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Initial Treatment for Lithium And Boron Extraction From PT Pertamina Geothermal Energy Tbk Brine Via Chemical Precipitation for Sustainable Energy Transition

Bogie Lesmana, Bima Bharata Shena, Martha Aznury*, Anerasari Meidinariasty, Dilia Puspa

Department of Chemical Engineering, Politeknik Negeri Sriwijaya, Sumatera Selatan, Indonesia
***Corresponding author**: martha_aznury@polsri.ac.id

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Abstract

The increasing demand for critical minerals such as lithium and boron is driven by the rapid growth of electric vehicles, clean energy transition, and sustainable material applications. Geothermal brine, a by-product of geothermal power generation, offers significant potential as an alternative source of these elements. This study investigated the extraction of lithium and boron from geothermal brine sourced from PT Pertamina Geothermal Energy Tbk, Lumut Balai Area. Lithium was recovered using a chemical precipitation method with sodium carbonate (Na_2CO_3) at 80°C and pH 11, while boron was extracted via liquid–liquid extraction using 2-ethyl-1-hexanol in kerosene. For lithium, various reagent-to-brine ratios (1:5, 1:10, 1:15) and precipitation times (15–75 minutes) were tested, with optimal conditions at a 1:15 ratio and 60 minutes, yielding 28.9 ppm lithium and a 129.08% yield. For boron, the highest concentration of 43.6 ppm was obtained at a 1.5:1 phase ratio and 75 minutes, with subsequent purification returning boron to the aqueous phase. Application testing showed that the boron–borax mixture provided higher wood preservation performance (1.332 kg/m³) compared to pure borax (1.13 kg/m³), meeting SNI 03-5003.1-1999 standards. These findings demonstrate that geothermal brine can serve as a dual source of lithium and boron, supporting sustainable energy transition and eco-friendly material development in Indonesia.

Keywords: *lithium extraction, boron recovery, geothermal brine, chemical precipitation, sustainable energy transition*

Abstrak

Meningkatnya permintaan mineral kritis seperti litium dan boron didorong oleh pesatnya pertumbuhan kendaraan listrik, transisi energi bersih, serta kebutuhan material berkelanjutan. Brine geotermal, sebagai produk samping dari pembangkit listrik tenaga panas bumi, memiliki potensi signifikan sebagai sumber alternatif kedua unsur tersebut. Penelitian ini mengkaji ekstraksi litium dan boron dari brine geotermal yang berasal dari PT Pertamina Geothermal Energy Tbk, Area Lumut Balai. Litium diekstraksi menggunakan metode presipitasi kimia dengan natrium karbonat (Na_2CO_3) pada suhu 80°C dan pH 11, sedangkan boron diekstraksi melalui metode ekstraksi cair–cair menggunakan 2-etil-1-heksanol dalam kerosin. Untuk litium, variasi rasio pereaksi terhadap brine (1:5, 1:10, 1:15) dan waktu presipitasi (15–75 menit) diuji, dengan kondisi optimum pada rasio 1:15 dan 60 menit, menghasilkan konsentrasi litium 28,9 ppm dengan yield 129,08%. Untuk boron, konsentrasi tertinggi 43,6 ppm diperoleh pada rasio fase 1,5:1 dan 75 menit, dengan pemurnian berhasil mengembalikan boron ke fase air. Uji aplikasi menunjukkan bahwa campuran boron–boraks memberikan kinerja pengawetan kayu lebih tinggi (1,332 kg/m³) dibandingkan boraks murni (1,13 kg/m³) serta memenuhi standar SNI 03-5003.1-1999. Hasil ini membuktikan bahwa brine geotermal dapat menjadi sumber ganda litium dan boron, mendukung transisi energi berkelanjutan dan pengembangan material ramah lingkungan di Indonesia.

Kata Kunci: *ekstraksi lithium, boron, geothermal brine, presipitasi kimia, transisi energi terbarukan*

1. Introduction

Indonesia possesses the second largest geothermal energy reserves in the world, with an estimated total potential of approximately 29.5 GW, accounting for nearly 40% of the global geothermal potential [1]. Despite this abundant resource, the actual utilization remains relatively low, reaching only around 8.9% of the total available capacity [2]. In the geothermal power generation process, one of the significant byproducts is geothermal brine [1], a high-salinity formation water that emerges along with steam from geothermal reservoirs. This brine is characterized by its rich mineral composition, which includes valuable elements such as lithium [3]. However, its utilization remains relatively low, at only about 4–9% of the total capacity [2]. One of the significant by products of geothermal power generation is geothermal brine, a high-salinity formation water that emerges along with steam from geothermal reservoirs [1], [4]. This brine is enriched with economically valuable minerals such as lithium, boron, silica, magnesium, and calcium [3], [5]. The presence of these interfering ions, however, increases the complexity of extraction, requiring specific separation and purification techniques to effectively recover target elements [6], [7].

Lithium (Li) is a lightweight metal that plays a critical role in modern industry, particularly as the key component of lithium-ion batteries [8]. These batteries are widely used in portable electronic devices, electric vehicles (EVs), and large-scale energy storage systems [9], [10]. According to the International Energy Agency (IEA), global lithium demand is projected to reach 3.3 million metric tons of lithium carbonate equivalent by 2030 [11], driven by the rapid expansion of EVs, which are expected to experience a tenfold increase in global sales. While countries such as Chile, Argentina, and Australia dominate global lithium supply, Indonesia has not yet placed significant emphasis on large-scale lithium exploration, despite the promising potential of geothermal brine as an unconventional lithium source [2], [11].

A number of previous studies have been conducted with different approaches. [12] managed to achieve a Lithium recovery of 75.8% of the brine using the precipitation method. Meanwhile, [13] developed an MnO_2-based adsorption technique, but its efficiency decreased after several cycles. This suggests that although various approaches have been tested, the precipitation method remains the preferred choice for practical implementation [12], [13].

In addition to lithium, boron is another economically valuable element present in geothermal brine. Boron is widely applied in the glass, ceramics, and pharmaceutical industries, and is also used as a wood preservative [6]. However, the utilization of boron from brine in Indonesia remains very limited. Several methods have been studied for boron recovery from brine, including chemical precipitation, ion exchange, reverse osmosis, and liquid–liquid extraction [14], [15], [16]. Among these, liquid–liquid extraction using organic solvents such as 2-ethyl-1-hexanol offers significant advantages due to its high efficiency, good selectivity, and potential for industrial-scale application [2], [7], [17].

Therefore, this study focuses on the extraction of lithium and boron from geothermal brine sourced from the Lumut Balai Geothermal Power Plant in South Sumatra. Lithium is recovered through a gradual chemical precipitation process using sodium carbonate, while boron is extracted using liquid–liquid extraction [18], [19]. This research is expected to demonstrate the potential of geothermal brine as an alternative source of critical minerals, supporting both the sustainable energy transition and the development of eco-friendly materials in Indonesia.

2. Material and Methods

2.1 Materials and Chemicals

The geothermal brine used in this research was obtained directly from PT Pertamina Geothermal Energy Tbk, Lumut Balai Area, South Sumatra, Indonesia. The brine is characterized as a high-salinity solution containing various metal ions, with lithium and boron as the primary target elements. Based on preliminary analysis, the brine contained ±22.39 ppm lithium and ±81 ppm boron, alongside significant amounts of silica, calcium, and magnesium that may interfere with the extraction process.

The chemicals used in this study were sodium carbonate (Na_2CO_3, Merck, 99.5%) as the precipitating reagent for lithium, and 2-ethyl-1-hexanol (2.5 mol/L, analytical grade) dissolved in kerosene as the organic phase for boron extraction. Supporting reagents included deionized water for washing precipitates and aquabidest for stripping boron during purification. Nitric acid (HNO_3, Merck, 65%) was used to preserve boron samples before Atomic Absorption Spectrophotometry (AAS) analysis.

2.2 Equipment

The laboratory equipment included a hotplate magnetic stirrer (IKA C-MAG HS7) for heating and stirring, a vibrator cycling device for liquid–liquid extraction mixing, separating funnels for phase separation, and a pH meter (Hanna Instruments HI2211) for pH control. Drying was performed in a laboratory oven at 50–60 °C to avoid thermal decomposition of lithium carbonate. Analytical instruments comprised an X-Ray Fluorescence (XRF, Panalytical Zetium) spectrometer for lithium precipitate characterization and an Atomic Absorption Spectrophotometer (Shimadzu AA-7000) operated at a wavelength of 249.7 nm for boron analysis.

2.3 Boron Extraction Procedure

Boron extraction was carried out using the liquid–liquid extraction (LLE) method. The aqueous phase consisted of geothermal brine, while the organic phase was a solution of 2-ethyl-1-hexanol dissolved in kerosene at 2.5 mol/L [14]. The two phases were contacted at different organic-to-aqueous (O/A) ratios of 0.5:1, 1:1, and 1.5:1. Each mixture was stirred with a vibrator cycling device at room temperature (30 °C) for contact times of 15, 30, 45, 60, and 75 minutes. The natural brine pH of 5.6 was maintained throughout the process, as this condition is favorable for the formation of stable boron–alcohol complexes [20].

After mixing, the solutions were allowed to stand for 15 minutes to achieve clear phase separation. The organic phase, which contained the boron–alcohol complex, was subjected to a stripping (back-extraction) process using aquabidest at a 1:1 ratio [21]. This step was performed by stirring for 15 minutes followed by settling for 10 minutes to ensure complete transfer of boron back into the aqueous phase. Boron concentrations in the feed, raffinate, and stripped solution were measured by AAS at 249.7 nm. Calibration curves were prepared using standard boron solutions to ensure analytical accuracy.

2.4 Lithium Precipitation Procedure

Lithium recovery was conducted through a gradual chemical precipitation method. For each experiment, 1 L of geothermal brine was prepared as the aqueous feed solution. The brine was homogenized through gentle stirring to ensure uniform distribution of ions, minimizing the risk of localized supersaturation or uneven reaction kinetics [18].

The precipitation process was performed at a controlled temperature of 80 °C using a magnetic stirrer hotplate [12]. Sodium carbonate solution was gradually added into the brine at different reagent-to-brine ratios of 1:5, 1:10, and 1:15 (g Na_2CO_3 per L brine). The addition was carried out slowly to prevent sudden nucleation and allow uniform diffusion of carbonate ions (CO_3^{2-}) into the brine. The mixture was stirred continuously for varied reaction times of 15, 30, 45, 60, and 75 minutes to evaluate the influence of contact time on precipitation efficiency [6].

After the reaction, the system was cooled to room temperature and allowed to settle for 10–15 minutes, promoting sedimentation of lithium carbonate (Li_2CO_3) crystals. The precipitate was separated using a separating funnel, washed thoroughly with deionized water to remove soluble impurities such as residual sodium ions, and dried in an oven at 50–60 °C until a constant weight was achieved [6], [18]. The resulting lithium carbonate precipitate was subsequently subjected to XRF analysis to determine lithium purity and the extent of impurity removal (e.g., Ca, Mg, B, Si) [22], [23].

3. Results and Discussion

3.1 The Effect of Time and Phase Ratio (O/A) Comparison on Extraction

The boron extraction process is carried out by mixing a solution of 2-ethyl-1-hexanol in kerosene (2.5 mol/L) as an organic phase with geothermal brine in a varied volume ratio (0.5:1, 1:1, and 1.5:1). The mixture is stirred using a Cycling Vibrator at room temperature for a certain time (15–75 minutes) to allow the formation of a boron-alcohol complex that dissolves in the organic phase. After the extraction process, the mixture is left to allow the phases to be gravitationally separated, and the organic phases containing boron are then purified using aquabidest in a 1:1 ratio to return the boron to the aqueous phase.

The extraction results showed that the larger the volume of organic solvents and the longer the contact time, the more boron was successfully extracted. However, at times above 60 minutes, the increase in boron levels becomes insignificant, indicating that equilibrium conditions have been reached. For example, at a 1.5:1 ratio, an increase from 41.5 ppm to 43.6 ppm between the 60th and 75th minutes showed only a small incremental efficiency. This is in line with previous studies by [7], [19] which showed that boron extraction systems tend to reach stability in less than 1 hour.

The effect of extraction time on boron levels (in ppm units) obtained through the liquid-liquid extraction process using 2-ethyl-1-hexanol solvent in kerosene. The process is carried out at three variations in the organic to aqueous phase volume ratio, namely 0.5:1, 1:1, and 1.5:1. Each ratio was tested in five extraction time intervals, namely 15, 30, 45, 60, and 75 minutes at a constant temperature of 30°C and a pH of 5.6. The main objective of this analysis is to identify the most optimal combination of time and solvent ratios in producing the highest boron levels through the extraction and purification process.

The results of the observation showed that the increase in extraction time and the ratio of organic phase volume to aqueous phase (O/A) had a significant effect on the amount of boron successfully extracted from geothermal brine. At a ratio of 0.5:1, boron levels increased gradually from 15.8 ppm to 24.6 ppm, while at ratios of 1:1 and 1.5:1, the increase was much more significant, reaching 35.7 ppm and 43.6 ppm at the 75th minute, respectively. This increase is due to the increasing volume of organic solvents that are able to increase the contact area between phases, as well as facilitate the formation of stable boron-alcohol complexes in the organic phase. The longer contact time also provides a greater opportunity for the complex to form, thus increasing the efficiency of extraction [14], [19].

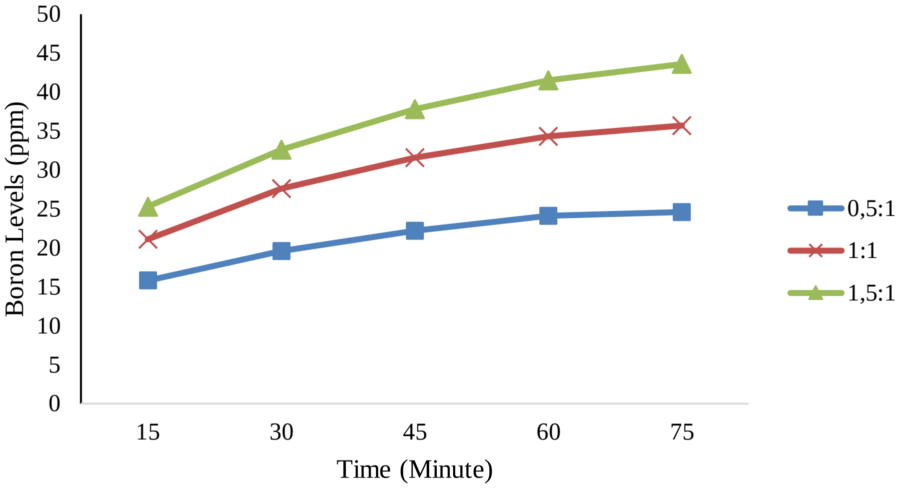

Figure 1. The Effect of Time and Phase Ratio (O/A) Comparison on Extraction

Nonetheless, the extraction efficiency shows a downward trend after 60 minutes, which indicates that the system is starting to approach equilibrium. This plateau phenomenon can be seen from the slow rate of increase in boron levels at a ratio of 1 and 1.5. These results are in line with findings [7], [14] which state that boron extraction with aliphatic alcohols such as 2-ethyl-1-hexanol tends to be stable after a certain time [20]. Therefore, the optimal time for this process is estimated to be in the range of 45–60 minutes, and the efficient O/A phase ratio is at a value of 1:1 to 1.5:1. Selecting the right operating conditions is important to obtain maximum extraction results while still considering the aspects of solvent efficiency and operational costs.

3.2 Effect of Sodium Carbonate Concentration on the Lithium Extraction Process from Geothermal Brine

The lithium extraction process from geothermal brine commenced with the preparation of samples, in which 1 liter of brine was allocated for each treatment variation. Prior to any further processing, each sample underwent gentle stirring to ensure complete homogeneity. This step was crucial to achieve an even distribution of lithium ions (Li^+) and other dissolved constituents within the solution, thereby minimizing concentration gradients that could negatively affect the reproducibility of results. Ensuring uniform ion distribution is particularly important in precipitation-based extraction methods, as it promotes consistent reaction kinetics, enhances the efficiency of lithium recovery, and reduces the risk of localized supersaturation or incomplete precipitation during subsequent processing stages [12].

Next, the brine was heated to 80°C on a magnetic hotplate stirrer. This temperature, based on prior research [12], [23], was selected to accelerate the precipitation reaction without causing significant evaporation or degradation. Sodium carbonate (Na_2CO_3) was slowly added while stirring continuously to prevent clumping and ensure effective reaction between Li^+ and CO_3^{2-} to form insoluble lithium carbonate (Li_2CO_3). Three reagent ratios 1:5, 1:10, and 1:15 (g Na_2CO_3 per L brine) were tested to evaluate the effect of reagent quantity on precipitation efficiency. After reagent addition, the mixture was stirred and heated for 30 minutes to ensure full mixing and reaction completion.

Following the reaction, the solution was cooled to room temperature and left to settle for 10–15 minutes, allowing the Li_2CO_3 precipitate to fully deposit at the bottom for easy separation [18] Precipitation times were also varied (15, 30, 45, 60, and 75 minutes) to assess the effect of duration on the amount and quality of the precipitate. This experiment combined reagent ratio and reaction time variations to determine the optimum conditions for lithium precipitation from geothermal brine. The effectiveness of each treatment was evaluated based on the amount of precipitate formed and lithium content, providing a foundation for scaling up to industrial-level processes.

The graph shows that at a 1:5 ratio, *Lithium levels* increase until the 60th minute (20.5 ppm), but decrease at the 75th minute, indicating that precipitation efficiency decreases if the reaction takes too long. The 1:10 ratio showed a more stable increase with a high of 25.3 ppm at the 60th minute, and a slight decrease at the 75th minute. Meanwhile, the 1:15 ratio produced *the highest Lithium* levels, reaching 28.9 ppm in the 60th minute, but also decreased to 26.8 ppm in the 75th minute.

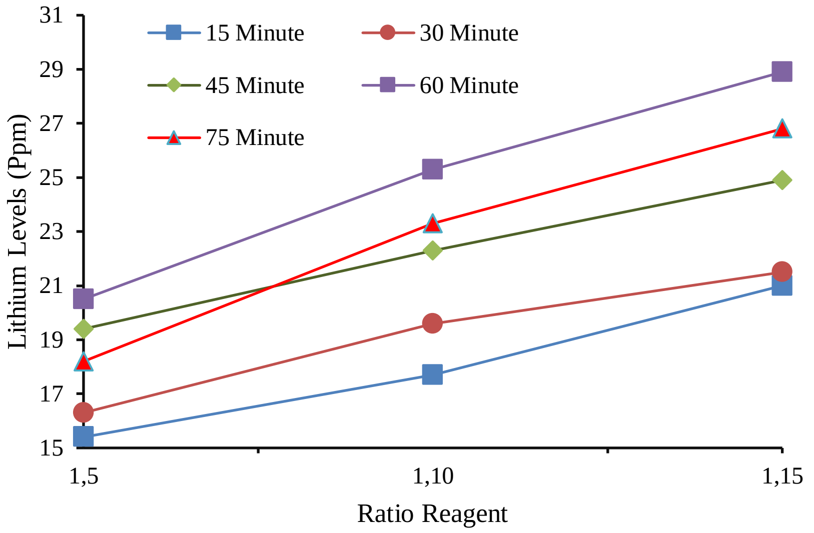

Figure 2. Effect of Sodium Carbonate Concentration on the Lithium Extraction Process from Geothermal Brine

These results confirm that the optimal reaction time is at 60 minutes for the entire ratio, with a ratio of 1:15 being the best condition for producing the highest Lithium levels. A decrease in levels after 60 minutes is suspected to be due to a backreaction or redissolution of the compound.

$$Na_2CO_3(aq) + LiCl\ (aq) \rightarrow\ Li_2CO_3(s) + NaCL\ (aq) \qquad (1)$$

This reaction is a precipitation reaction of lithium ions, and is the basis of the method for separating lithium from brine solutions. Therefore, the right combination of reaction time and reagent ratio is essential to optimize the efficiency of *the Lithium precipitation process* of brine [12], [18].

3.3 Analysis of the Composition of Extraction Results

X-Ray Fluorescence (XRF) is a non-destructive analysis method used to identify chemical elements in solid, liquid, or powdery samples. The principle is based on the emission of a secondary X-ray that is typical of each element when the sample is shot with a primary X-ray. In this study, XRF was used qualitatively to verify the presence of *Lithium elements* in the extraction results from *geothermal brine*. The analysis was carried out on one sample in a representative manner due to the limitation of the number of products, with the standard method of the tool without additional calibration.

Table 1. Xrf Analysis Results Lithium Carbonate

No	Parameter	Unit	Analysis Results
1	Li	%	73,563 ± 0,439%
2	Cl	%	12,219 ± 0,391%
3	Na	%	7,526 ± 0,312%
4	Mn	%	1,616 ± 0,131%
5	Mg	%	1,385 ± 0,488%
6	Ni	%	0,908 ± 0,150%
7	Ca	%	0,782 ± 0,123%

The XRF results showed that *the element Lithium* (Li) dominated with a level of 73.563 ± 0.439%, confirming the success of *Lithium* carbonate (Li_2CO_3) precipitation. Other elements detected were chlorine (Cl) at 12.219%, likely from *Lithium* chloride (LiCl) residues, as well as sodium (Na), manganese (Mn), magnesium (Mg), nickel (Ni), and calcium (Ca), which are thought to be derived from raw materials or the process environment. Copper (Cu) elements were detected only in trace amounts (0.078%), while other elements were below the detection limit. These results reinforce the presence of *Lithium* as a major component and indicate the presence of minor impurities from the initial process or material.

4. Conclusion

Strategic This study successfully demonstrated the potential of geothermal brine from PT Pertamina Geothermal Energy Tbk, Lumut Balai Area, as a dual source of critical elements—lithium and boron. Lithium recovery using a gradual chemical precipitation method with sodium carbonate proved effective, with optimal conditions at a reagent ratio of 1:15 and 60 minutes of reaction time, yielding 28.9 ppm lithium and lithium carbonate with 73.563% purity based on XRF analysis. Meanwhile, boron extraction using liquid–liquid extraction with 2-ethyl-1-hexanol in kerosene achieved optimal performance at an O/A ratio of 1:1.5 and 75 minutes of contact time, followed by successful purification using aquabidest. The extracted boron, when applied in a borax-based preservative, produced higher wood retention values (1.332 kg/m³) than pure borax (1.13 kg/m³), meeting the SNI 03-5003.1-1999 standard.

These findings highlight that geothermal brine is not only a promising unconventional resource for lithium to support battery manufacturing and national energy security, but also a valuable source of boron that can be utilized for eco-friendly material applications. The integration of both extraction processes demonstrates an innovative approach to maximize the value of geothermal byproducts, supporting sustainable resource utilization and the clean energy transition in Indonesia.

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6. Abbreviations

Na_2CO_3	Sodium Carbonate
Li_2CO_3	Lithium Carbonate
Li^+	Lithium ion
CO_3^{2-}	Carbonate ion
O/A	Organic-to-Aqueous phase ratio in boron liquid–liquid extraction
AAS	Atomic Absorption Spectrophotometry
XRF	X-Ray Fluorescence
ppm	Parts per million
SNI	Indonesian National Standard
EVs	Electric Vehicles
IEA	International Energy Agency

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