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A Review of Different Types of Battery Cooling Systems in Electric Vehicles

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Abstract: Electric vehicles (EVs) are becoming increasingly popular as they are more environmentally friendly than conventional vehicles. However, to ensure the longevity and efficiency of the EV batteries, a battery thermal management system (BTMS) is crucial. The temperature of the battery affects various aspects of its operation, including its performance, reliability, and life cycle cost. Therefore, it is essential to keep the battery temperature between 15°C to 35°C. This paper reviews different types of cooling systems used in lithium-ion batteries, including air cooling, liquid cooling, phase change material (PCM), heat pipe, thermo-electric module, and direct refrigerant cooling system. Depending on the conditions and requirements, a single or a combination of these cooling methods may be used. The paper also presents two of the most efficient BTMS. The study aims to help researchers choose the most effective cooling method for their EVs.
Keywords: Battery thermal management, EV, Lithium-ion battery, air cooling system, liquid system, PCM

I. INTRODUCTION

Electric vehicles (EV) are more environment friendly than the conventional vehicles as there are no carbon emissions. The emissions of conventional vehicles contain CO2, CO, NOx and even particulate matter. The energy conversion efficiency of EVs is 90% whereas that of the internal combustion engine (ICE) powered vehicles is only 25-50%. To increase the lifespan and efficiency of batteries of EV the battery thermal management system (BTMS) plays a significant role. Temperature affects several aspects of a battery including operation of the electrochemical system, round trip efficiency, charge acceptance, power and energy capability, reliability, life and life cycle cost. [3] It is suggested that the temperature range of battery of EV should range between 15°C to 35°C to avoid adverse effects of lithium-ion batteries. The increase in temperature has two different effects on the batteries. The beneficial effect is that, by increasing the temperature, Li-ion batteries work more efficiently and their performance becomes better. On the other hand, the unfavourable effect is that, they are closer to thermal runaway that decreases their reliability because of probable explosion. [7] This paper contains a summary of previous work on thermal management system of batteries.

II. AIR COOLING SYSTEM

Air systems utilize air as the heat transfer medium. The air intake can either be from the outside atmosphere or from the cabin, and it can also be conditioned air from an air conditioner's heater or evaporator. If it's directly from the atmosphere, it's known as a passive air system, while if it's conditioned air, it's referred to as an active air system. Active systems provide more cooling or heating capability compared to passive systems. A passive system can provide a few hundred watts of cooling or heating power, while an active system's capacity is limited to 1 kilowatt. [1]. Air cooling systems require more space and consume more energy because air has a higher volume than water. The air system provides complete heating, cooling, and ventilation functions. No separate ventilator is required, but it's important to remember that the exhaust air can't be recirculated back into the cabin. In some instances, an air-air heat exchanger is installed after the battery pack to recover heat from the exhaust air. This helps prevent the mixing of the exhaust air with the intake air and also offers additional energy savings.

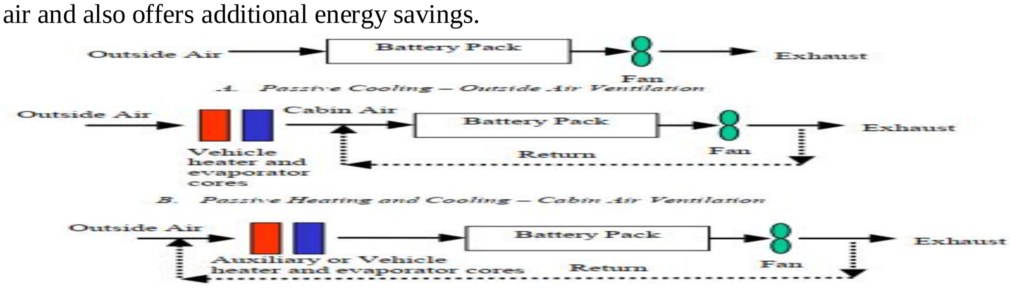

Fig 1. Air cooling system. [2]

III. LIQUID COOLING SYSTEM

Liquid cooling is the most effective and efficient method of cooling batteries. There are two types of liquid cooling systems: direct-contact liquid, which comes into direct contact with the battery cells, such as mineral oil, and indirect-contact liquid, which only indirectly contacts the battery cells, such as a mixture of ethylene glycol and water. Different designs are used based on the type of liquid. For direct-contact liquid, the common design is to submerge the modules in mineral oil. For indirect-contact liquid, possible designs include a jacket around the battery module, discrete tubing around each module, placing the battery modules on a cooling/heating plate, or combining the battery module with cooling/heating fins and plates. [3]

By different heat-sinks for cooling, liquid systems can also be categorized into either passive systems or active systems. In passive liquid system, the heat-sink for cooling is a radiator. This system has no ability to heat. Heat transfer fluid is circulated by the pump within a closed system. The circulating fluid absorbs heat from battery pack and releases heat via a radiator. The cooling power depends strongly on the temperature between ambient air and battery. Fans behind the radiator can improve the cooling performance, but if ambient air is higher than the battery temperature or the difference between them is too small, the passive liquid system becomes ineffective. [4]

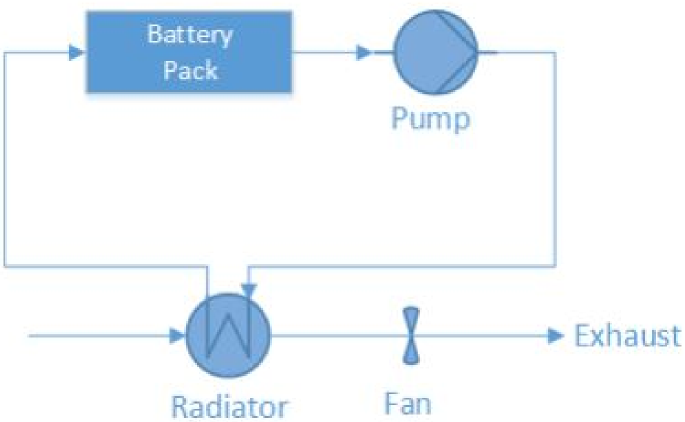

Fig 2. Passive Liquid Cooling System. [4]

In active system, there are two loops. The upper is called the primary loop and the lower the secondary loop. The primary loop is similar to the loop in a passive liquid system, where the heat transfer fluid is circulated by pump. The secondary loop is actually an air conditioning loop (A/C loop). The upper heat exchanger instead of being a radiator works as an evaporator (EVAP) for cooling operation and connects both loops. During heating operation, the 4-way valve will be switched, and the upper heat exchanger works as a condenser (COND) and the lower heat exchanger works as an evaporator. The heating operation loop is also called heat pump loop. The structure of active cooling system is complicated and difficult to maintain because of many auxiliaries and moving parts.

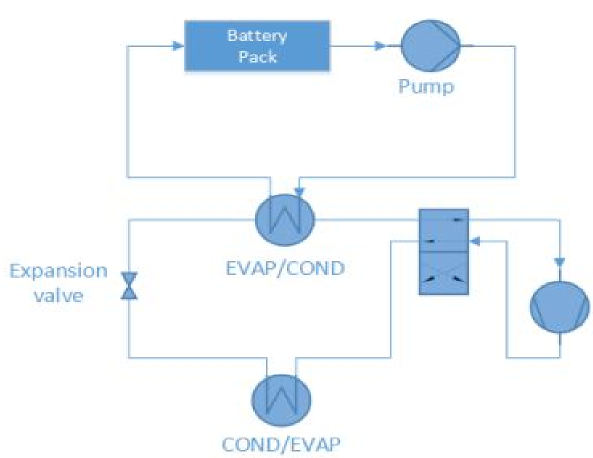

Fig 3. Active Liquid Cooling System. [4]

IV. PHASE CHANGE MATERIAL (PCM)

PCMs are heat-storage materials that utilize latent heat. They can charge or discharge this heat energy by changing the phase. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or "Phase". [5]. PCM has high fusion heat which stores and releases the amount of heat during melting and solidifying at a fixed point. When the temperature is lower than the melting point, PCM is solid and heat is absorbed as sensible heat with the temperature rise. When the temperature reaches the melting point, heat is absorbed and stored as latent heat until the latent heat is up to the maximum without the temperature increasing. At the same time PCM changes its phase from solid to liquid. After that, PCM becomes liquid and heat is absorbed by PCM and stored as sensible heat. [4]. Due to properties of PCM, it is flammable and has potential of electric conductivity.

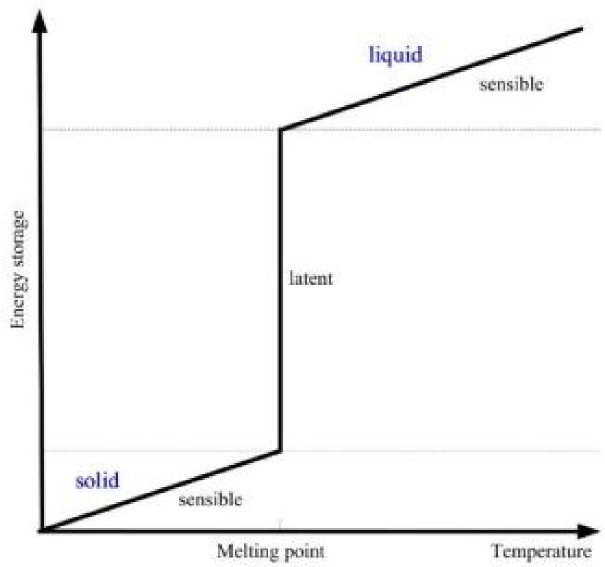

Fig 4. The relationship of temperature and energy storage of PCM [4]

There are different types of PCMs that can be used for battery cooling, including paraffins, hydrated salts, eutectic salts etc. The choice of PCM depends on various factors, such as melting temperature, thermal conductivity, and energy density. The design and implementation of PCM-based cooling systems also require careful consideration, as the location, size, and number of PCM components can all impact the cooling performance. PCMs are classified by their composition, e.g., organic, inorganic, or eutectic.

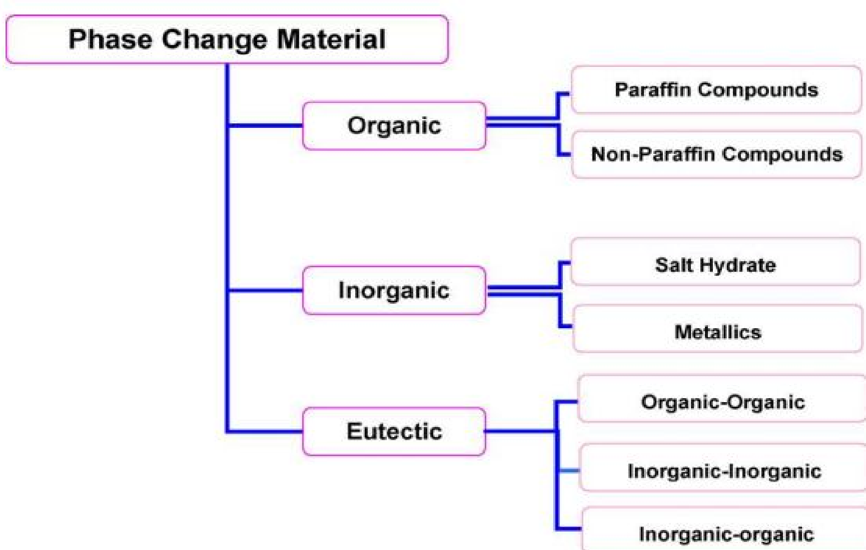

Fig 5. Classification of PCMs. [5]

V. HEAT PIPE

Heat pipes are a type of heat transfer device that are utilized for cooling purposes, including the cooling of batteries in electric vehicles. They work by utilizing a sealed tube filled with a working fluid and a small amount of vapor space. The working fluid absorbs heat at the hot end of the tube, vaporizes and travels to the cold end where it releases the heat and condenses back into a liquid. This creates a continuous cycle of heat transfer, effectively moving heat from one location to another.

A heat pipe is a device that can operate spontaneously without external pumped power and transport large amounts of heat energy at considerable distances with high speeds utilizing phase-change heat transfer even at very small temperature differences. It also has features such as compact structure, flexible geometry, long lifetime and low maintenance, so that this has used in many industries for efficient thermal management. [6]

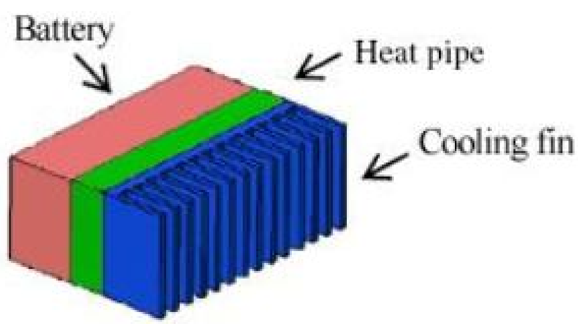

Fig 6. Heat Pipe Cooling System.

The heat pipes are placed in direct contact with the battery cells, acting as a heat transfer mechanism to regulate the temperature and keep the battery within a safe operating range.

VI. THERMO-ELECTRIC MODULE

Thermo-electric module can convert electric voltage to temperature difference and vice versa. Here the former effect is adopted. That means it transfers heat through the module by consuming electricity directly. Two fans are installed to improve heat transfer by forced convection. To combine a passive air system with thermo-electric module, the combined system is able to cool down the battery even lower than the intake air temperature, but the power is still limited to around some hundreds of watts and less than one kW. [1]. The factors such as low efficiency and poor performance at high temperature difference are major drawbacks of this cooling method.

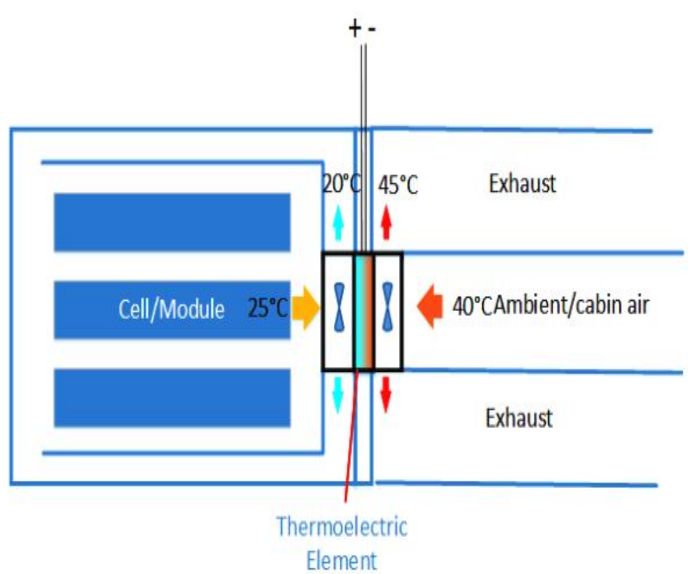

Fig 7. Thermoelectric Cooling System

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VII. DIRECT REFRIGERANT COOLING

Similar to active liquid systems, a direct refrigerant system (DRS) consists of an A/C loop, but DRS uses refrigerant directly as heat transfer fluid circulating through battery pack. However, the major disadvantage of direct refrigerant cooling is its complicated structure and tendency of leaking out.

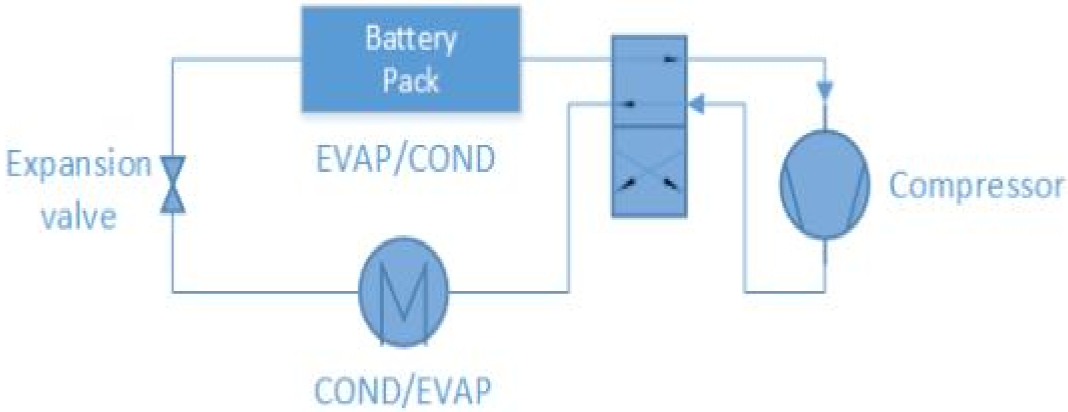

Fig 8. Direct Refrigerant Cooling System. [4]

VIII. RECOMMENDED COOLING SYSTEMS

The two most recommended cooling systems are Combined Liquid System and PCM Model.

A. *Combined Liquid System (CLS)*

The first is the liquid cooling system, which has four working modes: bypass with heater working; bypass without heater working; passive cooling system; and active cooling system. The cooling system takes advantage of both passive cooling system and active cooling system. Passive cooling system has simple structure and is able to dissipate heat under normal conditions with low energy consumption. Under extreme condition, active cooling system has good thermal performance to keep battery temperature in the required range.

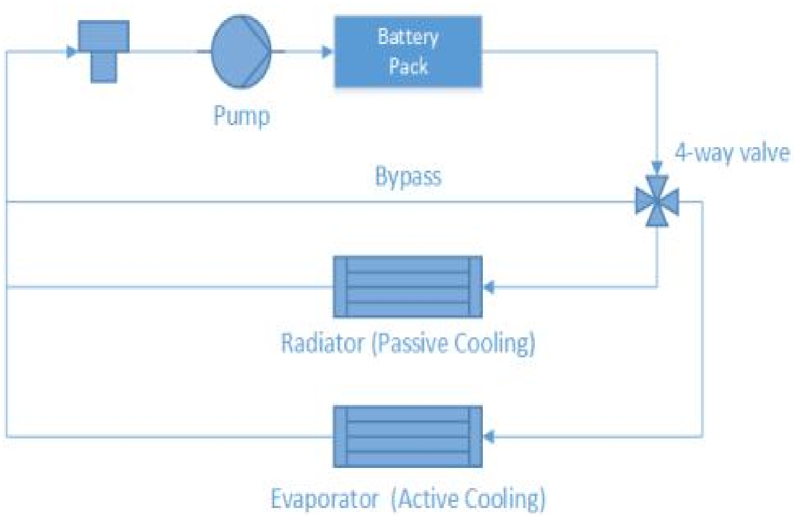

Fig 9. Combined Liquid System.

B. *PCM Model (CLS + PCM)*

The other preferred system is the combination of PCM material and CLS. PCM layers are inserted into battery pack. It uses the advantage of PCM to have good thermal performance, and CLS compensates for the limited operating temperature of PCM.

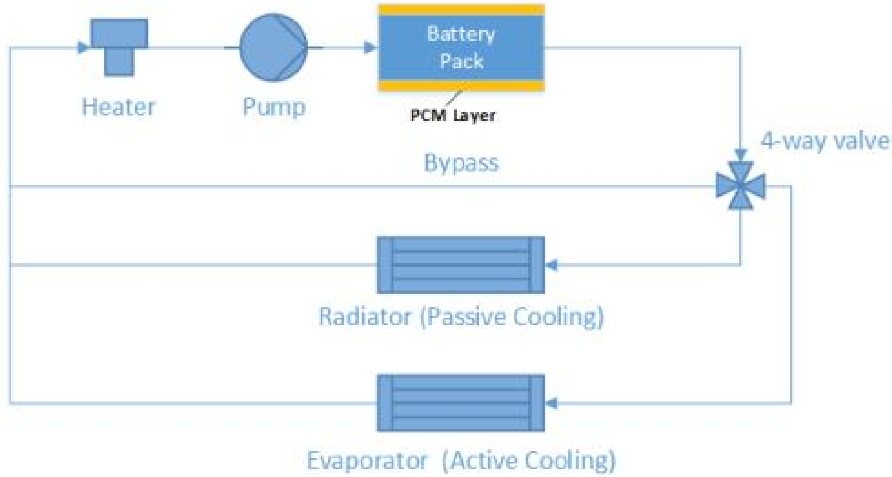

Fig 10. Combined Liquid System with PCM System. [4]

IX. CONCLUSIONS

In conclusion, the battery thermal management system (BTMS) is an essential component for electric vehicles (EVs) as it helps regulate the temperature of the battery cells and therefore, increases the lifespan and efficiency of the battery. Various types of cooling systems are used in lithium-ion batteries, including air cooling, liquid cooling, phase change material (PCM), heat pipe, thermo-electric module, and direct refrigerant cooling system. The choice of the most effective cooling system depends on several factors, such as the requirements and conditions of the battery. While the liquid cooling system is the most efficient, air cooling is a more common and cost-effective solution. In the future, research and development of more efficient BTMS should be conducted to increase the efficiency and lifespan of EV batteries, thus making electric vehicles more accessible and sustainable.

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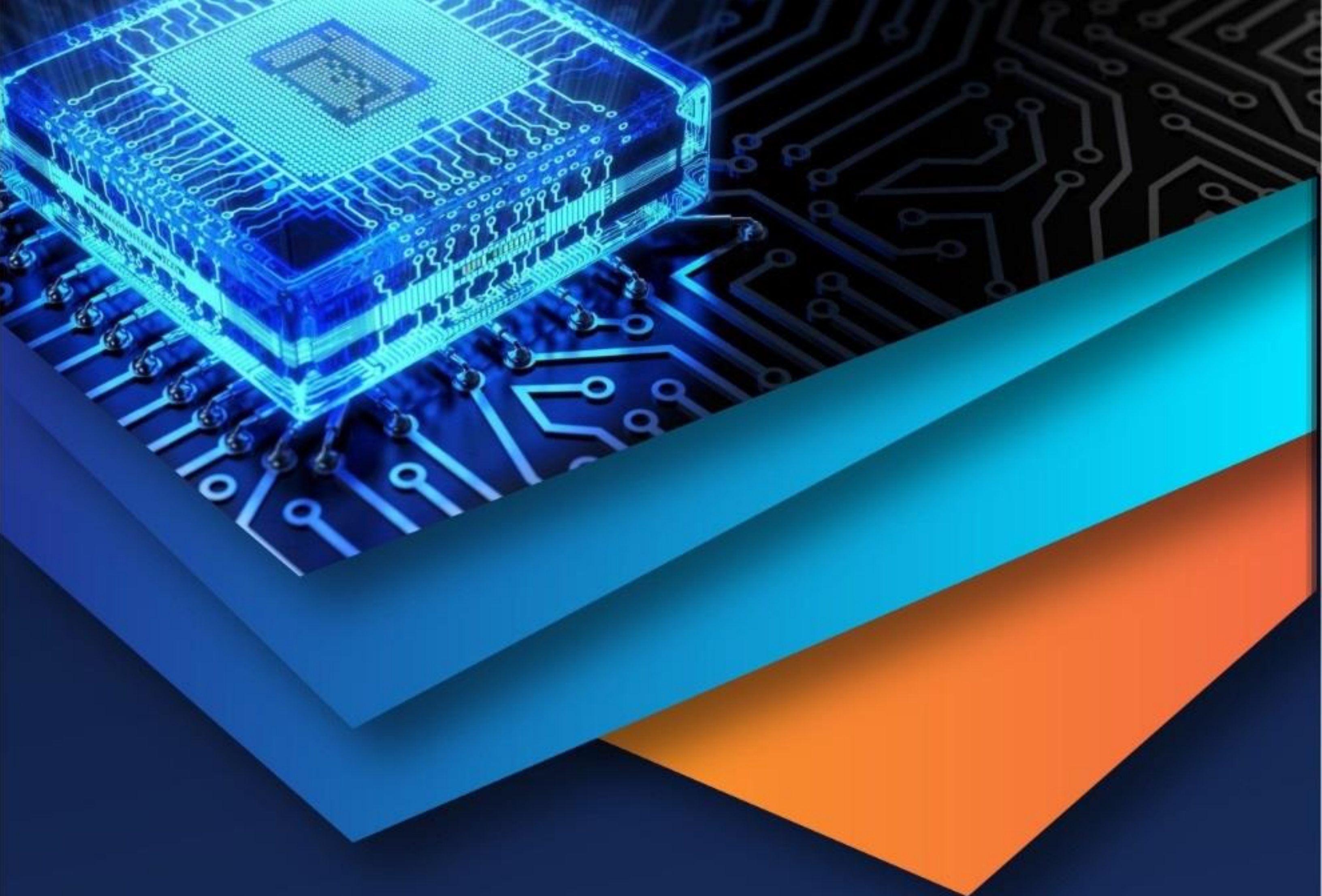

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