INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
K. Natesan and S. S. Prabhu, Vol.12, No.3, September, 2022

Recent Trends in Lithium-Ion Battery – A Critical Review

Kapilan Natesan *, Sadashiva Prabhu S **‡

* Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, P.B.No.6429, Yelahanka, Bangalore-560064

** Department of Mechanical and Industrial Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India-576104

(kapil_krecmech@yahoo.com, ss.prabhu97@gmail.com)

‡ Corresponding Author; Sadashiva Prabhu S, Department of Mechanical and Industrial Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, India-576104, Tel: +91 9483648850

ss.prabhu97@gmail.com

Received: 24.04.2022 Accepted:26.05.2022

Abstract- The usage of conventional energy sources leads to global warming and environmental degradation. Hence, there is a great demand for renewable energy sources. Further, there is a severe threat to non-renewable energy sources and their supply. Nowadays, electric vehicles and hybrid electric vehicles are used to replace conventional vehicles to avoid these problems. Batteries are used to store energy, and the stored energy is supplied. Lithium-ion batteries (LIB) are used for many applications as they have increased specific energy, longer life cycle and lower auto discharge. The performance of the batteries is improved by introducing novel materials for the electrodes and electrolytes. The working principle of this type of battery is based on an electrochemical reaction that releases heat during charging and discharging. However, this type of battery is susceptible to high temperatures and hence new technologies are developed for effective cooling and better performance of the batteries. This paper critically reviews various types of batteries, usage, novel materials for electrodes, battery cooling technologies, recent trends, future research and recommendations.

Keywords Renewable energy, energy storage, battery, lithium-ion battery, materials, cooling.

Abbreviations

3D-Three-Dimensional
AI- Artificial Intelligence
CFD-Computational Fluid Dynamics
CPCM-Composite Phase Change Materials
DOE-Design of Experiments
EOL-End of Life
EV-Electric Vehicles
HEV-Hybrid Electric Vehicles
LIB-lithium-Ion Battery
LTO- Lithium-Titanium-Oxide
ML-Machine Learning
NMC-Nickel-Manganese-Cobalt
PCM-Phase Change Materials
PHEV-Plug-In Hybrid Electric Vehicles
PSH-Pumped Storage Hydropower
RSM-Response Surface
RTIL-Room-Temperature Ionic
SEI-Surface Electrolyte Interphase
TMS-Thermal Management System

1. Introduction

Energy resources are required to generate electricity, which is necessary for industrial activities and human comfort. The burning of fossil fuels for electrical energy production results in the emission of exhaust gases which are responsible for global warming. Hence, there is a direct and indirect impact on the environment. It is reported that energy generation from fossil fuels is the highest emitter of greenhouse gases, around 75 % [1]. Wind and solar, being renewable energy sources, are considered a substitute for fossil fuels. The earth receives around 5 × 1024 J of solar energy, and it is spread over the entire area. This solar energy is 10000 times higher than the actual consumption of energy. Hence, it is necessary to use solar energy for electrical energy generation and any improvement in the energy conversion method will enhance the quality of the built environment. Many researchers are working to increase the energy conversion efficiency of solar energy conversion devices [2]. Hence it is suggested to accelerate the renewable energy program for energy generation [3]. Solar and wind energy are intermittent, seasonal and not stable [4]. The most famous solar energy conversion devices are solar water heaters, solar collectors and heating devices, etc. These devices convert solar radiation into useful energy or work. Since solar energy is intermittent, different types of energy storage systems are used to store the energy. The stored energy is utilized when renewable energy systems do not produce power.

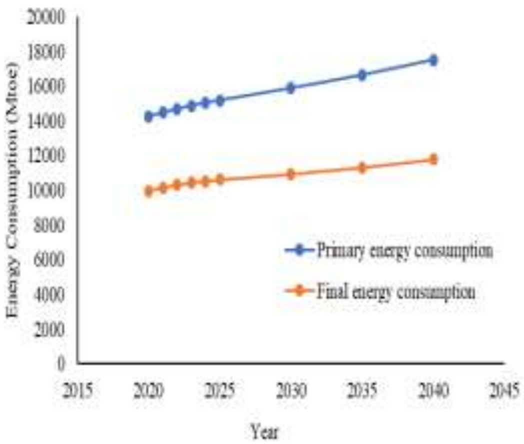

Fig.1. Global primary and final energy consumption requirements [5].

Fig.1 shows the forecasting of global primary and final energy consumption requirements. The final energy consumption shows the energy used by the customer without considering various types of losses. From the figure, we observe that the energy consumption increases steadily, and the primary energy consumption is higher than the final energy consumption. It is reported that the final energy consumption significantly increases in Europe, Asia, and Netherlands[5].

It is estimated that the combined transportation and stationary energy storage will grow about 2.5 to 4 terawatt-hours annually, by 2030 and it is about 4 times the current energy storage market due to an increase in electrified transportation, increase in renewable energy generation and reduction in battery storage price. In recent years, a significant number of developing countries are adopting electric vehicles which increases the demand for energy storage systems. Also, the incentives and promotional activities by government agencies increase the EV market. It is projected that China will have the highest medium-term mobility storage market. By 2030, annual global deployments of stationary storage (without PSH) are expected to surpass 300 GWh, [6].

Further, greenhouse gases have to be eliminated, there is a requirement for green energy technologies based on solar, wind, etc. Replacing the automotive sector run by fossil fuels with electric vehicles run by batteries avoids pollution. In the recent past, researchers introduced parameters towards decreased size and weight, increased life span, more security and reduced cost [7–9]. As a part of the research and design of battery management systems, some key issues like measurement of cell voltage, condition monitoring, battery uniformity and equalization, fault identification, etc. are discussed in the literature [10].

2. LIB Technology for Electric Vehicles

The advent of EV and hybrid electric vehicles is getting more attention due to their lower emission and lower green gas emissions. These vehicles also produce lower noise and vibrations. The increase in electrical power production from renewable energy can be used to drive these types of vehicles [11]. The electrical energy required for operating these types of vehicles can be stored in the LIB. These batteries have several advantages: higher power capacity, higher energy density, longer lifespan, and lower self-discharge [12]. However, the LIB generates heat generation to a larger extent, and it may affect the battery due to overheating. This overheating increases battery cell temperature and damages the cell and affects the battery's charging and discharging performance [13]. The operating temperature of LIB should be between 25 to 40°C and temperatures above and below this range will affect the performance and life. Hence, it is necessary to retain the operating temperature in LIB used in EV [14].

The rise of the temperature and its variation may affect the lifespan of batteries, and safe operating temperatures must be maintained. A suitable cooling system must be developed for the battery to maintain and control the temperature and its distribution within the permissible limit. Several researchers developed a battery cooling system with air as the cooling medium [15]. The battery temperature and temperature distribution are affected by the battery discharge rate, Reynolds number of coolant and atmospheric conditions, particularly atmospheric temperature. The battery can be cooled by coolants such as gas, air and liquids. It is reported that effective cooling is possible with liquid. In recent years, phase change materials (PCM) have proven their capability for better cooling of the battery [16].

The simulation work on cylindrical types of lithium-ion batteries (71types,18650 No.) to analyse thermal behaviour shows that the flow rate of coolant and the area between channel and battery affect the temperature uniformity [17]. The study related to cooling performance carried out on a 20-Ah lithium-ion pouch cell at two different discharge rates shows the optimum cooling temperature at the inlet as 15 °C and 20 °C and cooling fluid flow rate as 9 kg/hr to 12 kg/hr, respectively [2].

3. Types of Batteries

The different types of batteries are lead-acid, Ni-Cd, Ni-metal hydride, and lithium batteries, as shown in Fig.2. The lead-acid batteries contain a mixture with varying concentrations of water and acid. Generally, sulfuric acid is used in this kind of battery, and it is bulky and heavy. The nickel-cadmium batteries are heavier than an old lithium-ion battery and very susceptible to the “memory effect”. While recharging, it remembers the old charge and continues it till its use next time. The crystallization of battery substances leads to a shape memory effect and can permanently reduce the battery lifetime, even making them useless. Hence, this type of battery is recharged once it is completely discharged. The nickel-cadmium battery is better than the lead-acid battery. The cadmium present in this type of battery is toxic. So, precautions should be taken. The Ni-metal hydride does not contain cadmium and is affected less by the memory effect than nickel-cadmium batteries. Hence, this type of battery does not need much maintenance as compared to Ni-Cd batteries and has a higher capacity. Lithium-ion batteries are better than other batteries and light in weight. This type of battery is non-hazardous; however, it catches fire very easily and requires special handling [18]. This review considers different aspects of LIBs, challenges and research opportunities.

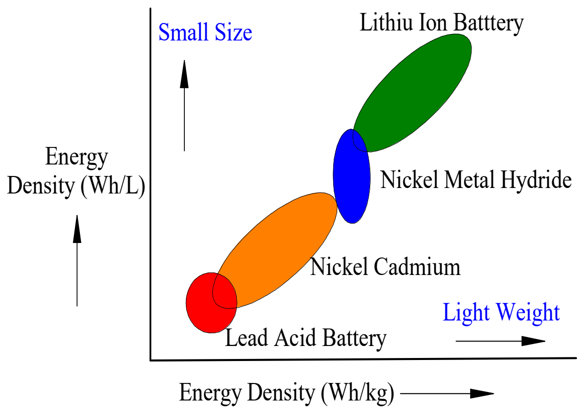

Fig.2. Different types of batteries.

3.1. Working Principle of LIB

The major components of LIB are electrodes, an electrolyte, separator between electrodes. The electrodes are immersed in the electrolyte. The electrode materials are selected to have better capacity, good cycle stability and improved safety.

In LIB, the Li-ions flow from the battery electrode to the electrolyte and intercalate into the battery cathode during discharging. This ion movement also causes a release of electrons and the electrons flow in the external circuit of the battery. However, this process will be reversed during charging, and Li-ion flows from the battery cathode to the electrolyte and intercalates in the anode. The metal oxides like lithium iron phosphate, Li-Mn oxide and Co-Li dioxide are used as cathode material. The binders and conductive materials are added to enhance the battery electrode's adhesion and increase the conductivity. Polytetrafluoroethylene and polyvinylidene difluoride are generally used as binders. The porous separator separates battery electrodes and is made of polypropylene or polyethylene. The separator is in the form of film and its thickness varies from 10 to 20 µm. It is immersed in an electrolyte. The ionic conductivity of electrolyte and separator should be high. The casing of the cell is made of metal. The construction and working of lithium batteries are shown in Figs. 3 and 4, respectively [19].

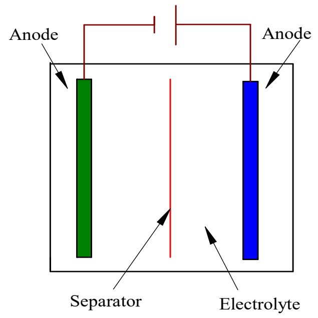

Fig.3. Construction of LIB.

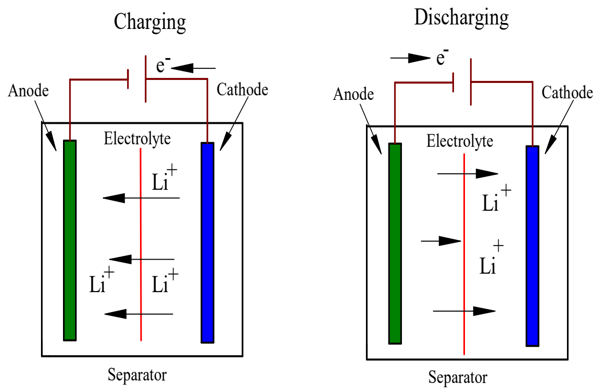

Fig.4. Working of LIB.

3.2. Types of LIBs

Based on the composition of positive electrodes, LIBs are classified into lithium titanate, lithium manganese oxide batteries, Li-Co oxide batteries, lithium iron phosphate, Li-Ni-Mn-Co oxide batteries, Li-Ni, and Co-Al oxide. Table 1 compares different types of LIBs.

In a lithium cobalt oxide battery, the cathode is of cobalt oxide and the anode material is graphite. The structure of the cathode is in the form of layers. The ions flow from the anode to the cathode during battery discharging. The flow reverses during charging. The structure of the anode is in the form of a 3-D spinel structure as it increases ion flow and provides low internal resistance. This helps in better current handling. In Li-Ni-Mn- Co-oxide, the cathode combination is generally 1/3rd Mn, 1/3rd Co, and 1/3rd Ni (1:1:1). The cobalt is available in limited quantities and is expensive. The properties of different types of LIBs are compared and given in Table 1 [18, 20].

Table 1 Properties of different types of LIBs

Sl.No	Name	Advantages	Disadvantages	Applications
1	Lithium Cobalt Oxide	1. Higher specific energy	1. Shorter life span 2. Low thermal stability 3. Limited load capabilities	1. Camera 2. Laptop 3. Mobile phones
2	Lithium Manganese Oxide	1. Design flexibility 2. Higher capacity 3. Higher thermal stability 4. Better safety	1. Lower life cycle 2. Safety issues	1. Power tools 2. Electric vehicles medical devices
3	Lithium Nickel Manganese Cobalt Oxide	1. Self-heating is low	1. Lower thermal stability 2. Shorter Life span	1. Power tools 2. Electric bikes Powertrains
4	Lithium Iron Phosphate	1. Higher current rating 2. Longer cycle life 3. Better thermal stability 4. Better safety	1. Higher self-discharge 2. Affected by moisture	1. Portable devices which need high load currents
5	Lithium Nickel Cobalt Aluminum Oxide	1. Better specific power 2. Longer life span 3. Higher energy density 4. Higher power density	1. High cost 2. Limited quantity of nickel and cobalt	1. Medical devices 2. Electric powertrain
6	Lithium Titanate (Lithium Titanium Oxide(LTO))	1. Faster charging 2. Better safety	1. Costlier 2. Lower specific energy	1. UPS 2. Powertrain Street lighting

4. Materials of Cathodes and Anodes

It is reported that the cathode and anode materials should have higher mechanical strength, shorter diffusion length and higher surface dimensions ratio. Also, it should have a better exposed active surface. Flame retardants, binders, electrolyte solvents, and gel precursors are other materials used. The materials used for the construction of cathodes and anodes are discussed below [21-22].

4.1. Cathode Materials

Li-phosphate, Li-Co oxide, Li-Mn, oxide of Li-Ni-Co-Mn oxide, etc., are commonly used cathode materials. Li-Co oxide is a cathode material that is commercially developed and commonly used. However, because it has a higher energy density, it is not preferred for off-grid products. This is due to low cycle life and inferior safety. The other material used is Li-Mn oxide, as it provides good heat stability and safety. However, it has lower cycle life, and hence nickel cobalt aluminium material is preferred. It provides better thermal stability. This type of battery is not preferred for off-grid products as they are costlier and have a lower cycle life.

The various blends of cobalt, manganese, and nickel are successful and have potential in LIBs. The cobalt, manganese, and nickel blend ratio can be listed in the electrode name. For example, the chemical formula of an equal blend mix is represented as NMC 1-1-1. These material blends provide better-cycled life, higher energy density and safety. The blend ratio is tailored to suit a particular application for a specific purpose. It is reported that the lithium iron phosphate battery is preferred for off-grid products due to its better cycle life and stability, lower cost and better safety. However, it has low output voltage and energy density.

4.2. Anode Materials

The materials like graphitic carbon, lithium titanate, silicon-based material, metallic lithium, hard carbon, synthetic graphite and tin-based alloy are used in the preparation of anode. In most LIBs, graphite formulations are used for the negative electrode. Graphite may be natural or synthetic. During first charging, a solid electrolyte layer is created on the surface of the graphite. This layer helps to stabilize the anode as it prevents the reaction between electrolyte and graphite. The LIB cell performance is affected by this layer. This type of cell has higher cycle life, better safety, low-temperature operation and better thermal stability. The drawback of this cell is lower energy density and lower cell voltage.

5. Cell Construction

The LIBs are made in the form of rectangular and cylindrical. The rectangular type cells are generally used in domestic electronic goods and mobile phones. The cylindrical type cells are used for various applications. In recent years, pouch-type cells have been used, and the shape of this cell is like a rectangular type. However, it is thin and has a flexible laminate. These features help reduce the size, cost, and cell weight. The LIB cell is designed to have a better safety mechanism. For example, if the temperature of the cell exceeds the safe limit, then immediately current flow stops [23-24].

5.1. Cylindrical Cells

The cylinder LIB cells consist of housing, anode foil, electrolyte and cathode foil as shown in Fig.5. The housing is made of aluminum or stainless steel and safety disks are provided at the top. This type of cell is hermetically sealed. The outer battery terminals are connected to the cell electrodes using welding.

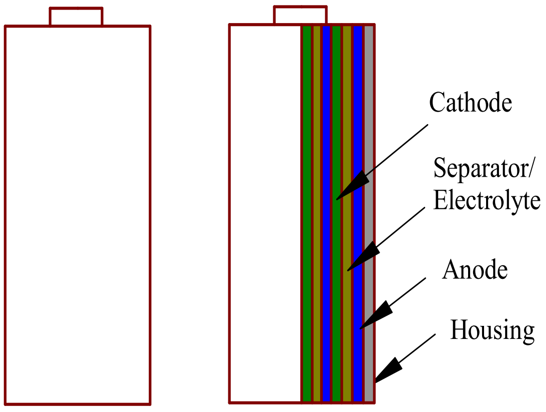

Fig.5. Cylindrical Cell Prismatic cells.

The shape of the prismatic cell is rectangular, and its construction is similar to a cylindrical cell. The anode, separator and cathode can be assembled as shown in Fig.6. The terminals of the battery are provided at the top of the housing. The thickness of this type of cell is small and hence preferred in consumer electronics where easy battery replacement is required.

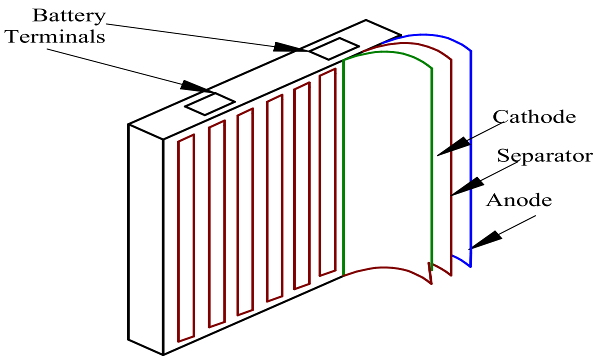

Fig. 6. Prismatic Cell.

5.2. Pouch Cells

The pouch cells consist of several rectangular stacks of individual cathode, anode and separator layers. This type of cell has a laminated aluminum bag or flexible polymer housing. The tabs of electrodes are joined together by the terminal of the battery on top of the bag. The setup is saturated with liquid electrolyte, and the bag is heat-sealed. The thickness, weight, and cost can be reduced by eliminating rigid housing. The swelling of the pouch may lead to a reduction of a lifetime and loss of capacity and safety. A typical pouch cell is shown in Fig.7.

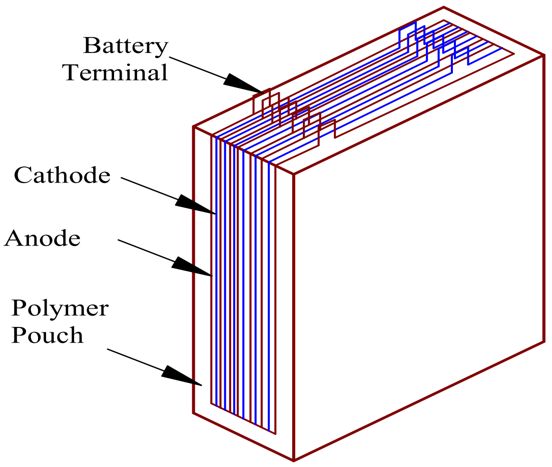

Fig.7. Lithium-ion pouch cell.

5.3. Electrolyte

The important part of LIB is the electrolyte which enables the movement of lithium ions across cathode and anode. The electrolyte should have higher ionic conductivity, which helps in the easy movement of ions between electrodes. The different types of electrolytes are discussed in the next sections.

5.3.1. Liquid Electrolytes

In LIBs, the liquid electrolytes consist of salts such as LiClO4, LiPF6, $LiBF_4$, solvents like dimethyl carbonate, diethyl carbonate, and ethylene carbonate. During discharge, the cations move from negative to positive electrodes. At room temperature (20°C), the liquid electrolyte has conductivities of 10 mS/cm. The conductivity value increases to about 30 to 40% at a temperature of 40°C, and the conductivity value decreases slightly at a temperature of 0°C. The mixture of dimethyl carbonate and carbonates (linear and cyclic) provides higher conductivity.

The organic solvents decompose easily on negative electrodes while charging. The initial solid layer that forms when the electrolyte decomposes on initial charging is known as "electrolyte interphase", which is of solid and insulating type, and enables conduction of ions. During the second stage, this prevents further decomposition of the electrolyte. For example, at 0.7V, Ethylene Carbonate decomposes and forms a solid layer interface. Composite electrolytes like polyoxyethylene provide a stable interface. They are available in both solid and liquid forms. To limit the flammability and volatility of organic liquids, room-temperature ionic liquids (RTILs) can be used[25].

5.3.2. Solid Electrolytes

Solid electrolytes are used as electrolyte material. Ceramics are the most promising among them. Lithium metal oxide is a ceramic electrolyte that allows Li-ion transport due to intrinsic lithium. As a significant benefit, there are no risks of leakages.

Ceramic electrolytes are available in two categories namely ceramic and glassy. Solid ceramic-type electrolytes have ordered compounds having ion transport channels. Perovskites and lithium super ion conductors are commonly used ceramic electrolytes. Electrolytes of solid glassy type have amorphous atomic structures similar to chemical composition as that of ceramic type with conductivity variation at grain boundaries.

By adding sulfur and oxygen, ionic conductivity can be obtained for glassy as well as ceramic electrolytes. The conductivity develops from 0.1 mS/cm to 10 mS/cm with solid electrolytes[25].

6. Characteristics of Lithium-Ion Batteries

The energy density, charge and discharge characteristics, size, toxicity impact, self-discharge profile, leakage, gassing, capacity, and life cycles are the important characteristics of LIBs [26]. The LIBs generally have negative and positive traits. Positive traits are power density, higher specific energy, better energy density, longer life, and better discharging and charging efficiency. The negative traits are price, greenhouse gas emission during manufacturing, disposal, and electronic protection system during discharging and charging [27]. Fig. 8 shows the LIB voltage and current characteristics.

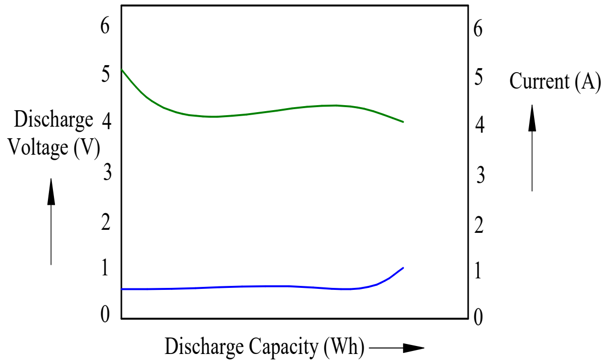

Fig.8. Voltage and current characteristics.

The LIB cooling is affected by its cell arrangement and required spacing should be provided around the cell for effective cooling. The hexagonal structure arrangement of the cell provides effective cooling for 19 batteries. Hence it is suggested that an optimized cell arrangement ensures better cooling performance and uniformity in temperature as the optimized cell structure ensures better airflow passage [28].

According to the battery pack size, the liquid cooling plate may be designed as it is easy to develop, has less space requirement, and is easy to repair. Fig. 9 shows the cooling plate structure. The battery structure and cooling plate fabrication decide the internal fluid area. The aluminium alloy is used in fabricating liquid plates due to its ductility, higher thermal conductivity, lower density and ease of manufacturing. The coolant used is ethylene, as it has lower freezing and high boiling points [29].

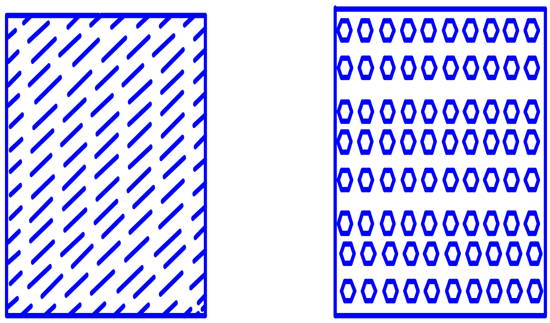

Fig.9. Cooling plate with different structures (CFD cooling).

In recent years, heat pipes and cold plates are used in the TMS of batteries as these batteries use liquid coolants. The heat pipe consists of a condenser and evaporator at its ends. The coolant in the evaporator is used to cool the battery and this absorbed heat is released from the condenser [30]. Heat pipes are also found useful in LIB cooling [31].

In battery cooling, forced convective cooling is better than natural convective cooling. The design parameters such as shape and cooling layout affect the battery cooling performance. It is reported that a better design, such as a serpentine channel, can reduce the temperature significantly [26]. Hence, liquid cooling is most widely used in battery cooling due to its better cooling efficiency and reliable operation.

It is reported that the passive liquid cooling system has higher energy loss than the passive cooling system and is used in liquid cold plates [32]. A numerical work carried out with a double-layered cooling channel shows that this type of design results in a better cooling effect than another cooling type. Also, it helps in better trade-off among pressure drop, maximum temperature and uniformity in temperature [33].

The cold plate absorbs the heat developed by the battery cell. The coolant in the cold plate absorbs heat and transfers heat sink and cools the battery cell. The cold plate dimensions affect the rate of heat transfer. The operating conditions and cold plate design affect the cold plate performance. The pressure drop, mean temperature, and temperature uniformity are important parameters that affect performance. The most sensitive parameter is temperature uniformity, depending on coolant and heat flux[34]. A numerical study carried out on a cold plate with a rectangular channel shows the uniformity of temperature, which is most important and affects the LIB performance. Also, it isn't easy to optimize all the operating parameters simultaneously [35].

The performance study on a water-cooled LIB(Fig.10) used in EVs with a micro-channel cold plate shows that the channel's coverage of surface area coverage ratio and diameter is to be optimized. The results of this study show an optimum channel hydraulic diameter of 1.54 and an area coverage ratio of 0.75 as optimum parameters that will help maintain a maximum temperature of less than 40°C and temperature variation within 4 °C [36].

The paraffin wax-based PCM is the most popular; however, this PCM has lower thermal conductivity and the value is below 0.4 W/mK [37] and hence it has a lower heat flow rate. If the heat transfer by application of PCM is not transferred to the environment, then it may affect the TMS of the battery. Various techniques are used to increase the performance of the PCM [38-39]. The fin structure, such as cylindrical or longitudinal, can be used to increase the heat transfer of the PCMs. It is reported that this technique enhances the heat transfer effectively as compared to PCM without fins. As the heat transfer area increases, it contributes positively to the battery performance for cooling. The fin dimensions, the number of fins, and the position of fins must be optimized for better performance of the PCM. It is reported that the fin system can be used in a battery cooling system with a heat generation rate of 20 W [40].

The battery bank consists of 42,100 cylinders that can be cooled with a mini-channel liquid cooling system, and it is suggested that the number of mini-channel required is four, and the inlet coolant flow rate is about 1,103 kg/s. The coolant mass flow rate limits the capability of T_{max} [41].

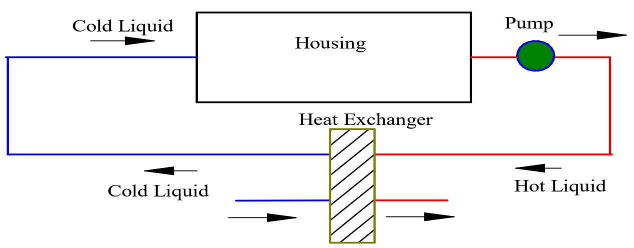

Fig.10. Air-Cooling of LIB.

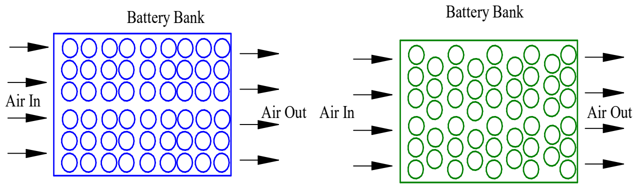

Fig.11. Liquid Cooling.

The passive or active cooling system (Fig.11) can be used for battery cooling. In the battery system, air temperature between 10 to 35°C is preferred to avoid overcooling and overheating. Passive cooling is simple in design and low cost as compared to an active cooling system. The liquid heat exchanger is used in an active cooling system to transfer the heat absorbed by the coolant. The hydrogel can be used in the passive cooling system, and it is easy to manufacture and cheap. However, active cooling is widely used due to effective heat transfer [42]. The temperature and its distribution affect the performance of LIBs and have limitations in their applications. The impact of temperature varies on the temperature value. Hence, measuring the temperature inside the LIBs effectively helps design a better battery thermal management system [43]. The non-uniform cell temperature and battery temperature increase during higher battery discharging conditions. It is reported that the large inter-cell spacing provides effective cooling air circulation and removes various gases generated [44].

In recent years, computational fluid dynamics (CFD) analysis is used to optimize the dimensions of the cold plate. CFD analysis of a cold plate with serpentine-channel configuration was carried out and the influences of channel number and the channel layout are studied. CFD study was extended on the effect of coolant intake temperature on the performance [45]. A typical cooling arrangement of the battery that can be analyzed using CFD is shown in Fig. 12.

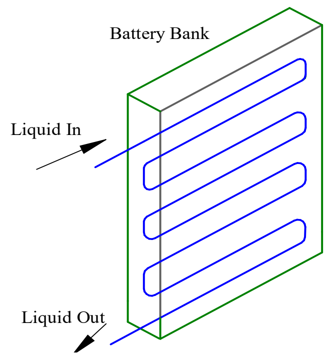

Fig.12. CFD analysis.

It reveals that the design of the cooling plate results in various temperature profiles and better design results in better design of the cooling plate for a battery pack [46].

An optimal cooling strategy can be obtained by optimizing the temperature of the coolant at the inlet and its flow rate, discharge rate, surface area, flow pattern layout, etc. It is reported that the flow pattern layout concerning crossflow with a single inlet and outlet channel alternately reduces temperature difference and maximum temperature by 950.1 and 32.2%, respectively, as compared to the flow pattern layout, which has ten inlet channels at one side in parallel flow. Hence, the temperature non-uniformity and maximum temperature can be maintained with optimized cooling parameters [49].

A phase change material (PCM) has a higher energy transfer capacity. Hence, it can provide effective cooling for the large-scale battery pack, and it is very effective in maintaining battery temperature and temperature distribution without any external cooling source. However, the PCM has a lower thermal conductivity, one of its main drawbacks [3]. The PCM thickness affects the heat transfer and performance of the battery. The use of PCM enhances the heat transfer and reduces both maximum temperature T_{max} and difference in temperature, ΔT effectively [50]. Cooling plate with PCM / water cooling of a battery pack, and it is suggested that the factors such as spacing of adjacent batteries, cooling plate height, rate of flow at the inlet, and direction of the flow should be optimized. Also, the selection of PCM is significantly affected by the thermal conductivity and melting point of PCM as it directly affects the cooling performance. It is reported that the water-cooling plate effectively removes heat generated during discharging of the battery and effectively reduces maximum temperature. One can achieve uniformity of the temperature by placing the PCM between the adjacent batteries [51].

The operating temperature affects the LIBs' durability, performance and safety, particularly in hot climates. Hence, LIB should have an efficient cooling system. It is reported that the novel PCM with fin structure can be used for the cooling of lithium iron phosphate batteries to enhance temperature uniformity in heated conditions and to reduce the maximum temperature. The PCM has lower thermal conductivity and hence providing fins will increase heat transfer. It is reported that the PCM with longitudinal fins will increase the heat transfer, and this arrangement is shown in Fig.13.

The heat transfer increases with the area of the fin structure, and the thermal conductivity of its material. However, the number of fins, position of fins, and materials of the fins affect the heat transfer [52]. Further, the thickness and spacing of fins, and the kind of PCM material affect the cooling performance of the LIBs. It is reported that the optimized PCM-fin structure results in better thermal management and helps to keep the maximum temperature within limits. The PCM-fin design increases heat conduction and natural convection and improves the cooling performance due to increased heat dissipation. It also minimizes the failure risk [53].

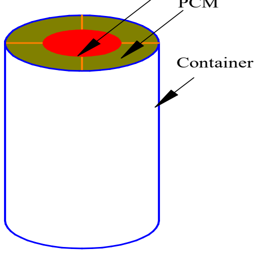

Fig.13. Cell cooling using PCM with fins.

The heat transfer characteristics of LIBs can be increased by thermally conductive CPCM. It is also found that heat transfer characteristics of CPCM are nearly the equivalent to copper foam/PCM material under varying temperature conditions. Further increment in local heat transfer for various regions for different sizes of power battery module CPCM cooling media. The maximum temperature was limited to 44.6 ^{0}C in a 36-battery module during the 3C discharge, while the temperature difference ΔT_{max} was restricted to 0.8°C. It showed a slight increment in max. temperature T_{max} (less than 1%), but it was found that a reduction in temperature difference by 46.7% for 16 batteries pack helped the temperature consistency [54]. It is reported that novel PCM materials and design technology have to be developed for the effective cooling of LIB [55].

7. Numerical studies on CFD Cooling of LIBs

7.1. 1D Analysis

Electrochemical-based 1-D simulation was performed on thermal stability analysis and the battery cell capacity loss was based on C-rate discharges of individual positive electrodes [56].

7.2. 3D Analysis:

The theoretical and computational insight gives the behavioural aspect of operational and extreme thermal environments. Further, 3-D simulation helps develop new materials and their shape. Further 3D simulations help develop new architectures as a complementary approach to experimental investigation [57].

Many simulation studies on air cooling, liquid cooling and PCM cooling are summarized for various arrangements [58]. Multiple techniques have been followed. Out of them, lumped system analysis is a commonly used technique in that each cell is considered for numerical analysis [59]. Further, many correlations were also defined through optimization techniques using data obtained from CFD results [60]. Multichannel systems can also be developed for effective thermal management of a cylindrical lithium-ion battery module [61]. In continuation, several factors were investigated for the selection of design variables to enhance the performance of cooling of batteries. Finally, many optimization methods like DOE and RSM can be applied for real optimal design [62].

8. Application of Artificial Intelligence in LIB

The LIBs are extensively employed in electric vehicles due to their lower discharge rate, longer cycle life and higher energy density. Hence, required to manage the LIBs to enhance the performance of the vehicle [63,10]. Also, it is necessary to get information about thermal runways, battery aging, condition of the battery, charging and discharging, etc. The integration of artificial intelligence (AI) with LIBs for battery management will help to overcome these issues and for the life cycle management of LIBs [64]. Hence the applications of LIBs have increased in recent years [65].

Machine learning (ML), the subset of AI, is also used in battery management [66]. The ML can also be used in the selection of materials, testing, etc. and helps in material development and enhances the battery's life [67]. Different types of ML algorithms are used in LIB applications and selection is based on the data available etc., to get better prediction results. For example, a random forest algorithm is preferred to predict the LIB's cathode materials crystal system [68]. The LIB's charging status can be predicted with the XGBoost method, and this method needs an optimal data set and provides better accuracy [69]. Recently, ML is used extensively for screening high-performing LIBs [70]. Hence, ML is recently used in the development of battery materials and many investigations have been done in this area [71]. It is reported that the ML has accurately predicted the redox potentials of LIBs [72]. In recent years, deep learning technology has also been used in battery management as it can handle large data samples and helps study multiphase reactions, complex structures, etc. [73].

9. Recycling of LIB

The major challenge with the reuse of LIBs is safe and non-destructive dismantling with required automatic processes [74]. The used LIBs are not included in the waste collection system in most countries. This may affect the recycling of used LIBs and the current recycling industry. It is reported that only 10% of LIBs are recycled, and the remaining goes to landfills [75].

The LIBs can contaminate groundwater and soil due to metal leaching and electrolyte. The LIBs release toxic gases when it interacts with moisture and may cause fire accidents [76]. The LIBs can be recycled; however, it is not easy and depends on recycling technology, safety, environmental impact, economic feasibility, etc. Al, Cu, steel, Co, and Ni are currently recycled in LIB recycling. The LIB plastic wastes are burnt for energy recovery, and the remaining metals, such as Li, Mn, etc., are not recycled. The recent advancements in recycling technology may help to recover about 25% of the materials depending on the separation method. Recycling is a concern and greatly influences sustainability; also, it leads to environmental pollution.

Recycling involves electrolyte separation and treatments, storage of used batteries and dismantling, and subsequent hydrometallurgical process using acid and alkali [77]. The recycling of LIBs may reduce CO_2 emissions and energy consumption, saving natural resources. Also, it reduces environmental toxicity, materials mining, imports, minimizes waste, etc. Recycling metals of LIBs' can save 13% of LIB cost per kWh [78].

Life and degradation are concerns with LIB and research works are underway related to them [79]. The LIBs sustainability is essential, and a life-cycle assessment must be carried out concerning the economy, resource management, etc. The ongoing technological development will provide suitable LIB recycling solutions and make it necessary to use environmentally friendly materials [80-81].

10. Future Trends in Battery Technology for The Benefit of The Improvement of Technology

As an advanced technology, high voltage cathodes are paramount and potential candidates for LIBs. More attention towards usage LIBs in HEV/PHEV by adopting high capacity Lithium-ion cathode. Especially Li-rich layered oxide cathode is under focus [82]. Enhancing the properties of the organic liquid electrolyte using additives finds importance as dendrite growth removal is a major challenge. New approaches towards the formation of artificial SEI by stable platting /stripping of lithium metal. Additionally, a new method of plating of metallic lithium in an electrochemical cell is presented by some authors [83].

For the adaptation of LIBs, validation of battery life is crucial beyond the warranty period. Precise equipments are needed to avoid uncertainty during the measurement of battery power and energy [83,84]. The other major major challenge is finding the degradation rate and confirmation of degradation rates which may significantly accelerate at some later stage [85]. Emphasis is to be given to find high-energy materials which offer high energy density and, also on causes and remedies for the firing of LIBs[85].

11. Challenges and Research Opportunities

The research community carried out several works to overcome the problems faced in battery technology. However, there are several research opportunities. New materials can be synthesized for LIB components and in recent years, properties of existing LIB components have been improved through surface treatments and doping [85]. There is a scope for flexible Li-ion batteries based on carbon nanomaterials with a focus on design, synthesis and property optimization [86]. The higher price and fluctuation in cobalt supply allow the researchers to find cobalt-free cathode material. It is necessary to study characteristics after doping with new metals like manganese [87, 88].

Further, there is a demand for the flexible LIB for various applications which exhibits good stretchability and flexibility. Hence there is scope for the development of various flexible LIB components [89]. Few energy storage applications like micro-power sources for micro-sensors need thin LIB and hence the components of LIB should be thin [90]. Further, unscientific disposal of LIB may affect the environment due to contamination of toxic substances. There is scope for developing low-cost recycling disposal LIB wastes and assessment of the recycling methods finds importance [91,92]. Future development may involve the utilization of solar energy for charging batteries. Also, the reduction of charging time without compromising battery life is a challenge with LIBs of various applications. In recent years, substantial research work is intensive on increasing battery capacity and infrastructure development [93]. There is a scope in balancing load demand and power generation using battery energy system and demand response [94]. Further, research can also be extended to Hybrid Electric

System (HES), towards the reduction of hydrogen consumption by the application of ultracapacitors [95]. Research can also be extended EV load smoothing by SOC-based coordinated EV charging method [96]. A multi-agent system-based algorithm can be developed to control the battery energy storage system in addition [97].

12. Conclusion

The energy storage system is used in various applications. In recent years, EVs have been introduced in the market, and batteries are a major component of these vehicles. EVs mostly use LIBs as they have a higher energy density. Different LIBs are commercially available, and the selection is applications based. In the context of the development of technology, various aspects need to be focused. With that viewpoint, various aspects of future research are highlighted in this review. Innovation of new materials to enhance the performance of the LIBs and to avoid heat generation are thrust areas in the interest of using LIBs in EVs. The AI technique is used in LIBs to avoid thermal runaway and battery fire hazards. The used LIBs may cause environmental pollution; so, various recycling techniques have been used. From this paper, we conclude that LIBs will play a key role in the energy storage systems and substantial research works are underway to improve the performance of the LIBs.

Acknowledgments

The authors acknowledge Nitte Meenakshi Institute of Technology, Bangalore and Manipal Institute of Technology, Manipal for their support to write this paper.

References

[1] P. Cambeiro F, J. Armesto, G. Bastos, J.I. Prieto-López, F. Patiño-Barbeito, "Economic appraisal of energy efficiency renovations in tertiary buildings", Sustainable Cities and Society, DOI:10.1016/j.scs.2019.101503, Vol.47, Article No.101503.

[2] M.V. Diamanti, M. Ormellese, M.P. Pedeferri, "Characterization of photocatalytic and super hydrophilic properties of mortars containing titanium dioxide", Cement and Concrete Research, DOI:10.1016/j.cemconres.2008.07.003, Vol.38, No.11, pp. 1349-1353.

[3] Y.E. Milián, A. Gutiérrez, M. Grágeda, S. Ushak, "A review on encapsulation techniques for inorganic phase change materials and the influence on their thermophysical properties", Renewable and Sustainable Energy Reviews, DOI:10.1016/j.rser.2017.01.159, Vol.73, pp. 983-999.

[4] V.V. Tyagi, A.K. Pandey, D. Buddhi, R. Kothari, "Thermal performance assessment of encapsulated PCM based thermal management system to reduce peak energy demand in buildings", Energy and Buildings, DOI:10.1016/j.enbuild.2016.01.042, Vol.117, pp.44–52.

[5] T. Ahmad, D. Zhang, "A critical review of comparative global historical energy consumption and future demand: The story told so far", Energy Reports, DOI:10.1016/j.egyr.2020.07.020, Vol.6, pp.1973–1991.

[6] US Department of Energy, Technical Report (NREL/TP-5400-78461 DOE/GO-102020-5497), accessed on 10th Jan 2022.

[7] G.E. Blomgren, "The Development and Future of Lithium Ion Batteries", Journal of The Electrochemical Society, DOI:10.1149/2.0251701jes,Vol.164, Article No.A5019.

[8] N. Nitta, F. Wu, J.T. Lee, G. Yushin, "Li-ion battery materials: Present and future", Materials Today, DOI:10.1016/j.mattod.2014.10.040, Vol.18, pp. 252–264.

[9] V. Etacheri, R. Marom, R. Elazari, G. Salitra, D. Aurbach, "Challenges in the development of advanced Li-ion batteries: A review". Energy and Environmental Science, DOI:10.1039/c1ee01598b,Vol.4, pp.3243–3262.

[10] L. Lu, X. Han, J. Li , J. Hua, M.Ouyang,"A review on the key issues for lithium-ion battery management in electric vehicles", Journal of Power Sources, DOI:10.1016/j.jpowsour.2012.10.060, Vol.226, pp.272–288.

[11] R.Zhu, D.Kondor, C.Cheng, X.Zhang, P.Santi, M. S.Wong, C.Ratti,"Solar photovoltaic generation for charging shared electric scooters", Applied Energy, DOI:10.1016/j.apenergy.2022.118728, Vol. 313, Article No.118728.

[12] G. Xia, L. Cao, G. Bi, "A review on battery thermal management in electric vehicle application", Journal of Power Sources, DOI:10.1016/j.jpowsour.2017.09.046, Vol.367, pp.90–105.

[13] T. Wang , K.J. Tseng, J. Zhao, Z. Wei, "Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies", Applied Energy, DOI:10.1016/j.apenergy.2014.08.013, Vol.134, pp.229–238.

[14] R. Liu, J. Chen, J. Xun, K. Jiao, Q. Du. "Numerical investigation of thermal behaviors in lithium-ion battery stack discharge", Applied Energy, DOI:10.1016/j.apenergy.2014.07.024, Vol.132, pp.288–297.

[15] S. Al-Hallaj, J.R. Selman, "Thermal modeling of secondary lithium batteries for electric vehicle/hybrid electric vehicle applications", Journal of Power Sources, DOI:10.1016/S0378-7753(02)00196-9, Vol.110, No.2, pp.341-348.

[16] S. Shaikh, K. Lafdi, "Effect of multiple phase change materials (PCMs) slab configurations on thermal energy storage", Energy Conversion and Management, DOI:10.1016/j.enconman.2005.12.012, Vol.47, pp.2103–2117.

[17] A. Castell, I. Martorell, M. Medrano, G. Pérez, L.F. Cabeza, “Experimental study of using PCM in brick constructive solutions for passive cooling”, Energy and Buildings, DOI:10.1016/j.enbuild.2009.10.022, Vol.42, pp. 534–540.

[18] Lithium-ion Battery Overview. Technical Notes, Issue #30, June 2019.

[19] T. Kim, W. Song, D.Y. Son, L.K. Ono, Y. Qi, “Lithium-ion batteries: outlook on present, future, and hybridized technologies”, Journal of Materials Chemistry A, DOI:10.1039/C8TA10513H2019, Vol.7, pp.2942–2964.

[20] https://batteryuniversity.com/learn/article/types_of_lithium_ion, accessed on 10th Jan 2022.

[21] A. Mishra, A. Mehta, S. Basu, S.J. Malode, N.P. Shetti, S.S. Shukla, “Electrode materials for lithium-ion batteries”, Materials Science for Energy Technologies, DOI:10.1016/j.mset.2018.08.001, Vol.1, pp.182–187.

[22] A.O.Soge, “Anode Materials for Lithium-based Batteries: A Review”, Journal of Materials Science Research and Reviews, Vol.5, No.3, pp.21-39, Article No.JMSRR.56496.

[23] H. Löbberding, S. Wessel, C. Offermanns, M. Kehrer, J. Rother, H. Heimes, “From cell to battery system in BEVs: Analysis of system packing efficiency and cell types”, World Electric Vehicle Journal, DOI:10.3390/wevj11040077, Vol.11. pp.1–15.

[24] R.E. Ciez, J. Whitacre, “Comparison between cylindrical and prismatic lithium-ion cell costs using a process based cost model”, 2016. Journal of Power Sources, DOI:10.1016/j.jpowsour.2016.11.054, Vol.340 pp.273-281.

[25] E. Quartarone, P. Mustarelli, “Review—Emerging Trends in the Design of Electrolytes for Lithium and Post-Lithium Batteries”, Journal of The Electrochemical Society, DOI:10.1149/1945-7111/ab63c4, Vol.167, Article No.050508.

[26] I. Mudawar, “Assessment of High-Heat-Flux Thermal Management Schemes”, IEEE transactions on components and packaging technologies, DOI: 10.1109/6144.926375, Vol. 24, No.2, pp.122-141.

[27] G.E. Blomgren, “The Development and Future of Lithium Ion Batteries”, Journal of The Electrochemical Society, DOI:10.1149/2.0251701jes, Vol.164, No.1, pp.A5019–5025.

[28] M. Lu, X. Zhang, J. Ji, X. Xu, Y. Zhang Y. “Research progress on power battery cooling technology for electric vehicles”, Journal of Energy Storage, DOI:10.1016/j.est.2019.101155 ,Vol.27, Article No.101155.

[29] M. Li, J. Wang, Q. Guo, Y. Li, Q. Xue, G. Qin, “Numerical Analysis of Cooling Plates with Different Structures for Electric Vehicle Battery Thermal Management Systems”, Journal of Energy Engineering, DOI:10.1061/(asce)ey.1943-7897.0000648, Vol.146 Article No.04020037.

[30] R.A. Wirtz, K. Swanson, M. Yaquinto, “Thermal energy storage thermal response model with application to thermal management of high power-density hand-held electronics”, Journal of Electronic Packaging, Transactions of the ASME, DOI:10.1115/1.4005915, Vol.134, No.1. Article No.011002.

[31] C. Zhao, B. Zhang, ,Y. Zheng, S. Huang, T. Yan, X. Liu “Hybrid battery thermal management system in electrical vehicles: A review”, Energies (Basl), DOI:10.3390/en13236257, Vol.13, No.23, Article No.6257.

[32] P.S. Lee, S.V. Garimella, D. Liu “Investigation of heat transfer in rectangular microchannels”, International Journal of Heat and Mass Transfer, DOI:10.1016/j.ijheatmasstransfer.2004.11.019, Vol.48, pp.1688–1704.

[33] R. Chein, G. Huang,“Analysis of microchannel heat sink performance using nanofluids”, Applied Thermal Engineering, DOI:10.1016/j.applthermaleng.2005.03.008, Vol. 25, No.17–18, pp.3104-3114.

[34] K. Iqbal, A. Khan, D.Sun, M. Ashraf, A. Rehman, F. Safdar, “Phase change materials, their synthesis and application in textiles—a review”, Journal of the Textile Institute. DOI:10.1080/00405000.2018.1548088, Vol.110, pp.625–638.

[35] Y.Shin, D.Yoo-Il, K. Son, “Development of thermoregulating textile materials with microencapsulated Phase Change Materials (PGM). IV. Performance properties and hand of fabrics treated with PCM microcapsules”, Journal of Applied Polymer Science, DOI:10.1002/app.21846, Vol.97, pp.910–915.

[36] A. Khoddami A, O. Avinc, F. Ghahremanzadeh, “Improvement in poly(lactic acid) fabric performance via hydrophilic coating”, Progress in Organic Coatings, DOI:10.1016/j.porgcoat.2011.04.020, Vol.72, pp.299–304.

[37] G. Zhang, S. Xu, M. Du, G. Liu, L. Zhou, “Temperature regulating fibers of high latent heat and strength: Mass production, characterization and applications”, Journal of Energy Storage, DOI:10.1016/j.est.2021.103030, Vol.42, Article No.103030.

[38] Nguyen X, T.Tran, “Experimental Study on Phase Change Materials for Cold Energy Storage System”, Journal of Energy and Natural Resources, DOI:10.11648/j.jenr.20200902.11, Vol.9, No.2, pp.51-55.

[39] A. Al-Abidi, S. Bin Mat, K. Sopian, M. Sulaiman, C.Lim, A.Th, “Review of thermal energy storage for air conditioning systems”, Renewable and Sustainable Energy Reviews, DOI:10.1016/j.rser.2012.05.030, Vol.16, pp.5802-5819.

[40] F. Agyenim, P. Eames, M. Smyth, “Experimental study on the melting and solidification behaviour of a medium temperature phase change storage material (Erythritol)

system augmented with fins to power a $LiBr/H_2O$ absorption cooling system", Renewable Energy. DOI:10.1016/j.renene.2010.06.005, Vol.36. pp.108–117.

[41] M. Helm, C. Keil, S. Hiebler, H. Mehling, C. Schweigler, "Solar heating and cooling system with absorption chiller and low temperature latent heat storage: Energetic performance and operational experience", International Journal of Refrigeration, DOI:10.1016/j.ijrefrig.2009.02.010,Vol.32, pp.596–606.

[42] O. Kalaf, D. Solyali, M. Asmael, Q. Zeeshan, B. Safaei, A. Askir, "Experimental and simulation study of liquid coolant battery thermal management system for electric vehicles: A review", International Journal of Energy Research, DOI:10.1002/er.6268, Vol.45, pp.6495–6517.

[43] S. Ma, M. Jiang, P. Tao, C. Song, J. Wu, J. Wang, "Temperature effect and thermal impact in lithium-ion batteries: A review", Progress in Natural Science: Materials International , DOI:10.1016/j.pnsc.2018.11.002, Vol.28, pp.653–666.

[44] R.D. Jilte, R. Kumar, "Numerical investigation on cooling performance of Li-ion battery thermal management system at high galvanostatic discharge" Engineering Science and Technology, an International Journal,957–969, DOI:10.1016/j.jestch.2018.07.015, Vol.21, No.5,pp. 957-969.

[45] T. Deng, G. Zhang, Y. Ran, "Study on thermal management of rectangular Li-ion battery with serpentine-channel cold plate", International Journal of Heat and Mass Transfer, DOI:10.1016/j.ijheatmasstransfer.2018.04.065, Vol.125, pp.143-152.

[46] K. Benabdelaziz, B. Lebrouhi, A. Maftah, M. Maaroufi, "Novel external cooling solution for electric vehicle battery pack", Energy Reports, DOI:10.1016/j.egyr.2019.10.043, Vol.6, pp. 262–272.

[47] N. Om, R. Zulkifli, P. Gunnasegaran, "Influence of the oblique fin arrangement on the fluid flow and thermal performance of liquid cold plate", Case Studies in Thermal Engineering, DOI:10.1016/j.csite.2018.09.008, Vol.12, pp.717-727.

[48] Z.Lua,X.Z.Meng,L.C.Wei,W.Y.Hu,L.Y.Zhang, L.W.Jin "Thermal management of densely-packed EV battery with forced air cooling strategies", Energy Procedia, DOI:10.1016/j.egypro.2016.06.098, Vol.88, pp.682-688.

[49] M.S.Patil, J.H.Seo, S.Panchal, S.W.Jee, Lee MY. "Investigation on thermal performance of water-cooled Li-ion pouch cell and pack at high discharge rate with U-turn type microchannel cold plate", International Journal of Heat and Mass Transfer, DOI:10.1016/j.ijheatmasstransfer.2020.119728,Vol.155 Article No.119728.

[50] T.Kumirai, J.Dirker, J.Meyer, "Experimental analysis for thermal storage performance of three types of plate encapsulated phase change materials in air heat exchangers for ventilation applications", Journal of Building Engineering, DOI:10.1016/j.jobe.2018.11.016, Vol.22, pp.75-89.

[51] F.Bai, M.Chen, W.Song, Z.Feng, Y.Li, Y.Ding, "Thermal management performances of PCM/water cooling-plate using for lithium-ion battery module based on non-uniform internal heat source", Applied Thermal Engineering,DOI:10.1016/j.applthermaleng.2017.07.141, Vol.126, pp.17-27.

[52] Z.Sun, R.Fan, F.Yan, T.Zhou, N.Zheng, "Thermal management of the lithium-ion battery by the composite PCM-Fin structures", International Journal of Heat and Mass Transfer, DOI:10.1016/j.ijheatmasstransfer.2019.118739, Vol.145, Article No.118739.

[53] P.Ping, R.Peng, D.Kong, G.Chen, J.Wen, "Investigation on thermal management performance of PCM-fin structure for Li-ion battery module in high-temperature environment",Energy Conversion and Management, DOI:10.1016/j.enconman.2018.09.025,Vol.176, pp.131-146.

[54] D.Zou, X.Liu, R.He, S.X.Zhu, J.Bao, J.Guo, "Preparation of a novel composite phase change material (PCM) and its locally enhanced heat transfer for power battery module", Energy Conversion and Management, DOI:10.1016/j.enconman.2018.11.064,Vol.180, pp.1196-1202.

[55] J.Weng, X.Yang, G.Zhang, D.Ouyang, M.Chen, J.Wang "Optimization of the detailed factors in a phase-change-material module for battery thermal management", International Journal of Heat and Mass Transfer DOI:10.1016/j.ijheatmasstransfer.2019.04.050, Vol.138, pp.126-134.

[56] H.Choi, N.Lim, S.J.Lee, J.Park. "Numerical approach for lithium-ion battery performance considering various cathode active material composition for electric vehicles using 1D simulation", Journal of Mechanical Science and Technology, DOI:10.1007/s12206-021-0540-1, Vol.35, pp.2697-2705.

[57] D.Grazioli, M.Magri, A.Salvadori, "Computational modeling of Li-ion batteries", Computational Mechanics, DOI:10.1007/s00466-016-1325-8, Vol.58, pp.889-909.

[58] P.R.Tete, M.M.Gupta, S.S.Joshi, "Numerical investigation on thermal characteristics of a liquid-cooled lithium-ion battery pack with cylindrical cell casings and a square duct", Journal of Energy Storage, DOI:10.1016/j.est.2022.104041, Vol.48, Article No.104041.

[59] Kausthubharam, P.K.Koorata, N.Chandrasekaran, "Numerical investigation of cooling performance of a novel air-cooled thermal management system for cylindrical Li-ion battery module", Applied Thermal Engineering,DOI:10.1016/j.applthermaleng.2021.116961, Vol.193. Article No.116961

[60] A.Verma, P. Saikia, D.Rakshit, "Unification of intensive and extensive properties of the passive cooling

system under a single envelope for the thermal management of Li-ion batteries", Journal of Energy Storage, DOI:10.1016/j.est.2022.104184. Vol.50, Article No.104184.

[61] Z.Tang, X.Min, A.Song, J.Cheng, "Thermal Management of a Cylindrical Lithium-Ion Battery Module Using a Multichannel Wavy Tube", Journal of Energy Engineering, DOI:10.1061/(asce)ey.1943-7897.0000592, Vol.145, Article No. 04018072.

[62] Z.Z.Li, T.H.Cheng, D.J.Xuan, M.Ren, G.Y.Shen, Y.D.Shen Y. "Optimal design for cooling system of batteries using DOE and RSM", International Journal of Precision Engineering and Manufacturing, DOI:10.1007/s12541-012-0215-z, Vol.13, pp.1641-1645.

[63] V.Etacheri, R.Marom, R.Elazari, G.Salitra, D.Aurbach, "Challenges in the development of advanced Li-ion batteries: A review", Energy and Environmental Science, DOI:10.1039/c1ee01598b, Vol.4, pp.3243–3262.

[64] Y.Wang, J.Tian, Z.Sun, L.Wang, R.Xu, M.Li, "A comprehensive review of battery modeling and state estimation approaches for advanced battery management systems", Renewable and Sustainable Energy Reviews, DOI:10.1016/j.rser.2020.110015, Vol.131, Article No.110015.

[65] S.K.Kauwe, T.D.Rhone, T.D.Sparks, "Data-driven studies of li-ion-battery materials", Crystals (Basel) 2019, DOI:10.3390/cryst9010054, Vol.9, No.1 pp.1-9.

[66] A.Hodges, "The essential turing: the ideas that gave birth to the computer age", The British Journal for the History of Science, DOI:10.1017/s0007087406448688, Vol.39, No.3, pp.470–471.

[67] Z.Luo, X.Yang, Y.Wang, W.Liu, S.Liu, Y.Zhu, "A Survey of Artificial Intelligence Techniques Applied in Energy Storage Materials R&D", Frontiers in Energy Research, DOI:10.3389/fenrg.2020.00116, Vol.8, Article No. 116.

[68] M.Attarian Shandiz, R.Gauvin. "Application of machine learning methods for the prediction of crystal system of cathode materials in lithium-ion batteries", Computational Materials Science, DOI:10.1016/j.commatsci.2016.02.021,Vol.117, pp.270-278.

[69] J.Li , W.Ziehm, J.Kimball, R.Landers , J.Park , "Physical-based training data collection approach for data-driven lithium-ion battery state-of-charge prediction", Energy and AI, DOI:10.1016/j.egyai.2021.100094, Vol.5, Article No.100094.

[70] K.Liu, Z.Wei, Z.Yang, Li K, "Mass load prediction for lithium-ion battery electrode clean 1 production : a machine learning approach", Journal of Cleaner Production, DOI:10.1016/j.jclepro.2020.125159, Vol. 289, Article No.125159.

[71] G.Houchins, V.Viswanathan, "An accurate machine-learning calculator for optimization of Li-ion battery cathodes", Journal of Chemical Physics, DOI:10.1063/5.0015872, Vol.153, Article No. 054124.

[72] Y.Okamoto, Y.Kubo, "Ab Initio Calculations of the Redox Potentials of Additives for Lithium-Ion Batteries and Their Prediction through Machine Learning", ACS Omega, DOI:10.1021/acsomega.8b00576, Vol.3, No.7, pp.7868–7874.

[73] Y.Liu O.C.Esan, Z.Pan, L.An, "Machine learning for advanced energy materials", Energy and AI, DOI:10.1016/j.egyai.2021.100049, Vol.3, Article No.100049.

[74] S.Arora, A.Kapoor, W.Shen, "Application of robust design methodology to battery packs for electric vehicles: Identification of critical technical requirements for modular architecture", Batteries, DOI:10.3390/batteries4030030,Vol.4, No.30.

[75] F.Gu, J.Guo, X.Yao, P.A.Summers, S.D.Widijatmoko, P.Hall, "An investigation of the current status of recycling spent lithium-ion batteries from consumer electronics in China", Journal of Cleaner Production, DOI:10.1016/j.jclepro.2017.05.181, Vol.161, pp.765-780.

[76] O.E.Bankole, C.Gong, L.Lei, "Battery Recycling Technologies: Recycling Waste Lithium Ion Batteries with the Impact on the Environment In-View", Journal of Environment and Ecology, DOI:10.5296/jee.v4i1.3257, Vol.4, No.1, pp. 14-28.

[77] E.Fan, L.Li, Z.Wang, J.Lin, Y.Huang, Y.Yao, "Sustainable Recycling Technology for Li-Ion Batteries and Beyond: Challenges and Future Prospects", Chemical Reviews, DOI:10.1021/acs.chemrev.9b00535,Vol.120, pp.7020-7063.

[78] A.Sonoc, J.Jeswiet, V.K.Soo, "Opportunities to improve recycling of automotive lithium ion batteries", Procedia CIRP,DOI:10.1016/j.procir.2015.02.039, Vol.29, pp.752-757.

[79] N.Natkunarajah, M.Scharf, P.Scharf, "Scenarios for the return of lithium-ion batteries out of electric cars for recycling", Procedia CIRP, DOI:10.1016/j.procir.2015.02.170, Vol.29, pp.740-745.

[80] E.Mossali, N.Picone, L.Gentilini, O.Rodrìguez, J.M.Pérez, M.Colledani, "Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments", Journal of Environmental Management, DOI:10.1016/j.jenvman.2020.110500, Vol. 264, Article No.110500.

[81] H.J.Kim, T.N.V.Krishna, K.Zeb, V.Rajangam, C.V.V.Muralee Gopi, S.Sambasivam, "A comprehensive review of Li-ion battery materials and their recycling techniques", Electronics (Switzerland), DOI:10.3390/electronics9071161, Vol.9, pp.1-44.

[82] T.Kim, W.Song, D.Y.Son, L.K.Ono, Y.Qi, "Lithium-ion batteries: outlook on present, future, and hybridized

technologies", Journal of Materials Chemistry A, DOI:10.1039/C8TA10513H, Vol.7, pp.2942-2964.

[83] J.Ma, Y.Li, N.S.Grundish, J.B.Goodenough, Y.Chen, L.Guo, "The 2021 battery technology roadmap", Journal of Physics D: Applied Physics, DOI:10.1088/1361-6463/abd353, Vol.54, No.18, Article No.183001.

[84] A.Masias, J.Marcicki, W.A.Paxton, "Opportunities and Challenges of Lithium Ion Batteries in Automotive Applications", ACS Energy Letters, DOI:10.1021/acsenergylett.0c02584, Vol.6, pp.621-630.

[85] J. Wold, J. Marcicki, A. Masias "Derived Quantities Uncertainty Propagation in High Precision Battery Testing", DOI:10.1149/2.1461709jes, J Electrochem Soc Vol.164, No.9, A2131.

[86] Y.Zhanga, Y.Jiaoa,M.Liao, B.Wang, H.Penga, "Carbon nanomaterials for flexible lithium ion batteries" DOI:10.1016/j.carbon.2017.07.065, Carbon, Vol.124, pp. 79-88.

[87] S.Zhang, P.Gao, Y.Wang,J.Li, Y.Zhu, Cobalt-free concentration-gradient $Li[Ni_{0.9}Mn_{0.1}]O_2$ cathode material for lithium-ion batteries, Journal of Alloys and Compounds,Vol. 885, Article No. 161005

[88] N.Muralidharan, R.Essehli, R.P.Hermann, A.Parejiya, R.Amin, Y.Bai, "$LiNi_xFe_yAlzO_2$, a new cobalt-free layered cathode material for advanced Li-ion batteries", Journal of Power Sources, DOI:10.1016/j.jpowsour.2020.228389, Vol.471. Article No. 228389.

[89] Z.Fang, J.Wang, H.Wu ,Q.Li, S.Fan, J.Wang, " Progress and challenges of flexible lithium-ion batteries", Journal of Power Sources, DOI:10.1016/j.jpowsour.2020.227932, Vol.454, Artcle No.227932.

[90] S.Kanazawaa,T.Baba,K.Yoneda,M.Mizuhata, I.Kannoa, "Deposition and performance of all solid-state thin-film lithium-ion batteries composed of amorphous Si/LiPON/VO-LiPO multilayers", Thin Solid Films, DOI:10.1016/j.tsf.2020.137840, Vol.697, Article No.137840

[91] Z.J.Baum, R.E.Bird , X.Yu, J.Ma "Lithium-Ion Battery Recycling─Overview of Techniques and Trends", ACS Energy Letters, DOI:10.1021/acsenergylett.1c02602, Vol.7, pp.712-719.

[92] C.P.Makwarimba, M.Tang, Y.Peng, S.Lu, L.Zheng, Z.Zhao, A.G.Zhen, "Assessment of recycling methods and processes for lithium-ion batteries" iScience, DOI:10.1016/j.isci.2022.104321 Vol. 25, No. 5, Article No.104321.

[93] B. Elibol et al., "Battery Integrated Off-grid DC Fast Charging: Optimised System Design Case for California," 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), pp. 327-332, DOI: 10.1109/ICRERA52334.2021.9598644.

[94] U. Cetinkaya, R. Bayindir and S. Ayik, "Ancillary Services Using Battery Energy Systems and Demand Response", 2021 9th International Conference on Smart Grid (icSmartGrid), pp. 212-215, DOI: 10.1109/icSmart Grid52357.2021.9551253.

[95] S. Gherairi, "Zero-Emission Hybrid Electric System: Estimated Speed to Prioritize Energy Demand for Transport Applications", Vol.3, No.4, December, DOI:10.20508/ijsmartgrid.v3i4.76.g65.

[96] Murat Akil, Emrah Dokur, Ramazan Bayindir, "Impact of Electric Vehicle Charging Profiles in Data-Driven Framework on Distribution Network" 2021 9th International Conference on Smart Grid (icSmartGrid), DOI:10.1109/icSmartGrid52357.2021.9551247

[97] J. Ma and X. Ma, "Distributed Control of Battery Energy Storage System in a Microgrid," 2019 8th International Conference on Renewable Energy Research and Applications (ICRERA), 2019, pp. 320-325, DOI: 10.1109/ICRERA47325.2019.8996504.