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Investigation of Effect of Natural Salts on Discharge Time of Remaining Voltage of Lithium-Ion Batteries during Crushing Stage

Mohammad Reza Veshadi Arani, and Seyed Mohammad Razavian*

Department of Mining Engineering, Faculty of Engineering, University of Kashan, Kashan-Iran

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Abstract

The use of lithium-ion batteries has increased significantly in recent years due to their high energy density and the presence of valuable materials such as cobalt and nickel, making them an important source for secondary material recovery. However, recycling these batteries presents substantial safety risks, primarily from fire and explosion hazards caused by unwanted short circuits and high voltage components. These risks are especially pronounced during mechanical preparation, crushing, storage, and transportation, where damaged or improperly handled batteries can ignite or explode. To mitigate these hazards, rapid and controlled discharge of batteries before recycling is critical. Discharging using salt solutions is recognized as a simple, fast, and cost-effective method to reduce residual charge and minimize the risk of fire during subsequent handling. In this research, four different types of natural salts at various concentrations were tested, prioritizing the use of accessible, low-cost, and impure salts over pure laboratory-grade salts to enhance scalability and economic feasibility. Initial experiments involved direct immersion of batteries in salt solutions at concentrations of 10%, 15%, and 20% by weight. Among the complementary processes evaluated, the use of a high-speed magnetic stirrer, iron powder, and ultrasonic operations (ultrasonic bath and probe) were found to further reduce discharge time and help achieve target voltages more quickly. Notably, ultrasonic agitation at 28 kHz was particularly effective, significantly accelerating the discharge process and enabling the batteries to reach lower voltage thresholds such as 0.5 volts in a shorter time.

1. Introduction

The depletion of fossil fuels and environmental issues have paved the way for the use of renewable energy sources such as batteries. The current energy economy, based on fossil fuels, faces significant risks due to factors such as continuously increasing oil demand, depletion of non-renewable resources, and dependence on politically unstable oil-producing countries. Fossil fuels are a limited resource, and the world is facing an emerging energy crisis [1]. It takes millions of years to produce the fossil fuels consumed in the past 200 years. Their consumption is the main cause of many environmental problems, including global warming, air pollution, and acid rain. Another concerning aspect of the current fossil fuel energy economy is the increasing level of carbon dioxide emissions, which have almost doubled in the past 30 years. Therefore, the use of renewable energy sources has grown. One of the most important renewable sources is batteries [2, 3]. Due to their rich composition of valuable materials such as cobalt, nickel, lithium, copper, and aluminum, batteries are used as sources of secondary raw materials. Batteries consist of one or more electrochemical cells capable of converting chemical energy into electrical energy and are a common energy source for many industrial and household applications. Rapid technological advancement and the growing need for rechargeable batteries as energy sources have raised many concerns regarding the disposal of used batteries. Generally, batteries can be divided

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Corresponding author: razavian@kashanu.ac.ir (S.M. Razavian)

into primary batteries and rechargeable batteries, which mainly include lead-acid batteries, nickel-cadmium (Ni-Cd) batteries, nickel-metal hydride (Ni-MH) batteries, and lithium-ion batteries. Compared to other rechargeable batteries, some lithium batteries have higher energy density, higher cell voltage, less memory effect, lower self-discharge, longer cycle life, and are environmentally friendly, simple to charge, and maintain [4]. Various lithium-containing batteries first entered the market in the 1990s and are now widely used in modern equipment and life. Lithium-containing batteries are classified into rechargeable and non-rechargeable types, with primary lithium batteries being non-rechargeable and lithium-ion batteries (LIBs) considered a key technology enabling the transition to electric vehicles, thus replacing the traditional internal combustion engine design [5-7].They are also the most suitable means for storing electrical energy. Renewable energies in electrical grids are currently the dominant power sources for various portable electronic devices. Lithium-ion batteries are noted for their high working voltage, low memory effects, and high energy density compared to traditional batteries [8]. As the use of alternative energy sources like solar and wind increases, the need for electrical energy storage becomes more pronounced. One of these storage methods is the use of lithium-ion batteries. The use of lithium-ion batteries is growing worldwide. This type of battery is increasingly being used in innovative applications, such as the aerospace industry, power transmission, consumer electronics, automotive industry, and renewable energy industry [9]. The increased use of personal electronic devices has led to a remarkable rise in lithium-ion battery waste. Meanwhile, electric vehicles are also on the rise, leading to the future production of large amounts of battery waste from vehicles. For instance, in 2019, about 50% of the cars sold in Norway were electric [10, 11]. Thus, the issue of lithium-ion batteries used in electric vehicles has gained justified attention in recent years. Generally, electronic waste is one of the fastest-growing solid waste streams globally, posing significant challenges [12, 13].

1.1. Chemistry of lithium-ion batteries and materials

Since Sony first commercialized lithium-ion batteries using carbon as the anode and $LiCoO_2$ (LCO) as the cathode in 1991, billions of lithium-ion battery cells have been produced for portable electronic devices and other large electrical devices. The four main components of a lithium-ion battery are the cathode, electrolyte, separator, and anode. The anode stores lithium ions during charging, and lithium ions move towards the cathode during discharge to drive electrical applications. Therefore, the lithium-ion battery is also called a rocking-chair battery because lithium ions are exchanged between the cathode and anode. Common cathodes contain transition metal oxides such as LCO, $LiMn_2O_4$ (LMO), $Li(Ni_xCo_{\gamma}Alz)O_2$ (NCA), and $Li(Ni_xCo_{\gamma}Mnz)O_2$ (NCM), which can be categorized accordingly. The crystal structures of LCO, NCA, and NCM are layered, with high specific energy and voltage, but cobalt is expensive, toxic, and thermally unstable. NCM contains less cobalt and is cheaper. LMO has high thermodynamic stability and high voltage but relatively low capacity. $LiFePO_4$ (LFP) cathode materials have a stable olivine structure and are safer than NCM and LCO, but they have low capacity and low charge/discharge rates [14]. The demand for energy density and power density in lithium-ion batteries is continuously increasing. Many new high-capacity, high-voltage cathode materials have been identified, including nickel-rich, manganese-rich, and lithium-rich materials. Based on the nickel content, the ratio of nickel, cobalt, and manganese in commercial NCM cathodes varies, with different $Li(Ni_xCo_{\gamma}Mnz)O_2$ (NCM) compositions such as 8.5:0.75:0.75, 8:1:1, 7:1.5:1.5, 6:2:2, 5:2:3, 4:3:3, 1:1:1, etc. Increasing nickel and lithium contents can enhance the specific capacity of cathode materials but also lead to thermal instability. Nickel-rich commercial NCM materials such as $Li(Ni_{0.8}Co_{0.1}Mn_{0.1})O_2$ and $Li(Ni_{0.6}Co_{0.2}Mn_{0.2})O_2$ both exhibit higher specific capacities (specific capacity: 203 and 187 mAh/g respectively for $Li(Ni_{0.8}Co_{0.1}Mn_{0.1})O_2$ and $Li(Ni_{0.6}Co_{0.2}Mn_{0.2})O_2$ but lower thermal stability compared to low-nickel NCM materials like $Li(Ni_{0.5}Co_{0.2}Mn_{0.3})O_2$ or $Li(Ni_{0.33}Co_{0.33}Mn_{0.33})O_2$ (specific capacity: 175 and 163 mAh/g respectively for $Li(Ni_{0.5}Co_{0.2}Mn_{0.3})O_2$ and $Li(Ni_{0.33}Co_{0.33}Mn_{0.33})O_2$ [15]. The common anode is made of graphite or $Li_4Ti_5O_{12}$ (LTO). The theoretical capacities for graphite and $Li_4Ti_5O_{12}$ are 372 and 175 mAh/g respectively [16]. The potential required for lithium insertion in $Li_4Ti_5O_{12}$ is 1.5 volts versus Li/Li^+, which is higher than the carbon-based anode, thus the full cell voltage with the $Li_4Ti_5O_{12}$ anode for a given cathode material decreases, and the energy density of the lithium-ion battery with $Li_4Ti_5O_{12}$ is lower compared to a graphite cell. However, the $Li_4Ti_5O_{12}$ anode has better cycle performance at high temperatures and better thermal stability compared to the graphite anode [17]. Similar to cathode materials, new high-capacity, high-voltage anode materials have also attracted special attention. These materials include silicon (approximately 4140 mAh/g, but with nearly 400% volume fluctuation during a cycle), tin (992 mAh/g), antimony sulfide (Sb_2S_3) (720 mAh/g, after 50 cycles at a current density of 250 mA/g), germanium (about 1200 mAh/g) [18, 19]. and transition metal oxides (MO) where M is cobalt, nickel, copper, or iron, around 700 mAh/g), and silicon oxide. However, these new anode materials have yet to be commercialized. High volume expansion, low conductivity, instability of the solid electrolyte interphase (SEI) layer, and poor capacity retention are the main obstacles to the development of new anode materials [20].

1.2. Necessities of recycling lithium-ion batteries

The use of lithium-ion batteries in consumer electronics and electric vehicles is rapidly growing, leading to increased demand for resources such as cobalt and lithium. Therefore, recycling these batteries is essential not only to reduce energy consumption but also to address the scarcity of rare resources and eliminate the pollution of hazardous components, ensuring sustainability in industries related to consumer electronics and electric vehicles. Below are some main reasons for recycling these types of batteries: High number of consumed batteries, Environmental importance of consumed batteries, Resources available in consumed batteries, Protecting resources for future generations [21-23]. This research examines the discharge process using chemical solutions containing four types of natural salts obtained from salt lakes and salt mountains, with these samples containing impurities. Advantages of using these types of salts include the use of natural, inexpensive, and readily available resources, reducing ongoing costs in the large-scale and industrial recycling process of lithium-ion batteries, shortening the discharge process time, and maintaining more stable voltage reduction in lithium-ion batteries.

2. Material and methods

In this research, four different types of natural salts from Khur and Biabanak Playa (A), Aran and Bidgol Salt Lake (B), Urmia Salt Lake (C), and Garmsar-Semnan Salt Mountain (D) used. Sample A indirectly obtained with analysis from Khur Potash Complex. Samples B, C, and D directly collected from their locations through intermediaries residing near the salt sites.To identify the elements and compounds present in the salt structures, XRD and XRF analyses were conducted at University of Kashan and and Mineral Exploration Organization's laboratories in Kerman, respectively. For sample A, since it indirectly obtained from a processing company, the exact analysis results provided with the sample. For the other three samples (B, C, and D), XRD and XRF analyses were performed. XRD provided qualitative information on the elements in the natural salt structures, while XRF measured the percentage of different elements quantitatively with an accuracy of hundredths. According to XRD results, halite (NaCl) and calcite (CaCO3) were present in sample B, only halite (NaCl) was in sample C, and halite (NaCl) and anhydrite (CaSO4) were in sample D. The elemental composition of each sample was then determined using XRF results (Table 1). The batteries obtained from a battery recycling company in Tehran. The batteries were from smartphones of the Motorola brand and model BP6X; all used uniformly (Figure 1). The salt solution in this case acted as a controlled short circuit or initial resistance to discharge the batteries. Using this approach allowed monitoring the evolution of the electrical potential of lithium-ion batteries solely due to discharge (i.e., not attributable to physical battery damage). The salts dissolved in ultra-pure and deionized water.

Figure 1. Image of used batteries of Motorola brand and model (BP6X)

Table 1. Percentage of Elements and Compounds in Natural Salt Structures

Sample	Na (%)	K (%)	Ca (%)	Mg (%)	NaCl (%)	$Ca(CO_3)$ (%)	Ca (SO_4) (%)	SiO_2 (%)	SO_3 (%)	Volatile matters (%)
A	38.30	0.08	0.16	0.06	97.36	---	---	---	---	0.15
B	37.57	0.02	0.45	0.80	95.45	1.125	---	0.07	1.01	1.45
C	37.85	0.06	0.01	1.02	96.16	---	---	---	0.41	0.72
D	37.25	0.03	0.015	0.02	94.64	---	0.056	---	2.08	0.03

After examining indirect discharge and failing to achieve the research objectives, immersion testing adopted. According to previous research [1], 20% mass concentration was selected as the most effective for the discharge process, as it achieved the fastest voltage reduction without considering corrosion and water pollution. Therefore, the discharge process was tested with solutions containing salts A, B, C, D at 20% mass concentration, followed by tests at 10% and 15% concentrations. The 20% mass concentration showed the best performance for all solutions compared to other concentrations. Then, additional processes incorporated to shorten the discharge process duration. Complementary processes for discharging lithium-ion batteries in salt solutions included: discharge at 20% mass concentration with high-speed magnetic stirring, discharge with iron powder, discharge with iron and zinc powders, discharge using ultrasonic bath with 28 kHz ultrasonic waves, and discharge using ultrasonic probe (homogenizer) with 50 kHz ultrasonic waves in solutions containing salts A, B, C, D.

3. Results and Discussion

3.1. Effect of type and concentration of natural salts

Upon observing the test results, it found that the batteries in all solutions began to decrease voltage at a normal rate during the first hour, but a significant drop in voltage observed in the second hour. From the third hour onward, the voltage drop returned to a normal rate. After one hour, the battery voltage in solutions A, B, C, D reached 3.38, 3.54, 3.52, and 3.61 volts, respectively. After a significant drop in the second hour, the battery voltage in solutions A, B, C, and D dropped to 0.63, 0.74, 0.64, and 0.69 volts, respectively. Following this second significant drop, the voltage reduction process normalized again, and the battery voltage in solutions A, B, C, and D reached 0.51, 0.51, 0.46, and 0.54 volts, respectively. The battery in solution A reached a voltage of 0.01 volts after 23 hours, the batteries in solutions B and C reached zero volts after 22 hours and 21.5 hours, and the battery in solution D reached its lowest voltage of 0.02 volts after 24 hours. According to previous studies, one of the objectives of this research is to reduce battery voltage and reach voltage levels of approximately 1 volt and 0.5 volts. The main reason for using the 1-volt threshold is based on research indicating that this voltage level is considered safe for discharging lithium-ion battery recycling lines, and batteries below 1 volt are safer with minimized self-ignition risk. The 0.5-volt threshold is due to the duration of the process, requiring approximately 3 to 4 hours reducing the voltage from the initial level to 0.5 volts, whereas the reduction from 0.5 volts to zero takes 19 to 20 hours. In some salts, the voltage reduction to zero not achieved even after this time. In this series of tests, with a 20% concentration, the battery voltage in solutions containing salts A, B, C, D reached 1 volt after 80, 80, 70, and 95 minutes, respectively, and reached 0.5 volts after 185, 180, 150, and 245 minutes, respectively. It observed that the solution containing salt C performed better in achieving voltages of 1 and 0.5 volts (Figure 2).

3.2. Effect of using a high-speed magnetic stirrer in battery discharge process

Based on better performance over time, the best concentration used considered 20% mass concentration, and all subsequent experiments aimed at examining various processes to reduce discharge time were prepared with this concentration. Unlike the indirect method, which halts battery voltage reduction, the direct method using appropriately concentrated solutions effectively reduced battery voltage to zero volts. However, aside from examining salt concentrations, another primary objective of this research is to reduce discharge time by considering various factors affecting this period. In the fourth step, to reduce discharge time, the battery discharge process was conducted in solutions containing salts A, B, C, D at a 20% concentration using a high-speed magnetic stirrer. The results of this series of experiments showed that this series also follows the voltage reduction trend of previous tests. In this series, after one hour, the battery voltage in solutions A, B, C, D reached 3.69, 3.61, 3.71, and 3.60 volts, respectively. In the second hour, the battery voltage in solutions A, B, C, D reached

0.84, 0.71, 0.93, and 0.63 volts, respectively. In the third hour, the battery voltage in solutions A, B, C, D reached 0.60, 0.56, 0.58, and 0.48 volts, respectively. Achieving voltage levels of 1 volt and 0.5 volt considering the voltage ratio graphs, 1 volt and 0.5 volts can be equated to 0.26 and 0.13. It indicates 26% and 13% remaining battery voltage for solutions A, B, C, D took 105, 70, 115, and 65 minutes to reach 1 volt and 260, 240, 250, and 165 minutes to reach 0.5 volt respectively. Comparing these results with the discharge process without using a magnetic stirrer, solution A performed poorly in reaching 1 volt and 0.5 volts. Solution B performed better in reaching 1 volt, reducing the time by 10 minutes, but performed poorly in reaching 0.5 volts, significantly increasing the time. Solution C showed poor performance in reaching both 1 volt and 0.5 volts, with significantly increased time. Solution D showed satisfactory performance in reaching 1 volt and 0.5 volts, improving the time by 30 minutes and 80 minutes, respectively. In this test, salt D reduced the battery voltage in a shorter time, making it the most suitable option for achieving the target voltage (Figure 3).

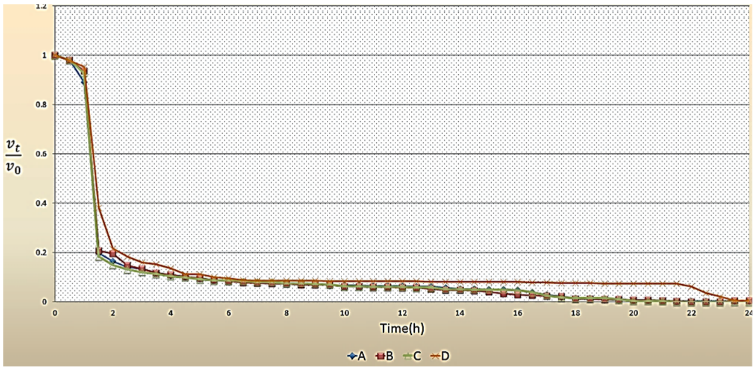

Figure 2. Voltage-time ratio graphs for batteries directly in solutions containing salts A, B, C, D at a 20% mass concentration

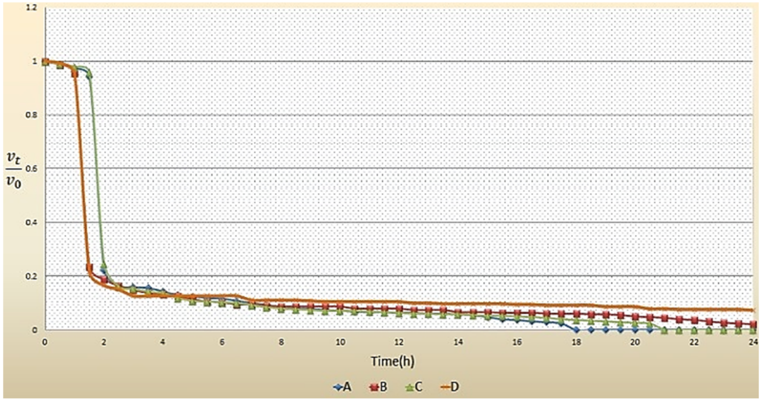

Figure 3. Voltage-time ratio graphs for batteries discharging in solutions containing salts A, B, C, D at a 20% mass concentration using a high-speed magnetic stirrer

3.3. Discharge in presence of metal particles

3.3.1. Effect of iron powder in battery discharge process

Based on the obtained results, the battery discharge trend follows the same trend as in other tests. Like other tests, the batteries in all solutions began to decrease voltage at a normal rate during the first hour, but a significant drop in voltage observed in the second hour, returning to a normal rate from the third hour onward. In the initial hour, the battery voltage in solutions A, B, C, D reached 3.64, 3.59, 3.70, and 3.58 volts, respectively. In the second hour, the battery voltage in solutions A, B, C, D reached 0.71, 0.71, 0.77, and 0.63 volts, respectively. In the third hour, the battery voltage in solutions A, B, C, D reached 0.50, 0.56, 0.64, and 0.48 volts, respectively. Achieving voltage levels of 1 volt and 0.5 volts (considering the voltage ratio graphs, 1 volt and 0.5 volts can be equated to 0.26 and 0.13) for solutions A, B, C, D took 95, 75, 110, and 70 minutes to reach 1 volt and 180, 240, 290, and 165 minutes to reach 0.5 volts, respectively. Comparing the 1 volt and 0.5 volt thresholds in this test with the base test without adding iron powder. Solution A showed positive feedback in reaching 0.5 volts, solution B in reaching 1 volt, and solution D in reaching both 1 volt and 0.5 volts, reducing the time, while other solutions performed similarly or worse, increasing the time to reach the target voltages (Figure 4).

3.3.2. Effect of iron and zinc powders in battery discharge process

After conducting the battery discharge process in solutions containing salts A, B, C, and D at a 20% mass concentration with the addition of iron powder, the results indicated no significant improvement in reducing discharge time. To further assess the impact of metal additives, pure iron and zinc powders (Merck brand) were also tested, and a magnetic stirrer was employed to enhance mixing during the experiments. In the solution containing salt B with iron powder, the battery voltage was recorded as 3.73 V after the first hour, 1.01 V after the second hour, and 0.72 V after the third hour. The battery reached target voltages of 1 V and 0.5 V after 122 minutes and 310 minutes, respectively. Similarly, in the solution with salt B and zinc powder, the voltage was 3.70 V after one hour, 0.97 V after two hours, and 0.76 V after three hours. The target voltages of 1 V and 0.5 V were achieved after 115 minutes and 470 minutes, respectively. When comparing these results to experiments without iron and zinc powder additives, no positive effect was observed in reducing the discharge time. In fact, the addition of pure iron and zinc powders did not enhance the battery discharge process, which is consistent with research indicating that the performance of metal powder additives is highly dependent on the electrolyte composition and the presence of specific additives or surfactants. While certain additives and optimized slurry compositions can improve discharge capacity in zinc-based systems, the simple addition of pure iron or zinc powder without further modification or the use of specialized additives does not necessarily yield better discharge performance. This highlights the importance of electrolyte engineering and the careful selection of additives to achieve meaningful improvements in battery discharge kinetics (Figure 5).

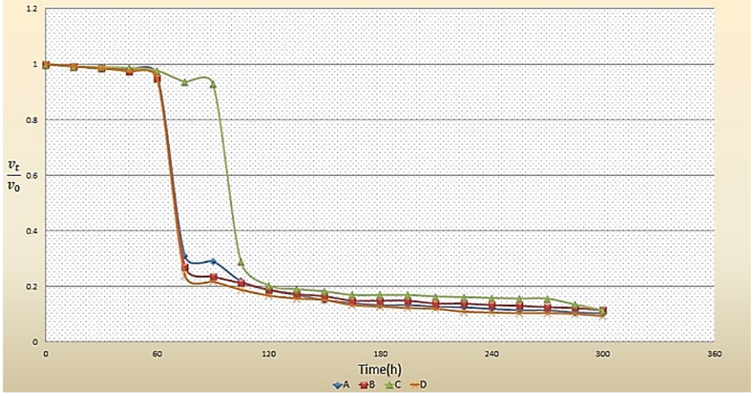

Figure 4. Voltage-time ratio graphs for batteries discharging in solutions containing salts A, B, C, D at a 20% mass concentration with iron powder

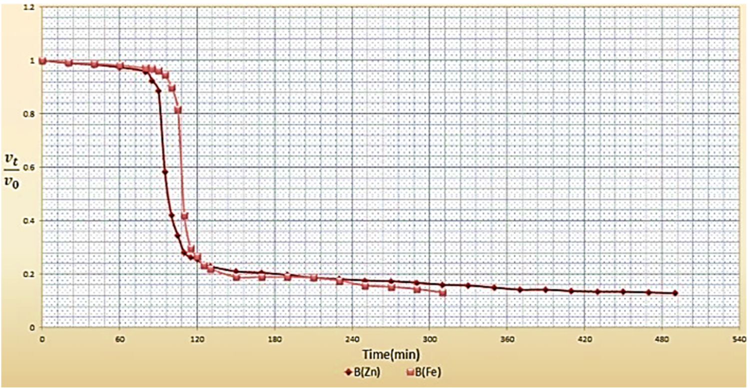

Figure 5. Voltage ratio graph over battery discharge time in solutions containing salt B at a concentration of 20% by mass with the addition of iron and zinc powders

3.4. Effect of using an ultrasonic treatment in battery discharge process

After evaluating the effects of various physical and chemical processes-including magnetic stirring, the addition of iron and zinc powders, and the use of pure iron powder-on reducing the discharge time of lithium-ion batteries, the study progressed to explore the role of salt solutions and ultrasonic treatment. In this phase, batteries were discharged in 20% by mass salt solutions (salts A, B, C, and D), utilizing an ultrasonic bath operating at 28 kHz. The results demonstrated that the discharge profiles in these salt solutions, when combined with ultrasonic agitation, generally followed the decreasing voltage trends observed in earlier experiments. However, the timing and duration of normal, rapid, and resumed discharge phases varied between solutions. Notably, in all solutions except A, a sudden voltage drop occurred before the one-hour mark, indicating a more pronounced effect compared to previous methods. Specifically, after 6 minutes of ultrasonic treatment, the voltages of batteries in solutions A, B, C, and D dropped to 3, 1.36, 1.10, and 0.93 volts, respectively. At the 80-minute mark, all solutions reached the 1-volt threshold, with final voltages of 1, 0.76, 0.78, and 0.73 volts for solutions A, B, C, and D, respectively. The voltage reduction then returned to a normal trend. The time required for the voltage to reach approximately 1 volt was 80, 74, 70, and 66 minutes for solutions A, B, C, and D, respectively. To reach 0.5 volts, solutions A, B, C, and D required 112, 110, 118, and 106 minutes, respectively.Comparative analysis with baseline experiments (without ultrasonic treatment) revealed: Solution A: No change in reaching 1 volt, but a 73-minute reduction in reaching 0.5 volts. Solution B: Improved time to 1 volt, though not as effective as the best result with stirring; 70-minute reduction to 0.5 volts. Solution C: No change to 1 volt, but a 32-minute reduction to 0.5 volts. Solution D: Improved time to 1 volt (matching best performance with stirring) and a 139-minute reduction to 0.5 volts. These findings indicate that ultrasonic agitation at 28 kHz significantly accelerates the discharge process, especially in reaching the lower voltage threshold of 0.5 volts. Among the tested salts, solution D was the most effective, achieving the fastest voltage reduction and making it the most suitable option for rapid battery discharge in this context. (Figure 6)

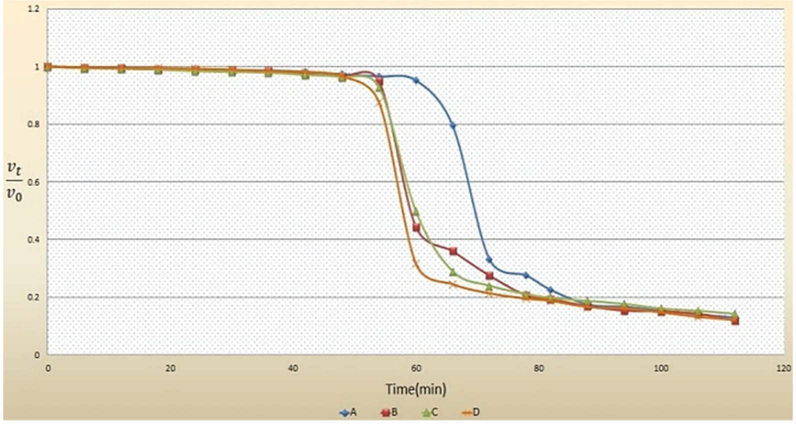

Figure 6. Voltage ratio graph over battery discharge time in a solution containing salt A at a concentration of 20% by mass with use of an ultrasonic bath with 28 kHz ultrasonic waves

4. Conclusions

According to the findings of this research, the most effective method for discharging lithium-ion batteries involves chemical processes and the direct immersion of the batteries in salt solutions. The primary objective was to identify the optimal salt concentration among the tested natural salt solutions for efficient battery discharge. Another aim was to achieve battery voltages at the thresholds of 1 and 0.5 volts. Initially, a series of experiments was conducted using salt solutions at concentrations of 10%, 15%, and 20% by mass. The results indicated that the 20% by mass salt solution provided superior performance in reducing battery voltage and achieving the target voltages compared to the lower concentrations. Among these, salt C enabled the fastest reduction in battery voltage, making it the most suitable option for reaching the desired voltage limits under standard conditions. Subsequently, the effect of enhanced mixing was examined by employing a high-speed stirrer in 20% by mass salt solutions. Under these conditions, salt D demonstrated the most rapid voltage reduction, indicating that mechanical agitation can influence the effectiveness of certain salts. The next phase involved the addition of iron powder to the 20% by mass salt solutions. When comparing the times required to reach 1 V and 0.5 V with and without iron powder, only solution A showed an improvement at the 0.5 V threshold, while solution B exhibited a slight improvement at the 1 V threshold. In most other cases, the addition of iron powder either had no effect or resulted in increased discharge times. Further experiments tested the impact of adding pure iron and zinc powders (Merck brand) to salt B solutions at 20% by mass. The results showed no positive effect on reducing discharge time compared to the base experiment without these metal powders. Finally, the discharge process was evaluated in 20% by mass salt solutions using an ultrasonic bath operating at 28 kHz. In this series of experiments, salt D facilitated the fastest reduction in battery voltage, establishing it as the most effective option for achieving the target voltages. In summary, the optimal battery discharge process identified in this study involves the direct immersion of batteries in a 20% by mass solution of salt D, particularly when combined with ultrasonic agitation. This method consistently achieved the most rapid and efficient reduction of battery voltage to the desired thresholds.

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دانشگاه صنعتی شاهرود

بررسی اثر نمک‌های طبیعی بر کاهش زمان تخلیه ولتاژ باقی‌مانده باتری‌های لیتیوم-یون در مرحله خردایش

محمدرضا وشادی آرانی و سیدمحمد رضویان*

گروه مهندسی معدن، دانشکده مهندسی، دانشگاه کاشان، کاشان، ایران

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کلمات کلیدی

باتری‌های لیتیوم-یون

نمک طبیعی

ولتاژ تخلیه

فراصوت

چکیده

در سال‌های اخیر، استفاده از باتری‌های لیتیوم-یون به‌طور چشم‌گیری افزایش یافته است، که این امر به دلیل ظرفیت انرژی بالا و وجود مواد ارزشمندی مانند کبالت و نیکل در این باتری‌هاست. این ویژگی‌ها، باتری‌های لیتیوم-یون را به منبعی مهم برای بازیابی ثانویه مواد ارزشمند تبدیل کرده‌اند. با این حال، فرآیند بازیافت این نوع باتری‌ها با خطرات ایمنی قابل توجهی همراه است؛ به‌ویژه خطر آتش‌سوزی و انفجار ناشی از اتصال کوتاه ناخواسته و وجود قطعات با ولتاژ بالا. این خطرات به‌ویژه در مراحل آماده‌سازی مکانیکی، خردایش، انبارداری و حمل‌ونقل شدت می‌یابند؛ جایی که باتری‌های آسیب‌دیده یا به‌درستی مدیریت‌نشده ممکن است دچار احتراق یا انفجار شوند. برای کاهش این خطرات، تخلیه سریع و کنترل‌شده باتری‌ها پیش از آغاز فرآیند بازیافت امری حیاتی است. یکی از روش‌های مؤثر، ساده، سریع و مقرون‌به‌صرفه برای کاهش بار الکتریکی باقی‌مانده و کاهش احتمال آتش‌سوزی در مراحل بعدی، استفاده از محلول‌های نمکی جهت تخلیه بار باتری‌هاست. در این پژوهش، از چهار نوع نمک طبیعی در غلظت‌های مختلف استفاده شد. تمرکز بر استفاده از نمک‌های در دسترس، کم‌هزینه و ناخالص به‌جای نمک‌های خالص آزمایشگاهی بود تا امکان‌پذیری اقتصادی و مقیاس‌پذیری فرآیند افزایش یابد. آزمایش‌های اولیه شامل غوطه‌وری مستقیم باتری‌ها در محلول‌های نمک با غلظت‌های ۱۰، ۱۵ و ۲۰ درصد وزنی بود. برای کاهش هرچه بیشتر زمان تخلیه، چند فرآیند مکمل مورد بررسی قرار گرفت، از جمله استفاده از همزن مغناطیسی با دور بالا، افزودن پودر آهن و اعمال امواج فراصوت (با استفاده از حمام اولتراسونیک و پروب فراصوت). نتایج نشان داد که به‌ویژه تحریک فراصوتی با فرکانس ۲۸ کیلوهرتز بسیار مؤثر است و فرآیند تخلیه را به‌طور قابل توجهی تسریع کرده و امکان رسیدن باتری‌ها به ولتاژهای پایین‌تر، نظیر ۰/۵ ولت، را در مدت زمان کوتاه‌تری فراهم می‌سازد.

✉ **نویسنده مسئول مکاتبات**: *razavian@kashanu.ac.ir* (س.م. رضویان)