AIP Conference Proceedings

RESEARCH ARTICLE | OCTOBER 06 2023

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AIP Conf. Proc. 2932, 020009 (2023)
https://doi.org/10.1063/5.0174844

Study of Scaling Up Production on Lithium-Ion Batteries (LIB) Cathode Material at National Battery Research Institute

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Abstract. Energy storage technology becomes the crucial aspect for supporting electrification agenda. The rise of renewable energy and electric vehicles trend for the past decade creates unexpected number of demands on battery technology. Lithium-ion batteries (LIB) has been touted as a revolutionary technology on energy storage development. Besides LIB has been well-performed for electronic application due to its promising performance, it also has been well-known on its scalability for mass production. Although LIB is projected will still dominate the market for the next ten years, the growth of battery giga-factory, however, remains slow. The difficulty of production process and the numbers of machine used become the main reluctancy factor for bolstering end-to-end battery production on the industry scale. Because the absence of precise calculation on battery production chain possibly affects business sustainability. Hence, it is necessary to investigate scaling-up battery cathode production from laboratory into industry scale. The object study for this research was Indonesian leading battery research institute, National Battery Research Institute. The calculation was focused on NMC 811 cathode active material by considering cost structure factor such as raw materials, machinery, power consumption, and manpower. The result has successfully estimated the total cost for scaling-up 100 Kg production of NMC 811 cathode per batch or 36 Tons in a year. As a note, the data that was discussed in this manuscript limited on raw materials cost, while machinery, power consumption, and manpower aspect will be discussed separately in another article.

INTRODUCTION

The global trends on electrification are massively adopted. For the past five years, automotive sector towards e-mobility in parallel with energy sector towards huge amount of renewable energies share has dominated the trend of clean transition market. Both sectors heavily depend on the durability of energy storage technologies[1]. Lithium-ion batteries (LIB) have been recognized as the state of the art for energy storage technology for the last decades. This type of battery has been widely used in range of electronic-based application including portable electronics,

The International Conference on Battery for Renewable Energy and Electric Vehicles (ICB-REV) 2022
AIP Conf. Proc. 2932, 020009-1–020009-6; https://doi.org/10.1063/5.0174844
Published by AIP Publishing. 978-0-7354-4692-2/$30.00

grid storage for renewables and electric vehicles. High energy density, high power density, and long-life cycle counted as its superiority compared to other energy storage technology[2]–[4].

Another LIB competitive advantage lays on its affordable cost. The biggest portion of LIB production comes from its material such as cathode, anode, and separator. In fact, LIB cell manufacturing costs are extremely susceptible to scrap and process deviation since material costs account for roughly 75% of the overall manufacturing cost. Fortunately, since Whittingham discovered intercalation electrodes in the 1970s, Goodenough *et al.* created some essential cathode materials (spinel, layered, and polyanion) in the 1980s and 1990s, and Yoshino developed the first secure, producible LIB using $LiCoO_2$ as the cathode and carbon/graphite as the anode, the production cost has been plummeted over time. Such significant progress has affected energy and power density, cycle life as well as safety[5].

Globally, the cost of LIBs has dropped from over USD 1,000/kWh in the early 2000 to USD 200/kWh today, approximately. At the same time, the specific energy density has escalated from 150 Wh/kg to almost 300 Wh/kg for only a decade[3], [5]. Specific on Europe, the cost has dropped into EUR 75/kWh in 2022 compared to EUR 400/kWh in 2013. Although some beyond LIBs technology have been developed and proposed, such as solid-state batteries, sodium-ion batteries, lithium-sulfur batteries, lithium air batteries and other advanced battery technology. It is predicted that LIB will most likely still dominate the market at least for the next decade[6].

Obviously, the battery production process is divided into two stages, from raw material to cathode and cathode to the battery cell. The first step of the production is chemical reaction in which involves raw material (nickel sulphate, manganese sulphate, and cobalt sulphate) processing into the active material of NMC cathode. Afterwards, cell fabrication is processed using NMC cathode active material[7]–[9]. However, due to the difficulty of the battery production process and the numbers of machine used, only few companies in Indonesia could possibly produce batteries end-to-end. Because it needs robust calculation on entire production line for avoiding business flop[10].

Therefore, it is essential to investigate the calculation on scale up battery production for shifting from the laboratory invention into producible industry. This research has pointed two main objectives, battery production analysis and scale-up calculation, particularly on the first stage of the production process from raw material into cathode active material at National Battery Research Institute. It is expected, this study can provide the insight for industry to maintain their efficiency on LIB production.

METHODOLOGY

There are three methods that has been used to attain the study objectives, literature study, interview, and observation. The main method is literature study in which discuss battery production to gain new knowledge and understand battery production process. Thus, the problems can be identified and analysed properly. The process during literature study is researching, reading, analysing, evaluating, and summarizing numbers of scientific manuscripts. By combining an insights and perspectives from many empirical findings, those method can address research questions and broaden the alternative solution perspective.

After collecting various secondary data from literature study, interview has been conducted with an expert in the company. The aim of this step is to know the production target. It has been revealed some data consists production process target, machinery specification, and real condition in the line production along with its obstacles. During interview, it has also been inspected the real production process including input and output in each line production using observation method. Clearly, figure 1 depicts the research methodology that has been used for this research.

The aim to be achieved through this research is study the scaling-up for the first stage of battery production process from raw material to cathode active materials. Furthermore, the research at this company provides some prominent suggestions for solving the company problem. Limitations for this research are the scope of the problem or an attempt to limit the scope of the problem that is too broad. So that the work can be carried out carefully. Based on the research aim, limitations for this research are as follows: (1) This research will only study the first stage of battery production process, from raw materials to cathode active materials, (2) this research will study the escalation of cathode production capacity with the exact target 100 kg per batch, (3) the specification of the cathode under study is NMC 811 with hydroxide as the precipitant.

Besides some limitations, there are also a few assumptions that the research remains focused. Assumptions need to be determined before conducting the research. This assumption is used as the basic thesis in conducting research. The assumption that is applied in this work are as follows: (1) there are no failures in the product, (2) All supporting tools and machines are ready for use, and (3) the procedures have no significant changes throughout the research process.

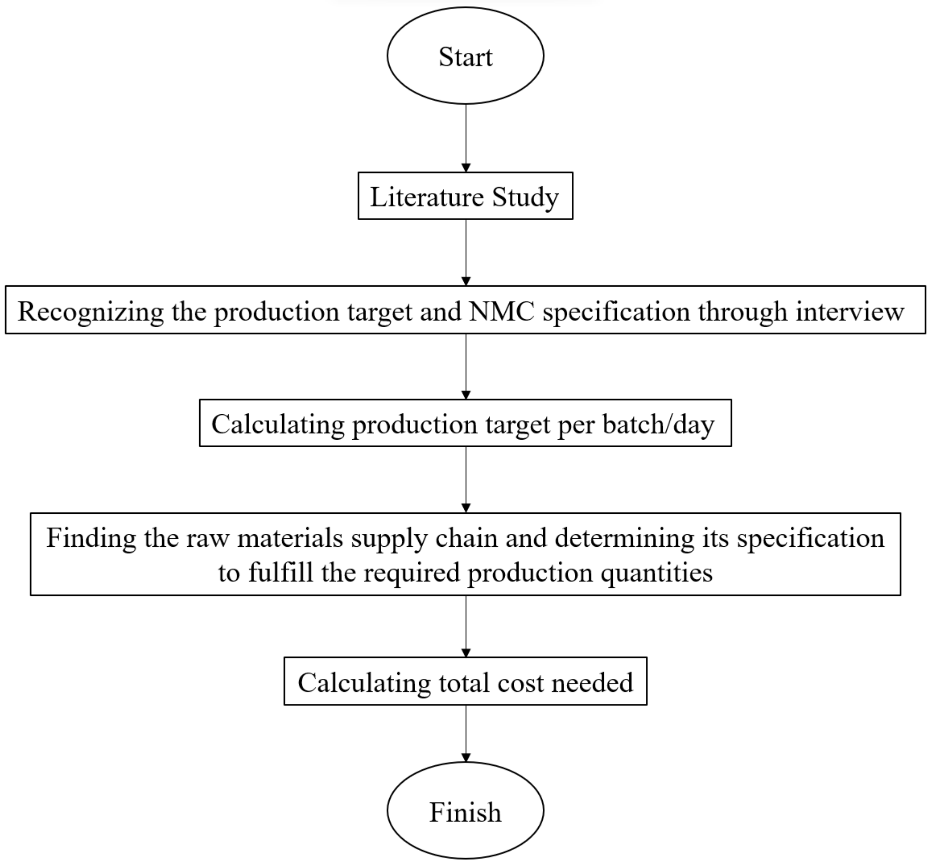

FIGURE 1. Research methodology.

RESULTS AND DISCUSSION

LIB Production

Manufacture of LIB starts with the production of cathodes and anodes. Cathodes are manufactured in several steps from the raw material. The steps are precursor synthesizing, precursor washing, precursor drying, mixing, sieving, and calcinating. The end product of this process is NMC cathode active material which is used in the next step of battery fabrication. For making cathodes, active materials (NMC) are mixed with a binder and carbon black to make a cathode paste. The cathode paste is coated onto aluminium foil which serves as a current collector[1], [8].

In contrast, to make anodes, the paste containing a binder and graphite is coated onto a copper foil current collector. The foils are then dried and pressed to the desired density and thickness[11]. The next step is the cutting process, the foils are cut to the desired size and inserted into the battery cell container. The cells are then filled with electrolyte and sealed. In detail, it will be explained the steps on producing cathode active material below[2], [12].

Co-precipitation

Co-precipitation becomes one of well-known method for synthesizing cathode active material. Co-precipitation is a simple, economical, and industrially viable technique that can be used for the synthesis of technologically important oxide materials. Co-precipitation is the carrying down by a precipitate of substances normally soluble under the conditions employed. Co-precipitation method is a bottom-up synthesis method that used to obtain nanometer-sized small particles[7], [9]. This is the first process of cathode production process. The goal of this process is to incorporate the MSO_4 such as nickel sulphate, manganese sulphate, and cobalt sulphate and precipitant such as natrium hydroxide and ammonia. This process uses a continuous stir tank reactor for about 24 hours to fully mix the MSO4 and the precipitant. Co-precipitation process uses demineralized water for mixing the MSO_4 and the precipitant[8].

Precursor Filtering & Washing

After the Co-precipitation process, the mixture of the MSO4 and the precipitant is shaped like a slurry or condensed water. The purpose of this process is to wash away the dissolved sulphates and carbonates from the precipitates that were used in the Co-precipitation process before and to remove any excess water (demineralize water) that was also used in the Co-precipitation process before[8]. This precursor filtering & washing process uses a filter press machine to filter and wash the slurry.

Precursor Drying

The next step of the production process after the filtering and washing process is the drying process. The purpose of this process is to drain any excess water that is still contained in the precursor. This process will use an oven as a heater or dryer. The drying temperature is around 80-120°C for 12 hours. After the drying process, the precursor will be transformed into dry powder.

Precursor + Li Mixing

After all the precursor dried in the drying process before, the next step of production is adding lithium powder to the precursor. Lithium needs to be mixed with the precursor to make a cathode. To mix the precursor and lithium together, a ball mill machine is used. The goal of this process is only to mix the lithium and precursor.

Calcination

Calcination is the heating of solids to a high temperature for the purpose of removing volatile substances, oxidizing a portion of mass, or rendering them friable. Calcination itself is a 2-stage process. For the first process about 450 - 480°C for 3 to 5 hours under flowing oxygen enriched air, and for the second process followed by 750°C for 12 to 15 hours[8], [9].

Cathode Sieving

Sieving is a physical mechanism of particle removal, where a particle is denied access through a pore or passageway that is smaller than the particle itself. Cathode sieving itself means that the particle of the cathode is removed down to a low level. The sieving process for the cathode is to get the smoothness level based on the specification needed.

Scaling-up Calculation

Scale-up is a distinct phase of company growth. It is a company that has achieved a lot, had some impressive success, and is ready to take it to the next level. Scale-up is not a simple linear increase in size, but also must maintain the identical product quality. A similar result of the product quality but on a larger production scale. While scaling up, there are so many ways of processes to produce the product, and each one of the processes and methods has different challenges that we need to consider when producing the product with the requirements needed. By scaling up the company, surely the company needs to upgrade its production processes by using more advanced technology and machines for larger production quantities[13].

The result of calculation on scaling-up cathode production for this study covers raw material cost, machinery cost, labour cost, and operational cost. As a note, the data that was discussed in this manuscript limited on raw materials cost, while machinery, power consumption, and manpower aspect will be discussed separately in another article.

Raw Material Cost

Table 1 shows the estimated of raw materials that is needed for producing 100 kg of cathodes per batch.

TABLE 1. Number of raw materials needed

Raw Materials	Amount	Unit
Nickel Sulphate	227.53	Kg
Manganese Sulphate	18.28	Kg
Cobalt Sulphate	28.46	Kg
Demineralized Water	1,082.046	Litre
Sodium Hydroxide	86.557	Kg
Lithium	48.927	Kg
Ammonia	40.814	Litre

There are many required raw materials from the beginning until the end of cathode production processes. For producing 100 Kg NMC 811 cathodes with hydroxide as the precipitant, it is needed 227.53 Kg of nickel sulphate ($NiSO_4.6H_2O$), 18.28 Kg of manganese sulphate ($MnSO_4.H_2O$), 28.46 Kg of cobalt sulphate ($CoSO_4.7H_2O$), 86.557 Kg of sodium hydroxide (NaOH), 40.81 litre of ammonia (NH_3), 1,082 litre of demineralized water, and 48.927 Kg of lithium. Because the first process of battery cathode production which is co-precipitation process is continuous, the first process will run 24/7 and the material needed will be constant. Therefore, the material needed for each month can be multiplied by 30. Table 2 exhibits the recapitulation of raw materials needed, raw materials quantity, and raw material cost to produce 100 Kg cathode per batch, per month, and per year.

TABLE 2. Raw material cost

Material	Amount/day	Amount/month	Unit	Cost (USD/kg)	Cost (USD)	Cost (IDR)
$NiSO_4.6H_2O$	227.53	6825.9	Kg	5	34,129.52	511,942,825
$MnSO_4.H_2O$	18.288	548.648	Kg	2	1,097.30	16,459,453
$CoSO_4.7H_2O$	28.467	854.015	Kg	10	8,540.16	128,102,372
NaOH	86.557	2596.71	Kg	1	2,596.71	38,950,723
NH_3	40.814	1224.43	L	0.5	612.21	9,183,224
H_2O	1.082	32.46	Kl	0.07	2.27	34,083
LiOH	48.927	1467.81	Kg	8	11,742.53	176,137,877
Total Cost per Month					58,720	880,810,559
Total Cost per Year					704,648	10,569,726,719

The raw material quantity needed is achieved from the amounts of raw materials needed in the beginning of the process (Co-precipitation). The quantity of materials is calculated to fulfil the production target which is 100 Kg per batch with continuous production. The raw materials will cost $704,648.85 per year or $58,720.70 per month.

CONCLUSION

The analysis and calculation on scaling up cathode production at National Battery Research Institute was successfully conducted through literature study, interview, and observation method. As a note, the specification of the cathode under study is NMC 811 with hydroxide as the precipitant. The data that has been obtained are scaling-up process for the first stage of battery production on raw materials. By calculating all of the cost structure on raw materials and scaling-up aspect on battery production, it can be estimated that the total cost for raw materials to scale-up NMC 811 cathode production into 100 Kg per batch are USD 704,648 or IDR 10,569,726,719. Within a month, the system possibly produces 3,000 Kg of cathode active material or 36 Tons in year. For further research, it is suggested that the external aspect such as interest rate and investment trends need to be added into account for gaining more specific calculation cost.

ACKNOWLEDGMENTS

This work is fully financially supported by the National Battery Research Institute (NBRI) in fiscal year 2022.

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