environmental sciences proceedings

MDPI

Proceeding Paper

Use of Hydrogels for Seawater Desalination Processes: A Patent Landscape Report †

Ahmed Fatimi

Chemical Science and Engineering Research Team (ERSIC), Department of Chemistry, Polydisciplinary Faculty of Beni Mellal (FPBM), Sultan Moulay Slimane University (USMS), P.O. Box 592 Mghila, Beni Mellal 23000, Morocco; a.fatimi@usms.ma

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

Abstract: This patent landscape report encapsulates the state by introducing what has been invented concerning hydrogels for seawater desalination processes. As a result, 81 patent documents were found, and 62% of all patent documents have been published during the last three years. According to the findings, China was ranked as the first jurisdiction, and the most prolific patenting companies are from China and the United States, while William Marsh Rice University (United States) and Tianjin Polytechnic University (China) are the academic institutions leading the way. The patent classifications indicate that most inventions are intended for the treatment of seawater (e.g., desalination), processes specially adapted for manufacturing semi-permeable membranes for separation processes, and the treatment of water using ion-exchange sorbent compositions, dialysis, osmosis, or reverse osmosis. According to the knowledge clusters and expert driving factors in this patent landscape analysis, research and development are centered on methods and apparatus for desalination, which are the focus of the majority of patents, as well as macromolecular gels and synthetic macromolecular substances.

Keywords: seawater; desalination; hydrogels; patent landscape; innovation.

Citation: Fatimi, A. Use of Hydrogels for Seawater Desalination Processes: A Patent Landscape Report. *Environ. Sci. Proc.* **2023**, *4*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 15 March 2023

1. Introduction

For humans, animals, agriculture, and a lot of different sectors, including agrifood and pharmaceutics, pure water is a necessary raw material. Due to climate change and the increase in population, the demand for and needs of people are also growing rapidly, which has resulted in problems such as water availability. With what the world is currently experiencing in shortage of such material, other sources or alternatives to improve the current resources are needed [1].

As an alternative, seawater desalination could help to overcome this issue in water-stressed countries. The process implies the use of membranes to remove salt compounds and obtain fresh water, which is necessary for human health and the better functioning of society [2]. In sea basins, for example, the continuous exposure of agriculture to saline water causes soil salinity, which directly affects the morphology, physiology, and metabolism of plants and/or fruits (i.e., poor or no yields, reduced root growth, reduced nutritional status, etc.) [3].

Despite significant advances in desalination technology, seawater desalination continues to consume more energy than traditional fresh water treatment technologies [2]. A novel approach for seawater desalination using hydrogels is currently being explored by researchers around the world [4]. The fundamental benefit of the hydrogel-based process is that it does not require a membrane because the hydrogel surface itself serves as the

interface, as well as the high water uptake that such materials can offer. In practical applications, a dry hydrogel is swollen in the seawater, and the hydrogel with absorbed seawater is squeezed to obtain fresh water [5].

Hydrogels are polymer-based materials that can be created from a large number of synthetic polymers, polysaccharides, proteins, or hybrid polymers [6]. The three-dimensional structure of these hydrogels remains in equilibrium in an aqueous medium due to the balance between the elastic forces of the crosslinked macromolecular network and the osmotic forces of the liquid [7]. Furthermore, the chemical composition and the crosslink density of such materials determine the swelling and permeability properties of the structure [8].

Through the innovation and improvement of raw materials (such as polymers and biopolymers), chemical synthesis, formulation, and chemical engineering related to the desalination process, hydrogels for seawater desalination processes are developing quickly. This is also supported by the rise in the number of patent applications submitted in this field of study and development each year.

This study presents a patent landscape report on innovative and emerging seawater desalination technologies based on hydrogels. It's a family of techniques for studying the information present in and attached to patents in a specific area [9–12]. It is established as a tool for research planning in accordance with criteria for patent analysis [13–16]. The results are then examined by responding to specific queries, such as who, what, and where queries regarding patenting patterns.

2. Methods

Patent data for this study was extracted from the Lens online database using different keyword searches in patent titles, abstracts, and claims [17]. Title, abstract, and claim keyword searches are common tools for patent extraction [9–12]. The search was then filtered to include only patent documents (i.e., patent applications, granted patents, and three limited patents) until 2022, and the information was extracted according to patent document type, patent family, publication date, patent applicant, patent owner, patent jurisdiction, legal status of patents, and patent classification [13–16].

3. Results and Discussion

3.1. Documents Type and Patent Families

A total of 81 patent documents were collected between 1985 and 2022 that concern the use of hydrogels for seawater desalination processes. The selection includes 66 patent applications, 12 granted patents, and three limited patents. With 57 simple families and 57 extended families, it has been confirmed that 57 patent documents covering the same technical subject are published at different times in the same country or in different countries or regions.

3.2. Publication Date of Patent Documents

Based on the earliest priority date, it is possible to precisely assume that 1985 is considered the starting year of patenting of hydrogels for seawater desalination [18]. 31 patent documents have been published between 1985 and 2019; however, 62% of all patent documents have been published during the last three years. Furthermore, 2022 was the year with the maximum recorded number of patent documents and patent applications with 16 and 15, respectively, while 2011 was the year with the maximum number of granted patents at five (Figure 1).

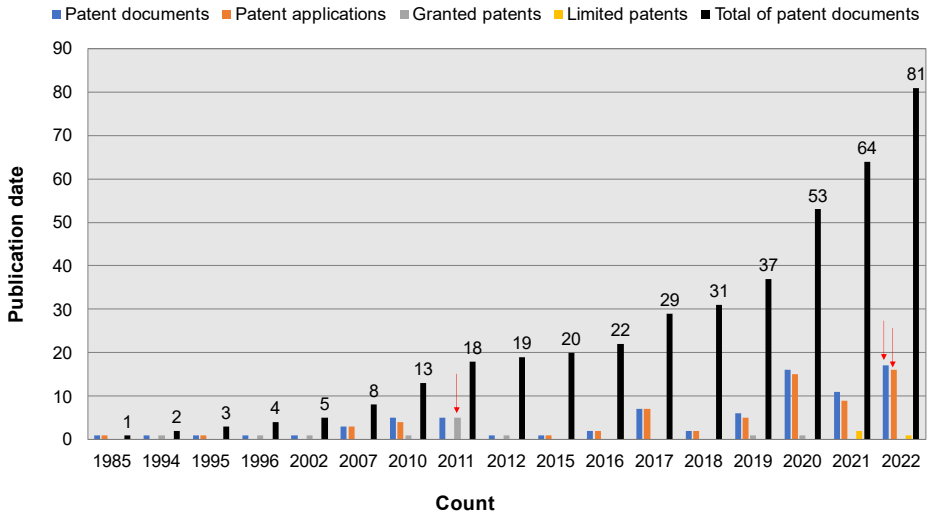

Figure 1. Publication dates of patent documents related to the use of hydrogels for seawater desalination processes.

3.3. Patent Applicants and Owners

The patent applicant is the person or organization that has filed a patent application. On the other hand, the patent owner is the organization with rights to the property of the granted patent [15].

The top 10 applicants for patent documents related to the use of hydrogels for seawater desalination processes until 2022 are displayed in Figure 2. The list includes natural persons and organizations (i.e., companies and academic institutions). The companies "Kraton Polymers US LLC" (Houston, TX, United States) and "Baoshan Iron & Steel CO LTD" (Shanghai, China) are the most prolific patenting companies with nine and four patent documents, respectively, while William Marsh Rice University (Houston, TX, United States) and Tianjin Polytechnic University (Tianjin, China) are the academic institutions leading the way with four patent documents each. On the other hand, different natural people are the lead applicants with four or three patent documents.

Table 1 presents the owners of patent documents related to the use of hydrogels for seawater desalination processes until 2022. The ownership of the rights to the property of the patent concerns eight owners: four companies and four academic institutions. Three of them are, at the same time, already applicants according to the top 10 applicants.

Figure 2. Applicants (top 10) of patent documents related to the use of hydrogels for seawater desalination processes.

Table 1. Owners of patent documents related to the use of hydrogels for seawater desalination processes.

Owners	Type (Headsquare)	Count
Baoshan Iron & Steel CO LTD	Company (Shanghai, China)	2
Kraton Polymers US LLC	Company (Houston, TX, United States)	2
City University of Hong Kong	Academic institution (Kowloon Tong, Hong Kong)	1
Lockheed Martin Corporation	Company (Bethesda, MD, United States)	1
Saudi Basic Industries Corporation	Company (Riyadh, Saudi Arabia)	1
South China University of Technology	Academic institution (Guangzhou, China)	1
William Marsh Rice University	Academic institution (Houston, TX, United States)	1
Zhejiang University	Academic institution (Hangzhou, China)	1

3.5. Jurisdictions and Legal Status of Patents

Patent jurisdictions correspond to the countries in which the patent is protected through the appropriate patent office at which the patent application is filed. When a patent application is filed, it is examined by the appropriate patent office (e.g., the China National Intellectual Property Administration (CNIPA), the Moroccan Office of Industrial and Commercial Property (OMPIC), the United States Patent and Trademark Office (USPTO), etc.), and a decision is delivered according to the specific patentability criteria that an invention must meet. Finally, a claimed invention through a patent application becomes a granted patent in one or more designated countries if it is qualified for patent protection [13].

For patent documents related to the use of hydrogels for seawater desalination processes, the jurisdictions of patent documents until 2022 are presented in Figure 3. China, through the CNIPA, encompasses 45 patent documents, with a patent contribution per document total of 55.56%. The United States, through the USPTO, encompasses 23 patent documents, with a patent contribution per document total of 28.4%. On the other hand, the global system for filing patent applications, known as the Patent Cooperation Treaty (PCT) and administered by the World Intellectual Property Organization (WIPO), encompasses seven patent documents with a patent contribution per document total of 8.64%.

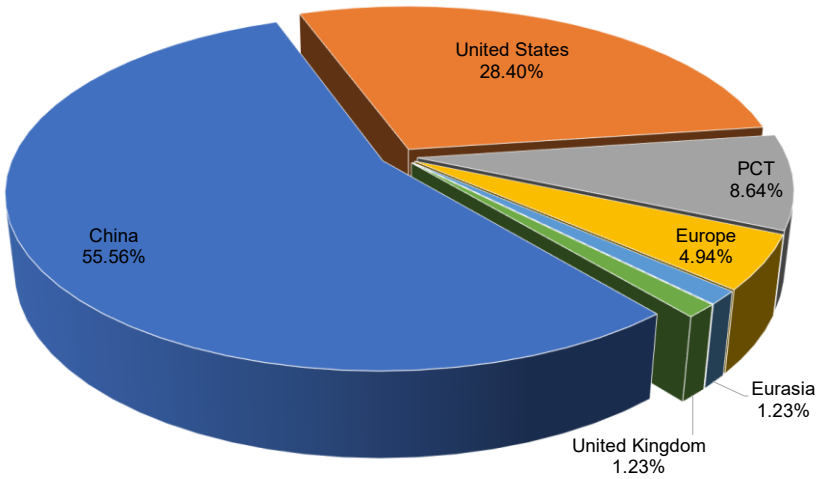

Figure 3. Jurisdictions of patent documents related to the use of hydrogels for seawater desalination processes.

Moreover, these jurisdictions of patent documents related to the use of hydrogels for seawater desalination processes ensure the following five legal statuses:

- 40 patent documents are in force (i.e., active status);
- 30 pending applications (i.e., pending status);
- six withdrawn or rejected applications (i.e., discontinued status);
- Four patents that have reached the term date and are no longer in force (i.e., expired status);
- One PCT application that has been granted in one or more designated countries (i.e., patented status).

3.6. Patent Classifications

As a technology indicator in a specific area, the patent classifications help inventors and researchers to categorize claimed inventions and retrieve different patent documents. The International Patent Classification (IPC) is the most widely used hierarchical system in the form of codes. It divides all technology areas into a range of sections, classes, subclasses, groups, and subgroups [13].

For patent documents related to the use of hydrogels for seawater desalination processes, the top 10 IPC codes until 2022 are presented in Table 2. The patent classifications reveal that most IPC code corresponds to C02F103/08, with 29 patent documents. It concerns the treatment of seawater using the desalination process. The IPC codes related to hydrogels and presented into these top 10 correspond to B01J13/00 and C08J3/075 which are categorized for colloid chemistry and macromolecular gels, respectively.

Table 2. IPC codes (top 10) of patent documents related to the use of hydrogels for seawater desalination process.

IPC	Description	Count
C02F103/08	Treatment of seawater (e.g., desalination)	29
C02F1/14	Treatment of water by distillation or evaporation using solar energy	21
B01D67/00	Processes specially adapted for manufacturing semi-permeable membranes for separation processes or apparatus	14
C02F1/44	Treatment of water by dialysis, osmosis, or reverse osmosis	12
B01J13/00	Colloid chemistry (e.g., the production of colloidal materials or their solutions)	10
C08J3/075	Treatment or compounding of macromolecular substances, such as macromolecular gels	10
B01J20/26	Organic material, such as synthetic macromolecular compounds to make solid sorbent compositions or filter aid compositions sorbents for chromatography processes	9
C02F1/04	Treatment of water by distillation or evaporation using solar energy	8
C02F1/00	Treatment of water, waste water, or sewage	7
C02F1/28	Treatment of water by sorption using ion-exchange sorbent compositions	6

4. Conclusions

The novel approach for seawater desalination using hydrogels was successfully explored by researchers around the world. Inventors proposed various claimed inventions through this innovation. In this study, a patent landscape report has been proposed regarding patent document types, patent families, publication dates, patent applicants, patent owners, patent jurisdictions, the legal status of patents, and patent classifications. Therefore, this research reveals that China and the United States are leading the way in innovation, and the most prolific patenting organizations correspond to companies and universities. On the other hand, most inventions are intended for the treatment of seawater using desalination processes specially adapted for manufacturing semi-permeable

membranes for separation processes, and the research and development are based on macromolecular gels and synthetic macromolecular compounds.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available within this article content.

Acknowledgments: The author acknowledges the Cambia Institute for the Lens patent data set used in this study.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Arfin, T. Current innovative chitosan-based water treatment of heavy metals: A sustainable approach. In Handbook of Biopolymers. In *Handbook of Biopolymers: Advances and Multifaceted Applications*; Shakeel, A., Suvardhan, K., Gopalakrishnan, K., Eds.; Jenny Stanford Publishing: New York, NY, USA, 2018; pp. 167–182.
2. Elimelech, M.; Phillip, W.A. The Future of Seawater Desalination: Energy, Technology, and the Environment. *Science* **2011**, *333*, 712–717, doi:doi:10.1126/science.1200488.
3. Hafiane, F.Z.; Fatimi, A. An emulsion-based formulation for increasing the resistance of plants to salinity stress: US20160302416A1 patent evaluation. *Environ. Sci. Proc.* **2022**, *16*, 4. https://doi.org/10.3390/environsciproc2022016004.
4. Ali, W.; Gebert, B.; Altinpinar, S.; Mayer-Gall, T.; Ulbricht, M.; Gutmann, J.S.; Graf, K. On the Potential of Using Dual-Function Hydrogels for Brackish Water Desalination. *Polymers* **2018**, *10*, 567. https://doi.org/10.3390/polym10060567.
5. Höpfner, J.; Richter, T.; Košovan, P.; Holm, C.; Wilhelm, M. Seawater Desalination via Hydrogels: Practical Realisation and First Coarse Grained Simulations. In *Intelligent Hydrogels*; Sadowski, G., Richtering, W., Eds.; Springer International Publishing: Cham, Switzerland, 2013; pp. 247–263.
6. Fatimi, A. Chitosan-based embolizing hydrogel for the treatment of endoleaks after endovascular aneurysm repair. *Int. J. Polym. Mater. Polym. Biomater.* **2019**, *68*, 107–114. https://doi.org/10.1080/00914037.2018.1525729.
7. Fatimi, A.; Okoro, O.V.; Podstawczyk, D.; Siminska-Stanny, J.; Shavandi, A. Natural hydrogel-based bio-Inks for 3D bioprinting in tissue engineering: A review. *Gels* **2022**, *8*, 179. https://doi.org/10.3390/gels8030179.
8. Akhramez, S.; Fatimi, A.; Okoro, O.V.; Hajiabbas, M.; Boussetta, A.; Moubarik, A.; Hafid, A.; Khouili, M.; Simińska-Stanny, J.; Brigode, C.; et al. The circular economy paradigm: Modification of bagasse-derived lignin as a precursor to sustainable hydrogel production. *Sustainability* **2022**, *14*, 8791. https://doi.org/10.3390/su14148791.
9. Fatimi, A. Chitosan-based hydrogels: Patent analysis. *Mater. Proc.* **2022**, *9*, 1. https://doi.org/10.3390/materproc2022009001.
10. Fatimi, A. Trends and recent patents on cellulose-based biosensors. *Eng. Proc.* **2022**, *16*, 12. https://doi.org/10.3390/IECB2022-12253.
11. Fatimi, A. Patentability of biopolymer-based hydrogels. *Chem. Proc.* **2022**, *8*, 39. https://doi.org/10.3390/ecsoc-25-11653.
12. Fatimi, A. Hydrogel-based bioinks for three-dimensional bioprinting: Patent analysis. *Mater. Proc.* **2021**, *7*, 3. https://doi.org/10.3390/IOCPS2021-11239.
13. Fatimi, A. A patent data analysis of the innovation trends in biological control agent formulations. *Recent Adv. Food Nutr. Agric.* **2022**, *13*, 59–69. https://doi.org/10.2174/2772574X13666220831122154.
14. Fatimi, A. Cellulose-based hydrogels: Patent analysis. *J. Res. Updates Polym. Sci.* **2022**, *11*, 16–24. https://doi.org/10.6000/1929-5995.2022.11.03.
15. Fatimi, A. Exploring the patent landscape and innovation of hydrogel-based bioinks used for 3D bioprinting. *Recent Adv. Drug Deliv. Formul.* **2022**, *16*, 145–163. https://doi.org/10.2174/2667387816666220429095834.
16. Fatimi, A. Seaweed-based biofertilizers: A patent analysis. *Recent Pat. Biotechnol.* **2022**, *16*, 144–154. https://doi.org/10.2174/1872208316666220128105056.
17. Cambia Institute. The Lens Patent Data Set. Version 8.7.0. Available online: www.lens.org (accessed on 4 December 2022).
18. Gould, F.E.; Johnston, C.W. Hydrophilic Polyurethane Acrylate Compositions. UK Patent GB2150938A, 10 July 1985.