STUDY OF THE PHYSICOCHEMICAL FUNDAMENTALS OF LITHIUM CARBONATE PRODUCTION FROM INDUSTRIAL WASTE

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Abstract. This study investigates the physicochemical fundamentals of lithium carbonate production from industrial waste materials, including spent lithium-containing batteries and alkaline wastewater generated during liquid rubber production. The influence of roasting temperature, leaching conditions and carbonation parameters on lithium extraction efficiency and lithium carbonate crystallization was systematically studied. Thermal treatment of lithium-containing materials was carried out at temperatures ranging from 450 to 750°C, followed by hydrometallurgical leaching and controlled carbonation processes. Experimental results demonstrated that roasting temperature significantly affects lithium phase transformation and subsequent extraction efficiency. The highest lithium recovery, approximately 80%, was achieved under optimized leaching conditions at moderate calcination temperatures. Carbonation and evaporation processes promoted efficient crystallization of lithium carbonate with a purity exceeding 99%. X-ray diffraction and chemical analyses confirmed the formation of high-purity crystalline lithium carbonate with minimal impurity content. The obtained results indicate that industrial waste materials can serve as promising secondary lithium resources for environmentally sustainable lithium carbonate production. The developed approach contributes to resource conservation, reduction of environmental pollution and improvement of secondary raw material utilization technologies.
Keywords: lithium carbonate, industrial waste, lithium extraction, carbonation process, hydrometallurgical treatment, crystallization, physicochemical properties.

INTRODUCTION

Lithium carbonate is one of the most important lithium compounds widely used in glass, ceramics, metallurgy, pharmaceuticals, lubricants and electrochemical industries. In recent years, the global demand for lithium compounds has increased sharply due to the rapid growth of lithium-ion battery production for electric vehicles, portable electronic devices and renewable energy storage systems. According to recent industrial statistics, more than 70% of the world's lithium consumption is associated with battery technologies, while the remaining portion is used in glass-ceramic production, aluminum metallurgy and specialty chemical industries. The increasing consumption of lithium resources has intensified the need for alternative and sustainable technologies for lithium recovery from secondary and industrial waste materials.

Conventional lithium production is mainly based on the processing of natural brines and hard-rock lithium minerals. However, these technologies require significant energy consumption, long processing periods and high operational costs. In addition, depletion of high-grade lithium ores and environmental concerns related to mining activities have stimulated scientific interest toward the utilization of industrial waste as a secondary lithium source. Various technogenic materials, including metallurgical slags, chemical production residues and spent lithium-ion batteries, contain valuable lithium compounds that can be recovered through physicochemical treatment methods.

The physicochemical production of lithium carbonate from industrial waste involves several important stages such as roasting, leaching, carbonation, precipitation and crystallization. Process efficiency is strongly influenced by parameters including temperature, pH, reaction time, reagent concentration, solid-to-liquid ratio and carbon dioxide pressure. Studies have shown that lithium extraction efficiencies may exceed 85–95% under optimized processing conditions. In many technological schemes, lithium-containing compounds are converted into soluble lithium bicarbonate in the presence of carbon dioxide and water, followed by thermal decomposition to obtain lithium carbonate crystals.

The principal physicochemical reactions involved in lithium carbonate formation can be expressed as follows:

$$Li_2CO_3(s) + H_2O(l) + CO_2(g) \rightarrow 2LiHCO_3(aq) \quad (1)$$

In this reaction, lithium carbonate interacts with carbon dioxide and water to form soluble lithium bicarbonate, which facilitates lithium transfer into solution during carbonation processing.

$$2Li_2CO_3(aq) \rightarrow Li_2CO_3(s) + H_2O(l) + CO_2(g)$$

During subsequent heating, lithium bicarbonate decomposes, resulting in the precipitation of lithium carbonate with simultaneous release of carbon dioxide and water vapor. The low solubility of lithium carbonate at elevated temperatures enables efficient separation and purification of the final product.

Recycling of lithium-containing industrial waste not only reduces environmental pollution but also contributes to the conservation of natural lithium resources and the development of circular economy technologies. Therefore, investigation of the physicochemical fundamentals governing lithium carbonate production from industrial waste is of considerable scientific and industrial importance.

The present study focuses on analyzing the physicochemical mechanisms of lithium extraction and lithium carbonate synthesis from industrial waste materials. Special attention is devoted to determining the optimal technological parameters affecting lithium recovery efficiency, carbonation behavior and crystallization processes in order to develop an environmentally sustainable and resource-efficient lithium recovery technology.

MATERIALS AND METHODS

In the present study, lithium-containing industrial waste materials including spent Li/MnO_2 batteries and alkaline wastewater generated during liquid rubber production were used as raw materials for lithium carbonate production. Prior to physicochemical treatment, the spent batteries were roasted in a laboratory furnace at temperatures ranging from 450 to 750°C for 1 h in order to deactivate residual electrochemical activity and facilitate subsequent separation of electrode materials. After cooling under atmospheric conditions, metallic casings were separated from active cathode materials using vibration screening and magnetic separation methods. The obtained electrode material was ground to obtain a homogeneous powder suitable for hydrometallurgical processing.

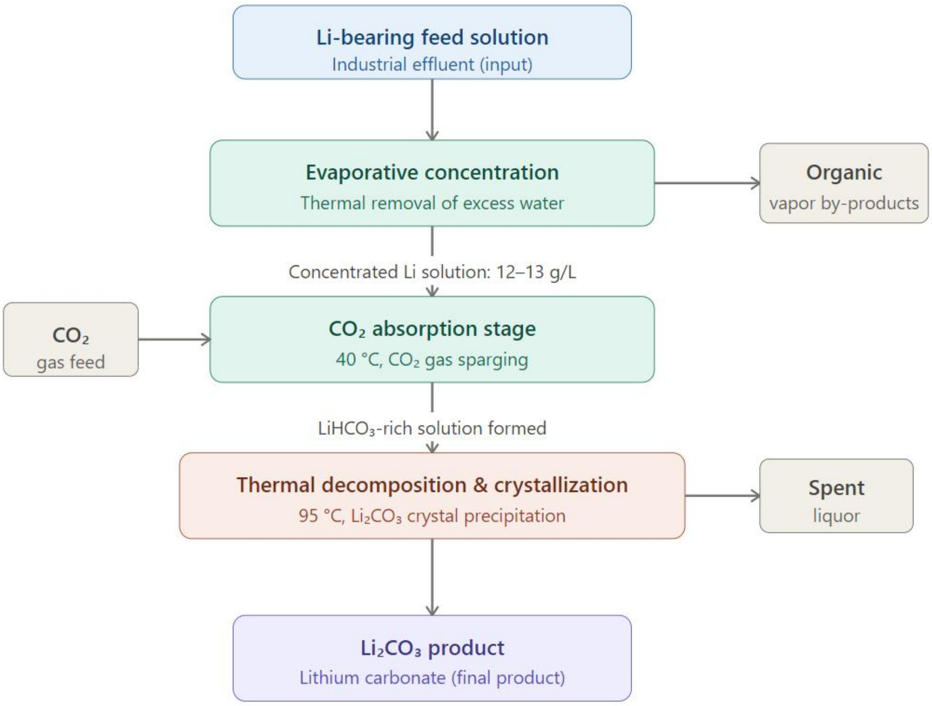

Figure 1. Technological flow diagram for lithium carbonate production from industrial wastewater solutions

Leaching experiments were carried out in a thermostatically controlled glass reactor equipped with a mechanical stirrer. Sulfuric acid solution was used as the primary leaching reagent for lithium dissolution. During the experiments, process parameters including temperature, acid concentration, reaction time and liquid-to-solid ratio were varied systematically to determine their influence on lithium extraction efficiency. The leaching duration ranged from 1 to 3 h at laboratory temperature conditions with a liquid-to-solid ratio of 20–30:1. During leaching, periodic solution samples were collected for determination of lithium concentration using atomic absorption spectroscopy analysis. After completion of the experiments, the obtained residues were filtered, dried and subjected to chemical and X-ray diffraction analyses.

Special attention was devoted to investigating the solubility behavior of lithium carbonate in aqueous media because the precipitation process strongly depends on temperature conditions. Experimental observations confirmed that the solubility of lithium carbonate decreases with increasing temperature, facilitating its crystallization from concentrated solutions. Lithium carbonate precipitation was performed by controlled evaporation and carbonation of lithium-containing filtrates. During evaporation, the influence of residual moisture on the precipitation process was examined. The resulting suspensions were filtered and separated into liquid and solid phases for further chemical characterization.

Alkaline wastewater originating from liquid rubber production was additionally investigated as a secondary lithium source. Preliminary analyses revealed the presence of lithium compounds predominantly in the form of lithium hydroxide and organo-lithium species. Prior to carbonation treatment, wastewater samples were concentrated by distillation until lithium concentration reached approximately 12–13 g/L. Carbonation experiments were conducted in a glass reactor equipped with a gas distribution system, magnetic stirrer, condenser and temperature controller. Carbon dioxide gas was continuously introduced into the alkaline solution at 40°C for 2 h in order to promote lithium carbonate formation. After completion of the carbonation process, the reaction mixture was heated to 95°C and maintained for 3 h to enhance lithium carbonate crystallization and separation.

The precipitated lithium carbonate products were filtered, washed with distilled water, dried and analyzed using chemical and X-ray diffraction methods to determine phase composition and product purity. Experimental data obtained during the study were used to evaluate lithium recovery efficiency, precipitation yield and physicochemical characteristics of the synthesized lithium carbonate.

RESULTS AND DISCUSSION

The experimental results demonstrated that roasting temperature had a significant influence on the physicochemical behavior of lithium-containing materials and the subsequent lithium extraction efficiency. During thermal treatment of spent Li/MnO_2 batteries at temperatures ranging from 450 to 750°C, noticeable changes in the chemical composition and phase structure of the calcined products were observed. Increasing roasting temperature promoted partial volatilization of lithium compounds and simultaneously reduced the concentration of several impurity elements. X-ray diffraction analysis revealed that the major phases present in the calcined materials were manganese oxide and lithium-containing compounds, while minor graphite residues originating from electrode materials were also detected.

Leaching experiments showed that lithium dissolution strongly depended on calcination temperature and liquid-to-solid ratio. The highest lithium extraction efficiency was achieved for samples calcined at approximately 650°C, where lithium recovery reached about 80% under optimized conditions. Lower extraction efficiencies obtained at reduced calcination temperatures were associated with incomplete decomposition of electrode materials and limited lithium phase transformation. At higher roasting temperatures, partial lithium losses caused by volatilization negatively affected the extraction process. The obtained results confirmed that moderate roasting temperatures provide favorable conditions for lithium phase conversion and enhance subsequent hydrometallurgical recovery.

Lithium concentration in the obtained filtrates varied depending on leaching parameters and evaporation conditions. Controlled evaporation of lithium-containing solutions enabled gradual crystallization of lithium carbonate due to its decreasing solubility at elevated temperatures. Experimental observations demonstrated that the purity of the precipitated lithium carbonate was strongly influenced by the degree of solution evaporation and the presence of accompanying alkali and alkaline-earth metal impurities. Under optimized conditions, lithium carbonate with a purity exceeding 99% was obtained after additional washing and purification stages. Residual impurities detected in the precipitated products mainly consisted of sodium, potassium, calcium and trace transition metals.

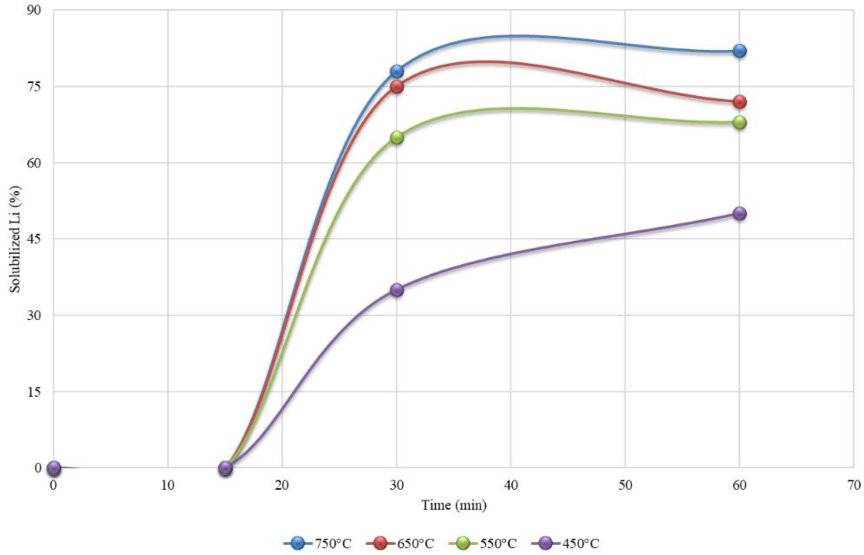

Figure 2. Dependence of lithium extraction efficiency on roasting temperature at a liquid-to-solid ratio of 25:1 during leaching of calcined electrode materials

Investigation of lithium-containing alkaline wastewater generated during liquid rubber production demonstrated that such technogenic solutions can serve as promising secondary lithium resources. Preliminary concentration of wastewater by distillation significantly increased lithium concentration and improved the efficiency of subsequent carbonation and crystallization processes. During carbonation treatment, introduction of carbon dioxide into the alkaline solution promoted the conversion of dissolved lithium compounds into lithium carbonate precursor species. Approximately 90% of lithium carbonate crystallized after controlled heating and evaporation of the processed solutions, while residual lithium concentration in the mother liquor remained relatively low.

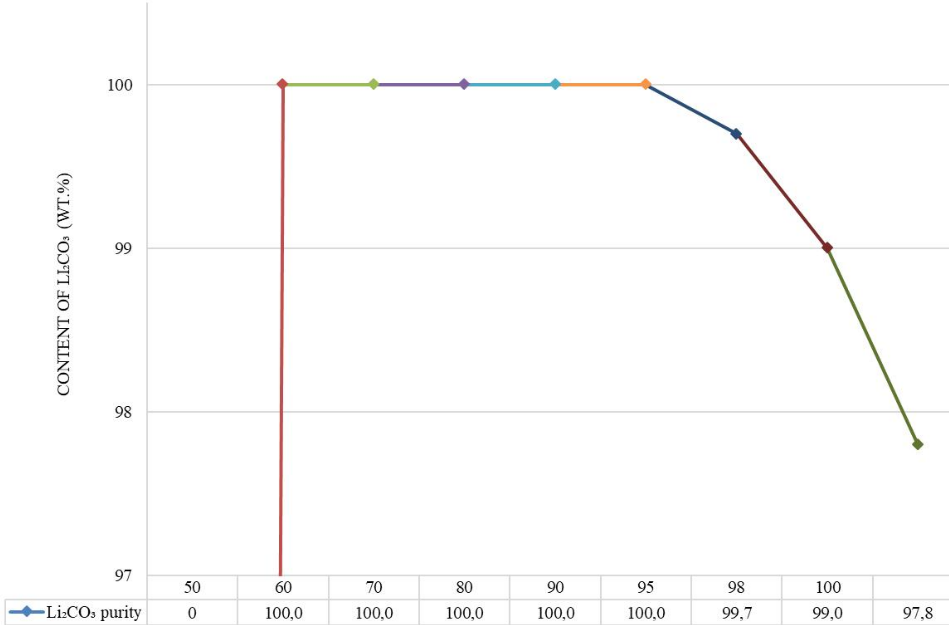

Figure 3. Effect of evaporated solution volume on the purity of lithium carbonate crystals

Chemical analysis of the synthesized lithium carbonate confirmed high lithium content and low concentrations of silicon, iron, zinc and aluminum impurities. X-ray diffraction analysis indicated the formation of crystalline lithium carbonate as the dominant phase without the presence of significant secondary compounds. The obtained results demonstrate that industrial lithium-containing waste materials can be effectively utilized for lithium carbonate production through combined thermal, hydrometallurgical and carbonation processing methods.

CONCLUSION

The conducted research demonstrated that industrial waste materials, including lithium-containing batteries and alkaline wastewater, can be effectively utilized as secondary raw materials for lithium carbonate production. Experimental investigations confirmed that roasting temperature, leaching conditions and carbonation parameters significantly influence lithium extraction efficiency and the physicochemical properties of the obtained lithium carbonate. The highest lithium recovery was achieved at moderate calcination temperatures, where favorable phase transformation and improved lithium dissolution conditions were observed. Controlled evaporation and carbonation processes enabled the production of high-purity lithium carbonate with low impurity content.

The obtained results indicate that the developed physicochemical approach provides an environmentally sustainable and resource-efficient method for lithium recovery from industrial waste. Application of thermal treatment, hydrometallurgical leaching and carbonation technologies contributes to the reduction of environmental pollution and the conservation of natural lithium resources. Furthermore, the proposed process demonstrates considerable potential for industrial implementation in secondary lithium recovery systems and supports the development of circular economy technologies for strategic raw materials.

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