (PA) from the women stocking in filtration. The filtration efficiency of rPA and rPA/MAG (monoacylglycerol) was 98.49 and 99.87% of particles with sizes about 600 nm; 92.70 and 96.10% of particles with sizes about 100 nm the pressure drop about 129 and 189 Pa, respectively. Moreover, the rPA/MAG membrane demonstrated antibacterial activity against *S. aureus* and antifouling activity against *E. coli* and *S. aureus* [14].

In **Table 1**, the filtration efficiencies of electrospun membranes from selected synthetic virgin and recycled polymers are compared.

The data in **Table 1** encourage the utilizing plastic waste for filtration.

3.2 Water treatment

Industrial wastewater discharges and oil spills have precipitated significant damage to water resources in recent years. Water pollution not only causes an imbalance in the ecological environment but also has a direct impact on human health. Scientists urgently need to develop effective wastewater purification technology in order to address this pressing problem. Several previously identified techniques for wastewater treatment, such as adsorption, filtration, centrifugation, catalysis, biological

Polymer	Fiber diameter [nm]	Basis weight [g.m^{-2}]	PM Size [nm]	E [%]	ΔP [Pa]	Ref.
Virgin polymer						
Polyamide 66 (PA66)	60	0.46	300	90.9	69	[35]
Polyamide 6 (PA6)	120	0.63	300–500	99.9	95	[38]
Polyurethane (PU)	120	0.4–0.9	20–400	99.7	96–190	[36]
Poly(ethylene terephthalate)/ thermoplastic polyurethane (PET/ TPU)	395	NA/ the thickness is given 35 μm	50–500	83.6	28.9	[37]
Recycled polymer						
Poly(ethylene terephthalate) (PET)	95	14	120	98.3	NA	[44]
Poly(ethylene terephthalate) (PET)	230	12	120	99.9	414	[48]
Poly(ethylene terephthalate) (PET)	230	3	120	96.0	123	[48]
Polyamide 66 (PA66)	640	8.7	300	97.7	129	[14]
Poly(ethylene terephthalate) (PET)	1290	The thickness was given 342–392	up to 100	98.4	212	[45]
Poly(ethylene terephthalate) (PET)	650	The thickness was given 186–392	up to 100	99.0	19.4	[45]
PET	1240–3180	The thickness is given over 100 μm	500–10,000	98.2	36	[38]

Table 1.
Filtration performance of electrospun virgin and recycled polymers.

treatment, and electro-coalescence, have been commonly implemented [49–54]. Whereas high energy consumption, secondary pollution, and unrepeatable usage still appear inescapable.

At the beginning of twenty-first century, nanotechnology has become one of the most competitive scientific fields. It has been widely regarded as the most significant technology of the new industrial revolutions [55, 56]. As a result, nanofibers are predicted to be appropriate materials for wastewater treatment. The following subsections describe and illustrate (**Figure 3**) the most recent and significant applications of nanofibers from recycled plastics in wastewater treatment to remove various pollutants, especially in oil/water filtration and removal of pharmaceutics.

3.2.1 Oil/water filtration

Metallurgy, transportation, food processing, petrochemicals, petroleum, natural gas, and pharmaceuticals usually produce a significant amount of oily wastewater daily [57]. Oily compounds are insoluble in water and can be toxic. Therefore,

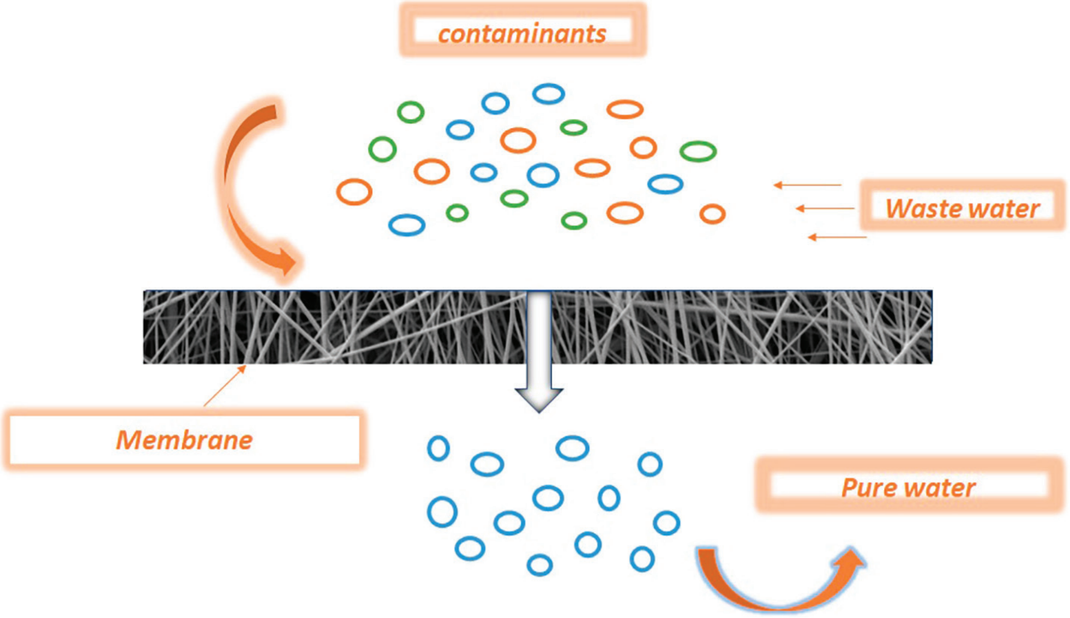

Figure 3.
Schematic representation of the liquid filtration process. Figure is from the archive of authors.

approaches such as coagulation, flocculation, air flotation, chemical degradation, and membrane filtration have been used to separate oil/water [58, 59]. However, the general oil/water separation method has low separation efficiency, high energy cost, and complicated operation. In correlation, membrane separation generally exhibits superior separation performance, lower energy requirements, and more straightforward preparation methods. The nanofiber membranes' performance is particularly outstanding [60].

In response to the growing demand for cost-effective and sustainable methods of producing fibrous membranes, numerous studies have been conducted to determine the efficacy of using waste polymers in separating oil and water. For instance, Liu et al. coated a stainless mesh with waste cigarette filters to create an electrospun membrane capable of separating oil–water mixtures and emulsions [61]. Sow et al. also used waste polystyrene (PS) to fabricate superoleophilic fiber-coated membranes for oil recovery through blow spinning. These membranes demonstrated a separation efficiency of up to 97% [62]. Regrettably, recycled PET (rPET) bottles are frequently utilized to produce low-cost products, resulting in relatively low market profits. Utilizing rPET as a starting material for the fabrication of fibrous membranes for oil–water separation could result in cost savings and environmental benefits. Several studies on the use of rPET in fibrous filters have already been performed. Zander et al. recently designed rPET nanofibers for filtering particles dispersed in water with diameters ranging from 30 to 2000 nm [63]. Additionally, the oil–water separation performance of functionalized rPET was evaluated previously, with separation efficiencies exceeding 98.5%. Doan et al. produced flexible fibrous membranes with a high capacity for oil–water separation based on recycled rPET via electrospinning. Dip coating the rPET membrane with polydimethylsiloxane (PDMS) improved the rPET fibrous membrane's water intrusion pressure and anti-water-fouling property [64]. Nanofibrous membranes have recently been developed to control oil and water separation. Smart materials with the ability to respond to temperature [65], pH [66], light [67], ions [68], electric fields [69], and prewetting are emerging candidates for on-demand oil–water separation. Prewetting appears to be the most promising strategy due to its facile fabrication and operation [70, 71]. The prewetting membrane should have amphiphilic properties, which means it should be superoleophobic underwater and superhydrophobic underoil. Baggio et al. developed a nanofibrous membrane from the blend of rPET and chitosan, which have amphiphilic properties because of the presence of the hydrophobic groups of rPET and the hydrophilic groups of chitosan. The resulting filter exhibited high antifouling properties and separation efficiency [72].

3.2.2 Removal of pharmaceuticals and dyes

A literature review shows that only a few studies on the preparation membranes from recycled plastic waste have been conducted for the removal of organic compounds.

Zander et al. synthesized nanofibrous microfiltration membranes from recycled PET and evaluated their filtration performance with latex beads [63]. Xu et al. utilized recycled PET bottles to develop electrospun nanofibrous membranes, modified them through fluorination, and applied them in membrane distillation [73]. Arahman et al. fabricated rPET/polyvinylpyrrolidone (PVP) ultrafiltration membranes for humic acid separation from water [74]. Pulido et al. prepared rPET/PEG ultrafiltration membranes to filtrate PEG/water and PEG/dimethylformamide solutions [75]. Waste PET bottles were used to fabricate PET ultrafiltration membranes via Kusumocahyo et al. [76]. They utilized phenol as the solvent, PEG as the additive, water-ethanol, water-n-propanol, and water-n-butanol as the non-solvent bath. Using waste PET bottles as a starting point, Kusumocahyo et al. confirmed the fabrication and characterization of PET ultrafiltration membranes, PEG 400 as the additive, and water-ethanol as the non-solvent. Higher porosity and smaller pore sizes were achieved by increasing the number of additives. Utilizing recycled PET will unquestionably minimize waste synthetic polymer production [77]. Kiani et al. demonstrated an environmentally friendly nanofiltration membrane with high performance synthesized through recycled PET bottles. Xanthan gum (XA) was introduced to the membranes as a hydrophilic additive during membrane fabrication, using water and methanol as coagulation baths. The produced membranes were used in the nanofiltration of an aqueous solution incorporating diltiazem [78], a calcium channel blocker used to treat hypertension. It frequently causes edema, headaches, and dizziness [79].

Preparation and application of electrospun membranes composed of lignin extracted from palm fronds and banana bunches as biomass sources and PET from bottle waste were studied by Attia et al. [80]. The electrospun fibers with smooth morphology for the adsorption of methylene blue dye from the water were investigated. Fibers with 1800 ± 500 nm diameter were obtained. The iodine-treated membrane was carbonized at 500°C, and the achieved carbon content did not exceed 62 wt %. The reported adsorption capacity was about 9 mg of MB/g CFs of capacity. The work describes the potential of combining biomass waste as a lignin source with sustainable waste (PET) to produce fibers as a core material that can be used for environmental remediation. Similar work was described by Yasin et al. [81], where the electrospinning made PET nanofibers from the wasted PET polymer containing CuO nanoparticles. The nanoparticle was cross-linked on the surface of the electrospun PET nanofibers to enhance photodegradation of the methylene blue dye and adsorption of the degradation products. Thus produced eco-friendly, cheap, sustainable, and effective nanocomposite has high efficiency at the dye removal (above 99% in 30 min). The composite of the base of TiO_2/styrofoam membranes prepared using electrospinning was developed by Rajak et al. [82] to purify water from harmful organic compounds such as bacteria, viruses, or even textile dyes. Styrofoam from waste was used for the study, and TiO_2 as a semiconductor catalyst was used in the environmentally friendly photocatalysis process. Because TiO_2 has high photocatalytic activity, the fibrous composites showed photocatalytic activities too.

4. Future perspectives

Future perspectives could be concluded from the following aspects:

In many cases, plastic waste is a composite, so it is necessary to combine electrospinning with other technology that will ensure a high yield of polymer, which could be subsequently processed into nano/micro-fibers;

I. Study of the effect of additives in the wasted plastics coming to the recycling process on the processing parameters and resulted properties.

II. Vice versa, study of advantageous additives, nanofillers, or mixed plastic waste to make the electrospun composites with special functions for special applications, for example, with antibacterial or antifouling activity;

III. The morphology and properties of electrospun membranes are sensitive to electrospinning parameters; therefore, the deep research on the optimization of electrospun processing parameters for different types of plastic waste to produce high-value products;

IV. Further study of natural or benign solvents for solution electrospinning or practical design solutions for melt spinning. To realize “green” production;

V. Combination of electrospinning with other auxiliary devices to enhance the mechanical properties, for example, ultrasound sonication; or device to collect the evaporated solvent and its reuse.

VI. Intensive study on mass production of electrospun membranes from plastic waste to reach commercialization and standardization.

5. Conclusions

Rising worldwide attention on polymeric waste leads to the founding of new ways for their environmentally safe utilization. A European strategy for polymeric waste use focuses on designing and producing polymeric materials, which can be reused or recycled. For this reason, there is an urgent need to promote the utilization of polymeric waste after its end of life. Upcycling plastic waste into high-value products for various applications is a sustainable solution with a promising future. As it is shown in this study, plastic waste is an excellent material source for the production of filter materials and the protection of human health and the environment.

Moreover, electrospinning is undoubtedly a superior method to process plastic waste into functional nano/micro-fibers due to the randomly placed ultrafine fibers, high surface area to volume ratios, nanoporosity, vapor permeability, and good mechanical properties. These properties predestined the nanofibrous membranes for air or water filtration or even personal protection against fine dirt and microbes with smaller dimensions than 100 nm or volatile organic compounds. In this review, reusing plastic waste, especially non-degradable polymers PET, PS, PUR, and PA, and the present advances in recycling plastic waste by electrospinning were briefly summarized. The filtration efficiency was from 80 to 99.9%, depending on the thickness and basis weight of the membranes. The average diameter of the fibers also plays a role in the efficiency. It must be noted that the pressure drop, which represents the ease of air passage when breathing, also depends on the basis weight and thickness. However, as the thickness increases, the filtration efficiency improves, but pressure drop increases, so the breathability is more complicated. Therefore, talking about using these materials in face masks or respirators, it is necessary to look for the golden mean in all the parameters affecting the parameters of the final product. Here was also shown that the membranes are a good alternative to the EPA and HEPA filters. The suitable additives such as carbon fibers, CuO, TiO_2 or other polymers as PVP, PEG, or Xanthan gum give the membranes functionalities used in air and water cleaning or remediation. The excellent availability of waste plastics and electrospinning-induced formation of tough fibrous mats pave the way for using recycled plastics in industrial air filters or membranes for water treatment.

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Conflict of interest

Authors declare that there is no conflict of interest.

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