



HEAT EXCHANGE SYSTEM FOR ELECTRIC VEHICLE BATTERY

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Abstract –Heat dissipation in various applications often relies on efficient thermal management techniques, particularly the use of heat exchangers with aluminum and copper tubes. This abstract explores the principles and benefits of utilizing aluminum and copper tubes in heat exchangers. Aluminum is valued for its lightweight nature, corrosion resistance, and high thermal conductivity, making it ideal for applications where weight reduction and heat transfer efficiency are critical. Copper, known for its superior thermal conductivity and durability, excels in situations requiring high heat transfer rates and robustness against mechanical stresses. The abstract examines how these materials are integrated into heat exchanger designs to optimize heat transfer, enhance energy efficiency, and ensure reliable operation in diverse industries such as automotive cooling systems, HAC (Heating, Air Conditioning), and industrial processes.

I. INTRODUCTION

The widespread adoption of EVs hinges on overcoming battery limitations. One critical challenge is thermal management. Lithium-ion batteries, the dominant technology in EVs, perform best within a specific temperature range. Deviations from this range can lead to decreased performance, accelerated degradation, and even safety hazards. This paper presents a promising approach to EV battery thermal management by combining air and fluid cooling with real-time IoT monitoring. This system has the potential to significantly improve battery performance, lifespan, and safety, paving the way for a more sustainable and reliable electric transportation future.

II. LITERATURE REVIEW

Maintaining optimal battery temperature is crucial for the performance, lifespan, and safety of Electric Vehicles (EVs). This review explores research on battery thermal management systems (BTMS) utilizing fluid and air cooling for EVs. Fluid and air cooling systems offer effective solutions for EV battery thermal management. Research suggests that hybrid systems combining these technologies hold

promise for achieving optimal battery performance, safety, and lifespan in future EVs. Research efforts are underway to improve the effectiveness of air cooling systems for EVs.

Xin et al. explore hybrid systems utilizing both air and liquid cooling for efficient temperature management in large battery packs, leveraging the strengths of each technology. A study by Alaoui et al examines the effectiveness of using Thermoelectric Coolers (TECs) in conjunction with air cooling for localized battery temperature control in specific areas of the pack. Battery technology has come a long way, and so has the need for efficient battery cooling systems (BTMS). Here's a glimpse into the evolution of BTMS, highlighting key milestones.

Aluminum and Copper Tube Colling

Aluminum and copper tubes are integral components in heat exchangers, playing crucial roles in thermal management across various industrial and consumer applications. This abstract explores their significance in heat transfer processes, emphasizing their distinct thermal properties and applications. Aluminum, valued for its lightweight nature, corrosion

resistance, and reasonable thermal conductivity, is commonly used where weight reduction and cost-effectiveness are paramount, such as in automotive radiators and air conditioning units. Copper, renowned for its superior thermal conductivity, durability, and compatibility with brazing techniques, excels in applications requiring high heat transfer efficiency and reliability, such as in HVAC systems, heat exchangers for electronics, and industrial processes. The abstract examines how these materials are selected and integrated into heat exchanger designs to optimize performance, enhance energy efficiency, and ensure robust thermal management solutions across diverse industries. Understanding the specific attributes and applications of aluminum and copper tubes is essential for designing effective cooling systems tailored to specific operational requirements and environmental conditions.

Lithium battery (Since- 1985)

Lithium-ion batteries (LIBs) are pivotal in modern technology, powering a wide array of devices from portable electronics to electric vehicles and renewable energy storage systems. This abstract explores the fundamental principles, components, and advancements in lithium-ion battery technology. It covers the basic structure of LIBs, including electrodes (anode and cathode), electrolytes, and separators, emphasizing their role in storing and releasing electrical energy through the movement of lithium ions during charge and discharge cycles. Key factors influencing battery performance such as energy density, cycle life, safety considerations, and environmental impact are discussed. Advances in materials science, including electrode materials (such as lithium iron phosphate, nickel manganese cobalt oxide), electrolyte formulations, and solid-state battery technologies, are highlighted for their potential to enhance performance and safety while addressing current challenges. Understanding the complexities and innovations in lithium-ion battery technology is crucial for developing sustainable energy solutions and advancing towards a greener future.

Active Liquid Cooling : Liquid cooling, often referred to as liquid cooling or liquid cooling systems (LCS), is a method of thermal management that uses a liquid coolant to transfer heat away from

components. This abstract explores the principles, benefits, and applications of liquid cooling.

Liquid cooling systems typically consist of:

1. **Coolant:** A specialized liquid (such as water, glycol-water mixtures, or dielectric fluids) that has high thermal conductivity and is circulated through the system to absorb heat from hot components.
2. **Heat Exchangers:** Components that transfer heat from the liquid coolant to the surrounding environment. This can include radiators with fins or other methods of dissipating heat.
3. **Pumps:** Devices that circulate the coolant through the system, maintaining a steady flow to ensure efficient heat transfer.
4. **Tubing and Connectors:** Channels through which the coolant flows between the components of the cooling system.

Focus on Efficiency and Weight : Liquid cooling systems offer distinct advantages in terms of efficiency and weight compared to traditional air cooling methods, especially in demanding applications where thermal management is critical. Here's a breakdown of these factors:

Efficiency:

1. **Heat Transfer Efficiency:** Liquid cooling systems generally have higher thermal conductivity than air, allowing them to transfer heat away from components more effectively. This efficiency means that they can keep components cooler under heavy loads or overclocked conditions, improving overall system stability and performance.
2. **Uniform Cooling:** Liquid cooling systems can provide more uniform cooling across components compared to air cooling. This helps in preventing hot spots and ensures that all parts of the system operate within optimal temperature ranges.
3. **Noise Reduction:** Liquid cooling systems often operate more quietly than air cooling setups, particularly when using larger radiators and fans at lower speeds. This can be advantageous in environments where noise levels are a concern.

4. **Overclocking Potential:** Due to their superior thermal management capabilities, liquid cooling systems enable enthusiasts and professionals to overclock CPUs and GPUs more effectively, pushing performance beyond stock settings without risking overheating.

Functionalities:

Wi-Fi Connectivity: The ESP8266 can connect to Wi-Fi networks, act as an access point, or even function as a Wi-Fi repeater.

TCP/IP Stack: It has a built-in TCP/IP stack, enabling communication protocols like TCP and UDP for data exchange with other devices on the network.

General-Purpose Input/Output (GPIO) Pins: The ESP8266 has a number of GPIO pins that can be configured for various purposes like reading sensor data, controlling LEDs, or interfacing with other components.

Serial Communication: It supports serial communication protocols like SPI, I2C, and UART for connecting with sensors, displays, and other peripherals.

Analog-to-Digital Converter (ADC): The ESP8266 has an integrated ADC that allows it to convert analog signals from sensors (e.g., temperature sensors) into digital values for processing.

Advantages of ESP8266:

Low Cost: The ESP8266 is a highly affordable microcontroller, making it ideal for budget-friendly IoT projects.

Ease of Use: With readily available development platforms and libraries, programming the ESP8266 is considered relatively beginner-friendly compared to some other microcontrollers.

Wi-Fi Integration: Built-in Wi-Fi eliminates the need for additional modules, simplifying project design and reducing complexity.

Versatility: The ESP8266's functionalities allow it to be used in a wide range of IoT applications from simple data logging to complex control systems.

Here are some key characteristics of aluminum fins used in heat radiators:

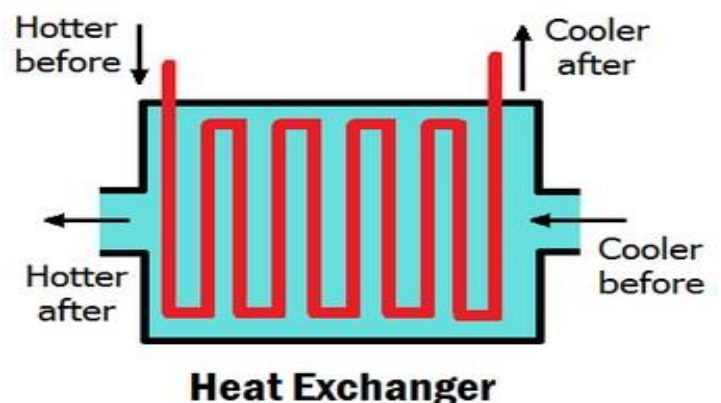
Material: Aluminum is the most commonly used material for heat sink fins due to its good thermal conductivity, meaning it efficiently conducts heat away from the source. It is also lightweight, relatively inexpensive, and resistant to corrosion.

Condenser and Evaporator Coils: Aluminum fins are also used in condenser and evaporator coils of air conditioning systems. They help to increase the surface area for heat transfer between the refrigerant and the surrounding air, thereby improving cooling performance.

Heat Exchangers: In HVAC (Heating, Ventilation, and Air Conditioning) systems, aluminum fins are integral components of air-cooled heat exchangers. They facilitate efficient transfer of heat between air and refrigerants or water, contributing to the overall energy efficiency of the system.

Fin Attachment: Aluminum fins can be attached to the heat pipes or base plate of the radiator through various methods, such as soldering, brazing, or pressfitting.

In conclusion, aluminum fins are essential components in heat radiators, significantly enhancing their ability to transfer heat and keep systems cool. Their affordability, good thermal conductivity, and lightweight properties make them a popular choice for various heat dissipation applications.



COPPER TUBES



Copper tubes are versatile components widely used across various industries due to their excellent thermal and electrical conductivity, corrosion resistance, and durability. Here are some key aspects and common applications of copper tubes

Copper excels in several key areas that make it ideal for cooling systems:



Heat Dissipation: Aluminum fins are commonly used in heat sinks to dissipate heat generated by electronic components such as CPUs, GPUs, power transistors, and other heat-generating devices. The high thermal conductivity of aluminum

(approximately 205 W/m·K) allows efficient transfer of heat from the source to the ambient environment.

Excellent Corrosion Resistance: Copper naturally resists corrosion, ensuring long-term system integrity. This is particularly important in applications where the cooling liquid might be slightly acidic or contain anti-corrosive additives.

Cooling Efficiency: Fins increase the surface area exposed to air or another cooling medium, thereby enhancing the rate of heat transfer through convection. This improves the overall cooling efficiency of the system.

Solderability: Copper can be easily soldered, creating strong and leak-proof connections with other copper components or fittings within the cooling system. This simplifies assembly and maintenance.

How Copper Tubes Function in Cooling Systems:

Copper tubes form the backbone of various cooling system designs. Here's a general overview of their function:

Heat Source: The cooling system is designed to remove heat generated by a source, such as an engine in a car, a compressor in an air conditioner, or electronic components in a computer.

Heat Transfer Fluid: A liquid coolant (e.g. waterglycol mixture) or air circulates through the copper tubes.

Heat Absorption: As the coolant or air flows through the tubes, it absorbs heat from the surrounding source due to copper's high thermal conductivity.

Features and Properties:

1. **High Thermal Conductivity:** Copper is an excellent conductor of heat and electricity, with a thermal conductivity of approximately

400 W/m·K. This property makes copper tubes ideal for applications where efficient heat transfer is essential, such as heat exchangers and refrigeration systems.

2. **Corrosion Resistance:** Copper is naturally resistant to corrosion, particularly when exposed to air and water. This resistance can be further enhanced through various protective coatings or treatments.
 3. **Malleability and Ductility:** Copper tubes are easy to shape, bend, and solder, making them versatile for a wide range of plumbing and HVAC applications. They can withstand deformation without cracking or breaking.
 4. **Longevity:** Copper is durable and has a long service life, often lasting decades without degradation under normal operating conditions.
 5. **Antimicrobial Properties:** Copper has intrinsic antimicrobial properties, which can help inhibit the growth of bacteria and fungi on its surface. This is particularly beneficial in plumbing systems where hygiene is critical.
1. **Plumbing:** Copper tubes are extensively used in plumbing systems for transporting potable water and other fluids. They are suitable for both hot and cold water distribution due to their heat resistance and reliability.
 2. **HVAC and Refrigeration:** In HVAC systems, copper tubes are used in heat exchangers, condensers, evaporators, and refrigerant lines. Their high thermal conductivity and resistance to corrosion make them ideal for efficiently transferring heat in air conditioning and refrigeration equipment.
 3. **Industrial Applications:** Copper tubes find applications in industrial processes for fluid transportation, heat exchange, and cooling systems where reliability and efficiency are paramount.
 4. **Renewable Energy:** Copper tubes are used in solar thermal systems for collecting and transferring heat from solar collectors to water or heat transfer fluids.
 5. **Electronics:** Copper tubes are also used in electronics for thermal management, such as heat sinks and cooling solutions for high-power components.

1) Advantages:

Efficiency: Copper's high thermal conductivity allows for efficient heat transfer, reducing energy consumption and enhancing system performance.

Reliability: Copper tubes have a proven track record of reliability and durability, making them a preferred choice in critical applications.

Ease of Installation: Copper tubes are easy to work with due to their malleability and compatibility with standard soldering and brazing techniques.

Environmental Friendliness: Copper is fully recyclable and retains its properties indefinitely, contributing to sustainability efforts in manufacturing and construction.

In conclusion, copper tubes offer a combination of thermal performance, durability, and versatility that make them indispensable in various industries, from residential plumbing to complex industrial applications. Their unique properties contribute significantly to the efficiency and reliability of systems where they are employed.

Electronic Device Cooling: High-performance computers and other electronic devices often utilize copper heat pipes with flattened copper tubes to transfer heat generated by processors and other components to heat sinks for cooling.

Battery Cooling: Cooling battery packs in electric vehicles (EVs) is crucial for maintaining optimal performance, longevity, and safety. Here's a detailed overview of battery cooling systems:

Important Battery cooling

1. Temperature Control:

Lithium-ion batteries used in EVs operate best within a specific temperature range (typically 15-35°C). Cooling helps prevent overheating during charging and discharging cycles, which can degrade battery life and affect performance.

2. **Safety:** Overheating batteries can lead to thermal runaway—a potentially dangerous situation where batteries can catch fire or explode. Cooling systems mitigate this risk by maintaining safe operating temperatures.

3. **Performance Optimization:** Cooling ensures consistent performance by reducing thermal stress on the battery cells. This improves overall efficiency and extends the driving range of the vehicle.

Liquid Cooling:

Direct Liquid Cooling: Coolant (usually a mixture of water and glycol) flows directly through channels or tubes integrated into the battery pack. This method efficiently removes heat from the cells.

Indirect Liquid Cooling: Coolant circulates through a separate cooling loop, cooling a heat exchanger that then cools the battery pack. This method isolates the battery from direct contact with coolant.

Functioning:

Inactivated State: Without voltage applied to the coil, the armature remains in its original position. One set of NO terminals stays disconnected, and the other set of NC terminals remains connected. This represents the default state of the circuits being controlled.

Activated State: When voltage is applied to a designated Common terminal, the coil energizes, creating a magnetic field. This magnetic field attracts the armature, causing it to switch positions. Consequently, one of the NO terminals connects to its corresponding Common terminal, and the connection between the NC terminals is broken. This changes the state of the two circuits controlled by the relay.

III. SYSTEM DESCRIPTION

Fluid Cooling: If the temperature reaches a critical threshold, the MCU activates the fluid cooling system:

The pump circulates coolant through the copper tubes attached to the battery pack.

The heated coolant travels to the radiator, where aluminum fins facilitate heat dissipation into the surrounding air.

Load Control: If the temperature reaches an extremely high and unsafe level, the MCU triggers the SSR to disconnect power delivery to the load connected to the battery pack, preventing further heat generation.

IoT Integration: The MCU can transmit temperature and humidity data to a cloud platform or mobile app for remote monitoring and visualizations. Alerts can be sent if critical temperature thresholds are reached.

Software Development:

The MCU will require programming to handle sensor data acquisition, temperature analysis, cooling system control (fan activation, pump control), and potential load shut down via the relay unit.

Libraries for the specific sensors, ESP8266 functionalities, and (if applicable) cloud communication protocols need to be integrated into the code.

Utilities

Efficient Cooling: Combines air and fluid cooling for optimal temperature management.

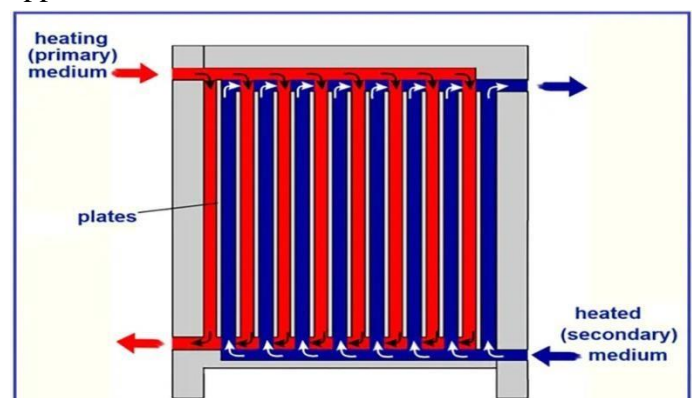
Smart Control: Utilizes an MCU for automated cooling based on sensor data.

Safety Features: Automatic load shut down at critical temperatures prevents damage.

IoT Monitoring : Enables remote monitoring and data visualization for proactive maintenance.

3.2 FLOW PROCESS

This project utilizes an Internet of Things (IoT) approach to create a battery cooling system that automatically adjusts air and water flow based on real-time temperature readings. Data is monitored and visualized through a user-friendly Blynk application.



The future of Battery Management Systems (BMS) is bright, driven by the ever-increasing demand for efficient and safe energy storage solutions in various

sectors. Here are some exciting trends shaping the future of BMS:

Advanced Cell Monitoring and Control:

Cell-Level Monitoring: Moving beyond pack-level monitoring, future BMS will focus on individual cell health and performance. This will involve highfidelity sensors and advanced algorithms for precise control and early detection of cell imbalances.

Adaptive Charging and Discharging: BMS will adapt charging and discharging profiles based on real-time cell data, optimizing battery life and performance. Machine learning algorithms can personalize charging strategies for user behavior and environmental conditions.

Thermal Management Innovations:

Phase Change Materials (PCMs): Integrating PCMs within the battery pack will allow for passive heat absorption during operation and heat release during cool down periods, enhancing thermal regulation.

Advanced Cooling Systems: Liquid cooling systems with improved efficiency and miniaturization will be developed. Microfluidic channels embedded within the battery pack itself are a potential future direction.

Safety and Reliability Enhancements:

Self-Diagnosis and Prognostics: BMS will incorporate advanced diagnostics to predict potential battery failures and trigger preventative maintenance actions. This will improve system reliability and safety.

Functional Safety Standards: Standardization efforts will lead to robust BMS designs that comply with stringent safety regulations for various battery applications, such as electric vehicles and grid storage.

Integration and Communication:

Cloud-based BMS: Cloud connectivity will enable remote monitoring, diagnostics, and firmware updates for BMS, facilitating proactive maintenance and optimizing performance across geographically dispersed battery systems.

Vehicle-to-Grid (V2G) Integration: BMS will play a crucial role in V2G communication, allowing electric vehicles to participate in demand-response programs by intelligently managing battery charge and discharge cycles.

Focus on Sustainability:

Second-Life Battery Management: BMS will be adapted to manage repurposed batteries from electric vehicles for stationary storage applications, extending battery life and reducing environmental impact.

Recyclability Considerations: BMS designs will consider future recyclability of battery materials, potentially incorporating features to simplify disassembly and material recovery processes.

Additionally, the future of BMS might see:

Bio-inspired Battery Management: Drawing inspiration from biological systems for self-healing and self-regulation mechanisms to enhance battery safety and longevity.

Brain-inspired BMS: Utilizing neuromorphic computing techniques to mimic the human brain's ability to learn and adapt, enabling BMS to handle complex data and make real-time decisions for optimal battery performance.

System Working:

Temperature Monitoring: The MCU continuously reads data from the temperature sensors placed on the battery pack.

Data Processing: The MCU analyzes the temperature data to determine the cooling requirements.

Blynk App Integration (Optional): Temperature data can be sent to the Blynk app for real-time visualization and potential user intervention through controls.

Dynamic Cooling Control: Based on predefined temperature thresholds:

Airflow Control:

Variable Speed Fan: The MCU adjusts the fan speed based on the temperature severity. Higher temperatures trigger faster fan speeds for increased airflow.

Waterflow Control:

Adjustable Flow Rate Pump: The MCU adjusts the pump's flow rate based on the cooling needs. Higher temperatures necessitate a higher flow rate for more efficient heat transfer.

Safety Features: If the temperature reaches an extremely high and unsafe level, the system can be programmed to trigger additional safety measures (not covered in this basic outline) like alarms or emergency shutdowns.

Software Development:

The MCU code will involve:

Sensor data acquisition from temperature sensors.

Temperature analysis and control logic for air and water flow adjustments.

Communication with the Blynk app .

Libraries for the specific sensors, ESP8266 functionalities, Blynk app integration (if applicable), and motor/solenoid control (if applicable) need to be included.

**IMPLEMENTATION OF THE PROJECT**

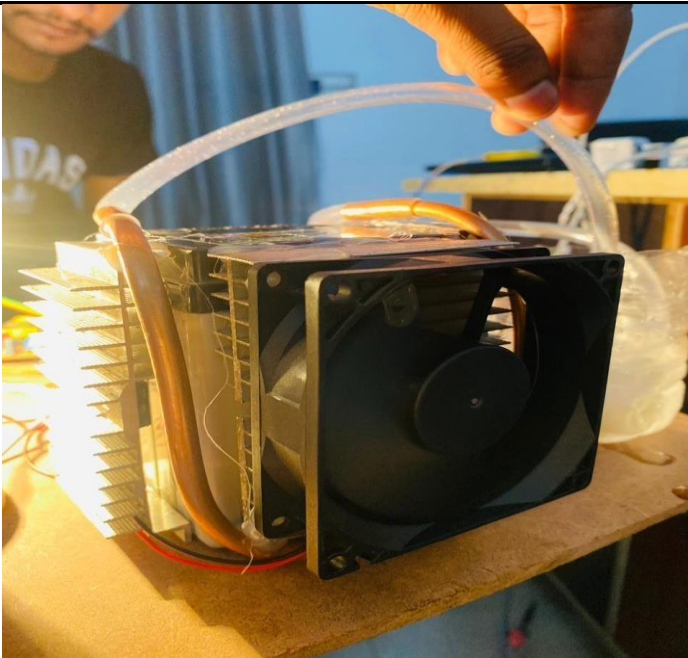
The implementation of the project is comprised of following parts –

- .1 Hardware Implementation
- .2 Software Implementation
- .3 Technology Implementation

1 HARDWARE IMPLEMENTATION

Aluminum and copper tube image1





Project Image 3

This project outlines a comprehensive Battery Management System (BMS) designed to ensure optimal performance, safety, and longevity for battery packs. It leverages the power of the Internet of Things (IoT) for real-time monitoring, control, and user awareness. The system employs a multi-tier cooling approach, combining air and fluid cooling mechanisms for efficient thermal management. Additionally, it incorporates an alarm system and automatic load shut down to prevent potential damage caused by overheating.

To develop a BMS that effectively monitors and regulates battery temperature to prevent thermal runaway. It requires implement a dynamic cooling system that adapts to varying cooling demands, utilizing air and fluid cooling methods. It was good to integrate an alarm system to alert users of critical temperature conditions. It is to include an automatic load shut down mechanism as a safety measure for extreme temperatures. It also includes leverage IoT capabilities for remote monitoring and potential user interaction.

Airflow System: Strategically placed variable-speed fans actively circulate air around the battery pack for initial cooling.

Fluid Cooling System:

Reservoir tank to hold the coolant (e.g., water-glycol mixture).

Pump with adjustable flow rate to circulate the coolant based on cooling requirements.

Radiator with aluminum fins for efficient heat dissipation into the surrounding air.

Copper tubes to transport the coolant between the battery pack, pump, and radiator.

System Working:

Temperature and Humidity Monitoring: The MCU continuously reads data from the temperature sensors placed on the battery pack and the DHT sensor for ambient conditions.

Data Processing: The MCU analyzes the temperature data in real-time to identify potential overheating situations. The ambient temperature and humidity data from the DHT sensor can be used to adjust cooling strategies and improve overall efficiency.

Cooling System Activation: Based on predefined temperature thresholds:

Fluid Cooling: If the temperature reaches a critical threshold, the MCU activates the fluid cooling system:

The pump with adjustable flow rate circulates coolant through the copper tubes attached to the battery pack.

The heated coolant travels to the radiator, where aluminum fins facilitate heat dissipation into the surrounding air.

Alarm and Load Control:

Alarm System: If the temperature reaches a predefined critical level, an alarm is triggered to alert the user of the potential danger.

Load Shut Down: As a final safety measure, if the temperature reaches an extremely high and unsafe level, the MCU triggers the SSR to disconnect power delivery to the load connected to the battery pack, preventing further heat generation and potential damage.

IoT Integration (Optional): The MCU can transmit temperature and humidity data (including data from the DHT sensor) to a cloud platform or mobile app for remote monitoring and visualizations. Alerts can be sent if critical temperature thresholds are reached, allowing for proactive intervention.

Software Development:

The MCU code will involve:

Sensor data acquisition from temperature sensors and the DHT sensor.

Temperature analysis and control logic for air and water flow adjustments, considering ambient conditions.

Alarm system activation and load shut down control based on temperature thresholds.

Communication with the Blynk app or similar platform (if applicable) for remote monitoring and user interaction.

Libraries for the specific sensors, ESP8266 functionalities, and (if applicable) cloud communication protocols or Blynk app integration need to be incorporated into the code.

IV. CONCLUSION

This project proposes a robust Battery Management System (BMS) that combines multiple functionalities to ensure optimal battery performance, safety, and longevity. By integrating this BMS offers a comprehensive approach to battery thermal management. The system leverages sensor data to activate air cooling for initial temperature control and seamlessly transitions to fluid cooling for more demanding situations. The alarm and automatic shut down features provide additional safety measures, preventing potential damage caused by overheating.

Key Advantages:

Prevents Thermal Runaway: Proactive cooling and safety features mitigate the risk of thermal runaway, a critical safety concern for lithium-ion batteries.

Extends Battery Life: Efficient thermal management reduces battery degradation, leading to a longer lifespan.

Improves System Reliability: Real-time monitoring and control ensure that the battery operates within safe temperature ranges, enhancing system reliability.

User Awareness: Integration with a mobile application (using the DHT sensor data) can provide valuable insights into ambient conditions and potential cooling needs.

V. FUTURE SCOPE

The future scope of heat rejection using aluminum and copper tubes involves several exciting advancements and applications across various industries. Here are some potential areas of development:

1) Enhanced Thermal Management in Electronics

Microprocessors and GPUs: Integrating aluminum and copper tube heat rejection systems into computer processors and graphics cards can improve cooling efficiency, allowing for higher processing speeds and reduced thermal throttling.

Data Centers: Efficient heat rejection systems can optimize cooling in data centers, reducing energy consumption and operational costs while maintaining reliability.

2. Automotive Applications:

- **Electric Vehicles (EVs):** Improving battery cooling systems with aluminum fins and copper tubes can enhance energy efficiency and extend battery life, crucial for increasing driving range and accelerating adoption of EVs.
- **Internal Combustion Engines (ICE):** Enhancing radiator designs with advanced heat rejection systems can improve fuel efficiency and reduce emissions in traditional vehicles.

3. Industrial and Manufacturing Processes:

- **Heat Exchangers:** Advancements in aluminum and copper tube configurations can lead to more efficient heat exchangers in industrial processes, such as HVAC systems, chemical processing, and power generation.
- **Waste Heat Recovery:** Utilizing efficient heat rejection systems can enable better recovery and utilization of waste heat from industrial processes, improving overall energy efficiency.

4. Renewable Energy Systems:

- **Solar Thermal Systems:** Improved heat rejection technologies can enhance the efficiency of solar thermal collectors, increasing the amount of heat converted into usable energy.
- **Geothermal Power Plants:** Utilizing advanced heat rejection systems can optimize heat dissipation from geothermal power generation systems, enhancing their overall efficiency.

5. Medical and Pharmaceutical Applications:

- **MRI Machines:** Effective heat rejection systems using aluminum and copper tubes can improve the cooling efficiency of MRI machines, ensuring optimal performance and patient safety.

Laboratory Equipment: Enhancements in heat rejection technologies can benefit various laboratory equipment, maintaining stable operating temperatures for sensitive experiments and analyses.

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