Nano Research Energy

ISSN 2791-0091 (print); 2790-8119 (online)
https://doi.org/10.26599/NRE.2023.9120059

Perspective

Industrial pathways to lithium extraction from seawater: Challenges and perspectives

Chenyang Dang[1], Ahmed S. Helal[2], Liping Zhu[1] (✉), Guiyin Xu[1] (✉), and Meifang Zhu[1]

[1] *State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, China*

[2] *Nuclear Materials Authority, 3rd Settlement, New Cairo and Housing and Building National Research Center, Giza, Egypt*

Received: 13 January 2023 / **Revised:** 1 February 2023 / **Accepted:** 19 February 2023

Lithium ion batteries (LIBs) are widely used in electric vehicles and portable electronic devices due to their high energy density, long cycling life, and low cost [1]. With the rapid commercialization of LIBs, the growing demand for the lithium source will cause the shortage of lithium supply [2–4]. The commercial lithium salts mainly come from the onshore resources (ores and salt lakes) [4]. However, the extremely uneven geographical distribution of ores and lakes, and the long mining cycles limit the development of LIB related industries [4, 5]. Although the recycling of some retired lithium batteries could alleviate the lithium shortage to some extent, there is still a need to find a reliable supply to meet the huge future demand of lithium [6–8]. According to the survey, the marine lithium reserve (~230 billion tons) is more than 16,000 times of onshore ones (~14 million tons) [4]. Seawater is abundant and cheap, which makes the lithium extraction from seawater a promising potential solution to alleviate the lithium resource shortage.

The core process of extracting lithium from seawater mainly includes *Enrichment*, *Purification*, and *Recovery* (Fig. 1). The purpose of the enrichment process is to concentrate the lithium ions, which can be achieved through the concentration technologies, such as evaporation, adsorption, and dialysis [9, 10]. The enrichment process can significantly decrease the workload of lithium recover process, reduce the cost of subsequent extraction process, and improve the production efficiency. The purification process removes the impurities and interfering ions (Na^+, Mg^{2+}, Ca^{2+}, etc.), and further concentrates the lithium ions. This process typically involves the solvent extraction, ion exchange, and characteristic adsorption [11, 12]. The final recovery process plays a dual role in lithium extraction. On the one hand, it aims to separate the lithium ions from the extraction system to obtain pure lithium ingredients. On the other hand, this process is also responsible for regenerating the extracted materials and refreshing the extraction system, so these refreshed materials and systems can be reapplied to a new round of lithium extraction. The flocculation and precipitation, acid elution and stripping, and electroanalysis methods are generally used in the recovery process [13].

Since the concentrated seawater can be regarded as a kind of brine, the lithium extraction from it can be based on the process related to lithium extraction from brine. At present, lithium extraction from brine mainly processes by the adsorbent adsorption and solvent extraction, but the intermittent operation seriously affects the extraction efficiency. The membrane dialysis process can achieve a flow extraction, realize continuous production, and greatly improve the production efficiency. With the development of the electrochemical technology, the efficiency of lithium extraction has been highly increased [13]. Because it greatly improves the adsorption kinetics and adsorption capacity of lithium ions, and avoids the excessive use of chemical reagents, the electrochemical technology is a promising lithium extraction process [12]. For the design and development of the seawater lithium extraction process, in addition to the influence of lithium content in solution, interference ions, etc. also need to be comprehensively combined with extraction cost, extraction cycle, and extraction efficiency. In foreseeable circumstances, it can be one of the above processes or a combination of multiple processes.

There are still many challenges in extracting lithium from seawater, making it difficult to achieve large-scale industrial applications. To fundamentally solve these challenges, it is important to deeply explore the scientific mechanism, design lithium extraction functional materials from a multiscale aspect, and develop advanced lithium extraction processes. Despite the marine lithium resource is abundant, the concentration is low to only 0.17 $mg \cdot L^{-1}$. At such a low concentration, ~5800 ton seawater need to be treated to obtain 1 kg of extracted lithium making the lithium extraction from seawater a huge workload. If the lithium-ion concentration is increased to 1.7 $mg \cdot L^{-1}$, ~580 ton seawater could be extracted 1 kg lithium, which significantly reduce the workload of lithium extraction. The average lithium concentration in some salt lakes can reach up to 400 $mg \cdot L^{-1}$ [14], thus only ~2.5 ton brine could obtain 1 kg of extracted lithium. Therefore, concentrating the lithium ingredients is a top priority in the development of lithium extraction processes. The selectivity of lithium ions is another key to determine the efficiency of lithium extraction. Functional materials with high lithium-ion selectivity can improve extraction kinetics during the lithium-ion enrichment and purification. In addition, temperature, pH value

Address correspondence to Liping Zhu, zhulp@dhu.edu.cn; Guiyin Xu, xuguiyin@dhu.edu.cn

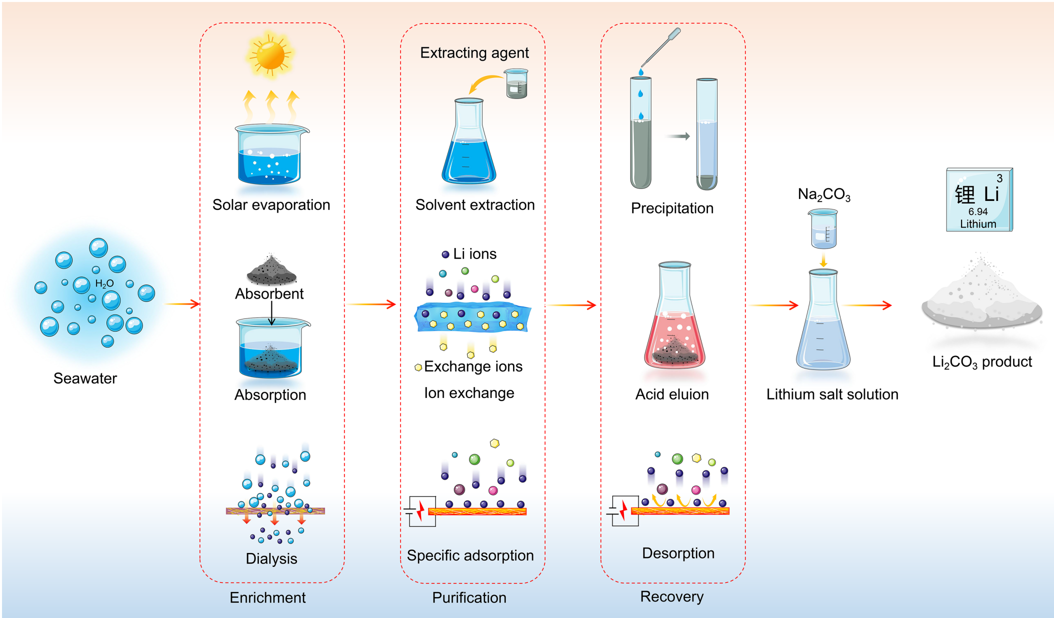

Figure 1 Schematic illustration of main steps and overall technical routes for extracting lithium from seawater.

and especially the electric field distribution of the solution also affect the extraction kinetics of lithium ions [13]. In summary, the low lithium-ion concentration in the ocean, poor lithium-ion selectivity, and slow lithium-ion extraction kinetics lead to low extraction efficiency and high extraction cost for extracting lithium from sea (Fig. 2). Therefore, to achieve large-scale industrial lithium extraction from seawater, these challenges must be systematically considered.

In addition, for the industrialized lithium extraction from seawater, it is necessary to establish some indicators to improve and evaluate the feasibility and prospect of the process. However, due to the differences in active materials (e.g., lithium manganese oxide and alumina), process (e.g., adsorption, extraction and dialysis), energy type (e.g., solar energy and electric energy), labor expenditure and final products (e.g., lithium carbonate and lithium manganate) used in the actual extraction process, it is difficult to establish a reasonable evaluation standard to screen out promising lithium extraction processes. Therefore, economic benefit becomes an ultimate consideration. Given that the proportion of water in seawater reaches ~96.5%, the extraction of lithium from seawater necessarily requires the treatment of a large amount of seawater. Therefore, future economically feasible lithium extraction process from seawater can be realized based on desalination process. By combining seawater desalination and using the profits of freshwater to compensate for the cost of lithium extraction from seawater, it is expected that large-scale lithium extraction from seawater will eventually be achieved.

Acknowledgements

We acknowledge support by National Key Research and Development Program of China (2022YFB3803502), National Natural Science Foundation of China (52103076), and the Science and Technology Commission of Shanghai Municipality (20JC1414900), and State Key Laboratory of Electrical Insulation and Power Equipment (EIPE22203).

Declaration of conflicting interests

The authors declare no conflicting interests regarding the content of this article.

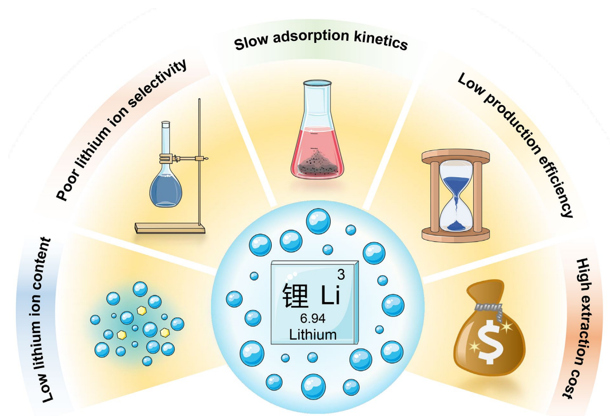

Figure 2 Challenges of lithium extraction from seawater.

References

[1] Wang, C. Y.; Liu, T.; Yang, X. G.; Ge, S. H.; Stanley, N. V.; Rountree, E. S.; Leng, Y. J.; McCarthy, B. D. Fast charging of energy-dense lithium-ion batteries. *Nature* **2022**, *622*, 485–490.
[2] Harper, G.; Sommerville, R.; Kendrick, E.; Driscoll, L.; Slater, P.; Stolkin, R.; Walton, A.; Christensen, P.; Heidrich, O.; Lambert, S. et al. Recycling lithium-ion batteries from electric vehicles. *Nature* **2019**, *575*, 75–86.
[3] Tran, M. K.; Rodrigues, M. T. F.; Kato, K.; Babu, G.; Ajayan, P. M. Deep eutectic solvents for cathode recycling of Li-ion batteries. *Nat. Energy* **2019**, *4*, 339–345.
[4] Yang, S. X.; Zhang, F.; Ding, H. P.; He, P.; Zhou, H. S. Lithium metal extraction from seawater. *Joule* **2018**, *2*, 1648–1651.
[5] Liu, C.; Li, Y. B.; Lin, D. C.; Hsu, P. C.; Liu, B. F.; Yan, G. B.; Tong, W.; Cui, Y.; Chu, S. Lithium extraction from seawater through pulsed electrochemical intercalation. *Joule* **2020**, *4*, 1459–1469.
[6] Wang, J. X.; Ma, J.; Jia, K.; Liang, Z.; Ji, G. J.; Zhao, Y.; Li, B. H.; Zhou, G. M.; Cheng, H. M. Efficient extraction of lithium from anode for direct regeneration of cathode materials of spent Li-ion batteries. *ACS Energy Lett.* **2022**, *7*, 2816–2824.
[7] Ma, J.; Wang, J. X.; Jia, K.; Liang, Z.; Ji, G. J.; Zhuang, Z. F.; Zhou, G. M.; Cheng, H. M. Adaptable eutectic salt for the direct recycling of highly degraded layer cathodes. *J. Am. Chem. Soc.* **2022**, *144*,

20306–20314.

[8] Wang, J. X.; Zhang, Q.; Sheng, J. Z.; Liang, Z.; Ma, J.; Chen, Y. M.; Zhou, G. M.; Cheng, H. M. Direct and green repairing of degraded $LiCoO_2$ for reuse in lithium-ion batteries. *Natl. Sci. Rev.* **2022**, *9*, nwac097.

[9] Dang, C. Y.; Wang, H.; Cao, Y. T.; Shen, J.; Zhang, J.; Lv, L. T.; Xu, G. Y.; Zhu, M. F. Ultra salt-resistant solar desalination system via large-scale easy assembly of microstructural units. *Energy Environ. Sci.* **2022**, *15*, 5404–5414.

[10] Wei, Z. C.; Wang, J.; Guo, S.; Tan, S. C. Towards highly salt-rejecting solar interfacial evaporation: Photothermal materials selection, structural designs, and energy management. *Nano Res. Energy* **2022**, *1*, 9120014.

[11] Li, Z.; Li, C. Y.; Liu, X. W.; Cao, L.; Li, P. P.; Wei, R. C.; Li, X.; Guo, D.; Huang, K. W.; Lai, Z. P. Continuous electrical pumping membrane process for seawater lithium mining. *Energy Environ. Sci.* **2021**, *14*, 3152–3159.

[12] Li, P.; Jiang, H. B.; Barr, A.; Ren, Z. C.; Gao, R.; Wang, H.; Fan, W. W.; Zhu, M. F.; Xu, G. Y.; Li, J. Reusable polyacrylonitrile-sulfur extractor of heavy metal ions from wastewater. *Adv. Funct. Mater.* **2021**, *31*, 205845.

[13] Battistel, A.; Palagonia, M. S.; Brogioli, D.; La Mantia, F.; Trócoli, R. Electrochemical methods for lithium recovery: A comprehensive and critical review. *Adv. Mater.* **2020**, *32*, 1905440.

[14] An, J. W.; Kang, D. J.; Tran, K. T.; Kim, M. J.; Lim, T.; Tran, T. Recovery of lithium from Uyuni salar brine. *Hydrometallurgy* **2012**, *117–118*, 64–70.