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Adsorption-type aluminium-based direct lithium extraction: The effect of heat, salinity and lithium content

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HIGHLIGHTS

- Conventional lithium recovery methods are time-consuming and water-intensive.
- DLE technologies produce high-purity lithium products in a shorter time.
- Adsorption is a commercially proven and eco-friendly method for lithium recovery.
- Presence of lithium, salinity, and heat are key factors to a high TRL adsorption.
- Future studies should find the ideal range and combined effects of these factors.

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ABSTRACT

Conventional lithium production through solar evaporation is considered a time-consuming procedure, taking a substantial 12 to 18 months with significant environmental impacts such as aquifer depletion and damaging the basin’s complex hydrological system. Direct Lithium Extraction (DLE) has emerged as a promising alternative for lithium extraction from brines, offering reduced environmental impact. Although adsorption-type DLE with aluminium-based adsorbents is the sole commercial technology of DLE, a debate persists concerning its Technology Readiness Level (TRL), which challenges the prevailing notion that adsorption-type DLE undeniably reaches a TRL of 9. Within this narrative, we propose that adsorption is capable of attaining its highest potential TRL in lithium recovery from brines when three critical conditions are met: the presence of a certain level of salinity, a minimum lithium content in the brine, and a heat source to heat up the brine. In this account, an attempt has been made to elucidate the role of these three minimum criteria during adsorption-type DLE.

1. Introduction

Lithium demand for batteries has surged over the past decades due to the widespread use of rechargeable lithium-ion batteries (LIBs) in portable electronic devices, electric vehicles, and grid storage [1]. Within two decades, the battery industry has evolved from a relatively small lithium consumer to the leading market driver, primarily due to the rapid growth in electric vehicle adoption. The number of sold electric vehicles has shown significant growth over the last decade, rising from a few thousand in 2010 to expected 14 million in 2023, with a projected increase to 142 million by 2030 [2]. Correspondingly, global production of lithium has tripled between 2010 and 2020 [3,4]. According to various forecasts, if present extraction policies continue, demand for lithium is expected to surge by 18 to 20 times by 2050. However, a shift toward more ecologically sound extraction practices could result in an even more dramatic increase in demand, with estimates ranging up to 40-fold by 2050 [5,6]. Currently, the main sources of lithium supply are hard rock (e.g., spodumene and lepidolite) and brine, which are reported to contain 34 % and 66 % of the world’s lithium, respectively [7,8]. Compared to hard rock sources, lithium extraction from brine is more cost-effective and energy efficient. Typically, brines contain lithium concentrations ranging between 20 and 1750 mg/L, significantly higher than in the world’s major lakes, oceans, and freshwater [9].

Conventional solar evaporation has been the most common industrial technique for lithium recovery from brine [10]. Despite its easy-to-
use and cost-effective nature, it is considered time-consuming, land-intensive, water-intensive, and weather-dependent [11–13]. Thus, Direct Lithium Extraction (DLE) technology, with the desired results of recovering lithium and minimal environmental impacts, has gained considerable attention as a replacement for the conventional lithium production method. In the future, brine-based lithium production will heavily rely on DLE processes [14]. In an ideal DLE technology, lithium ions would be extracted selectively from a brine while all other salts would remain in the solution [15]. DLE processes have the main advantage of producing Li₂CO₃ or LiOH in a shorter time compared to the conventional extraction methods that require up to two years to produce a concentrate for feeding the downstream processing plant. As further advantages, DLE processes can be lower in carbon footprint and less dependent on weather conditions [16,17]. There are four major types of DLE technologies, including solvent extraction, adsorption, ion exchange, and membranes.

Among them, adsorption is the only method with TRL 9 commercially used for directly extracting lithium from brines due to its low regeneration losses, high theoretical lithium uptake capacity, and low energy consumption [10,15]. During the adsorption-type DLE process, lithium is extracted from multi-ion aqueous environments using aluminium-based adsorbents selective toward lithium, then desorbing with fresh water. These adsorbents meet the following requirements: high lithium selectivity, adequate adsorption capacity, and appropriate operation stability [19]. Despite the commercial success of adsorption in lithium recovery from brines with complex compositions, there are still challenges with its feasibility in specific brine environments. In most brines, a lack of salinity and/or heat source to drive the adsorption process could hinder the performance of adsorbents to extract lithium, decreasing their TRL [15].

Drawing from a multitude of studies in this field, it becomes evident that adsorption technology can realize its utmost potential in lithium recovery from brines when three critical conditions are thoughtfully satisfied: a minimum lithium content within the brine, the presence of a specific salinity level, and a reliable heat source for brine heating. Firstly, a certain threshold of lithium content, commonly >100 mg/L, must be met to ensure the efficacy of adsorption-type DLE processes [20]. Secondly, the temperature of the brine plays a crucial role in the adsorption process, as it influences the adsorption kinetics and efficiency [21,22]. The careful management of heat, often sourced from renewable or sustainable energy systems, is a key factor in achieving the desired lithium recovery rates. Finally, the high concentration of salts in brine creates a competitive environment that disrupts the formation of double hydration layers around lithium ions, subsequently leading to the adsorption of lithium onto the surface of adsorbents [23,24]. In this regard, it can be proposed that if three essential conditions of lithium presence, heat, and salinity are met, adsorption-type DLE methods can be considered at TRL 9, i.e. commercially proven. Hence, a brief overview of adsorption-type DLE technology for recovery from brines with an emphasis on the significance of the three essential requirements for attaining a high TRL in this technology will be provided herein.

2. Conventional solar evaporation

Lithium is usually found in brines containing high concentrations of other major cations like sodium, potassium, magnesium, and calcium [25]. The conventional method of producing lithium involves increasing its concentration by solar evaporation in evaporation ponds [26]. The solar evaporation-precipitation method has been widely adopted as a commercially viable method for producing lithium from brines [27]. Firstly, undesirable ions are removed from brine before it is concentrated in solar evaporation ponds, and then lithium compounds are chemically precipitated from the concentrated liquor [28]. In a 12–18-month process, lithium is typically concentrated by pumping the lithium-rich brine to ponds at the surface covering thousands of acres through passive solar evaporation. Lithium is sufficiently concentrated to approximately 6000 mg/kg after water evaporation, followed by adding chemical reagents, such as slaked lime (Ca(OH)₂) to precipitate non-lithium components that are not removed by the consecutive evaporation steps [15,29]. The elimination of magnesium content occurs through the formation of magnesium hydroxide and gypsum via a reaction with lime, followed by the use of sodium oxalate. The resulting solution is filtered and washed, leaving a calcium-lithium-salt solution. The calcium component of this solution is subsequently eliminated through precipitation with sodium carbonate (Na₂CO₃) in the form of calcium carbonate [30]. A processing plant takes the remaining lithium-enriched solution to eliminate the remaining undesired constituents from it using proprietary non-evaporative methods, including ion exchange, reagent addition, solvent extraction, and filtration [31,32]. By solar evaporation-precipitation, LiCl is produced from the South American salt lakes such as Salar de Atacama. In a post-refinery process, LiCl will be converted to LiOH or Li₂CO₃ [27,33].

Despite the easy-to-use and cost-effective technology of open ponds for evaporation and concentration of lithium brines, the solar evaporation process shows many disadvantages [12]. Firstly, it is considered a time-consuming method that requires up to two years for lithium production. It is reported that the high market demand for lithium will soon exceed the global production capacity of lithium from brines through solar evaporation [11,13]. Secondly, this technique is land intensive and wasteful of water such that 100–800 m³ of brine must be evaporated to produce one ton of Li₂CO₃ [5]. Moreover, due to the strong dependence of efficiency and evaporation rate on weather conditions, solar evaporation is geographically limited to regions with long summer days [16,34].

3. Emerging technologies for lithium production

To meet the growing demand for lithium, there is a need for modern approaches to lithium recovery that can increase efficiency, reduce costs, and minimize environmental impact. DLE is one such approach that involves selectively extracting lithium ions (increasing Li/TDS ratio) from their sources using various technologies such as sorption, ion exchange, or solvent extraction [32]. DLE can produce high-purity lithium products with low impurities and reduce the need for energy and carbon-intensive traditional mining and processing of lithium ores [5]. However, for an advanced lithium recovery, downstream processing is required to produce high-quality lithium products suitable for use in various applications. Post-processing is a pivotal step that follows DLE, which involves Concentrating, Refining, and Conversion (CRC) of lithium chloride solutions into technical or battery-grade lithium carbonate or lithium hydroxide (Fig. 1) [35,36]. The CRC process is essential in ensuring that the final product meets the stringent quality standards required for batteries. The combination of DLE and CRC provides an efficient approach to lithium processing that can increase efficiency, reduce environmental impact, and meet the growing demand for high-quality lithium products. In the following, the manuscript concentrates on the specific aspects of DLE technologies, emphasizing crucial parameters during adsorption as the sole fully commercialized type of DLE. It will offer a comprehensive and positive perspective on the efficiency and ability to meet the growing demand for high-quality lithium products that DLE technologies can provide.

3.1. Direct lithium extraction (DLE)

DLE technologies are classified into four main categories: adsorption, ion exchange, solvent extraction, and membranes (Table 1). In the adsorption process, lithium ions are intercalated onto the surface of an aluminium-based adsorbent from a lithium-loaded solution and eluted from the adsorbent using fresh water [9]. In ion exchange, lithium ions...
are chemically absorbed into a solid ion exchange material (typically metal-based adsorbents such as titanium-based (LTO) and manganese-based (LMO) adsorbents, reviewed recently by our team [19]), resulting in the displacement of other positively charged ions e.g. H⁺ through ion swapping [21], which requires high volumes of acid and base to work. The solvent extraction process involves the exchange of LiCl or lithium ions between a brine and an organic liquid phase (mainly tributyl phosphate (TBP)/FeCl₃) containing an extractant that interacts with lithium or lithium compounds in brine [37]. There is currently a plant using solvent extraction with an annual lithium carbonate production capacity of 10,000 tons at Qinghai Chaidamu Xinghua Lithium Salt Co., Ltd. Membrane processes utilize pressure, electrical field, and thermal gradient to selectively move lithium ions through their nanochannels, while keeping the feed and outlet streams separated [38,39].

Many studies have comprehensively reviewed the recent developments in lithium recovery by extractants in solvent extraction [26,40] and adsorbents in ion exchange and adsorption [9,19,41]. Considering the extensive body of literature covering these topics, our aim is to focus on areas of particular significance in this account, ensuring both depth and relevance in our exploration. Other types of DLE technologies, like membrane processes [39], are at their initial stages of industrial implementation, exhibiting lower TRL typically ranging from 3 to 5. Table 1 compared these methods in terms of their mechanisms, materials, advantages, and disadvantages.

### 4. Aluminium-based lithium adsorption technology

Adsorption is the method of applying adsorbents to adhere to lithium so that it can be selectively extracted. Using this technique, lithium ions physically attach to the adsorbents while unwanted ions remain in the feed solution, enabling lithium to be extracted from brines. The key to lithium extraction is aluminium-based adsorbents with a high adsorption capacity for lithium [43]. Adsorption is considered the effective technology for DLE from brine among the advanced extraction methods [44] since it is the only DLE technology already used at commercial scale in multiple brine locations around the world. The main advantage of adsorption is that less brine pre-treatment is required compared to other methods like solvent extraction [9,45]. Besides, even for seawater that is not a viable source of lithium, adsorption can achieve up to 90 % of lithium recovery [46]. At the same time, other technologies mostly show a lower efficiency, even for brines with high lithium concentrations [34]. The extracted lithium can be concentrated even more by changing the pH of the brine, while other techniques like nanofiltration technology involve an additional step to concentrate lithium. One of the most considerable advantages of adsorption over ion exchange is its reliance on water instead of acid washing, making it a highly eco-friendly and cheaper approach for lithium recovery. Finally, adsorption offers several competitive advantages of lower regeneration losses, energy consumption, and carbon footprint compared to other methods [18,47].

Aluminium-based adsorbents, especially lithium-aluminium layered double hydroxides (LiAl-LDHs), are commercially used in adsorption-type DLE technology [48]. These adsorbents have a disordered layered arrangement with the common chemical composition Liₓ₂Alₓ(OH)₃₋ₓ.nH₂O, where X stands for anions, usually Cl⁻, and n represents the amount of H₂O [19,29]. LiAl-LDHs display a plate-like structure of aluminium hydroxide layers in two dimensions, linked by hydrogen bonds, electrostatic interactions, and van der Waals forces. These interactions allow for efficient adsorption of lithium within octahedral
The specific affinity of lithium for this process results from its capacity to penetrate the Al(OH) vacancies. The mechanism of lithium adsorption and desorption can be explained as follows:

$$x\text{LiCl} + (1 - x)\text{LiCl}_2\text{Al(OH)}_3 \rightarrow (N + 1)\text{H}_2\text{O} \leftrightarrow x\text{LiCl}_2\text{Al(OH)}_3 \cdot n\text{H}_2\text{O} + \text{H}_2\text{O}$$

LiAl-LDHs are fabricated by intercalating lithium ions, typically sourced from compounds like LiCl, LiOH, or lithium sulfate (Li₂SO₄) into aluminium hydroxides [50]. These aluminium hydroxides are often found in the form of naturally occurring minerals such as gibbsite (α-Al(OH)₃) or bayerite (β-Al(OH)₃). The techniques for producing LiAl-LDHs include solid-state synthesis [50], coprecipitation [51], and hydrothermal method [52]. The cyclic regeneration of LiAl-LDHs stands out as a crucial feature for their industrial application in lithium extraction from brines [53]. Saturated LiAl-LDHs can be easily desorbed and regenerated by neutral water with low conductivity, eliminating the risk of dissolution of adsorbents that can occur when using acidic eluents [54]. This water-based regeneration of LiAl-LDHs provides a distinct advantage over other types of lithium adsorbents [52]. Cyclic adsorption-desorption tests are typically employed to assess their reusability, consistently demonstrating substantial durability. For instance, in a large-scale column system containing 25 t of absorbent material, aluminium-based adsorbents exhibited remarkable stability after over 200 cycles [55]. In a patent by Harrison et al. [20], it was found that the adsorbent could undergo at least 1500 cycles without a significant decrease in the matrix’s performance, and ideally, up to approximately 6000 cycles without any noticeable reduction in the adsorbent’s efficiency.

While most hydrogen manganese oxide (HMO) and hydrogen titanium oxide (HTO)-based ion exchange plants are on a pilot scale, LiAl-LDHs have been commercially implemented at multiple locations globally since 1996, demonstrating various advantages, including comparatively lower production expenses, consistent adsorption effectiveness, straightforward manufacturing, long-term adsorption-desorption cycles, and convenient regeneration [15,56–58]. Due to requiring water instead of acid washing, adsorption consumes a substantially higher amount of water (3–5 times) compared to ion exchange. Nevertheless, implementing basic recycling methods in the process design enables the repetitive reutilization of water, leading to a very low net water footprint. Concerning lithium concentration adsorption capacity, HMO and HTO-based ion exchange have a slightly higher capacity than aluminium-based adsorbents. However, because of the high reagent consumption of ion exchange materials, their operating expenses (OPEX) are significantly higher [19,59].

Regarding the commercial growth of adsorption-type DLE, DOW was the first to develop lithium adsorbent for use in the Smackover region in the US in the 1970s. They used aluminium-based lithium adsorbent in an ion exchange resin, which became the fundamental of the future developed adsorbents [60]. To date, several companies have been actively involved in advancing the application of adsorption technology for lithium extraction. Fig. 2 presents an overview of the corporations engaged in adsorption-type DLE projects and the corresponding stages of their projects, also showing their country, project, and capacity (kt/LCE).

5. Key factors for enhanced adsorption

In contrast to earlier findings that emphasized the significance of pre-treatment for successful adsorption, it has been discovered that fulfilling minimum criteria leads to a high TRL without needing pre-treatment. This reduction in cost and environmental impact positions adsorption as a cost-effective and environmentally friendly technology. The mechanism of adsorption highlights three essential parameters critical for achieving substantial adsorption capacity and subsequent TRL advancement in adsorption-type DLE technology: salinity, heat, and a minimum concentration of lithium.

5.1. Salinity

Lithium adsorption is mostly applicable to brines with sufficiently high salinity [20]. Lithium ions tend to be strongly hydrated in aqueous solutions, indicating the presence of a second hydration shell to stabilize their electric charge within the solution. By using large angle X-ray scattering (LAXS) and double difference infrared spectroscopy (DDIR), Mahler and Persson [61] have revealed that other alkali ions like sodium, potassium, rubidium, and caesium possess a relatively weak level of hydration. In brines with high salinity, the stabilization of lithium ions through double hydration becomes hindered due to the intense competition with other

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Fig. 2. Adsorption-type DLE producers/developers and their project stage, indicating their country, project, and capacity (kt/LCE) [42].
present ions for water molecules. As a consequence of this competition, lithium ions tend to accumulate onto the surface of the adsorbents during the process of loading, which results in their adsorption to the adsorbent material, while the other ions remain suspended in the brine (Fig. 3). During the desorption process, the increased availability of water molecules facilitates the formation of the desired double hydration shell around the lithium ions, leading to their release from the adsorbents into water. The eluate with a high lithium concentration and a low impurities concentration is ideal for further processing into battery-grade lithium hydroxide [23]. Jiang et al. [24] have studied the adsorption of lithium ions on LiAl-LDHs adsorbents at different concentrations of magnesium chloride to investigate the effect of salinity. They reported an increase in lithium adsorption capacity from 0.6 to 3.0 mg/g by elevating magnesium chloride from 0 to 500 g/L, confirming the impact of salinity on lithium uptake. Considering the significant impact of salinity, further research should be dedicated to determining the minimum effective concentration.

5.2. Temperature

Brines temperature is proven to have a considerable effect on adsorption systems. The thermodynamics parameters like entropy, enthalpy, and Gibbs free energy define the adsorption systems as exothermic or endothermic. Thermodynamics offers valuable insights into the tendencies, behaviours, energy demands, cost considerations, and overall sustainability of adsorption processes [62,63]. Dong et al. [64] calculated the thermodynamic parameters during LiAl-LDHs adsorption and found ΔH positive, indicating the endothermic nature of lithium adsorption process. This observation suggests that higher temperatures lead to improved internal diffusion, mass transfer of lithium ions, and enhanced adsorption processes [21]. Several studies on lithium adsorption by aluminium-based adsorbents also have shown the improvement in adsorption capacity as the result of the increase in temperature, confirming that the process of lithium adsorption is driven by an endothermic reaction. Chen et al. [65] conducted lithium adsorption experiments at various temperatures ranging from 10 to 55 °C to evaluate the effect of temperature on recovery performance. The maximum adsorption capacity was reached at 55 °C. Furthermore, they determined a ΔH value of approximately 13.81 kJ/mol, which aligns with the experimental data. In a study on Qarhan Salt Lake old brine with an ultrahigh Mg²⁺/Li⁺ ratio, Zhong et al. [53] evaluated the Li⁺ adsorption performance of LiAl-LDHs at temperatures of 303, 318, 333 K. The adsorption capacity was reported 7.7579, 8.1067, and 8.3088 mg/g, respectively. Saturated LiAl-LDHs were subjected to various elution conditions to determine the best desorption parameters. It was observed that elevated temperatures were linked to the removal of Li⁺ ions from LiAl-LDHs. The maximum desorption capacity was attained at a temperature of 60 °C. In another study using granulated LiAl-LDHs [58], they verified the positive relationship between lithium adsorption capacity and temperature, obtaining the adsorption capacity of 4.8971 to 5.4743 mg/g with increasing temperature. Li et al. [66] also found an increase in the adsorption capacity of sodium alginate-granulated LiAl-LDHs adsorbents from 14.68 to 15.52 mg/g by elevating temperature to 318.15 K, in accordance with their prior report [67]. The temperature at which LiAl-LDHs is employed for extracting lithium values from brines can be raised, with a preference for temperatures above approximately 40 °C and an even more favourable range being above 50 °C. Increasing the temperature greatly improves the efficiency of the process. However, it is important to avoid the temperatures that cause degradation and potential dehydration of LiAl-LDHs, further resulting in a reduced capacity to adsorb lithium ions [68]. Based on the feasibility studies on adsorption, the ideal temperature range for effective adsorbent operation in brine mostly lies between 40 °C and 95 °C [22].

5.3. Lithium concentration

In addition to the necessary heat and salinity, a minimal content of lithium within the brine is essential to ensure an economically feasible production process. Higher concentrations of lithium are advantageous because they facilitate their penetration into the alumina layers [69]. In cases of low lithium content within brines, the efficiency of lithium extraction decreases, causing higher production costs compared to other lithium sources. In addition, as excessively large volumes of water are needed to be processed, adsorption becomes economically unsustainable and TRL is reduced in the absence of a proper amount of lithium. To address this issue, pre-treatment methods such as natural evaporation are employed to concentrate the lithium to a specific level, resulting in reduced productivity and increased expenses [70]. However, if the lithium concentration in brines is equivalent or more than a certain threshold, there is no need for pre-treatment, leading to a high TRL for the adsorption process without prior concentration steps. Hawash et al. [71] have demonstrated that higher initial lithium concentrations in treated solutions lead to improved efficiency in lithium adsorption,
aligning with prior findings. This observation is further supported by the lithium adsorption isotherms curves from various models such as Langmuir, Freundlich, and Temkin [65]. To confirm the effect of initial lithium concentration on adsorption capacity, Jiang et al. [24] studied the lithium adsorption at 350, 600, and 1000 mg/L, reporting lithium adsorption capacities of 0.61, 1.31, and 1.96 mg/g, respectively. Harrison et al. [20] suggested that the optimal lithium concentration should be at least around 100 mg/L.

Each lithium brine demonstrates unique geochemical characteristics, necessitating the optimization of the lithium adsorption process according to the distinct chemistry of each deposit (Table 2). A series of steps, ranging from initial screening to laboratory tests and piloting, determines the suitability of lithium adsorption for the brine chemistry. Salinity emerges as a key factor that its insufficient amounts limit the practical implementation. In the brines that are rich in lithium but lack adequate salinity, such as Cornwall’s granitic brines, unconventional techniques like ion exchange are explored, although their feasibility remains unverified due to the substantial acid and base requirements for lithium loading and unloading. In the case of Salars located in South America or China that employ adsorption, the brines typically contain the required salinity and lithium content but lack adequate heat, unlike geothermal brines. To overcome this challenge, applying gas is employed to raise the temperature of the brine.

6. Cost and environmental impact analysis of DLE vs. solar evaporation

In addition to the technological aspects of lithium extraction, it is crucial to compare the economic viability of DLE with conventional solar evaporation. DLE and solar evaporation exhibit comparable initial costs, with DLE slightly higher on the capital expenditures (CAPEX) front, ranging from US$26,000 to US$34,000 per tonne of Lithium Carbonate Equivalent per annum (tpa LCE), in contrast to solar evaporation’s range of US$23,000 to US$34,000 per tpa LCE [42]. This is attributed to the advanced technology and infrastructure required for DLE. On the operational expenditures (OPEX) front, DLE showcases a marginally lower cost, ranging from US$2800 to US$3600 per tonne of LCE, while solar evaporation demonstrates OPEX in the range of US$3300 to US$4900 per tonne of LCE [42]. The main reason of this lower OPEX is that DLE projects do not require large evaporation ponds. It is worth noting that the CAPEX and OPEX intensity may enhance as the technology and its implementation progress beyond the initial phase. One of the other key factors in assessing the economic viability of DLE is the projected returns on investment and payback periods. Although DLE projects have higher capital intensity compared to traditional lithium extraction methods, this can be offset by the potential for selective removal of by-products into their own saleable products, which may improve the economics of DLE projects. These factors can lead to increased efficiency and lower costs, which can improve the returns on investment and shorten the payback periods.

Besides the cost analysis, DLE projects have attracted attention because of their potential to increase efficiency and reduce environmental impact when compared to solar evaporation. DLE has been shown to have a substantially greater recovery rate, ranging from 70 % to 99 %, compared to lithium extracted from brine via solar evaporation, which has a recovery rate of 40 % to 60 % [77]. Furthermore, current DLE approaches have been shown to reduce greenhouse gas (GHG) emissions by up to 50 % when compared to traditional methods. DLE is also known for requiring less land and water input and being less weather-dependent [5]. In contrast, whereas solar evaporation requires less capital, it has lower recovery rates and can be costly both financially and environmentally. Vulcan’s zero-carbon project is an excellent case study of the adsorption type of DLE. This project has a significantly smaller environmental impact than solar evaporation operations, with zero carbon emissions, 1.6 t of water usage, and a land footprint of 6 m² [23].

Conclusion and future outlook

When considering the future of lithium production, DLE stands out as an innovative method providing an alternative approach to traditional techniques. Adsorption-type DLE has the potential to redefine industry standards by selectively extracting lithium from brines. As the global demand for lithium grows, adsorption-type DLE will play an increasingly important role in supplying this rising need. Because of its low environmental impact and ability to work with a variety of brine compositions, it is a key component in maintaining the growing lithium industry. Originating in the 1970s and achieving commercialization in the 1990s, this process involves the passage of brine through a specially prepared column loaded with aluminium-based adsorbents.

Commercial application of the technology has shown that three key ingredients are required: a certain degree of lithium content, typically over 100 mg/L Li; heat in the brine, typically between 40 to 95°C; and salinity to drive the adsorption process. Further study should concentrate on refining and enhancing the adsorption method to accommodate different lithium brine compositions and geochemical properties. This includes experimenting with different salinity levels, lithium concentrations, and brine temperatures to create a more resilient and adaptable system and identify the combined thresholds below which the project becomes unfeasible.

Given the changing landscape of lithium demand and extraction policies, future research could look into the scalability and economic feasibility of adsorption-type DLE at a wider geographical scale. Collaboration among researchers and industry stakeholders will be critical in driving the application of this technology and addressing challenges. Finally, our findings contribute to the continuing discussion over sustainable lithium extraction technologies and provide the foundation for future research endeavours aimed at improving the commercial feasibility of adsorption-type DLE. As we seek for a more environmentally friendly method for meeting the growing demand for lithium, the findings from this study open the way for a more sustainable future in lithium production.

CRediT authorship contribution statement

Yasaman Boroumand: Writing – review & editing, Writing – original draft. Amir RazaMJou: Writing – review & editing, Writing – original draft, Supervision, Resources.
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[27] O. Grosjo, et al., Recent advances in nanomaterial development for lithium ion-storing technologies, Desalination 529 (2022) 115624.
[37] I. Basadino, et al., Recent advances in the lithium recovery from water resources: from passive to electrochemical methods, Adv. Sci. 9 (27) (2022) 2201380.


[73] B. Sanjuan, et al., Lithium-rich geothermal brines in Europe: an up-date about geochemical characteristics and implications for potential Li resources, Geothermics 101 (2022) 102385.


[77] J. Farahbakhsh, et al., Direct lithium extraction: a new paradigm for lithium production and resource utilization, Desalination 575 (2023) 117249.