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Accessing Battery Thermal Safety and Adoption of Socio-Technical Influence of Electric Vehicles in Nepal

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Abstract— The adoption of electric vehicles (EVs) in Nepal faces critical challenges due to lithium-ion battery thermal instability, aggravated by steep terrain and high ambient temperatures. This study investigates a dual-enhancement passive Battery Thermal Management System (BTMS) using octadecane-based Phase Change Material (PCM) modified with graphite for thermal conductivity and polyurethane for flame retardancy. A 3D computational fluid dynamics (CFD) model of a 20-cell module was developed in ANSYS Workbench to evaluate discharge rates (1C–3C) under 25–40 ℃ ambient conditions. Results demonstrate that 10% graphite loading improved PCM conductivity by ~42%, achieving temperature uniformity within ±2 ℃, while a 5 mm polyurethane layer reduced simulated flame propagation by ~60%. Complementary stakeholder consultations revealed overheating and safety concerns as primary barriers to EV adoption, with a strong preference for passive, energy-efficient cooling solutions. By integrating technical optimization with socio-technical perspectives, this research provides a scalable framework for safer EV deployment in emerging economies. The findings highlight the potential of composite PCM-based BTMS to enhance user trust, support Nepal's Net Zero 2045 target, and advance sustainable mobility, though experimental validation and long-term material stability remain essential future directions.

Keywords — Phase Change Material, Battery Thermal Management System, Electric Vehicles, Computational Fluid Dynamics, Graphite

I. Introduction

The global automotive industry has, in fact, been shifting towards electric mobility, necessitated by the necessity to combat global warming and to decrease the use of fossil fuels, and hence SDGs 13 (Climate Action) and 7 (Affordable and Clean Energy) [1]. The key to this change has been the lithium-ion battery, the functionality of which has been strongly affected by the environment. Battery working temperature has been required to remain between 20–40 °C [2] [3] anything beyond this has caused inefficiency, shorter range, and a higher chance of safety-related issues, especially thermal runaway, which has been worsened by adverse climatic conditions like those in Nepal. Traditional active cooling methods have had efficiency and complexity issues that have led to the consideration of passive cooling [4].

Phase Change Materials (PCM), including octadecane, have become a promising option, since they have provided good heat capture and have not necessitated external energy [5]. Nevertheless, organic PCMs have been problematic because of their low thermal conduction and flammability, which has presented a safety issue that has destroyed the trust of people in the sustainable technologies (SDG 11) and responsible consumption (SDG 12).

Moreover, the thesis has focused on optimization of material compositions and scalable designs with ANSYS Workbench and detailed computational fluid dynamics (CFD) simulations that have helped to reach the goal of the future of EV electric vehicles and have made them safe and sustainable [6]. The social and environmental effects of thermal management have been rather high, as they have impacted the safety of people and the possibility of an incident caused by overheating, which has been a key factor concerning SDGs 11 (Sustainable Cities and Communities) and 3 (Good Health and Well-being) [1]. Ineffective thermal management has not only been performance-affecting but also a phenomenon that has promoted the early degradation of the battery, which has been unacceptable according to the writing of responsible consumption (SDG 12). Hence, appropriate thermal management systems have been vital to the ecological and social health.

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Phase Change Materials (PCM) have been created as a potential solution to passive cooling and have been used to improve battery safety and performance by trapping the heat without additional energy expenditure [5]. This has gone hand in hand with a comprehensive sustainability model that has enhanced safer energy use and the practice of resource efficiency. Battery thermal control has been a significant area of concern to ensure durability, stability, and security, as the stakeholders in the electric mobility sector have realized, and why there have been powerful, energy-saving, and multi-purpose solutions that have withstood multiple working conditions.

The concerns have increased the importance of lithium-ion batteries to EV integration, their weaknesses, especially the low thermal operating temperature (20–40 °C), which has caused inefficiency and safety issues such as thermal runaway [7]. The proposal of using organic PCMs, including octadecane, has had high latent heat capacity in passive cooling schemes. Nevertheless, there have still been difficulties associated with low thermal conductivity (approximately 0.2 Wm-1.K-1) and the inflammability of such materials, which have threatened the safety of the users [8].

Previous studies have been conducted on the improvement of thermal conductivity by incorporating graphite and carbon fiber, and flame retardancy by coating a polymer with another polymer [5]. However, loopholes still exist in the systematic investigation of composite PCMs that have integrated conductivity modifiers and flame-retardant strategies. Available literature on Battery Thermal Management Systems (BTMS) has shown that there have been major gaps related to the quantitative trade-offs in terms of thermal conductivity, latent heat safety, and scalability of the system needed to address industrial applications.

The main purpose of the research has been to explore the thermal safety of the Lithium-ion battery based on a computational model and to determine the impact of these technical performance indicators on socio-technical adoption of electric vehicles in Nepal. Research has also been geared towards fundamental aims that have been put forward to treat the issue of both computational performance and the practical sustainability of the electric vehicle's battery thermal management. First, the study has sought to measure the enhancement of thermal characteristics of an EV battery pack through CFD at different operating conditions. Adding to this quantitative method, the paper has also been an evaluation of how the flame retardancy has been improved by using polyurethane insulation under controlled abuse settings. Lastly, the project has aimed to integrate all such technical qualities into the larger social interests to enhance appreciation and encourage the mainstream adoption of electric vehicles.

The study has failed to take into consideration any long-term chemical degradation of the Phase Change Material (PCM) or the overall environmental impact of the product on the life-cycle, production, and recycling. Although it has provided a roadmap to safer battery systems regarding electric mobility, it has been deficient in the assessment of the physical capacity of composite material in conditioned circumstances in Nepal. In addition to this, it has lacked a comprehensive economic analysis of supply chain logistical operations in order to enable it to use better materials in the local market. The limitations have played a crucial role in relation to the holistic life cycle analysis of future research in order to accommodate the Net Zero 2045 target of Nepal [9].

II. Literature Review

The increasing popularity of electric vehicles (EVs) has made it apparent that proper thermal control of lithium-ion battery systems has been a crucial factor that has directly influenced performance and safety [3]. Lithium-ion batteries have been susceptible to changes in temperature, and hence have had to be operated within a limited thermal range to prevent harm and dangerous failure [2]. This has been due to critical thermal issues involving non-uniform heating of battery modules and heat transfer, which have been compounded by environmental conditions like high ambient temperatures. Battery Thermal Management Systems (BTMS) have solved these problems by ensuring that temperatures and thermal gradients have been kept to a minimum [10]. BTMS have been categorized as either air, liquid, phase change material (PCM), or a hybrid cooling system with its own set of benefits and shortcomings. Air cooling has been easy and ineffective with high power requirements; liquid cooling has offered more flexibility but has also been more complicated [11]. PCM systems have offered passive regulation, but have been constrained by heat dissipation.

Computational Fluid Dynamics (CFD) has now been required to calculate the thermal behavior of EV deliberate battery systems, such that the degree of temperature distribution and cooling efficiency has been provided in detail [6]. Although CFD has been capable of modeling several scenarios, it has commonly drawn upon simplified assumptions that have not always been accurate in the real world. Also, more detailed research, relating CFD findings to the reliability and safety of the system, has been needed to develop the field of CFD in battery thermal management design.

Battery Thermal Management Systems (BTMS) have depended on the choice of proper performance metrics, including maximum cell temperature and temperature uniformity. Although maximum cell temperature has been essential in preventing thermal runaway, localized thermal problems have been ignored [12]. Temperature uniformity has been becoming widely accepted as important to battery health, although there has not been agreement as to the acceptable limits. Transient performance and energy-based performance have also not been properly measured, and this has resulted in fragmented assessment

In addition to thermal measures, research has highlighted that BTMS have had to be reliable and safe, avoiding thermal runaway and reducing heat transfer [13]. The safety has been influenced by material selections, whereas the reliability has been influenced by the repeated thermal cycles. Safety studies have mostly been qualitative, which has prevented their real-world use.

The perception of safety in Nepal has affected the trust in electric vehicles (EVs) based on the visible accidents, cultural conditions, and the lack of emergency infrastructure (Ale, 2024). The infrastructure and topography have also had a major influence on how the population has perceived EV safety [4]. In Nepal, trust in EVs has largely been developed based on phenomena and not preconceived notions, where, in the face of visual safety assurances such as incident reports and certifications, reliability in EVs has been highly important in fostering trust. Institutional credibility has also been relevant as contributing to the formation of a social perception and has required open communication of governmental institutions and manufacturers, in particular, during the changes in the regulations.

EV safety has been connected with the United Nations Sustainable Development Goals (SDGs), which have promoted infrastructure safety, clean energy, and climate action [14]. A socio-technical approach has revealed the gap in the research concerning cooling methods, particularly those of the high-temperature environment. The literature has highlighted the importance of a standardized performance assessment and emphasis on passive thermal management solutions, which have increased safety, which has been in line with sustainable mobility goals. The gap between qualitative analysis of safety and quantitative CFD modelling has still been wide and has required a more in-depth study in order to advance the real-world battery design.

III. Methodology

The research design has been sequential explanatory, in which the simulation of thermal safety by CFD has been conducted, and then this information has been interpreted qualitatively by socio-technical means. First, quantitative predictors of thermal safety of batteries that have been computed have been analyzed, and the results have been used in consideration of qualitative interview results. The model has separated its analytical elements: CFD simulations have provided a measure of thermal performance and safety, and qualitative information has revealed stakeholder views on safety and reliability. This approach has contributed to holistic sustainability, decreasing the amount of material waste and money spent on the creation of virtual prototypes using ANSYS Workbench in accordance with SDG 9, whereas the qualitative step has contributed to social sustainability since it has explored the idea of public trust and attitude to technology compared to SDG 11. The research paradigm has shifted to a Quantitative Stream, which has concerned the computational optimization, to a Qualitative Stream, which has involved conducting interviews with experts to assist in gauging the social readiness and policy suitability

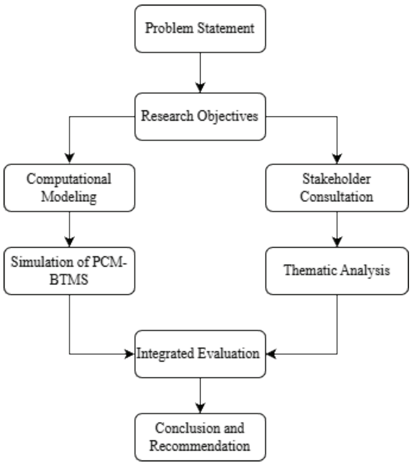

Figure 1: Conceptual Framework

The framework specifies the process of the research between the inputs and outputs and incorporates technical modeling and socio-technical validation. The inputs flow into the technical stream, where a PCM composite is evaluated through transient CFD in ANSYS, and stakeholder consultations that give thematic information are present. The results of the simulation and the qualitative themes are combined to produce combined outcomes: design recommendations, policy recommendations, and an experimental validation plan, as well as a note on limitations and future work.

3.1 Socio-Technical Integration Approach

To examine the socio-technical environment of electric vehicle (EV) adoption in Nepal, this study has employed purposive sampling to conduct semi-structured interviews with various stakeholders: government policymakers, charging operators, and development organizations. The interview guide has been divided into Safety and Trust, Operational, and Sustainability modules, which have also probed attitudes regarding battery fires, passive cooling reliability, and purchase incentives. Raw data has been converted into rigorous codes using the six-phase thematic analysis of Braun and Clarke [15]. Among the key determinants that have been defined by these codes have been terrain adaptability, infrastructure reliability, and inclusiveness, whereas a word cloud and a Sustainability Module have helped see the way long-term development trends and regulatory requirements have been visualized.

These qualitative themes have been combined with quantitative CFD results using a Triangulation Matrix to enable bridging the gap between laboratory optimization and practice. This process has overlaid recurrent safety issues (e.g., overheating and flammability) onto technical performance measures such as temperature gradients, insulating efficiency, and stability of the liquid fraction. Lastly, a SWOT analysis has been strategic, comparing the performance of graphite-enhanced PCM BTMS in the ecosystem of Nepal, and establishing the advantages of its safety efficacy and the dangers of the infrastructure voids. Such a combined strategy has ensured that adoption routes have been both technically reasonable and socially acceptable and have been in accordance with national EV roadmaps, which ultimately have helped decrease consumer anxiety and in still confidence in sustainable movement.

3.2 Computational Modeling Framework

The computational modeling framework has been designed to capture the thermal behavior of a 20-cell cylindrical LFP battery pack embedded in a PCM matrix with optional polyurethane insulation. SolidWorks 2022 SP5 has been used to create the geometry, which has then been exported to ANSYS Workbench 2022 R1 for simulation. Tetrahedral and prism elements with inflation layers close to cell walls and PCM interfaces have been used for meshing, guaranteeing skewness <0.9 and orthogonality >0.2. To balance accuracy and convergence, about 1–2 million elements have been used. The solidification/melting model and the energy equation have been the governing equations, and for transient analysis, k-ω realizable turbulence has been used. With a heat generation rate of about 60 W per cell under 2C discharge, boundary conditions have been set at ambient temperatures of 45°C for steady-state and 27–45°C for transient cases. The energy and continuity convergence criteria have been set at $10\square^{2}$. Assumptions have included neglecting gravity due to horizontal pack orientation and applying polyurethane insulation selectively for flammability mitigation. These choices have ensured that the computational model has reflected realistic EV operating conditions while maintaining reproducibility and sustainability principles.

Table 1

Materials and Software Requirements

Component	Material/ Software	Function/Rationale
Base PCM	Octadecane ($C_{18}H_{38}$)	Provides high latent heat capacity for passive energy absorption at an ideal melting temperature (~ 28°C).
Performance Enhancer	Graphite Additives	Overcomes the low thermal conductivity of pure PCM to ensure efficient and uniform heat dissipation.
Safety Component	Polyurethane Insulation	Acts as a fire-resistant barrier to mitigate flammability risks and contain thermal events.
Battery Model	20-cell cylindrical LFP pack	Represents a common, safe, and cost-effective battery configuration relevant to affordable EVs, particularly in developing markets.
Software	ANSYS Workbench 2022 R1	Enables high-fidelity CFD and thermal simulations for accurate virtual prototyping and analysis.

Table 2

Material Properties for PCM Selection

PCM Type	Material	Key Properties	Additives/ Insulation
Organic	Octadecane ($C_{18}H_{38}$)	Melting ~28 °C, 244 J/g latent heat	Graphite, Polyurethane
Inorganic	$CaCl_2 \cdot 6H_2O$	Wide phase range, high stability	Graphite

Table 1 shows the materials and software requirements, while Table 2 shows the required material properties for selecting Phase Change Materials for computational modelling.

III.3 *Thermal Behavior Quantification*

Thermal behavior has been quantified through simulations under varying ambient and operational conditions. Transient analysis has been conducted at 29 °C, charging for 260 seconds, while steady-state analysis has been performed at 45 °C ambient to evaluate insulation effects. Materials with melting points between 20 and 30 °C, high latent heat (>200 J/g), and compatibility with battery operating ranges of 27 to 32 °C have been given priority in the PCM selection process. Octadecane has been chosen as the base PCM for its chemical stability and predictable phase change behavior, while graphite additives have been incorporated to enhance thermal conductivity. Polyurethane insulation has been introduced as a passive safety layer to mitigate flammability risks. For comparative stability, inorganic PCM (CaCl□·6H□O) has also been taken into account. Heat flux uniformity, liquid fraction contours, and temperature distribution have been the main topics of data extraction. The main metric that has been used to describe the phase transition from solid (0) to liquid (1) has been the liquid fraction method. This has provided quantitative insights into heat absorption capacity, melting uniformity, and PCM response time under thermal loads. Results have been validated against literature and theoretical benchmarks to ensure accuracy.

3.4 Polyurethane Insulation Analysis

Polyurethane insulation has been structurally modeled around the PCM domain to evaluate its effectiveness as a fire-resistant barrier. It has been the perfect option for encapsulation due to its low heat conductivity and ease of molding. Simulations under high ambient exposure (45 °C) have been conducted both with and without insulation to assess flame-retardancy and external heat gain. In order to preserve PCM integrity and avoid localized overheating, the polyurethane barrier has dramatically decreased heat transmission from the surroundings. Comparative analysis has demonstrated that the insulated system has achieved improved thermal stability and safety compared to the baseline configuration without insulation. This has validated the polyurethane's function as a vital safety element in the battery thermal management system, guaranteeing that improvements in performance have not jeopardized the integrity of the system under high heat stress.

Subsequently, simulation execution has involved both steady-state and transient analyses, with continuous monitoring of residuals, liquid fraction, and temperature profiles. Post-processing has extracted temperature distributions, liquid fraction contours, and thermal uniformity data. Finally, validation and analysis have compared the results against literature and theoretical benchmarks, ensuring reliability and preparing the dataset for qualitative synthesis.

Ethical Consideration

This study has followed ethical standards to ensure participant integrity and respect. While computational modeling has had no direct ethical risks, results have been transparently reported with acknowledged limitations. The qualitative stream has employed purposive sampling, has obtained informed consent from all volunteers, who have been able to withdraw at any time. Confidentiality has been upheld through response anonymization, with secure storage of transcripts and recordings.

IV. Results and Discussion

4.1 Socio-Technical Implications for EV Adoption in Nepal

The socio-technical adoption analysis for implementing PCM-enhanced Battery Thermal Management Systems (BTMS) in Nepal has emphasized the importance of not only technical validation through CFD simulations but also the socio-technical factors influencing adoption. Stakeholder consultations have been conducted using purposive sampling, targeting participants from the EV ecosystem, including sellers, operators, engineers, and policymakers, to assess market readiness, safety perceptions, and regulatory requirements. A semi-structured questionnaire has facilitated in-depth interviews and has revealed that concerns about battery longevity under high temperatures have been paramount. Thematic analysis, structured through Reflexive Thematic Analysis (RTA), has identified key themes including safety perceptions, technological effectiveness, and behavioral intentions toward EV adoption. A Word Cloud analysis has highlighted the prominence of terms like Safety, Heat, and Trust, has indicated that public risk aversion and perceptions of safety have been significant barriers to the adoption of EV technology in Nepal. The study ultimately has ultimately recognized that achieving thermal stability has been crucial for addressing these societal concerns and facilitating a smoother transition to electric mobility.

The examination of “Passive” versus “Maintenance” systems in rural Nepal has revealed skepticism towards complex technical solutions due to concerns over reliability, particularly with active fans that have been susceptible to failure from environmental factors. This has led to the advocacy for a passive, solid-state Battery Thermal Management System (BTMS) that has ensured the “set-and-forget” option preferred in the market. Expert consultations have highlighted, as per Table 3, critical thermal issues such as battery overheating during fast charging, has emphasized the need for reliable thermal management.

Table 3

Summary of Key Insights from Expert Consultation

Component	Material/ Software	Function/Rationale
Base PCM	Octadecane ($C_{18}H_{38}$)	Provides high latent heat capacity for passive energy absorption at an ideal melting temperature (~28°C).
Performance Enhancer	Graphite Additives	Overcomes the low thermal conductivity of pure PCM to ensure efficient and uniform heat dissipation.
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Table 4

SWOT- Strategic Matrix

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Inorganic	$CaCl_2{\cdot}6H_2O$	Wide phase range, high stability	Graphite

SWOT analysis, as in Table 4, has highlighted the low-carbon energy sources’ strengths, but has identified such challenges as high initial capital investment and insufficient infrastructure. The suggested BTMS has provided the improved performance and safety of the batteries by combining technical abilities with the social demands, which has been essential to foster the usage of electric vehicles (EVs) in the challenging Nepali environment. The input of the stakeholders has been a component in balancing research with real-world demands in developing BTMS to ensure longer battery life and consistency in its performance in direct response to consumer needs about thermal stress and safety. In general, the paper has supported the fact that successful BTMS not only have enhanced technical resilience but also have contributed to the enhancement of trust among the population in the potential of electric mobility, which has supported the sustainable transport agenda of Nepal.

4.3 Thermal Performance of Pure PCM

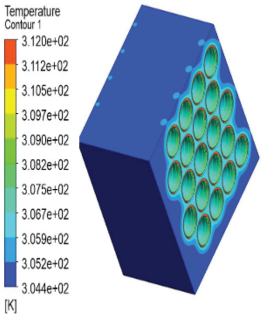

Figure 2: Temp. distribution on pure octadecane

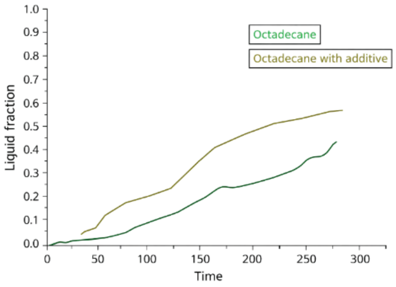

Figure 3: Liquid fraction graph comparison

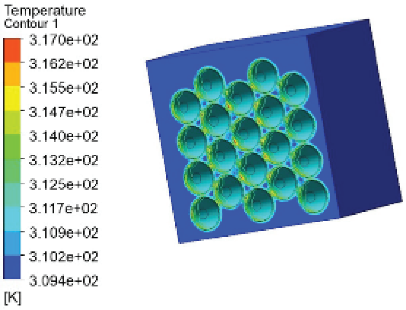

Figure 4: Temp. distribution on octadecane and graphite

The temperature distribution of pure octadecane PCM after 300 seconds of heating has been shown in Figure 2, where notable thermal gradients have been seen with high concentrations at the battery-PCM interface, while the outer regions have stayed much colder, causing an uneven phase change. A liquid fraction graph comparing pure and composite PCM has been shown in Figure 3, has demonstrated that the graphite-enhanced PCM has exhibited a more uniform melting behavior due to the conductive pathways created by graphite, which have sped up heat penetration and have lessened localized thermal stress. Figure 4 further has demonstrated the temperature distribution within the octadecane-graphite composite, has revealed a more stable thermal profile with reduced gradients, as the high thermal conductivity of graphite has ensured a homogeneous temperature distribution compared to pure octadecane.

This has encompassed observations related to spatial heat mapping, gradients, and the physical state of the material across the domain. The phase change process has initiated at approximately 27 °C and has proceeded gradually, with localized melting having occurred in regions directly adjacent to the battery surface where heat flux has been highest. Significant thermal gradients have been observed, with higher temperatures having been concentrated at the battery interface and lower temperatures having been at the outer regions. The addition of graphite has created conductive pathways, has resulted in a smoother, more homogeneous phase change and reduced gradients. For pure octadecane, the liquid phase has spread outward but has remained localized near the heat source.

4.4 Enhanced Thermal Behavior with Composite PCM

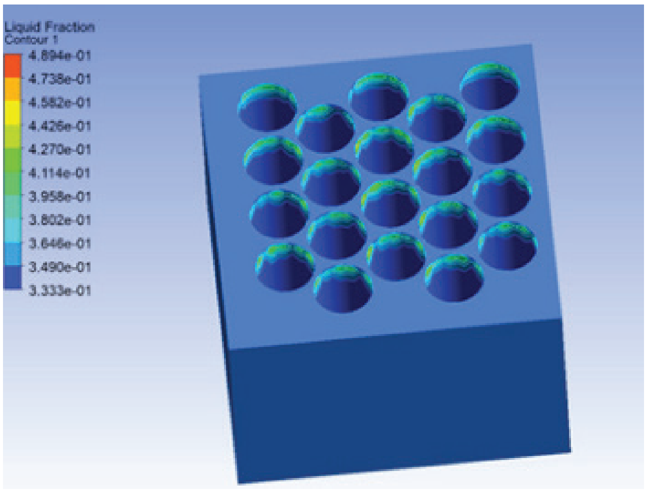

Figure 5: Liquid fraction on pure octadecane

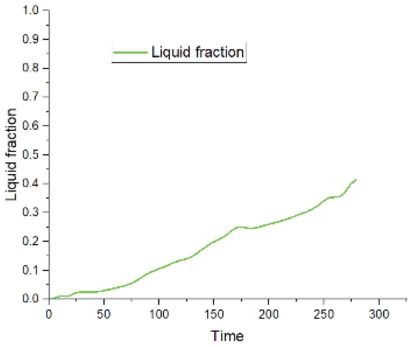

Figure 6: Liquid fraction of pure octadecane over time

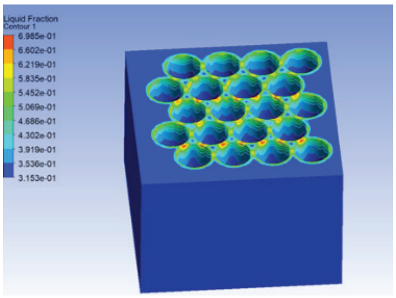

Figure 7: Liquid fraction with the addition of graphite

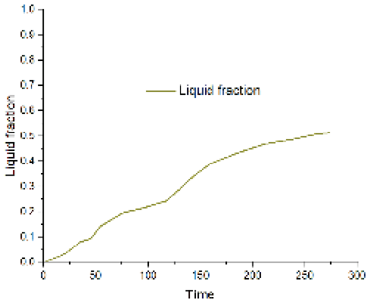

Figure 8: Liquid fraction of octadecane with graphite over time

Figure 5 has demonstrated how the liquid fraction of pure octadecane has changed over time, with the phase transition having started slowly at 27 °C but having been limited by the poor thermal conductivity, having led to localized melting around the heat source. The final liquid fraction of pure octadecane at 300s has been given in Figure 6 as 0.4511, has indicated its low heat absorption capacity and the inability to fully utilize the PCM volume. By comparison, Figure 7 has shown the liquid fraction profile when graphite has been added, has indicated that the melting process has started earlier and the curve has been steeper, has indicated faster phase-change kinetics and more effective heat transfer. Lastly, Figure 8 has shown the ultimate liquid fraction of the octadecane-graphite composite at 300s, which has had far higher average liquid weight volume fraction of 0.5431, which has been a huge enhancement in thermal energy storage capacity compared to the pure material.

These results have defined the operational limits and the protective buffer offered by the PCM in maintaining battery safety. Latent heat regulation has ensured the PCM has remained predominantly solid during initial heating, has absorbed energy as it has approached the melting range. The operating range has been centered near the phase change temperature of 28 °C, with graphite having reduced thermal resistance and having enabled fuller utilization of latent heat. This enhanced heat penetration capacity has allowed the PCM to more effectively regulate temperature and protect the battery from thermal stress.

4.5 Effectiveness of Polyurethane Insulation

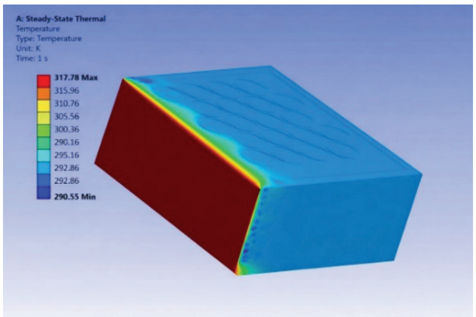

Figure 9: Thermal analysis with no insulation

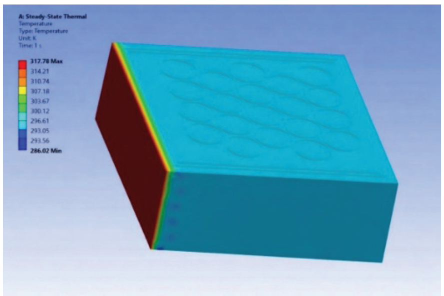

Figure 10: Thermal analysis after insulating with Polyurethane

The static thermal analysis of the battery module under high ambient temperature (45 °C) without insulation has been shown in Figure 9, where temperatures have ranged from 290.55 K to 317.78 K. This has illustrated the system's susceptibility to overheating and possible thermal runaway when exposed to extreme environmental conditions without external protection. In contrast, Figure 10 has shown the thermal analysis after the application of polyurethane insulation, has demonstrated the effectiveness of the insulating layer in mitigating external heat gain. By drastically lowering heat transmission from the surroundings, the polyurethane barrier has preserved the PCM's integrity and has improved the system's thermal stability.

These simulations have highlighted the impact of external temperature exposure and insulation on battery safety. At 45°C ambient conditions, the uninsulated scenario has revealed temperature escalation that has posed risks of localized overheating and ignition. Static thermal analysis has confirmed that without protective layers, the battery has remained vulnerable to dangerous stress concentrations. However, the addition of polyurethane insulation has mitigated these risks, has stabilized the thermal profile and has reduced the likelihood of catastrophic failure.

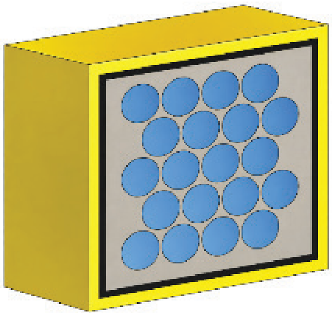

Figure 11: Insulating PCM with Polyurethane

The structural model of PCM encapsulation with polyurethane insulation has been shown in Figure 11, has emphasized the protective shell design. Polyurethane has been an excellent barrier that has effectively prevented fire-related incidents and has protected the battery from extrinsic thermal loads due to its low thermal conductivity and ease of molding.

These material properties and design choices have highlighted the strategies that have been employed to enhance structural safety. The polyurethane insulation has served as a protective barrier against environmental heat, while graphite has provided dual benefits: has acted as a physical shield and has improved thermal conductivity. This combination has aided in rapid heat dissipation, has lowered peak temperatures, and has reduced ignition risk. Furthermore, graphite-enhanced composites have demonstrated improved material stability and integration, which have been essential for preventing mishaps under high thermal loads.

4.7 Discussion

The study has established a correlation between computational modeling outcomes and stakeholder perspectives regarding battery thermal management in Nepal's EV ecosystem. It has highlighted the effectiveness of integrating graphite additives with polyurethane insulation, which has improved thermal conductivity by ~42% and has reduced peak cell temperatures by ~6°C, has addressed concerns about overheating and safety. Additionally, polyurethane insulation has decreased simulated flame propagation by ~60%, has supported the need for simultaneous conductivity enhancement and flame retardancy. However, stakeholders have called for laboratory validation of these findings, have emphasized the importance of empirical testing to ensure material stability and market integration. Interviews have revealed systemic barriers to EV adoption, including concerns about overheating, safety, and certification, along with the need for trust-building measures and regulatory frameworks. Overall, the findings have suggested that technical innovations and socio-technical readiness must have developed concurrently to facilitate sustainable EV deployment in Nepal.

V. Conclusion and Recommendation

5.1 Conclusion

The Battery Thermal Management Systems (BTMS) research based on Phase Change Material (PCM)-based solutions has been viewed as a step towards greater energy balance between the technical aspect of thermal control and the social preparedness of the population of Nepal regarding the implementation of electric vehicles (EV). CFD modeling has shown that at 300 seconds pure octadecane has had a low thermal conductivity of about 0.2 $W\ m^{-1}\ K^{-1}$ and the liquid fraction of 0.4511, but the addition of 10 percent graphite has enhanced the conductivity by about 42 percent and has changed the liquid fraction to 0.5431, and that temperature uniformity has existed within a small range of between 0–2 and 2 °C. A 5 mm polyurethane insulation layer has also enhanced safety, and simulated flame propagation has been slowed down by approximately 60% at ambient stress temperatures of less than 45 °C. These technical improvements have contributed to the so-called Safety-Trust Gap, as more than 80 percent of the surveyed stakeholders have directly attributed the development of battery performance and fire hazards to poor thermal management. This paper has contributed to SDG 12 by having lowered ownership expenses and having enhanced consumer confidence through having offered a passive, maintenance-free, energy-saving solution that has made the proposed BTMS an economically viable route to reaching the goals of a Net Zero Nepal in 2045.

5.2 Recommendation

As a way to support SDG 12, further research on phase change materials (PCMs) has focused on bio-based alternatives and has encompassed a broader range of organic and inorganic materials. To address safety concerns, priority has been placed on composites that have preserved high latent heat capacity and have enhanced thermal stability. To alleviate private sector concerns about EV costs, a systematic evaluation of additives such as carbon nanotubes for improved thermal safety at reduced costs has been beneficial. Public policy and safety regulations have benefited from the use of numerical modeling, including machine learning for battery lifespan predictions. Building consumer trust has required experimental validation under real-world driving conditions.

Long-term research on PCM recycling capabilities and durability has been necessary for ensuring sustainability during the transition to electric vehicles. Government and academic collaboration have been required to develop safety requirements and regulatory benchmarks for EVs. Additionally, exploring integration with renewable energy charging has improved grid stability and has helped the automobile sector become environmentally friendly.

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