CHEMICAL ENGINEERING TRANSACTIONS
VOL. 62, 2017

A publication of AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216

DOI: 10.3303/CET1762017

Research on Development of the Lithium-Ion Battery

Jingze Luo, Yi Zeng*

Department of Materials Science, Key Laboratory of Automobile Materials of Ministry of Educations (MOE), Jilin University, Changchun 130012, China
Zengyi@126.com

With the development of energy saving and environmental protection, the focus of lithium-ion battery applications will focus on power tools, light electric vehicles, new energy vehicles and energy storage systems. The industrial scale of those areas will keep a fast growth trend in the next few years, thus promoting the rapid development of the lithium battery market. The research on the lithium battery can provide theoretical basis for the development of the energy storage for the electric vehicle lithium battery and other new energy power generation system. Moreover, research on the core components of electric car lithium battery has been a hot spot of the current industry research, and lithium-ion battery performance determines the advantages of the electric vehicle in its service life, mileage, etc. Therefore, this paper analyzes the charge and discharge characteristics and other characteristics of the lithium-ion battery on the operating vehicles through experiment, and studies the 6-EVF-100 100AH model lithium battery pack in laboratory. Analysis of the charge and discharge performance of the electric car lithium-ion battery shows that the lithium battery pack owns the best performance at 25 °C, and its performance will be degraded in different degrees under other temperature conditions, but it's still in good overall consistency. During the charge and discharge process of the lithium battery pack, the module temperature changes in a relatively stable way, and the battery is in good overall operation condition, but the performance of the battery in spring and autumn is more stable than that in summer and winter

1. Introduction

Large-capacity energy storage system has become an important part of the future smart grid, the development of efficient energy storage technology has significant social and economic benefits in improving the efficiency of the existing power generation system, the power quality and promoting the wide application of the renewable energy (He et al., 2011). The developed countries attach great importance to the research on the development of new energy storage technologies, such as the "DOE project plan" of the United States, the "NEDO Plan" of the Japanese government and the "Framework plan" of the EU. With the rapid expansion of China's new energy power generation scale, wind power, distributed & centralized photovoltaic power generation, short-term adjustment of peak load, pure electric vehicle access will form an industrial energy storage market with a value of more than 200 billion yuan when the contradiction between the power grid and new energy development will become increasingly more prominent and there will be more urgent demand for energy storage development. Energy storage technology has been regarded as an important part of the six links in the process of "mining - hair - transmission - distribution - use - storage". At present, one of the most promising technologies in energy storage technology is the chemical energy storage technology. With the chemical energy storage technology various batteries have been developed such as the lead-acid batteries, nickel batteries, lithium batteries, liquid batteries, as well as the sodium and sulfur batteries (Li et al., 2012). The lead-acid battery, developed with cheap cost and mature technology, has been widely used in power systems. But it has low specific energy and specific power, short cycle life, and in its manufacturing process there exists a certain environmental pollution. The nickle and cadmium and other high efficiency batteries, though with a long cycle life, owns a charge capacity yet to be improved, and have been limited by the EU countries due to its heavy metal pollution (Cao, 2013).

Please cite this article as: Jingze Luo, Yi Zeng, 2017, Research on development of the lithium-ion battery, Chemical Engineering Transactions, 62, 97-102 DOI:10.3303/CET1762017

1.1 Function of the Lithium-Ion Battery

Lithium-ion batteries are used for chemical energy storage. Because of their light weight, high specific energy/specific power, long cycle life and other characteristics they have been regarded as one of the most competitive electrochemical energy storage technologies. And it has increasingly wide application in the field of energy storage, as shown in Figure 1. The mass production of various lithium-ion battery systems has laid a good technical foundation for its application in the energy storage system. The lithium-ion battery, requiring less maintenance costs, has a long cycle life and a high conversion efficiency. With the advancing of the battery management system technology, it has broken through the difficulties of large-scale integrated applications, and gradually developed into an ideal power medium for the new type of chemical energy storage technology (Konishi et al., 2015). They can be used for smart grid FM, phase modulation and voltage regulation so to ensure the quality of new energy power. At present, many lithium-ion battery energy storage systems are at the study and promotion phase around the world.

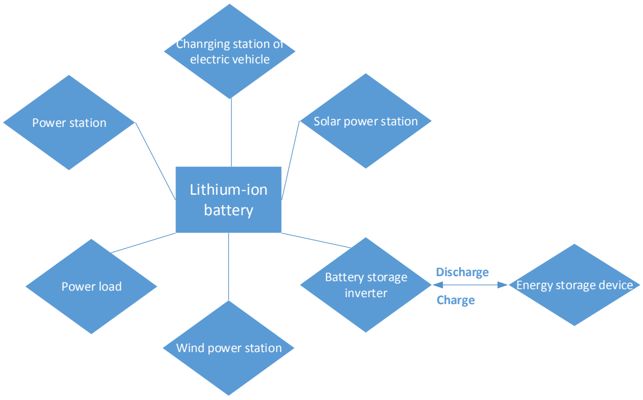

Figure 1: Schematic diagram of lithium-ion batteries in energy storage engineering

1.2 The Structure and Working Principle of the Lithium-Ion Battery

The lithium battery mainly comprises a positive electrode, a negative electrode, an electrolyte and a separator, wherein the positive electrode is composed of lithium metal oxide (represented by $LiMO_2$, and there's also $LiCoO_2$, $LiNO_2$, $LiMn_2O_4$, $LiFePO_4$, etc.). The cathode is generally made of graphite (C). And as the electrolyte requires high conductivity, high cycle efficiency, high stability, no pollution and etc., generally selected is $LiAsF_6$, $LiPF_6$, $LiBF_4$ and other lithium salts. The diaphragm is generally polyolefin porous membrane and the charge and discharge process of the lithium battery is actually the process of the lithium ions and electrons moving back and forth between the positive and negative electrodes (Li et al., 2012). During charge, the lithium metal compound in the positive electrode is ionized to release lithium ions which pass through the electrolyte and the separator to the negative electrode and nest on the graphite in micropores (Liao, 2017). At the same time, the electrons in the external circuit flow into the negative electrode while maintaining the charge balance. And during discharge, the lithium ions and electrons move in an opposite way, i.e. the lithium ions nested in the negative graphite will be ionized, flowing through the electrolyte toward the positive electrode and recombining with the electrons and the metal compound to reform the lithium metal compound (Yu, 2015).
The chemical reactions during charge and discharge are as follows:
Positive reaction:

$$LiMO_2 \Leftrightarrow Li_{(1-x)}MO_2 + xLi^+ + xe^- \tag{1}$$

Negative reaction:

$$Li^+ + e^- + 6C \Leftrightarrow LiC_6 \tag{2}$$

Total reaction:

$$LiMO_2 + 6xC \Leftrightarrow Li_{(1-x)}MO_2 + xLiC_6 \tag{3}$$

Among them, from left to right is the charge process, while the opposite is the discharge process. Figure 2 shows the schematic diagram for charge and discharge process of the lithium battery.

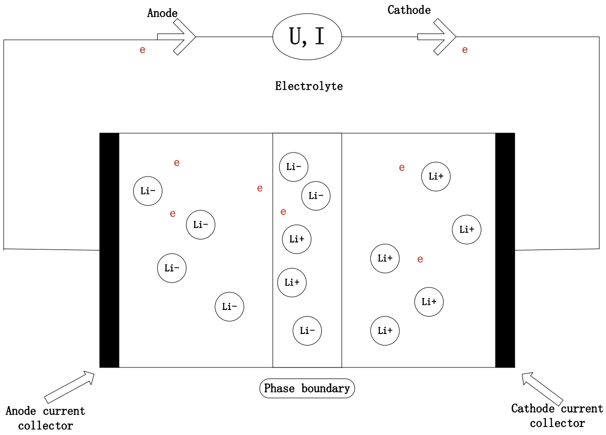

Figure 2: Schematic representation of the work principle of lithium battery

At the same time, with the development of energy conservation and environmental protection, the application of the lithium battery will focus on power tools, light electric vehicles, new energy vehicles and energy storage systems, which will continue the expansion trend in the next few years, thus promoting the rapid development of the lithium battery market (Fan et al., 2015). The research on lithium battery can provide theoretical basis for the energy storage of electric vehicle lithium battery and other new energy power generation system (Sun et al., 2017). Therefore, this paper mainly conducts the experiment on the lithium iron phosphate battery and the lithium battery of the electric vehicle, then carries out the research on the experimental data. Studying the charge and discharge performance of lithium-ion batteries at different ambient temperatures and during typical months in the Northern China, the research will do more data analysis of the lithium-ion battery application.

2. Study on the Charge and Discharge Performance of the Lithium-Ion Batteries

2.1 The Main Structure and Control System of the Lithium-Ion Battery Test Bench

Based on the actual situation of research, the lithium battery energy storage device is basically composed of: wind turbine, photovoltaic array, battery, controller, inverter, etc. (Zhou et al., 2016).

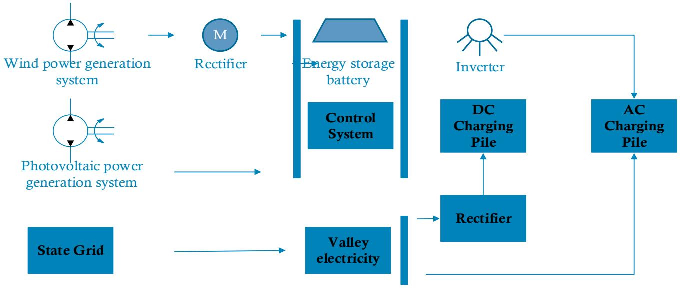

Figure 3: Experimental system diagram

Wherein the alternating current emitted by the wind turbine is converted into direct current by the AC/DC converter, and the direct current from the photovoltaic array flows through the DC/DC converter with the voltage adjusted and then enters the charge and discharge controller which sends out the command according to the status of the system (Zhang et al., 2017). When the power generating capacity is less than the electricity consumption, the electric energy is converted into AC power by the inverter, and the insufficient part is supplied via battery discharge; When the power generating capacity is greater than the electricity consumption, the power in the inverter is converted into AC power after direct supply to the load, and the battery will store the remaining power; When the battery is full, excess electricity is consumed by the unloader. And when battery-assisted charge cannot meet the load needed for the electric car, the power grid can be used directly to charge the electric car or to charge the battery storage power station (Wang et al., 2017). The grid can ensure the reliability of the system by ensuring that the system is still able to meet load needed in extreme weather conditions.

Laboratory battery pack can be divided into totally three groups. Select fifty 100Ah single battery in series for each group for the final capacity of 100Ah/120V, then parallel them in groups for the ultimate battery pack with a capacity of 500Ah/120V.

The control system of the test bench can be used to view in real time the current, voltage, power and other information during charge, record the data in real time and query historical data. Data can be independently inquired about the charge and discharge process of the battery. The device can also be used to view real-time basic information of the lithium-ion battery pack. The control system needs to meet the following requirements (Gang et al., 2017):

(1) The battery pack need meet a certain storage environment (DOD effect).

(2) Keep the charge constant current at 90A, and stop charge at 160V. Make sure the maximum discharge current does not exceed 200A.

(3) Keep dust off the battery box.

2.2 Charge and Discharge Characteristics of the Lithium-Ion Battery in the Laboratory

The charge and discharge performance of the battery pack has been studied at different ambient temperatures. In practical applications, advantages of the lithium batteries, an energy storage system, should be reasonably made use of so as to reduce damages caused by itself, thereby extending the service life of the battery. During the experiment, the lithium-ion battery pack was tested repeatedly, and the average values of the experimental data were analyzed and studied. Therefore, the results are of general value.

(1) Discharge Characteristics Analysis

At present, the nominal voltage of the lithium battery is generally 3.7V. And the 6-EVF-100 100Ah model lithium-ion battery was selected with a nominal voltage of 3.2V for the laboratory electric vehicle. When DOD is 80%, the cycle life can reach 3000 times, and the maximum continuous discharge current can reach 300A. The maximum and minimum voltage of the monomer changed with the discharge timing of the battery pack at the ambient temperatures of 5 °C,15 °C, 25 °C and 35 °C, and the discharge capacity ranged from 100% to 50% that of the battery. The change in voltage can reflect the overall performance of the merits in the discharge curve as shown in Figure 4-5.

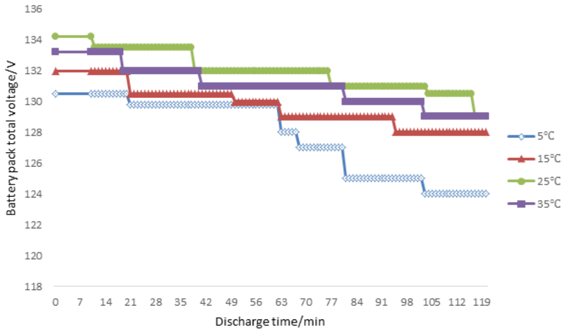

Figure 4: The total voltage of the battery changes at different temperatures during discharge

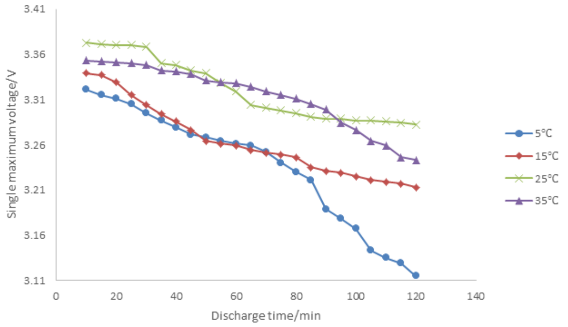

Figure 5: The maximum voltage of the battery cell at discharge is changed at different temperatures

As the discharge time was long, data was collected every 15 minutes during the discharge process while no experiments at noon or night. In order to ensure the consistency of the experimental curve, on the horizontal axis representing the discharge timing, each time represents the time interval of 15 minutes. Similarly, for the charge process, each charge sequence represents a time interval of 10 minutes.

In the process of discharge, the total voltage of the battery was declining. As can be seen from Figure 4, the total voltage of the battery was the highest at 25 °C, the average total voltage was 135V, the average total voltage was 129V at 5 °C, 135 V at 15 °C and 130 V at 35 °C. Within a certain range, the higher the total discharge voltage of the battery pack is, the better discharge performance the battery pack will have, and the longer the overall life of the battery pack will have. As can be seen from Figure 5, during discharge the battery voltage was the highest at 25 °C; at 35 °C, the maximum voltage 3.353V and the lowest 3.243V, ΔV = 0.110V ; at 15 °C, the highest 3.339V, the lowest 3.213V, ΔV = 0.126V; at 5 °C, the highest 3.321V, the lowest 3.115V, ΔV = 0.206V.

(2) Charge Characteristics Analysis

The 6-EVF-100 100Ah model lithium battery owns an over-discharge protection voltage of 2.8V, over-discharge release voltage of 3.2V, over-temperature protection at 58 °C, over-temperature release at 48 °C, overcharge protection voltage of 3.85V, overcharge release voltage of 3.5V, undervoltage alarm voltage of 2.9V, and an under-voltage release at 3V. In the whole process of experiment, the battery pack as a whole ran well with no alarm or failure, etc. This author studied the charge characteristics of the battery pack at different ambient temperatures (5 °C, 15 °C, 25 °C and 35 °C) and the total voltage of the battery during charge as well as the change in the maximum voltage as shown in Figure 6-7.

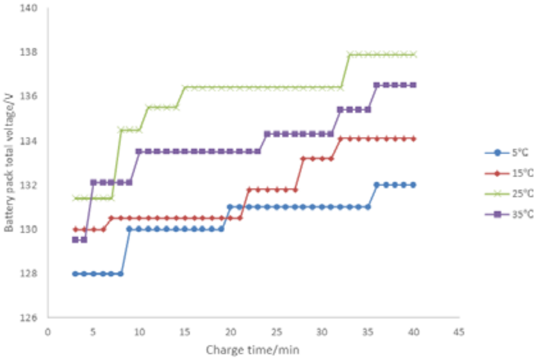

Figure 6: *The total voltage of the battery during charging changes at different temperatures*

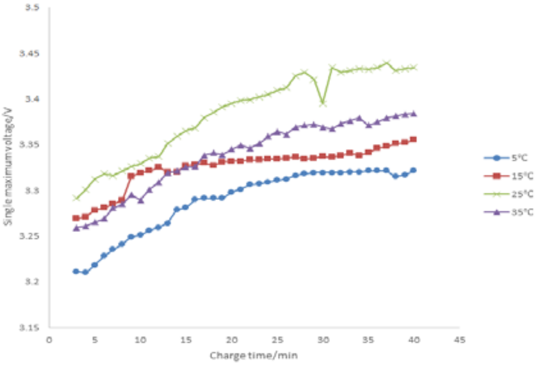

Figure 7: *The maximum voltage of the battery cell at the time of charging changes at different temperatures*

As shown in Figure 6, the total voltage of the battery pack was continuously increasing during charge, the maximum voltage of the lithium-ion battery pack being 138V at 25 °C and 131V at 15 °C. According to Figure 7, at 25 °C the total voltage of the battery was higher than that at other ambient temperatures, while the maximum voltage of the monomer was 3.434 V at 25 °C, 3.384 V at 35 °C, 3.355 V at 15 °C and 3.321 V at 5 °C.

2.3 Charge and Discharge Characteristics of the Electric Vehicle Lithium-Ion Battery

Electric vehicle intelligent monitoring and control system can not only manage the battery pack in an all-around way, but also detect problems timely. The system can monitor and record the total voltage and temperature of the logic cell as well as the charge/discharge current of the battery cluster in real time. Meanwhile it will set the protection measures in voltage, current and temperature, etc. for the system to provide a long-term safe and reliable operation. In order to ensure the reliability of the study results, the operation data have been analyzed in the typical month (January, April, July and October) with the same model. And comparison has been made in charge and discharge performance of the battery in a month and the data in the four typical months according to the daily average of the data in vehicle operation. Study on the charge and discharge performance of vehicle lithium battery pack is of a certain instructive significance for the promotion and popularization of the electric vehicles.

Analysis was made of the lithium-ion battery characteristics in an Changchun electric vehicle power station in charge. According to the operating norms, in order to extend the cycle life of the battery pack and improve vehicle performance, as it is cold in winter, the minimum charge temperature of the battery should be controlled above 5 °C, under which the system will stop charge. The battery capacity was 300AH, and there were totally 188 groups in 10 boxes. After two years of operation, the performance was good with a charge current of 80A. During the process the lithium battery SOC changed from 30% to 100%, and the typical months (January, April, July and October) were selected for data analysis of the lithium battery charge performance. Figure 8 shows the maximum temperature for the maximum voltage of the battery pack in use during charge every day. The electric car lithium-iron phosphate battery owns a nominal working voltage of 3.6V, and the battery voltage changes can reflect the merits of the battery performance.

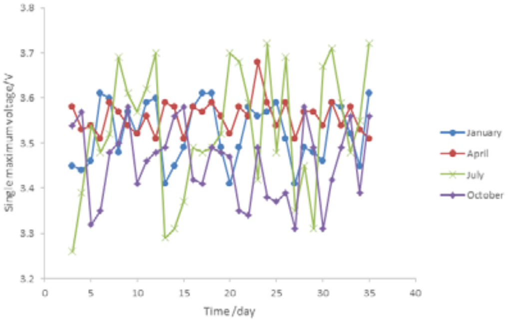

Figure 8: Comparison of the maximum voltage of the battery pack in different months during charging

As can be seen from Figure 8, in January and July the maximum voltage of the battery had relatively big fluctuations. In January, the maximum voltage was 3.61V, and the minimum value was 3.40V, ΔV = 0.21V; In July, the maximum value was 3.72V and the minimum was 3.24V, ΔV = 0.48V; In April, the maximum value was 3.59V and the minimum was3.51V, ΔV = 0.08V; In October, the maximum value was 3.58V and the minimum was 3.31V, ΔV = 0.27V.

3. Conclusion

Lithium-ion battery used in electric vehicle energy storage can not only meet the needs of vehicle operation, but also reduce vehicle fuel consumption. Through the research on the charge and discharge performance of the lithium battery in the experimental electric vehicles, below results can be obtained:

(1) At 5 °C, the 6-EVF-100100AH type lithium-ion battery pack has poor charge and discharge performance compared to other temperatures, especially at 25 °C when the overall lithium-ion battery pack owns the best good performance.

(2) During the actual operation of the vehicle, change in the battery voltage during charge in the winter and summer is greater than that in spring, and appropriate thermal management is required to extend the service life of the battery group. On the whole, the battery pack of the operating vehicle owns good stability.

Facing the needs of new energy storage and smart grid, China will require an urgent development of the key material preparation and integration technology for chemical energy storage with high security, long life and high specific. Compared with countries of international advanced level, China need make more efforts in research and development in this field to further enhance the safety, life, energy density and system integration technology for energy storage battery, which has a more important strategic significance to strengthen the intellectual property rights of relevant areas.

Acknowledgement

The research is supported by the Educational Commission of Hubei Province of China (Grant No. B2017257).

Reference

Cao S.X., 2013, Lithium-ion battery separator research and development status, Plastics Science and Technology, 41(8), 94-97, DOI: 10.15925 / j.cnki.issn1005-3360.2013.08.001.

Fan Y., Zhang Q.G., Hu X.H., 2015, Synthesis of layered x Li2MnO3 LiMnO2nanoplates and its electrochemical performance as Li-rich cathode materials for Li-ion battery, Electrochimica Acta, 165, 182-190, DOI: 10.1016/j.electacta.2015.03.004.

Gang J.J., 2017, Pure electric vehicle structure and principle introduction, Vehicle maintenance and repair, 2017, (1), 94-97, DOI: 10.13825 / j.cnki.motorchina.2017.01.041.

He C.Y., Liu E.H., Zhang J.H., 2011, Lithium-ion battery industry chain research, Beijing Automotive, (4), 9-11, DOI: 10.14175 / j.issn.1002-4581.2011.04.001.

Konishi H., Hirano T., Takamatsu D., Gunji A., Feng X., 2015, Effect of Composition of Transition Metals on Stability of Charged Li-rich Layer-structured Cathodes, Li12Ni02-xMn0.6-xCo2xO2 (x=0, 0.033, and 0.067), at High Temperature, Electrochimica Acta, 186, 591-597, DOI:10.1016/j.electacta.2015.10.155.

Li H., Zhang L.P., 2012, Research Progress of Cathode Materials for Lithium Ion Batteries, Chinese Journal of Ceramics, 31(6), 1486-1490, DOI: 10.16552 / j.cnki.issn1001-1625.2012.06.009.

Li W.W., Yao L., Chen G.R., 2012, Development of Cathode Materials for Lithium Ion Batteries, Electronic Components and Materials, 31(3), 77-81, DOI: 10.14106 / j.cnki.1001-2028.2012.03.017.

Liao H.Y., Yang G., et al, 2017. Effect of LiOB on Cyclic Stability of LiCoO2 Lithium Ion Batteries, Batteries, 47(2), 80-83, DOI: 10.19535 / j.1001-1579.2017.02.005.

Sun Y.X., Zhou Y., Shen Y., 2017, Development of lithium-rich ternary cathode materials for power lithium-ion batteries, Chemical Bulletin, 80(1), 34-40, DOI: 10.14159 / j.cnki.0441-3776.2017.01.003.

Wang W., Zhu H.H., 2017, Lithium-ion battery solid electrolyte research progress, Applied Chemicals, 46(4), 760, DOI: 10.16581 / j.cnki.issn1671-3206.20170222.035.

Yu R.B., Lin Y., Zhi H., 2017, Investigation on the enhanced electrochemical performances of Li 1.2Ni0.13Co0.13Mn0.54O2by surface modification with ZnO, Electrochimica Acta, 173(23), 515-522, DOI: 10.1016/j.electacta.2015.05.084.

Zhang J.G., Lu Y., Song Y.C., 2017, Lithium ion battery electrode material fracture phenomenon and its research progress, Acta Mechanica Sinica, 38(1), 14-33, DOI: 10.15959/j.cnki.0254-0053.2017.01.002.

Zhou D., Liang F., Yao Y.C., 2016, Research Progress of Film Forming Additives for Electrolyte of Lithium Ion Batteries, Progress in Chemical Industry, 35(5), 1477-1483, DOI: 10.16085 / j.issn.1000-6613.2016.05.031.