environmental sciences proceedings

Proceeding Paper

An Insight into the Next-Generation Smart Membranes †

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† Presented at the 7th International Electronic Conference on Water Sciences, 15–30 March 2023; Available online: https://ecws-7.sciforum.net/.

Abstract: Membranes are used in desalination or water treatment to separate pollutants from water based on characteristics such as size or charge. Nanofiltration (NF), ultrafiltration (UF), microfiltration (MF), and reverse osmosis (RO) are typical membrane techniques. However, traditional membranes have a number of disadvantages, including fouling both on surfaces and in internal structures, uncontrollable pore size, and membrane features. Smart membranes, also known as stimuli-responsive membranes, have recently attracted attention due to their selectivity, tunable permeability, and tunable and/or reversible attributes. This new generation of smart membranes is created by integrating various stimuli-responsive materials into membrane substrates. These multi-functional smart membranes can self-adjust their physical and chemical features in response to environmental signals such as temperature, pH, light, and other stimuli. Thermo-responsive membranes, pH-responsive membranes, ion-responsive membranes, molecule-responsive membranes, UV-light-responsive membranes, glucose-responsive membranes, magnetic-responsive membranes, and redox-responsive membranes are the current kinds of smart membranes. Because of their smart structures, they have the potential to improve performance by providing high selectivity without reducing permeability, high mechanical stability, and high resistance against fouling, and can meet requirements such as molecular weight cut-off (MWCO), removal efficiencies, and wastewater quality. Smart membranes can show tunable features based on the condition of the stimulus or stimuli present internally or externally, resulting in improved and desirable controllability over the process of pollutant removal from water. Because of their physicochemical stability, repeatability, and long life, stimuli-responsive smart materials (mainly adsorbents and filtration membranes) have the potential to be key materials for membrane production, particularly in the field of water treatment. Smart membranes have a bright future, and it is important to investigate and encourage their use and advancement. This review provides a comprehensive overview of smart membranes.

Keywords: membranes; smart materials; smart membranes; stimuli-responsive membranes; water treatment

Citation: Yildirim, M.; Candan, Z. An Insight into the Next-Generation Smart Membranes. *Environ. Sci. Proc.* **2023**, *25*, 19. https://doi.org/10.3390/ECWS-7-14256

Academic Editor: Athanasios Loukas

Published: 16 March 2023

1. Introduction

Membranes are used in desalination or water treatment to separate pollutants from water based on characteristics such as size or charge. Since the late 1950s, reverse osmosis, nanofiltration, ultrafiltration, and microfiltration techniques have been used in water and wastewater treatment and in different application areas. Rapid developments in membrane technologies in the last 50 years have made these technologies the preferred technologies in water and wastewater treatment. However, traditional membranes have a number of disadvantages, including fouling both on surfaces and in internal structures, uncontrollable pore size, and membrane features.

Developments in membrane production technology have also increased the use of membrane processes in many industries, such as chemistry, petrochemistry, mineral processing, food biotechnology, pharmacy, electronics, paper, etc. Although membrane filters are used as an alternative water recovery process in many areas, clogging is still one of the biggest problems. Clogging in membranes limits the membrane's permeability [1]. In other words, it causes a decrease in the flux passing through the membrane per unit membrane pressure and, therefore, in the production of treated clean water per unit membrane area. In membranes designed for particulate matter or microbial removal, clogging occurs as a result of the accumulation of materials on the membrane surface or in the membrane pores.

Smart membranes, also known as stimuli-responsive membranes, have recently attracted attention due to their selectivity, tunable permeability, and tunable and/or reversible attributes [2]. This new generation of smart membranes is created by integrating various stimuli-responsive materials into membrane substrates. These multi-functional smart membranes can self-adjust their physical and chemical features in response to environmental signals such as temperature, pH, light, and other stimuli [3].

Because of their smart structures, they have the potential to improve performance by providing high selectivity without reducing the permeability, high mechanical stability, and high resistance against fouling, and can meet requirements such as molecular weight cut-off (MWCO), removal efficiencies, and wastewater quality.

This review of smart membranes is briefly summarized.

2. Kinds of Smart Membranes

Positively and negatively responsive smart membranes can self-adjust their physical and chemical properties in response to environmental signals such as temperature, pH, light, and other stimuli.

The responsive gating function is divided into two models: positively and negatively responsive smart membranes [4].

Figure 1 represents positively responsive smart membranes.

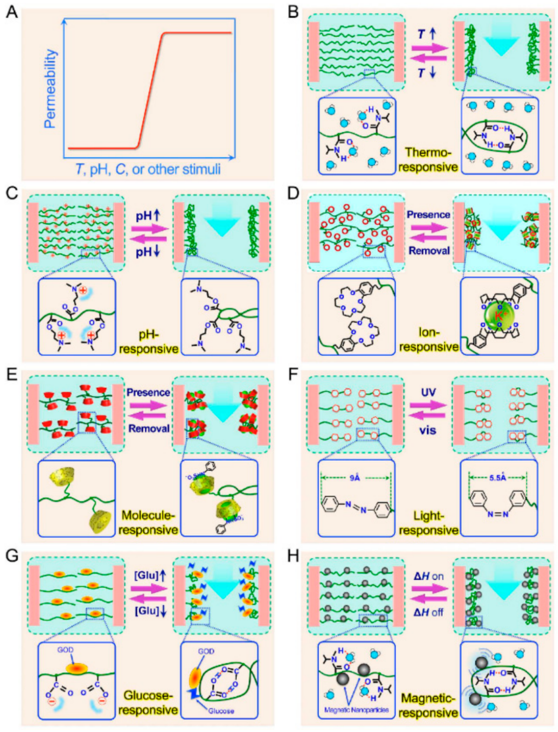

Figure 1. Positively responsive smart membranes (**A**). The permeability of the membrane increases in response to the presence or increase of a stimulus. (**B**) Temperature-responsive, (**C**) pH-responsive, (**D**) specific ion-responsive, (**E**) molecule-responsive, (**F**) UV light-responsive, (**G**) glucose-responsive, and (**H**) magnetic-responsive [4].

Figure 2 represents negatively responsive smart membranes.

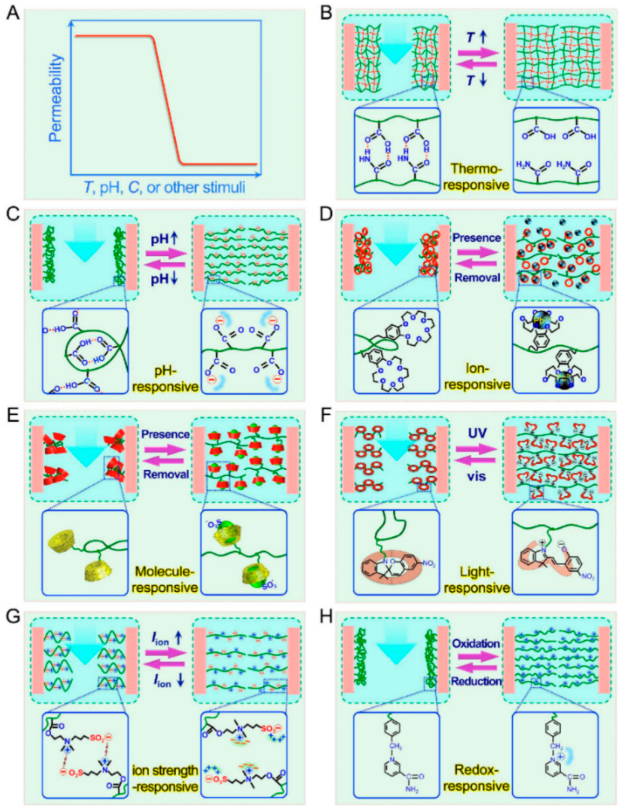

Figure 2. Negatively responsive smart membranes. (**A**) The permeability of the membrane decreases in response to the presence or increase of a stimulus. (**B**) Thermo-responsive, (**C**) pH-responsive, (**D**) ion-responsive, (**E**) molecule-responsive, (**F**) UV light-responsive, (**G**) ion strength-responsive, and (**H**) redox-responsive [4].

3. Conclusions

Membranes play significant roles in sustainable development, especially Goal 6: clean water and sanitation. It is necessary to consider the developments in membrane technologies in terms of new generation membrane production, module development, and related application areas of technology. Smart membranes can show tunable features based on the condition of the stimulus or stimuli present internally or externally, resulting in improved and desirable controllability over the process of pollutant removal from water. Because of their physicochemical stability, repeatability, and long life, stimuli-responsive smart materials (mainly adsorbents and filtration membranes) have the potential to be key materials for membrane production, particularly in the field of water treatment. Although they have advantages, current smart membranes suffer from complicated and difficult-to-scale-up production processes, low flux, and weak mechanical properties. Smart membranes have a bright future, and it is important to investigate and encourage their development, use, and advancement.

Author Contributions: M.Y. and Z.C. contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data and intellectual property belong to the Istanbul University-Cerrahpasa and Istanbul Gelisim University; any sharing needs to be evaluated and approved by the universities.

Acknowledgments: The authors would like to thank the Turkish Academy of Sciences for its support.

Conflicts of Interest: The authors declare no conflict of interest.

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