ANALYSIS OF LITHIUM-ION BATTERY COOLING SYSTEM USING REFRIGERANT

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report “**ANALYSIS OF LITHIUM-ION BATTERY COOLING SYSTEM USING REFRIGERANT”** is the Bona fide work of **“ ARAVINTH.S (211419114034), ARUNACHALAM A (211419114035), ARUNACHALAM P(211419114036) “** Who carried out the project work under my supervision.

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

We are at the end of the IC Engine era which has certain side effects such as global warming and exploiting our natural resources such as fossil fuels and we all are in a situation to adopt electric vehicles with better performance and efficiency, Silent during operation and comparatively less pollution than IC's. Batteries are the backbone of an Electric vehicle, so basically we use LI-ION battery as the power source of an electric vehicle. And seeking into the Problems of LI-ion battery, it heats exponentially when we draw power more than its rated value as well as charging it at high speed. If we left that as it is, it may lead to a thermal runaway. Thermal Runaway is a process where the electrolyte evaporates due to high temperature, which may lead to a reduction in its efficiency and its life, so a cooling system is required for this type of battery. There are many types of the cooling system, which includes liquid cooling, air cooling, Glycol Based cooling, Phase changing materials, Heat pipe, Oil based cooling, Refrigerant and so on. In this project, we use Refrigerant to cool the battery system with some tweaks and alterations to increase the efficiency by using techniques of Bernoulli's Principle (Conservation of energy) and Newton's law of cooling.

KEYWORDS: Battery cooling System, Refrigerant, Bernoulli's Principle, Newton's law of cooling

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1. INTRODUCTION

The world is facing major problems such as a hike in fuel prices, fast degradation of fossil fuels and environmental pollution. Hence, alternative resources are needed to cut the dependence on crude oil-based fuels for an enhanced economy and environment. The perfect alternative to this is Electric Vehicle. Today we are at the transition stage from Internal Combustion Engine to Electric Vehicles, even though both have their advantages as well as disadvantages. In terms of IC's advantages side, we can cover any range irrespective of distance and refilling of fuel time is less and disadvantages we need to do periodic maintenance and a lot of moving parts so we need to have a proper lubrication system for it, it has less operational efficiency which is around 30 to 35% and have its maximum power and efficiency in the particular rev range and to obtain its maximum efficiency we need to maintain within its band and it creates air pollution by emitting greenhouse gasses and have a noisy operation, it needs a complicated gearing system. A few good things about electric engine is, it is silent and much more efficient than IC's with approximately 80 to 84.8% operational efficiency and its disadvantages, we are at the starting stages of EV's and we need a large development in this field, manufacturing LI-Ion batteries are hectic process and raw materials of LI are not available in all areas and at the same time we don't have such disposal techniques of batteries, charging speeds and range, Dedicated cooling required for batteries. To reduce the disadvantages, we introduce a dedicated cooling system by using refrigerant as a cooling agent and a type used for cooling is Refrigerant based cooling system.

2. LITERATURE SURVEY

- "A Novel Refrigerant-Based Cooling System for Lithium-Ion Batteries in Electric Vehicles," by Zhiyuan Hu, published in Energies (2017). The study proposed a refrigerant-based cooling system for lithium-ion batteries in electric vehicles, using R134a as the refrigerant. The authors conducted numerical simulations and experimental tests to evaluate the performance of the cooling system and found that it was effective in improving battery performance and extending its life.
- "Design of a Refrigerant-Based Cooling System for Lithium-Ion Batteries in Electric Vehicles," by Xiaotong Wei, published in Applied Thermal Engineering (2018). This study proposed a cooling system that used R134a as the refrigerant and included an air-cooled condenser and a capillary tube expansion device. The authors conducted experiments to evaluate the performance of the cooling system and found that it could effectively control the battery temperature and improve its performance.
- “The hand book of Lithium-ion Battery pack design” by the author John Warner who explained in detail about Battery and it types till how does it works and created Major references regarding design are taken from this book
- “Thermal performance of direct refrigerant cooling for lithium-ion batteries in electric vehicles” by Seong Ho Honga, Seonggi Parka , Sungho Yuna, Yongchan Kima. This explains about Phase changing material absorbs high energy than normal cooling medium and much more about coolant.

- "Experimental Study on a Refrigerant-Based Cooling System for Lithium-Ion Batteries in Electric Vehicles," by Xiangyu Zheng, published in Applied Thermal Engineering (2020). This study proposed a cooling system that used R1234yf as the refrigerant and included a plate heat exchanger, a thermostatic expansion valve, and a liquid receiver. The authors conducted experiments to evaluate the performance of the cooling system and found that it could effectively maintain the battery temperature within a safe range and improve its performance.
- “Simulation on cooling Performance characteristics of a refrigerant-cooled active thermal management system for lithium-ion batteries” by Seonggi Park, Dong Soo Jang, DongChan Lee, Seong Ho Hong, , Yongchan Kim. This says about Simulation gives the efficient and need of the Cooling system.
- “A Thermal Performance Management System for Lithium-Ion Battery Packs” paper published by Marc A. Rosen, Maan Al-Zareer, Ibrahim Dincer. They say about Refrigerant application and its effective usage.
- "An Experimental Study on the Performance of a Refrigerant-Based Cooling System for Lithium-Ion Batteries," by Mingyu Chen.
- Published in International Journal of Refrigeration (2015). The study proposed a cooling system that used R134a as the refrigerant and included a finned-tube evaporator, a capillary tube, and a condenser. The authors conducted experiments to evaluate the performance of the cooling system and found that it was effective in reducing the temperature rise of the battery and improving its performance.
- "Thermal Management of Lithium-Ion Battery Packs: Benchmarking of Commercially Available Cooling Systems," by Kai Christian Schumann published in Energies (2018). This study evaluated the performance of various

commercially available cooling systems for lithium-ion battery packs, including systems that used refrigerant. The authors conducted experiments and numerical simulations to compare the performance of the cooling systems and found that the refrigerant-
based systems were more effective than air-cooled systems in controlling the temperature of the battery.

- "Design and Experimental Validation of a Refrigerant-Based Cooling System for Lithium-Ion Batteries in Electric Vehicles," by Yan Zhang, published in Applied Thermal Engineering (2019). The study proposed a cooling system that used R134a as the refrigerant and included a microchannel evaporator, a thermostatic expansion valve, and a plate heat exchanger. The authors conducted experiments to evaluate the performance of the cooling system and found that it was effective in maintaining the temperature of the battery within a safe range and improving its performance.

Overall, these studies demonstrate the potential effectiveness of refrigerant-based cooling systems for lithium-ion batteries in electric vehicles, but also highlight the importance of selecting appropriate refrigerants and designing the cooling systems appropriately to achieve optimal performance

3.OBJECTIVE

- The main objective of our project is to reduce li-ion battery heating and increase the battery efficiency of electric vehicles by maintaining the temperature within the optimum temperature range which ranges between 20^{o} C - 40^{o}C. Maintaining the temperature within this range during charging may increase the charging speeds.
- Exposing the Battery to high temperatures may lead to thermal runaway
- Thermal runaway is a process of Evaporation of liquid electrolyte which may lead to direct contact of positive and negative terminals which may lead to short-circuit or may cause firing.
- To prevent accelerated battery deterioration by managing heat to increase battery life and to operate under optimum temperature conditions (Battery life reduces when its temperature is high), which in turn increases the life of the Battery
- To Reduce the chance of overheating and the risk of explosion and fire hazard from battery
- Cooling system is much needed when we fast charge the batteries which may lead to increase in temperature.
- To maintain all this in control only way is to introduce cooling system for Li-ion Batteries. So we use Refrigerant to cool the Li ion battery
- We eliminate the traditional liquid cooling System and introduce this Refrigerant cooling. Which in turn reduces the overall weight of the Vehicle since we eliminate a separate system.

- Here we use the same system which is used for air conditioning of the vehicle along with few extra components such as valves, thermocouple and a marginal increase in their size.
- Therefore, vehicles overall weight and efficiency increases.

4.PRINCIPLES USED

The major principles used in this process is given below

- **Newtons law of cooling**
- **Bernoulli's principle (Conservation of energy)**

4.1 Newtons law of cooling:

Newton's law of cooling states that the rate of cooling of a body is directly proportional to the temperature difference between the object and its surrounding.

4.2 Bernoulli's principle (Conservation of energy):

Bernoulli's Principle states that the speed of a moving fluid increases, the pressure of the fluid decreases. We use this principle to increase the efficiency by reducing the cross section of the pipe wounded around the battery pack, which increases the flow of the refrigerant around it, therefore we use less energy to run the compressor and a considerable amount of heat is taken by it.

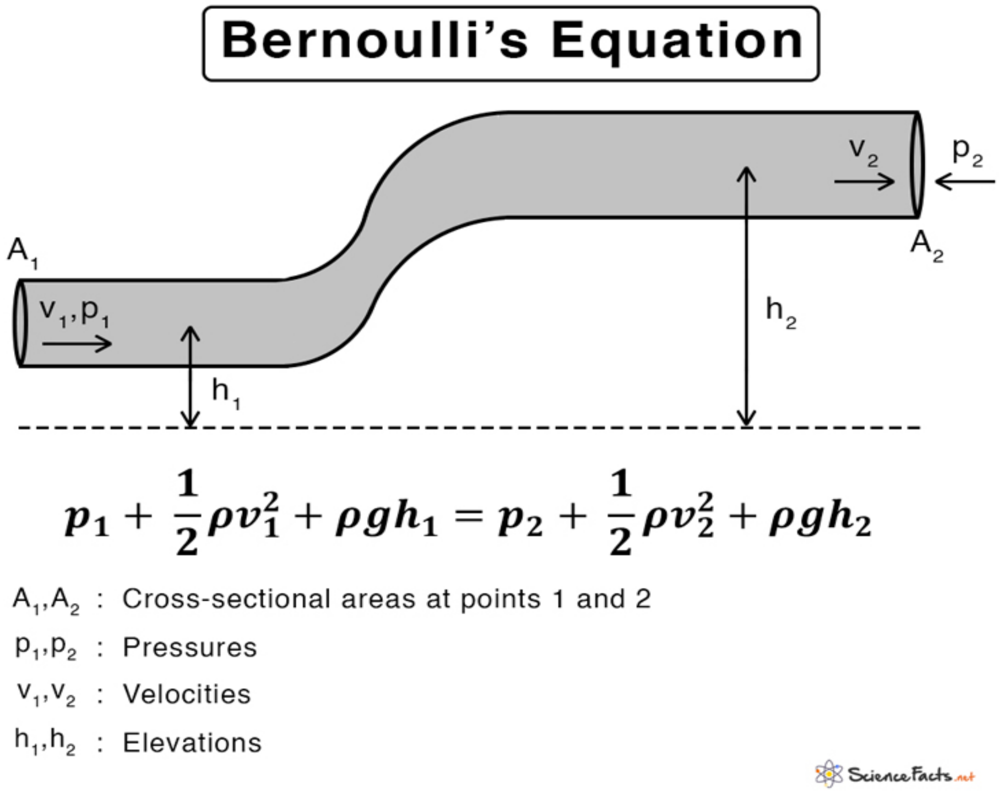

Figure-1. Bernoulli's Theorem and formula

5.REFREGERATION CYCLE

The cycle used in this process is **Vapor-Compressor Refrigeration cycle,** which is also called as the **Reverse Rankine Cycle.**

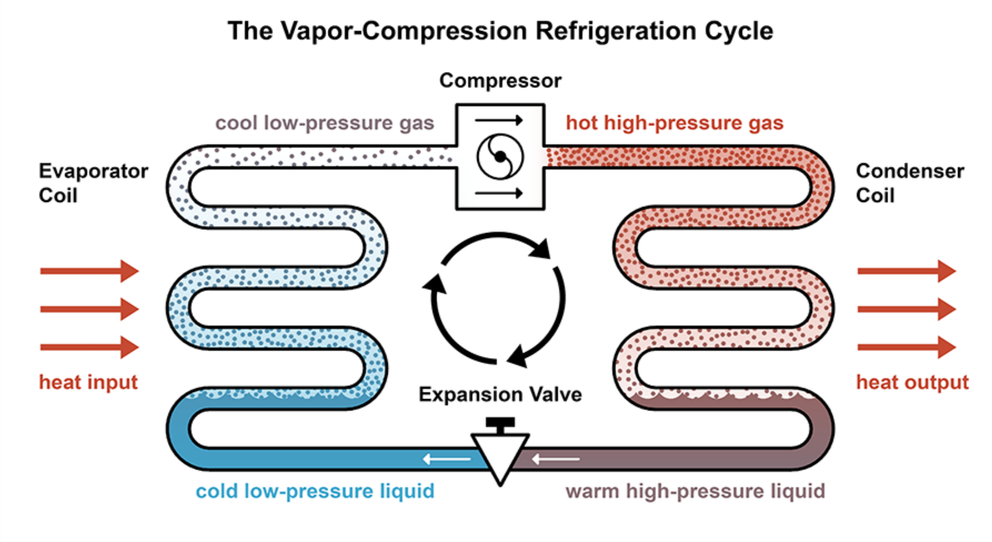

Figure-2. Vapor compression refrigerant cycle

The four stages of vapor compression refrigerant cycle is

- Compression
- Condensation
- Expansion
- Evaporation

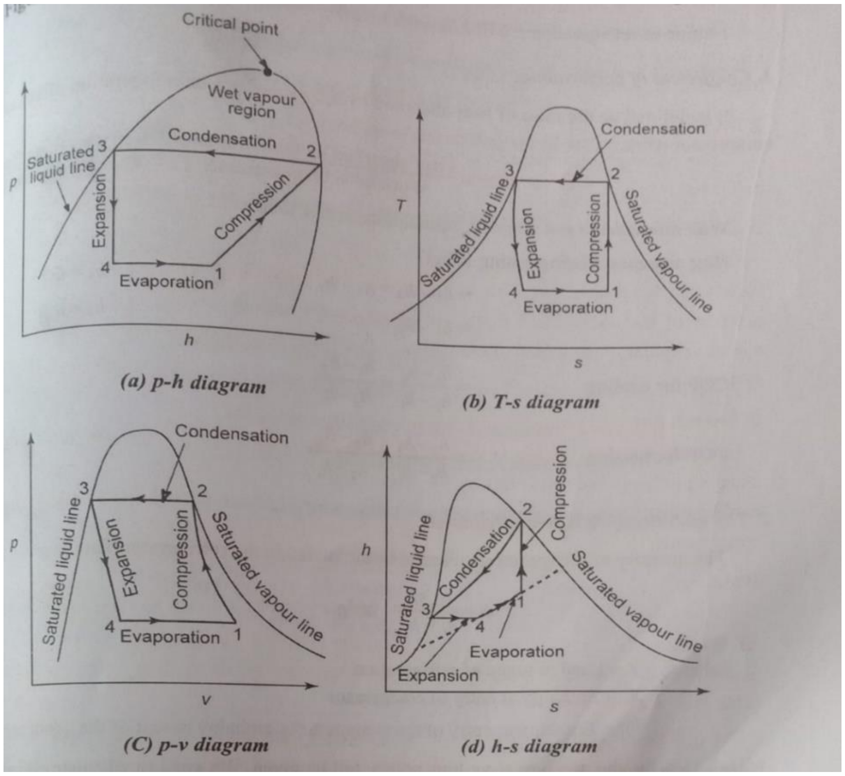

Figure-3. Vapor compression refrigeration plots

The job of the refrigeration cycle is to remove unwanted heat from one place and discharge it into another. To accomplish this, the refrigerant is pumped through a closed refrigeration system. It is closed cycle, the same refrigerant is used over and over again, as it passes through the cycle removing some heat and discharging it to the atmosphere. Refrigerant is in liquid phase during some parts of the cycle and a gas or vapor phase in others. Two different pressures exist in the cycle the evaporating or low pressure in the low side and the condensing or high pressure, in the high side. These pressure areas are separated by two dividing points: one is the metering device where the refrigerant flow is controlled, and the other is at the compressor, where vapor is compressed.

6.METHODOLOGY

Project begins with a compressor, Compressor is the main component of the cooling system, which compresses the refrigerant. The refrigerant enters the compressor at low temperature and low pressure. It is in a gaseous state. Here, compression takes place to raise the temperature and refrigerant pressure of the refrigerant approximately to 8 bar. The refrigerant leaves the compressor and enters the condenser. Since it requires external power to do the work, the same electricity produced from the battery is used here. Power is supplied to the bldc motor from the battery, which in turn is coupled with compressor. The compressor used is reciprocating type. The condenser is essentially a heat exchanger. Heat is transferred from the refrigerant to atmospheric air. This air is drawn from the atmosphere. As the refrigerant flows through the condenser, it is in a constant pressure. When the refrigerant enters the expansion valve, it expands and releases pressure. Consequently, the temperature drops at this stage. Because of these changes, the refrigerant leaves the expansion valve as a liquid vapor mixture, typically in proportions of around 75 % and 25 % respectively. Expansion valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator. At this stage of the Vapor Compression Refrigeration Cycle, the refrigerant is at a lower temperature than the battery casing. Once after passing the expansion valve the cross section of the pipe is reduced therefore Bernoulli's principle is applied and efficiency will increase (theoretically), here the coil is laid at the outer casing of the battery for cooling purposes as indicated in figure 7. Therefore refrigerant, evaporates and absorbs heat. Heat extraction from the refrigerant happens at low pressure and temperature. Compressor suction effect helps to maintain the low pressure.

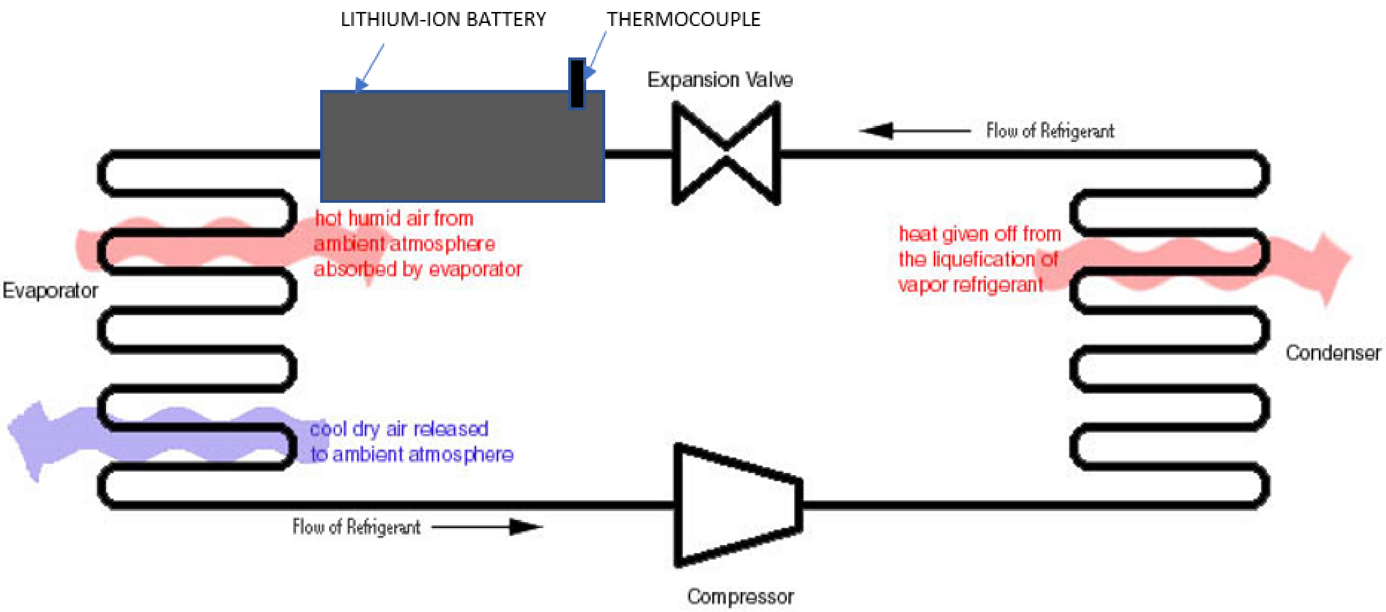

Figure-4. Simple methodological diagram

7.MAJOR COMPONENTS OF THIS REFRIGERANT COOLING SYSTEM

- **7.1 BATTERY PACK**

LI-ion battery was commercially made by Sony in 1991, which was a revolution. Now a days Li-ion batteries are used in most of the electric vehicles as power source. Li is the most energy density material and which is in the top of the table with power to size ratio. The li-ion battery pack consist of twelve battery in a module and eight module considered as a battery pack and number of battery pack is connected to form a power source of the electric vehicle. And the battery pack should be water and dust resistant because the battery is placed at the floor of the Vehicles and is exposed to Dust and water. Mostly batteries are small cells connected in series and parallel according to the required voltage. Lithium-ion batteries use three cells to provide 11.1 volt battery and four cells to provide 14.8 volts and ten cells to provide 37 volt battery output.

If we connect batteries in parallel the capacity of the battery increases and if connected in series the voltage increases.

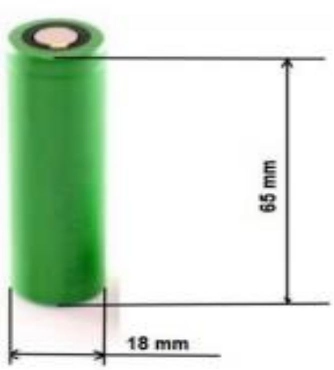

Figure-5. Li ion Battery

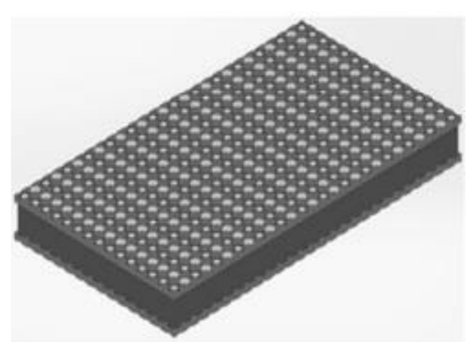

Figure-6. Battery Pack

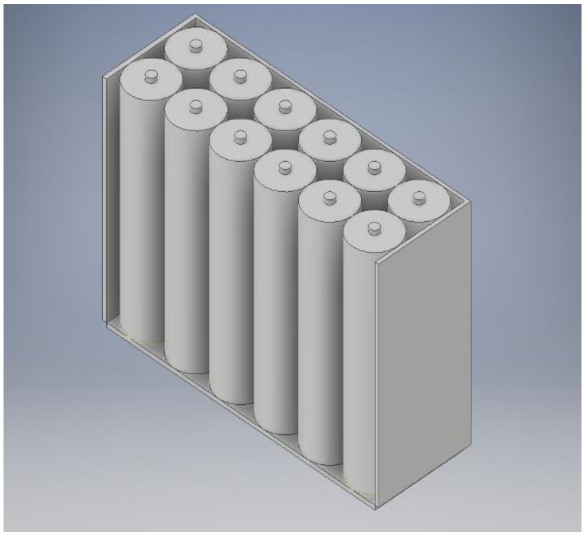

Figure-7 Li ion Battery dissected view

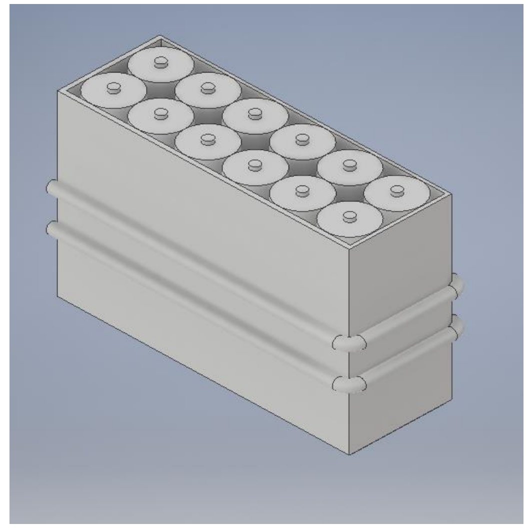

Figure-8 Li ion Battery isometric view

- **7.2 COMPRESSOR**

A compressor is a device that increases the pressure of a substance by reducing the volume. It is a Mechanical device for increasing the pressure of a gas by mechanically decreasing its volume. The compressor is the heart of a refrigerator. In our we use Reciprocating type compressor. Which gives a pulsated output. Compressor circulates the refrigerant through the system and increases the pressure within the closed circuit which increase both temperature and pressure. Once we compress a liquid it automatically increases its temperature. The refrigerant heats up to 90^{o}C and the output pressure will be around 8 bar [7.85 atm/116.03 psi]. The compressor works like an IC engine but we uses a BLDC motor as a offset crank shaft once we run the motor which makes the piston to move up and down the valves will open and close respectively. During suction stroke it sucks the refrigerant from the tank and the inlet valve is closed and then piston moves up and increases the pressure and then the exhaust valve is opened.

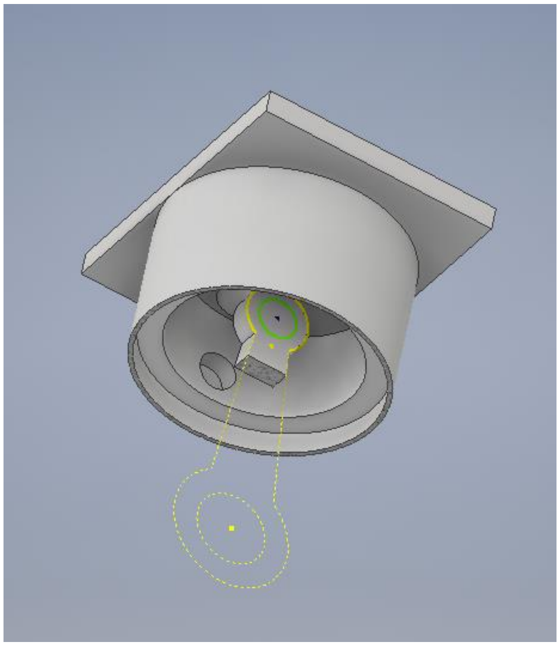

Figure-9 Reciprocating compressor piston

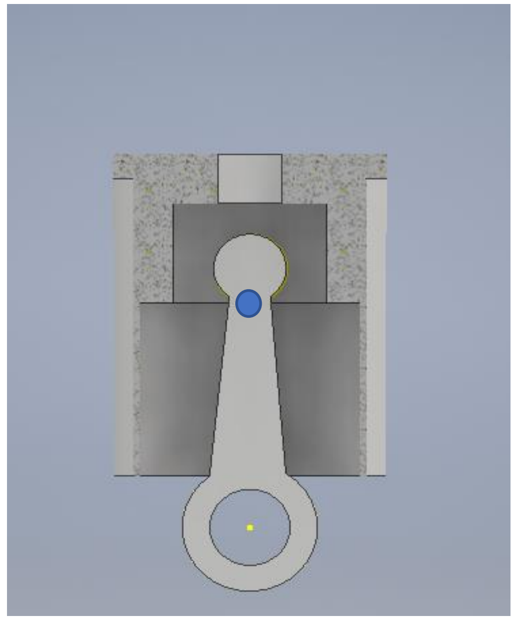

Figure-10 Reciprocating compressor dissected view

- **7.3 CONDENSER**

A condenser is a device used for condensing the gas and vapor phase into liquid phase. Condenser's function is to allow high pressure and temperature refrigerant vapor to condense and eject heat to the atmosphere. In simple terms it is a heat exchanger. Basically, the refrigerant is passed through copper or aluminum pipes because of its high thermal conductivity, so it can easily exchange temperature with atmosphere. Cooling is further enhanced by provision of fins to increase the surface area, which is placed adjacent to the pipes.

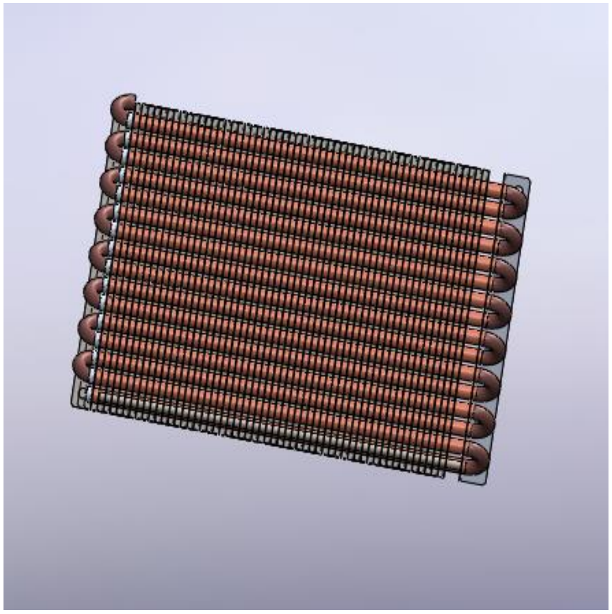

Figure-11 Condenser isometric view

- **7.4 EXPANSION VALVE**

The expansion valve reduces the pressure of the liquid refrigerant which allows to expansion or change of state from liquid phase to vapors phase. Expansion valve separates the high-pressure region and low-pressure region. The high-pressure liquid refrigerant enters the expansion valve in warm condition with high pressure and leaves the expansion valve at super cold condition with low pressure and further continue its path to evaporator. Once refrigerant pass through the expansion valves the it reduces the pressure by increasing its velocity, which is approximately 30 to 40 m/s, This allows the refrigerant to rapidly cool before entering the evaporator. Expansion valve must be paced as close to evaporator in order to minimize the heat gained by refrigerant.

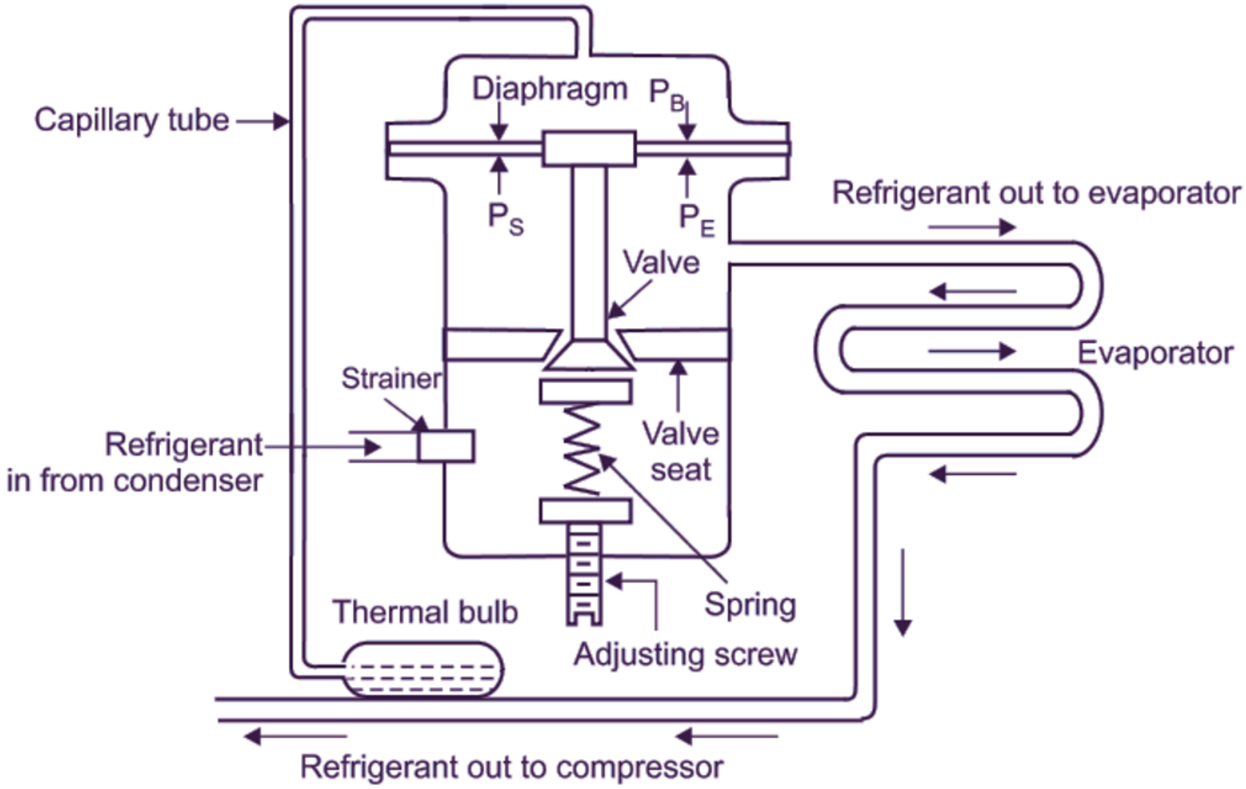

Figure-12 Expansion valve

- **7.5 EVAPORATOR**

The evaporator coil is a heat exchanging part which absorbs the heat from the batteries. Evaporator coil allows the cold low pressure refrigerant to flow inside it and allows to absorb the heat from the battery. The temperature of the refrigerant which enters the evaporator coil is around -20^{o}C to -30^{o}CMostly evaporator uses copper or aluminum to have maximum efficiency because they have good thermal conductivity. After absorbing the heat from the batteries they change their phase from gas to liquid phase.

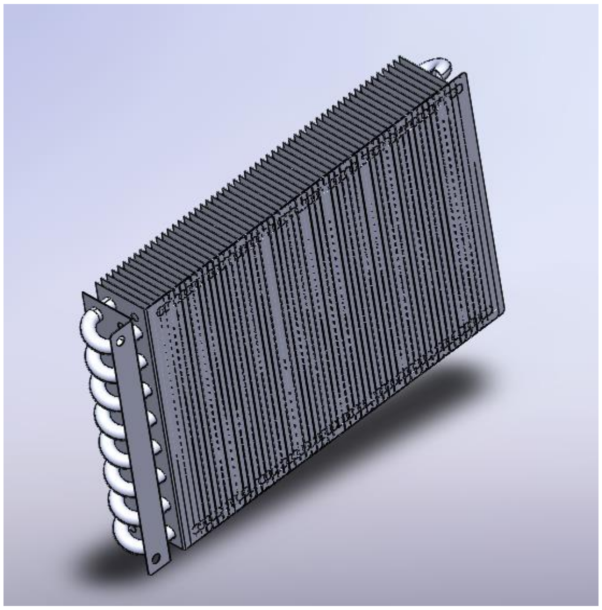

Figure-13 Evaporator isometric view

- **7.6 THERMOSTAT**

The thermostat controls the cooling process by monitoring the temperature and then switches on and off the compressor. When the thermostat senses that the battery temperature is lesser than the optimum temperature which is less than 20^{o}C the thermostat gives the information to the Battery management system and it Stops the compressor and once the temperature raises beyond the optimum temperature the thermostat indicates it to battery management system and which turns on the compressor and maintain the temperature and brings back to optimum temperature and this cycle goes on during charging process too.

Figure-14 Thermostat

8.BASICS ABOUT LITHIUM- ION BATTERY

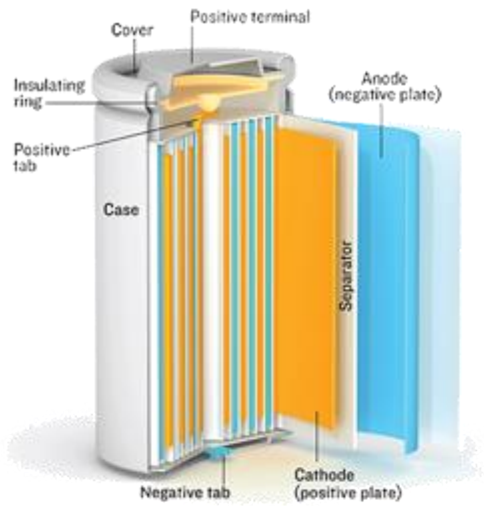

Figure-15 Li-Ion battery internal structure

Construction of the Lithium-ion battery begins with layers of Anode, Cathode and electrolyte along with a separator. Anode consist of a copper sheet coated with lithium oxides and cathode consist of graphite layers on to aluminum layer, whit the electrolyte placed in between them, electrolyte consist of organic salts whit a separator.

Lithium-ion batteries have high energy density than the TNT explosive. Lithium-ion battery can have around 1000 to 3000 cycles of charging based on the quality of Lithium. When we discharge the battery to the full extent it may lead to mixing of cobalt or nickel oxides with the Lithium and this is irreversible, hence causing damage to the battery.

For electric vehicles single cell is insufficient so many cells are connected in parallel and in series to create a module (a bunch of batteries) and many module are connected together to form a pack. When sets of batteries are connected in series the voltage increases and when connected in parallel the capacity increases with the same voltage output

The major design consideration onto the batterie are it must be placed in an isolated chamber where it must be vibration free as well water and dust proof, We must design accordingly that maximum amps or power must be sufficient to accommodate all the applications such as motor, lights, air conditioner and the cooling system. We must consider the size , weight and power output of the battery.

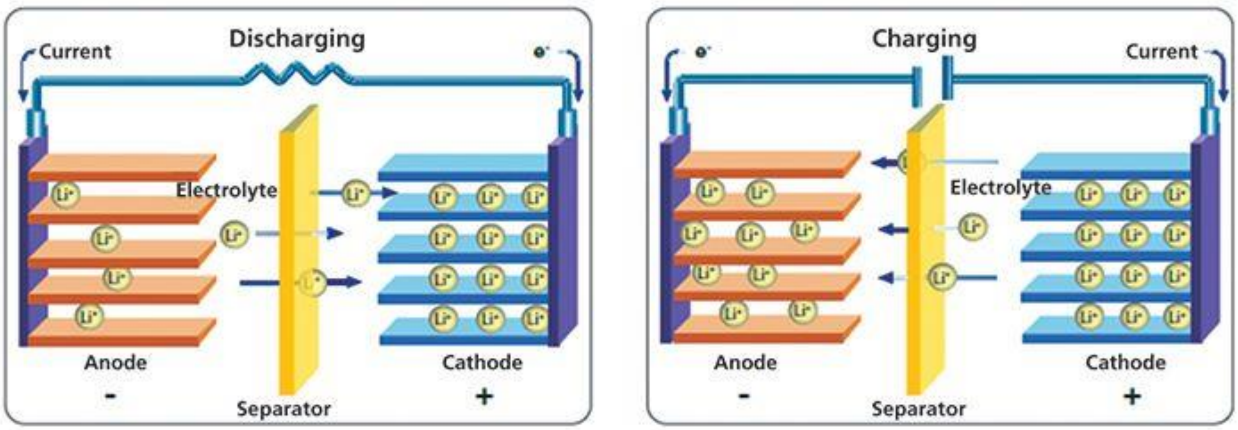

Figure-16 Li-Ion battery charging and discharging

8.1 CHARGING OF LITHIUM-ION BATTERY:

Lithium has only one electron in its outer shell, hence ready to lose its electron to become positively charged ion. So due to this, pure lithium is highly reactive in nature it even reacts with air and water. Li-ion battery uses Lithium oxides, electrolyte, graphite in its construction. Graphite is usually in layers, electrolyte acts as an insulator between the Lithium Metal Oxide (Anion, Cathode) and the Graphite layer (Cation, Anode)

During the charging process of the Li-ion Battery when the power source is connected the Cathode is ready to lose its electrons at the valance shell of the lithium atoms and flows through an external circuit and reaches the graphite shell, positively charged lithium-ion will be attracted by negative terminals and will flow through the electrolyte to the same graphite shell.

When all of the lithium atoms reach the graphite shell the battery gets fully charged. In this state the lithium-ion is in unstable, so the lithium ion wants to be in a stable position.

8.2 DISCHARGING OF LITHIUM-ION BATTERY:

We the Li-ion battery is connected with the load, the circuit is closed so lithium ion move through the electrolyte and electrons pass through the load. Since with the movement of electron we get electricity.

An additional separation medium is provided in the electrolyte called Separator, this is for safety if in case of liquid electrolyte evaporators it may lead to short circuit and may catch fire. Separator is capable of passing lithium ions inside then due to the micro porosity nature of the material.

During manufacturing of the Li-ion cell, graphite is coated on to the copper sheet and Metal oxides are coated onto aluminum foil. Organic salt acts as electrolyte coated on to the separator, which is rolled on to a steel core so that it would be compact. Mostly cobalt and nickel are used as oxides. Liquid electrolytes are also one of the reason for heating and firing leading to explosion and fire hazard. So research is going on solid electrolytes which includes plastic and glass etc.

9.TYPES OF CELLS BASED ON CONSTRUCTIONS

- Cylindrical cell

  It is the traditional cell in cylindrical shape, used for domestic purpose currently.

- Pouch cell

  It is in flat rectangular shape with lesser thickness and has higher capacities

- Prismatic cell

  It is rectangular in shape and produces comparatively higher voltage than others

- Coin cell

  It has comparatively less power output and mostly used in wrist watches

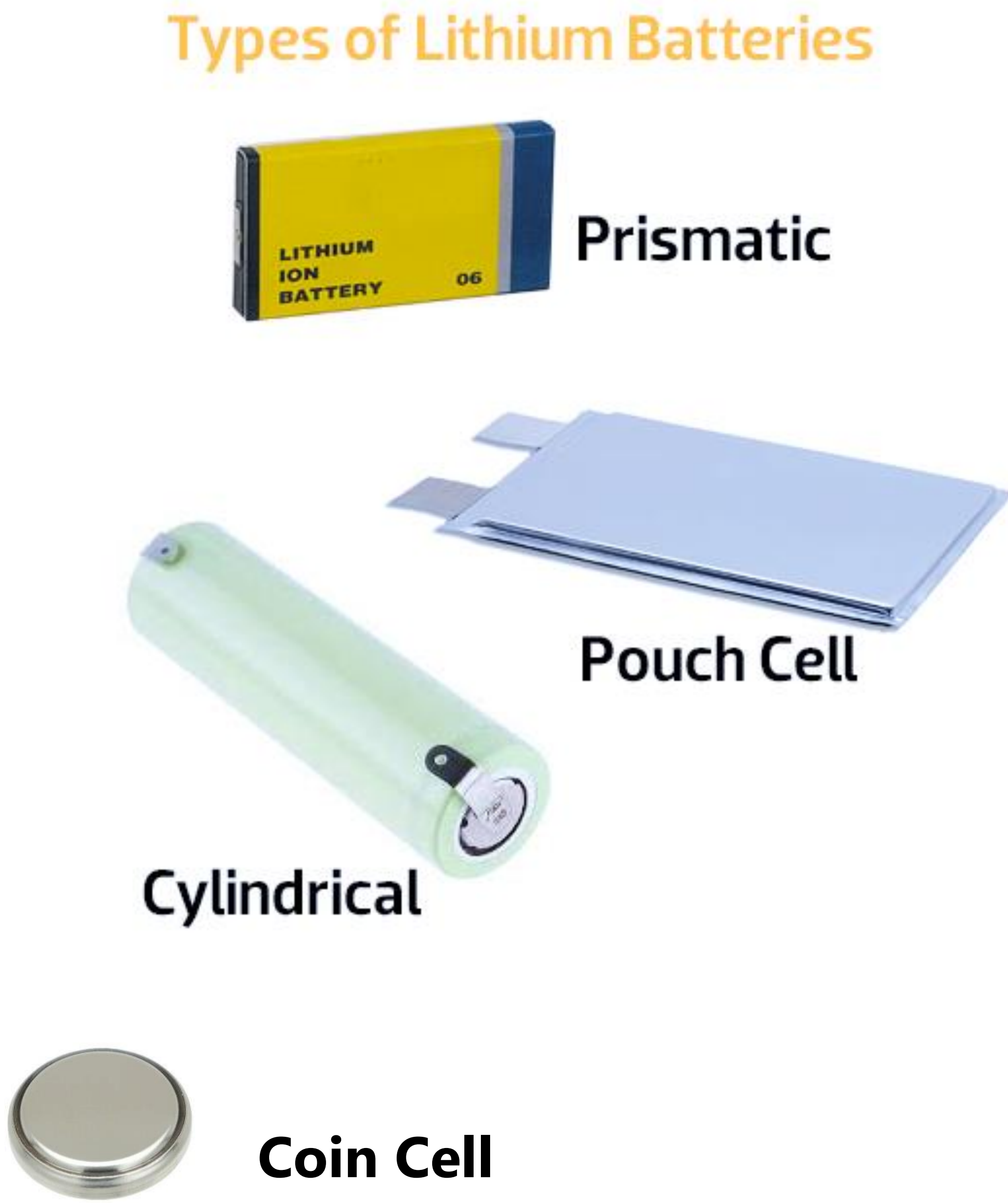

Figure-17 Li-Ion battery type

10.BATTERY MANAGEMENT SYSTEM

The role of the Battery management system maintain peak performance and peak health of the battery. Battery Management System is like an ECU in IC Engines, which monitor and control all the processes which takes place in the battery, such as Temperature, Charging speeds, Discharging, Regeneration, Coolant flow, etc. It is used to manage the temperature, rate of charging and discharging, voltage protection, cell health monitors, operation of cooling system by adjusting the refrigerants flow to maintain optimum temperature. The main job of BMS is voltage and charging protections, in a battery pack the health may vary from battery to battery, hence optimization of charging and discharging to be carried out properly to maintain the batteries in good health and allows the battery to charge and discharge equally in all the batteries of a pack.

11.IMPORTANCE OF BATTERY MANAGEMENT SYSTEM

A Battery management system monitors the temperature across the pack and opens and close various valve to adjust the coolant flow and maintains the temperature and to have a voltage protection which monitors each and every battery. So, it simply tries to maintain the following in neutral condition.

- Capacity Management
- Temperature Management
- Electrical Management Voltage
- Electrical Management Current
- Monitoring the battery
- Providing battery protection
- Estimating the battery's operational state
- Continually optimizing battery performance
- Reporting operational status to external devices

Functional safety is of the highest importance in a BMS. It is critical during charging and discharging operation, to prevent the voltage, current, and temperature variation of any cell or module under supervisory control from exceeding defined limits. If limits are exceeded for a length of time, not only is a potentially expensive battery pack compromised, but dangerous thermal runaway conditions could ensue. Moreover, lower voltage threshold limits are also rigorously monitored for the protection of the lithium-ion cells and functional safety. If the Li-ion battery stays in this low-voltage state, copper dendrites could eventually grow on the anode, which can result in elevated self-discharge rates and raise possible safety concerns. The high energy density of lithium-ion powered systems comes at a price that leaves little room for battery management error. Performance of the battery pack is the next highest important feature of a BMS, and this involves electrical and thermal management. To electrically optimize the overall battery capacity, all the cells in the pack are required to be balanced. This is exceptionally important because not only can optimal battery capacity be realized, but it helps prevent general degradation and reduces potential hotspots from overcharging weak cells. Lithium-ion batteries should avoid discharge below low voltage limits, as this can result in memory effects and significant capacity loss. Electrochemical processes are highly susceptible to temperature, and batteries are no exception. When environmental temperature drops, capacity and available battery decreases significantly. Additionally, since charging of frigid lithium-ion cells is detrimental to battery life performance, it is important to first elevate the battery temperature sufficiently. Most lithium-ion cells cannot be fast-charged when they are less than 5°C and should not be charged at all when they are below 0°C. For optimum performance during typical operational usage, BMS thermal management often ensures that a battery operates within a narrow region of operation (i.e. 30 – 35°C). This safeguards performance, promotes longer life, healthy and reliable battery pack.

12.INTRODUCTION TO COOLING SYSTEM

The cooling system is responsible to remove the heat from the battery and maintain it in optimum operational temperature to work at its peak efficiency, if there is no cooling system in battery's which may lead to thermal runaway and cause the electrolyte to evaporate or battery after usage for long duration may lead to decompose the electrolyte and form gas as a byproduct and which cause the battery to budge. Not only Thermal runaway drawing of extra power than the rated value from the batter leads to increase the temperature exponentially which may go till 900^{o}C. Cooling is more complicated than heating, so here we use air conditioner uses energy to take heat away. The air conditioning system uses a compressor cycle to transfer heat from the battery to the atmosphere.

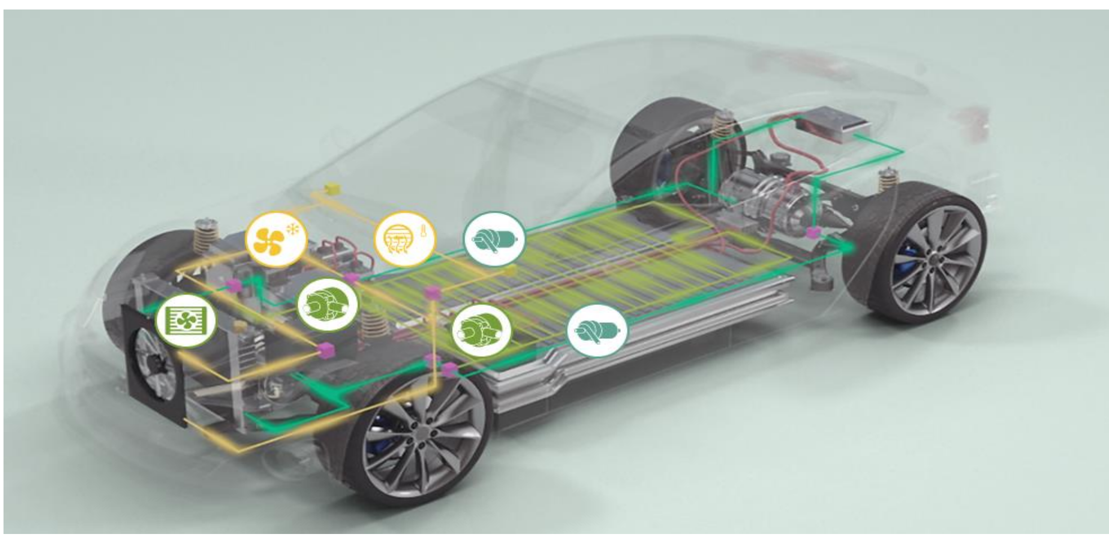

Figure-18 Li-Ion battery system of a EV car

13.IMPORTANCE OF COOLING SYSTEM

Refrigeration cooling systems are a type of cooling system used in electric vehicles (EVs) to regulate the temperature of the battery pack. The battery pack is a critical component in an EV, and it generates heat during charging and discharging cycles. If the temperature of the battery pack is not controlled, it can lead to reduced efficiency, decreased power output, and even permanent damage to the battery cells. The refrigeration cooling system in an EV battery pack consists of a compressor, evaporator, condenser, and refrigerant. The compressor circulates the refrigerant throughout the system, and the evaporator absorbs heat from the battery cells. The refrigerant then flows to the condenser, where it releases the absorbed heat into the surrounding air. The refrigeration cooling system in an EV battery pack is designed to maintain the temperature within a narrow range, typically between 20-25°C. If the temperature of the battery pack exceeds this range, it can lead to reduced battery life and performance. In extreme cases, high temperatures can cause thermal runaway, which can result in fires or explosions. One of the advantages of a refrigeration cooling system is that it can actively cool the battery pack, even when the vehicle is not in use. This is because the refrigeration system can be powered by a separate battery or by the main battery pack when the vehicle is not in use. This ensures that the battery pack remains at the optimum temperature, which helps to improve its lifespan and performance. In summary, a refrigeration cooling system is an effective way to regulate the temperature of an EV battery pack. It helps to ensure reliable and efficient operation of the battery cells, which is crucial for the performance and longevity of an EV. Lithium-ion batteries are known to generate heat during charging and discharging, and if the temperature rises too high, it can cause a thermal runaway reaction that can lead to a fire or even an explosion. Therefore, a well-designed cooling system can prevent these risks and increase the lifespan of the battery. The cooling system can also improve the battery's charging and discharging performance, as high temperatures can cause degradation and reduce the battery's capacity. The analysis of a lithium-ion battery cooling system typically involves evaluating the cooling capacity, efficiency, and cost-effectiveness of the system. Factors to consider include the thermal conductivity of the cooling medium, the flow rate and distribution of the coolant, the heat transfer coefficients, and the design and size of the heat exchanger. Other considerations may include the system's power consumption, weight, and size, as well as any maintenance requirements or potential failure modes. The analysis is done by experimental testing. Ultimately, the goal is to optimize the cooling system to ensure the battery cells operate within their safe temperature range, which will improve the overall performance and longevity of the battery.

14.DIFFERENT TYPES OF COOLING SYSTEMS

Cooling system plays a major role in the electric vehicles which keeps the battery cool and work with maximum efficiency. A properly designed cooling system may increase the health of the battery in multiples of two. A cooling system in an electric vehicle is an essential component that helps to regulate the temperature of the electric motor, battery pack, and other electronic components. Electric vehicles generate a lot of heat during operation, which can damage the sensitive components if not controlled properly. The cooling system in an electric vehicle is designed to maintain the temperature within a certain range, typically between 20-40°C, to ensure optimum performance and longevity of the electric motor and battery pack. If the temperature of these components exceeds the specified range, it can lead to reduced efficiency, decreased power output, and even permanent damage to the components. So majorly the cooling system of the electric vehicle is classified as

- Liquid Cooling
    - Glycol based liquid cooling
    - Coolant based liquid cooling
- Air cooling
    - Fin cooling
- Refrigerant cooling
    - Phase changing material

14.1 Liquid cooling:

Basically, liquid cooing is a traditional method of cooling. Liquid cooling is the most popular cooling technology. It uses a liquid coolant such as water or ethylene glycol to cool the battery. The liquid goes through tubes, cold plates, or other components that surround the cells and carry heat to another location, such as a radiator or a heat exchanger. Components carrying the liquid prevent direct electrical contact between the cells and the liquid coolant. Because liquid cooling involves pumps, fans, and other devices to actively extract and redirect the heat, it is an active form of cooling. Some thermal management systems use a direct-contact medium such as oil or other dielectric liquids that are directly in contact with the cells. This is mostly used in non-consumer EVs, as they are less safe and provide a less effective insulation between the cells and the surrounding environment.

14.2 Air cooling:

Air cooling uses the principle of convection to transfer heat away from the battery pack to the atmosphere while the car is moving. As the air runs along the surface, it will carry heat emitted in the pack. Air cooling is simple and easy but not very effective, Air cooling is done in a lethargic manner.

14.3 Refrigerant Cooling:

Refrigerate work by causing the refrigerant circulate in a closed circuit. It begins with the compressor, which compresses the refrigerant to high pressure and temperature and then which enters the Condenser where it exchange its temperature with atmosphere and then which enters the expansion valve, which reduces the pressure and convert the liquid phase refrigerant to gas phase, which cools the surrounding area and produced the desired value of the temperature you given as a value and then it comes back to compressor and repeat this cycle in a loop till we obtain the required temperature.

15.CHALLENGES FACED IN CURRENT COOLING SYSTEM

The most common thermal management challenges for EV batteries are leaks, corrosion, clogging, the climate, and aging. As you will see, liquid cooling systems present challenges that are inexistent for air cooling systems.

- **Leaks** can only occur in liquid cooling systems, whose pipe connections have risks of leaks as the battery ages. Any leaks will rapidly degrade the battery performance and life. They can even cause the EV to stop operating if humidity attacks the battery's electrical insulation. Battery modules, interconnections, pumps, and valves must all remain intact.
- The liquid cooling system can add weight to the vehicle, reducing the overall efficiency of the EV by increasing the **System weight**

- **Corrosion** can only occur in liquid cooling systems, whose cold plates can corrode as the liquid glycol gets older. Therefore, the cooling liquid must be replaced as part of the vehicle's maintenance.

- Proper temperature control is essential for effective cooling of Li-ion batteries. If the cooling system is not designed properly, it may not be able to maintain the optimal temperature range for the battery, which can lead to reduced performance and a shorter lifespan, therefore **Temperature control** is a tough task in Current cooling system such as air cooling and liquid cooling

- **Clogging** is a risk that is present in the hundreds of small channels where liquid travels in the battery.

- The fluid used in the cooling system must be compatible with the battery and other materials in the system. If not, it can cause corrosion and other issues, so **Fluid compatibility** also plays a major role

- **Climates** around the globe pose different thermal challenges for batteries. Examples include leaving the car under heavy sun for a long time, or living in a place where there are extremely low temperatures in winter. Batteries must be able to tolerate wide temperature ranges at all times. To achieve this, the battery cooling system must be active even when the vehicle is not in use.

- **Aging** causes thermal management problems that must be planned for, as batteries get older, a larger portion of energy is loss as heat. The thermal management system must be built for these tougher conditions that occur later in the battery life, not just for typical conditions during the first years.

16.PROBLEMS FACED IN TRADITION COOLING OF LI ION BATTERY COOLING SYSTEM

Traditional cooling systems for lithium-ion battery packs have several problems, including:

- **Inefficiency:** Traditional cooling systems are often inefficient, as they rely on bulky and heavy components such as heat exchangers, pumps, and coolant fluid to remove heat from the battery pack. These components can consume significant amounts of power, reducing the overall efficiency of the cooling system.

- **Complexity:** Traditional cooling systems can be complex and expensive to design and manufacture, as they require careful integration with the battery pack and other vehicle components. This can increase the cost and complexity of the overall system, making it more difficult to implement and maintain.

- **Safety risks:** Traditional cooling systems can pose safety risks if they are not designed and installed correctly. For example, coolant leaks or pump failures can lead to overheating of the battery pack, which can cause fires or explosions.

- **Limited thermal management:** Traditional cooling systems often have limited thermal management capabilities, as they rely on a single coolant loop to remove heat from the entire battery pack. This can lead to hot spots and temperature gradients within the pack, which can reduce its overall performance and lifespan.

- **Environmental impact:** Traditional cooling systems can have a significant environmental impact, as they often use coolant fluids that are toxic, flammable, or contribute to global warming. This can increase the carbon footprint of the overall system, which can be a concern for companies and consumers looking to reduce their environmental impact.

17.REFRIGERANT AS A COOLANT

Refrigerants are commonly used as coolants in various applications, including in the cooling systems of electric vehicles. In our project we use Refrigerant as a cooling source. And the type of refrigerant we used is **R32.** Lithium-ion batteries generate heat during operation, and if the temperature inside the battery pack is not regulated properly, it can lead to reduced battery life, performance, and safety concerns. In an electric vehicle, a cooling system that uses a refrigerant can be employed to regulate the temperature of the battery pack. The refrigerant circulates through a closed-loop system, absorbing heat from the battery pack and transferring it to a heat exchanger where it is dissipated to the environment. When selecting a refrigerant for a li-ion battery cooling system, it is important to consider factors such as compatibility with the materials used in the battery pack, environmental impact, energy efficiency, and safety. Some refrigerants commonly used in electric vehicle cooling systems include R134a, R1234yf, and R744 (carbon dioxide). However, each refrigerant has its own advantages and disadvantages, and the choice of refrigerant will depend on the specific requirements of the application. It is important to ensure that the refrigerant used is compatible with the battery chemistry and does not cause any damage or degradation to the battery.

R32 as a Refrigerant:

R32 (difluoromethane) is a refrigerant that has gained popularity in recent years due to its low global warming potential (GWP) and high energy efficiency. When used as a coolant in a li-ion battery cooling system, some advantages of R32 may include

Low GWP: R32 has a GWP of 675, which is significantly lower than other commonly used refrigerants such as R134a (GWP of 1430) and R1234yf (GWP of 4). This makes it a more environmentally friendly option and can help reduce the overall carbon footprint of the electric vehicle.

High energy efficiency: R32 has a higher heat transfer coefficient than other refrigerants, meaning it can absorb and transfer heat more efficiently. This can result in better cooling performance and improved battery life.

Compatibility with materials: R32 is compatible with many common materials used in li-ion battery packs, including aluminum and copper. This means that it can be used with a wide range of battery pack designs without causing any damage or degradation.

Safety: R32 is classified as an A2L refrigerant, which means it has a lower flammability than other refrigerants such as R1234yf. This can improve the overall safety of the cooling system.

However, it is important to note that R32 is a relatively new refrigerant and may not be as widely available as other options. It is also important to ensure that the cooling system is designed and installed correctly to ensure safe and effective operation.

18.PROPERTIES OF REFREGERANT

Refrigerant Gas R32 is used as a coolant for our project. Refrigerant R32 is a colorless, odorless, and non-toxic gas. It belongs to the hydrofluorocarbon (HFC) family of refrigerants and has a chemical formula of CH_2F_2. so properties of the refrigerant is given below

Some of the key properties of Refrigerant R32 are:

- Low global warming potential (GWP): R32 has a GWP of 675, which is significantly lower than some of the other commonly used refrigerants such as R410A and R134a. This makes it a more environmentally friendly option.
- High energy efficiency: R32 has a higher cooling capacity and energy efficiency compared to other HFC refrigerants, making it a popular choice for air conditioning and refrigeration systems.
- Flammability: R32 is classified as mildly flammable, which means that it can ignite when exposed to a heat source. However, its flammability is lower than some of the other refrigerants such as R290 (propane) and R600a (isobutane).
- Compatibility with materials: R32 is compatible with most of the common materials used in refrigeration and air conditioning systems, including copper, aluminum, and stainless steel.
- Toxicity: R32 is considered to be non-toxic, although it can displace oxygen in enclosed spaces and pose a risk of asphyxiation in high concentrations.

Overall, R32 is a popular choice for air conditioning and refrigeration systems due to its high energy efficiency, low GWP, and compatibility with common materials. However, its flammability requires careful handling and installation

Product		R32
Component		HFC-32
Chemical formula		CH_2F_2
Composition	mass%	100
Molar mass		52.0
Boiling point		-51.7
Freezing point		-136
Critical temperature		78.1
Critical pressure	MPa	5.78
Critical density	kg/m^3	424
Density Saturated liquid	kg/m^3	961
Density Saturated vapor	kg/m^3	47.34
Viscosity Saturated liquid	mPa·s	0.116
Viscosity Normal pressure vapor	mPa·s	0.0126
Isobaric specific heat Saturated liquid	kJ/kg·K	1.937
Isobaric specific heat Normal pressure vapor	kJ/kg·K	0.848
Latent heat of vaporization (Boiling Point)	kJ/kg	382
Thermal conductivity Saturated liquid	mW/m·K	125
Thermal conductivity Normal pressure vapor	mW/m·K	13
Breakdown voltage Normal pressure vapor	kV	2.8
Dielectric constant Saturated liquid		14.27
Acceptable concentration limit	ppm	1000[*2]
Ozone depletion potential ODP	CFC11=1	0
Global warming potential GWP [*1]	CO_2=1	675
Solubility of water	massppm	3400

Figure-19 Refrigerant R32 properties

Properties of refrigerant r32 Reference from DAIKIN.

19.ADVANTAGES AND DISADVANTAGES OF REFRIGERANT

Lithium-ion batteries are widely used in various applications such as electric vehicles, grid storage, and portable electronics due to their high energy density, high power density, and long cycle life. However, the performance and safety of lithium-ion batteries are greatly affected by their operating temperature. Therefore, an effective cooling system is essential to maintain the optimum temperature range and ensure the safe and reliable operation of lithium-ion batteries. One approach to cooling lithium-ion batteries is to use a refrigerant-based cooling system. This involves circulating a refrigerant through a closed-loop system that passes through the battery pack to absorb and remove the heat generated during battery operation. The refrigerant then transfers the heat to an external heat exchanger where it is dissipated to the ambient environment.

SI NO	**ADVANTAGES**	**DISADVANTAGES**
1.	High Cooling Efficiency: Refrigerants have high heat transfer coefficients, which means that they can absorb and transfer heat more efficiently than other cooling fluids such as water or air.	High Cost: Refrigerant-based cooling systems are a bit expensive due to the cost of the refrigerant and the additional components required such as valves and it share all the other components with Air Conditioner.
2.	Compact Design: A refrigerant-based cooling system can be designed to be compact, which is important for applications such as	Environmental Impact: R32 is one of the best and better eco-friendly refrigerant than others

	electric vehicles where space is limited.	
3.	Low Maintenance: Refrigerant-based cooling systems are generally low maintenance as they do not require frequent fluid changes and have a long service life.	Safety Risks: Refrigerants R 32 is a flammable gas, and leaks or malfunctions in the cooling system can lead to safety risks such as fire or explosions.
4.	Temperature Control: A refrigerant-based cooling system can provide precise temperature control, which is important for maintaining the optimal temperature range for lithium-ion batteries.	Complexity: Refrigerant-based cooling systems can be complex to install, which can add to the overall cost and complexity of the battery system.

Table-1 Advantages and Disadvantages of R32 as a refrigerant

In conclusion, refrigerant-based cooling systems can provide efficient and precise temperature control for lithium-ion batteries, but they also have some disadvantages such as high cost, environmental impact, safety risks, and complexity. Therefore, the choice of cooling system for lithium-ion batteries depends on the specific application and requirements of the battery system.

20.EXPERIMENTAL SETUP

Experimental set up begins with a frame which has the provision for all the components to hold with. So basically, the frame is made from cast iron rectangular cross section and arc welded together and have some drilled holes to accommodate the components. The major components begin with the reciprocating type compressor, which is from Samsung 192 Litters single door refrigerator. We bought this because it is compact in size as well as cost effective. This compressor is fixed to the frame with bolt and nuts with rubber bushes at the bottom. The compressor compresses the refrigerant to 8 bar pressure and Runs at an RPM around 3000 and around 70 to 90°C. Then the compressed refrigerant is then passed to the condenser where the hot and highly compressed refrigerant exchange heat with the atmosphere. In case of natural convection, the time duration for cooling is high as well as efficiency is low so we use a 120V 60 Hz AC fan which runs around 3000 rpm and the condenser is from LG window AC 1 tons which has higher Heat dissipation rate when compare to others and occupies lesser space than other condenser. Then it goes through the expansion valve where it expands to 0.25 bar pressure and there is a sudden drop in temperature where the temperature of the refrigerant drops to -5°C and there is a device called thermostat which monitors the coolant temperature once there is enough amount of temperature, it automatically cuts off the compressor then it pass through the evaporator where the gaseous refrigerant converts into liquid and then it pass through the walls of the battery and take the heat from the battery and then some of the unchanged gaseous refrigerant takes heat and turn into liquid where a phase change is done. Theoretically when there is a phase change there will be a huge amount of energy is taken for the process. Then after taking heat from batteries it goes back into the compressor again. This is a closed cycle so this process repeats again and again till the thermostat cuts off the compressor.

Figure-20 Hot and Cold region Separation

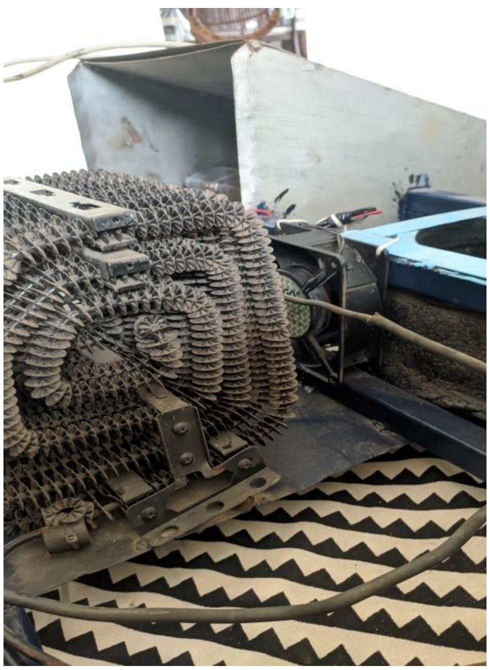

Figure-21 Condenser with fan

Figure-22 Evaporator

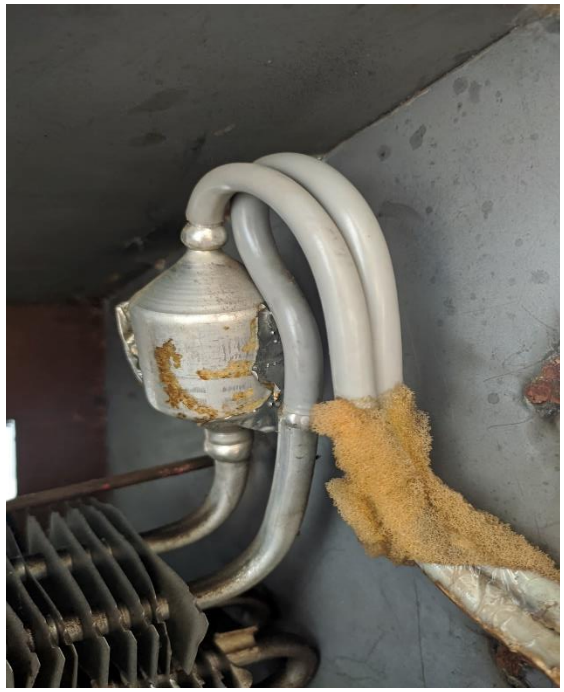

Figure-23 Compressor

Figure-24 Expansion Valve

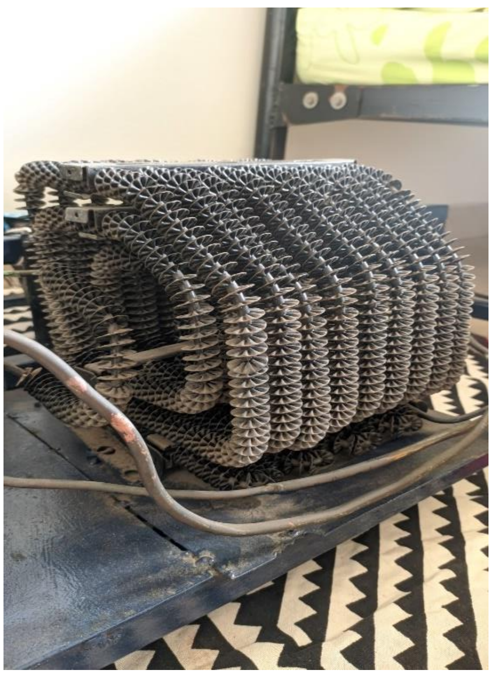

Figure-25 Condenser

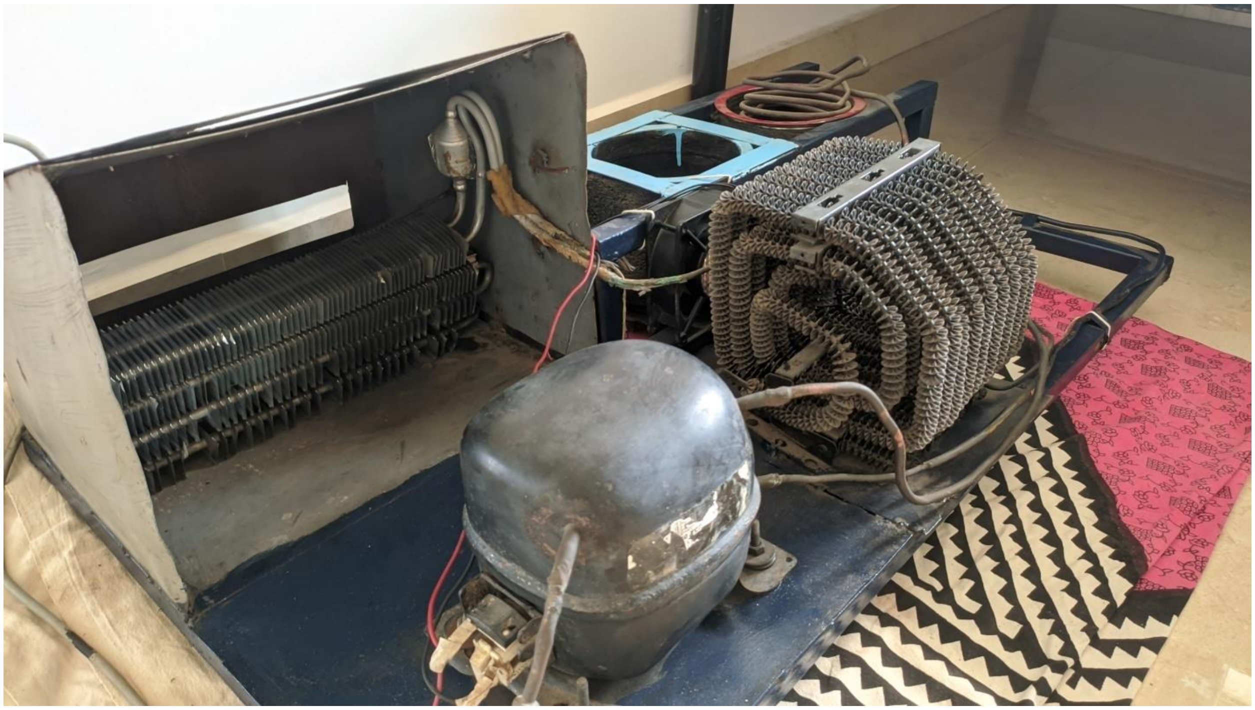

Figure-26 Overall Experimental Setup

21.PERFORMANCE

COP

The Coefficient of Performance (COP) is a measure of efficiency, It is defined as the ratio of the amount of heat that the system can remove from its interior to the amount of work required to remove that heat. In other words, it is the amount of cooling produced by the system per unit of energy consumed.

To calculate the COP of a system, you need to know the amount of cooling it produces and the amount of energy it consumes.

The formula for COP is:

$COP = Qc / W$

$Qc = m * c * \Delta T$

$COP = Q2/Q1-Q2 = T2/T1-T2$

$COP = (273+9) / ((273+80) - (273+9))$

$= 282 / (353-282)$

$=282 / 71$

$= 3.9718$ (No unit)

TONNAGE

Ton is a unit of measurement used in the air conditioning industry to describe the cooling capacity of an air conditioning system. One ton of cooling is equivalent to the amount of heat needed to melt one ton (2,000 pounds) of ice in a 24-hour period. Therefore, the tonnage of an air conditioning system refers to its cooling capacity**.**

It's important to note that the tonnage of an air conditioning system is not related to its weight. The weight of an air conditioning system will vary depending on the model and manufacturer, but it is not a reliable indicator of its cooling capacity.

TONNAGE = BTU / 12,000

BTU = FLOW RATE IN GPM * (TEMPERATURE LEAVING – TEMPERATURE ENTERING) * 24.69

The flow of refrigerant through an refrigeration system can be calculated using the following formula:

Flow Rate (in cubic feet per minute) = (displacement in inch* RPM) / 1728

Where:

Displacement is the volume of gas displaced by the compressor per revolution, measured in cubic inches

RPM is the speed of the compressor in revolutions per minute

We divide it by 1728 because we convert inches of displacement into foot

Displacement in mm = 7.94

Displacement in inch = 0.3125

Flow Rate (in cubic feet per minute) = (0.3125*3000) / 1728

= 0.5425 ft^3

To convert to Gallons per minute multiply Cubic feet per minute into **7.481**

Flow Rate is the amount of refrigerant flowing through the system, measured in kilograms per second (kg/s) or pounds per minute (lb/min).

Flow rate in gallons per minute = 0.5425 * 7.481

=4.0581 gpm

Cooling Capacity is the amount of heat that the air conditioning or refrigeration system is capable of removing, measured in Watts (W) or BTUs per hour (BTU/hr).

Enthalpy Difference is the difference in enthalpy (total heat content) of the refrigerant between the evaporator and condenser, measured in Joules per kilogram (J/kg) or BTUs per pound (BTU/lb).

The enthalpy difference can be calculated by subtracting the enthalpy of the refrigerant at the evaporator inlet from the enthalpy of the refrigerant at the condenser outlet.

It's important to note that the flow rate of refrigerant through a system will vary depending on the system design, operating conditions, and refrigerant used. The above formula provides a general calculation method, but actual flow rates may need to be determined through measurements or simulations specific to the particular system being analyzed.

BTU = 4.0581 * (80-9) * 24.6971

= 7,104.8073

We multiply **24.6971** because it is considered as a fluid factor of R32, which vary from liquid to liquid- Reference from

Tonnage = 7104.8073 / 12000

=0.5920

= 0.6 Tonnes Approx

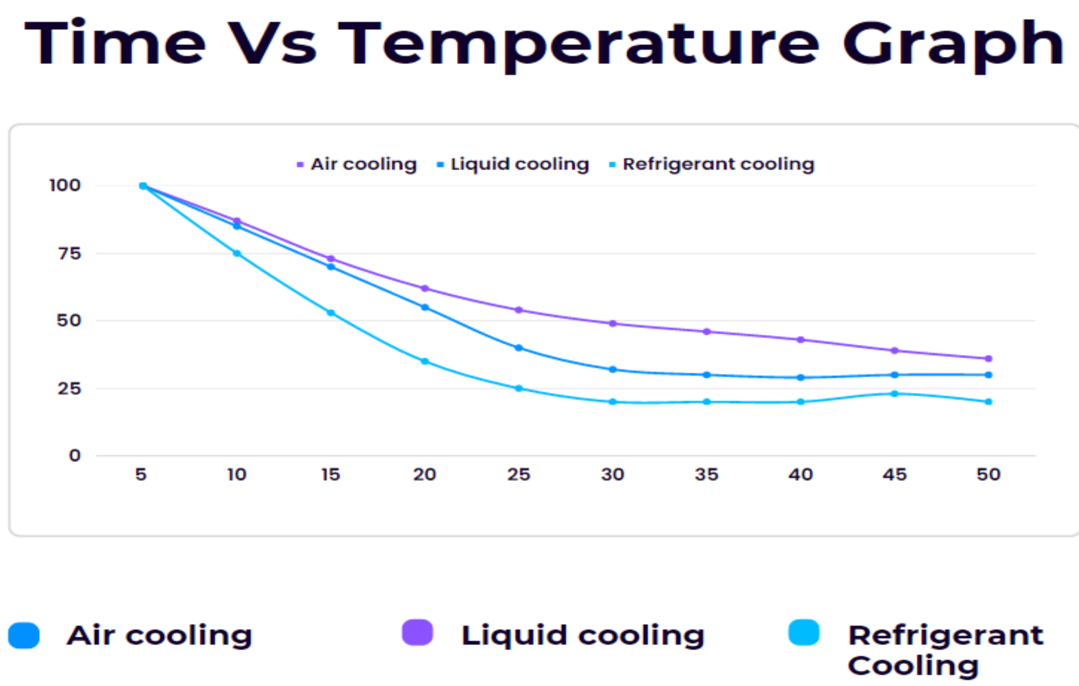

Figure-27 Graph plot between time vs temperature

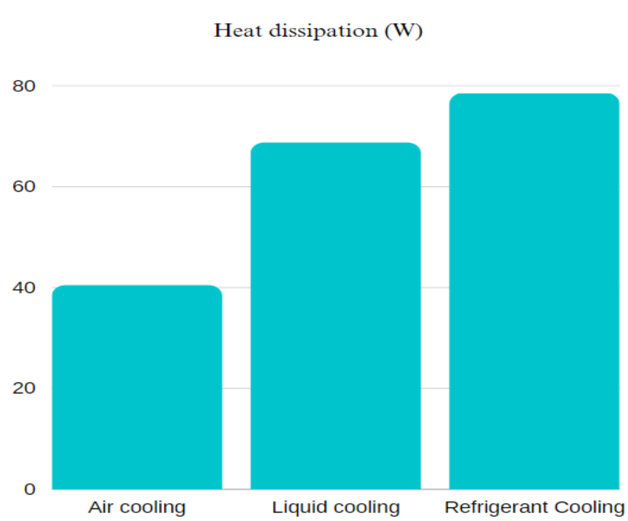

Figure-28 Graph plot between cooling system and heat dissipation

22.COST ESTIMATION

The cost estimation in a project is the process of forecasting the cost of all the components and resources utilized, all the components used for our project is listed below with their cost.

SI NO	DESCRIPTION	QUANTITIES	COST IN INR
1	Reciprocating Compressor	1 No	3,150
2	Refrigerant R32	3 kilograms	1,500
3	Condenser	1 No	750
4	120v 23W AC Fan	1 No	650
5	Evaporator	1 No	600
6	Expansion Valve	1 No	1,500
7	Copper pipes	4 Meter	800
8	Thermocouple	1 No	480
9	Frame	1 No	600
	Total		10,030

23.CONCLUSION

Refrigerant-based cooling systems are one of the most effective ways to maintain the temperature of lithium-ion batteries within their optimal range. By using a refrigerant as a coolant, heat is absorbed from the battery and transferred to the surrounding environment, keeping the battery within its recommended operating temperature range. The use of a refrigerant-based cooling system offers several advantages over other cooling methods, such as passive cooling or liquid cooling. Refrigerant-based cooling is typically more efficient at dissipating heat, which means it can provide better thermal management for the battery. Additionally, refrigerant-based cooling systems are typically more compact and can be designed to fit within the limited space available in most battery packs and not required for periodic maintenance, here we reduce the overall weight of the vehicle by eliminating the traditional cooling system thereby overall efficiency of the vehicle increases. Overall, the choice of cooling system for a lithium-ion battery will depend on various factors, such as the required cooling capacity, the size and weight constraints, the operating conditions, and the cost. Finally, we need cooling system which is much effective than other cooling and as we said in our objective we provide better cooling system than any other cooling system, which gives much better results.

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