

Thermal Behavior of Lithium-Ion Batteries in Electric Vehicles Under the Hot Climatic Conditions of The Republic of Uzbekistan and an Assessment of Potential Harm to Humans

Odil Shadiyevich Aminov¹, Khabib Khalikovich Razzakov²

^{1,2} Associate Professor, Candidates of Technical Sciences, Samarkand State Technical University named after Mirzo Ulugbek

ARTICLE INFO

Keywords:

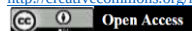
electric vehicle, lithium-ion battery, traction battery, thermal behavior, thermal runaway, high temperature, hazardous factors, toxic gases, human safety, Uzbekistan.

Vol.01, No.04, 2026

<https://doi.org/10.5281/zenodo.22683723>

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CCBY4.0).

<http://creativecommons.org/licenses/by/4.0/>



ABSTRACT

The article examines the thermal behavior of lithium-ion traction batteries in electric vehicles operated under the hot and sharply continental climatic conditions of the Republic of Uzbekistan. The relevance of the study stems from the rapid growth in the number of electric vehicles in the country and from the effects of high ambient temperatures on electrochemical processes, internal resistance, heat generation, and the operational safety of battery systems. According to the National Statistics Committee, 86,100 electric vehicles were registered in Uzbekistan as of 1 October 2025. High ambient temperatures, combined with solar radiation, heated road surfaces, intensive vehicle operation, and fast charging, are shown to increase battery-pack temperature. The issue is especially significant for Uzbekistan because summer air temperatures reach 35–40 °C across most of the country and rise to 43–48 °C or higher during certain periods.

The sequence through which a hazard develops is considered as follows: rising battery temperature → acceleration of electrochemical and parasitic reactions → increased heat generation → localized overheating → cell degradation → possible thermal runaway. Potential hazards to humans arising from accidental battery damage are analyzed separately, including high temperature, thermal radiation, toxic and flammable gases, aerosol particles, and products of electrolyte thermal decomposition. Recent studies show that lithium-ion batteries undergoing thermal runaway may release CO, CO₂, H₂, hydrocarbons, and HF, thereby creating simultaneous toxic, fire, and explosion hazards.

An approach is proposed for the integrated assessment of thermal hazards in electric-vehicle battery systems, taking into account Uzbekistan's climatic conditions, operating mode, state of charge, and the effectiveness of the thermal-management system.

Introduction

The expanding use of electric vehicles is one of the principal trends in the development of modern transport energy systems. The central component of an electric vehicle is its lithium-ion traction battery, which stores electrical energy and supplies it to the electric motor.

At the same time, increasing battery capacity and energy density imposes more stringent thermal-safety requirements. A lithium-ion battery is a complex electrochemical system in which charging, discharging, and ageing are accompanied by heat generation. Under normal operating conditions, this heat must be effectively removed by the battery thermal management system (BTMS).

This problem is particularly important in countries with hot climates. The Republic of Uzbekistan has a sharply continental climate characterized by long, dry, hot summers and substantial diurnal and seasonal temperature variations. The mean temperature in July, the warmest month, is approximately 27–29 °C, rising to about 30–32 °C in the south. Actual extreme temperatures, however, are considerably higher than these mean values. According to Uzhydromet, average maximum temperatures in July are 35–37 °C across most of the country and 38–40 °C in southern and desert regions. During severe heat waves, temperatures may reach 43–45 °C, while values of 46–48 °C have been recorded in some areas.

Consequently, the thermal load imposed on an electric-vehicle battery in Uzbekistan is determined by more than ambient air temperature alone. The following factors must also be considered:

- direct solar radiation;
- heating of the vehicle body and underbody components;
- heating of the road surface;
- air temperature beneath the vehicle;
- internal heat generation within the battery;
- current loads during acceleration;
- regenerative-braking mode;
- direct-current fast charging;
- battery state of charge (SOC);
- battery age and degree of degradation.

Recent studies indicate that the optimal operating temperature range for lithium-ion batteries is approximately 15–35 °C, while higher temperatures and larger temperature gradients between cells impair performance and safety. Operating electric vehicles in Uzbekistan therefore requires a dedicated assessment of battery-system thermal safety, aimed not only at preserving battery service life but also at protecting people.

2. Materials and Methods

The study was conducted through an analysis of the scientific literature on the thermal behavior of lithium-ion batteries, thermal-runaway mechanisms, thermal-management systems, and the toxicological hazards posed by products released during accidental decomposition.

Data from Uzhydromet and international climate studies concerning the Republic of Uzbekistan were used as the baseline climatic information. Statistical data on the adoption of electric vehicles in the country were also considered. As of 1 October 2025, 86,100 electric vehicles were registered in Uzbekistan.

A simplified heat balance may be used to assess the thermal state of a battery:

$$m_b c_p (dT_b/dt) = \dot{Q}_{gen} - \dot{Q}_{cool} \quad (1)$$

where:

- m_b — mass of the battery pack, kg;
- c_p — specific heat capacity of the battery, J/(kg·K);
- T_b — mean battery-pack temperature, °C;
- $\dot{Q}_{gen}$ — total heat-generation rate, W;
- $\dot{Q}_{cool}$ — rate of heat removal by the cooling system, W.

Total heat generation may be expressed as:

$$\dot{Q}_{gen} = \dot{Q}_J + \dot{Q}_{ent} + \dot{Q}_{side} \quad (2)$$

where:

- $\dot{Q}_J$ — Joule heat generation;
- $\dot{Q}_{ent}$ — entropic heat contribution;
- $\dot{Q}_{side}$ — heat generated by parasitic electrochemical reactions.

At high currents, the principal component may be approximated as:

$$\dot{Q}_J = I^2 R_{int} \quad (3)$$

where I is the battery current and R_{int} is its internal resistance.

It is particularly important to account for the following feedback relationship under certain battery conditions:

$$T \uparrow \rightarrow R_{int} \uparrow \rightarrow \dot{Q}_J \uparrow \rightarrow T \uparrow$$

The following groups of hazardous factors are proposed for assessing potential human exposure:

Group of factors	Source	Potential effect
High temperature	Battery overheating	Burns; thermal stress
Thermal radiation	Battery fire	Burns; overheating of the body
Toxic gases	Electrolyte decomposition	Inhalation toxicity
HF	Thermal decomposition of fluorine-containing components	Irritant and toxic effects
CO	Combustion and incomplete oxidation	Systemic toxicity
Flammable gases	Thermal runaway	Fire and explosion
Aerosols	Cell destruction	Inhalation exposure
Electrical voltage	High-voltage system	Electric shock

3. Results

3.1. Effect of Uzbekistan's Climate on Battery Thermal Behavior

The principal feature of electric-vehicle operation in Uzbekistan is the combined effect of high air temperature and intense solar exposure.

During summer operation, ambient temperatures may range from 35 to 45 °C and may rise even higher during extreme periods. In July 2026, Uzhydromet reported temperatures of 43–45 °C across the country and 46–48 °C in southern and desert regions.

For the battery system, this means that cooling must begin from an already elevated initial temperature. If the battery temperature is, for example, 35–40 °C before the vehicle starts moving, additional heat generated by electrical losses may push the battery into an unfavorable temperature range.

Accordingly, thermal risk is determined not only by the absolute battery temperature but also by:

$$\Delta T = T_{battery} - T_{ambient} \quad (4)$$

as well as by the rate of temperature change:

$$dT/dt$$

A rapid temperature rise in individual cells may be more hazardous than a comparatively high but stable temperature throughout the battery pack.

3.2. Fast Charging as an Additional Source of Thermal Load

A particularly substantial thermal load arises during direct-current fast charging.

As charging current increases, Joule losses rise approximately in proportion to the square of the current:

$$\dot{Q}_J \sim I^2 R \quad (5)$$

Therefore, doubling the charging current may theoretically produce an approximately fourfold increase in the corresponding resistive component of heat generation, provided that resistance remains constant.

This creates an additional problem in a hot climate: charging begins when the battery is already at an elevated temperature, while additional heat is simultaneously generated within it.

Thus, the following combination may be regarded as an adverse operating scenario:

high ambient temperature + high SOC + high charging power

3.3. Thermal Runaway

The most hazardous condition is thermal runaway—a self-accelerating process of thermal destruction within a battery cell.

Studies show that thermal runaway may be initiated by thermal, electrical, or mechanical abuse, including overheating, an internal short circuit, physical damage, overcharging, and other factors.

In simplified form, the process may develop as follows:

temperature rise → acceleration of parasitic reactions → additional heat generation → further temperature rise → destruction of cell components → gas release → thermal runaway → propagation to adjacent cells

At battery-pack level, this creates the risk of a cascading thermal reaction. Heat released by one cell may raise the temperature of adjacent cells and initiate their failure. Contemporary thermal-runaway models therefore treat heat transfer between neighboring cells as one of the principal mechanisms of failure propagation.

3.4. Hazards to Humans

Of particular importance is the fact that a battery accident presents not only a fire hazard but also chemical and toxicological hazards.

Thermal runaway releases large quantities of gaseous products. The scientific literature identifies, among others:

- CO;
- CO₂;
- H₂;
- CH₄;
- C₂H₄;
- HF;
- vapors of organic electrolyte.

Some of these substances are toxic, whereas others are flammable or explosive.

HF is especially hazardous. It is formed through the decomposition of fluorine-containing components in the electrolyte and other battery materials.

Battery destruction may also generate fine particulate matter and metallic aerosols. Studies indicate that particles released during thermal runaway contain substantial quantities of metallic elements.

Human exposure must therefore be considered across several dimensions:

$$R_{human} = f(T, q_{gas}, C_{gas}, t, E_{thermal}, P) \quad (6)$$

where:

- T — temperature;
- q_{gas} — gas-release rate;
- C_{gas} — concentration of the toxic substance;

- t — duration of exposure;
- E_{thermal} — thermal radiation;
- P — ventilation conditions.

4. Discussion

The results indicate that the thermal safety of electric vehicles in Uzbekistan comprises several interconnected levels.

First level: climatic

High ambient temperatures reduce the available thermal margin of the battery cooling system. During hot periods, the battery begins operating under an already elevated thermal load.

Second level: operational

Intensive driving, frequent acceleration, regenerative braking, and fast charging increase current loads and internal heat generation.

Third level: technical

The effectiveness of the BTMS becomes critically important. Current studies identify air cooling, liquid cooling, phase-change materials, and combined systems as the principal approaches to battery thermal management.

For Uzbekistan, a combined cooling system incorporating a liquid circuit and the use of conditioned cabin air or the air-conditioning evaporator as an additional source of cooling capacity is of particular interest.

This approach is especially promising for subsequent experimental study using an actual electric vehicle.

Fourth level: human safety

Under normal operating conditions, people are not exposed to battery-decomposition products. In the event of an accident, damage, fire, or thermal runaway, however, a complex set of hazards arises:

heat + toxic gases + aerosols + flame + electrical hazards

An assessment limited to fire hazards is therefore insufficient.

A comprehensive assessment of harm and risk to humans must be developed to include:

- temperature exposure;
- thermal radiation;
- CO concentration;
- HF concentration;
- concentrations of other toxic gases;
- aerosol-particle content;
- duration of exposure;
- ventilation effectiveness;
- distance from the source;
- accident scenario.

5. Proposed Concept for Assessing Thermal Hazards

For further research, it is advisable to use the following integrated indicator:

$$K_{\text{risk}} = K_T + K_G + K_F + K_E \quad (7)$$

where:

- K_T — temperature component;
- K_G — gas/toxicological component;
- K_F — fire and thermal component;

- K_E — electrical component.

For a scientific study, this framework could provide the basis for a new methodology for assessing the harmful effects of electric-vehicle batteries under Uzbekistan's hot climatic conditions.

The development of the following mathematical model is particularly promising:

$$T_b = f(T_a, I, SOC, SOH, V, v, t)$$

where:

- T_b — battery temperature;
- T_a — ambient air temperature;
- I — current;
- SOC — state of charge;
- SOH — state of health;
- V — vehicle speed;
- v — airflow velocity;
- t — time.

At the next stage, the model may be experimentally validated using a specific electric-vehicle model operated in Uzbekistan.

6. Conclusion

The analysis demonstrates that the thermal behavior of lithium-ion traction batteries is one of the key factors determining the safety of electric vehicles operated in the Republic of Uzbekistan.

High ambient temperatures, intense solar exposure, and prolonged hot periods create additional conditions that raise battery-pack temperature. Official climate data for 2025–2026 confirm periods during which air temperatures in certain regions of Uzbekistan reached 43–48 °C.

As battery temperature rises, the demand placed on the thermal-management system increases, ageing processes accelerate, and an unfavorable combination of factors heightens the risk of thermal runaway.

The danger posed to humans during a thermal-runaway accident is not limited to high temperatures and fire. Toxic and flammable gases, including HF and CO, as well as aerosol particles and products of thermal decomposition, also play a significant role.

Accordingly, assessments conducted for conditions in Uzbekistan must move beyond electric-vehicle electrical and fire safety alone and adopt an integrated evaluation of the climatic, thermal, chemical, toxicological, and electrical hazards associated with the battery system.

A promising direction for further research is the development of a mathematical model describing battery thermal behavior with due regard to Uzbekistan's climatic parameters, followed by experimental validation using an actual electric vehicle. Particular attention should be given to the effectiveness of air cooling based on the vehicle's existing air-conditioning system, since this approach may improve thermal-management performance without substantially increasing design complexity.

References

1. A state-of-the-art review on heating and cooling of lithium-ion batteries for electric vehicles. *Journal of Energy Storage*. 2024;76:109852. <https://doi.org/10.1016/j.est.2023.109852>.
2. A review on mechanisms, characteristics and relating hazards of vent gases from thermally abused Li-ion batteries. *Journal of Energy Storage*. 2024;84:110892. <https://doi.org/10.1016/j.est.2024.110892>.

3. Review of gas emissions from lithium-ion battery thermal runaway failure—Considering toxic and flammable compounds. *Journal of Energy Storage*. 2024;87:111288. <https://doi.org/10.1016/j.est.2024.111288>.
4. A comprehensive review on thermal runaway model of a lithium-ion battery: Mechanism, thermal, mechanical, propagation, gas venting and combustion. *Renewable Energy*. 2024;229:120762. <https://doi.org/10.1016/j.renene.2024.120762>.
5. Advancements in the safety of lithium-ion battery: The trigger, consequence and mitigation method of thermal runaway. *Chemical Engineering Journal*. 2024;481:148450.
6. Review of prevention and mitigation technologies for thermal runaway in lithium-ion batteries. *Aerospace Traffic and Safety*. 2024;1(1):55–72. <https://doi.org/10.1016/j.aets.2024.06.002>.
7. Insights into extreme thermal runaway scenarios of lithium-ion battery fire and explosion: A critical review. *Journal of Energy Storage*. 2024;88:111532.
8. Thermal runaway process in lithium-ion batteries: A review. *Next Energy*. 2025;6:100186. <https://doi.org/10.1016/j.nxener.2024.100186>.
9. Characteristics of particle emissions from lithium-ion batteries during thermal runaway: A review. *Journal of Energy Storage*. 2024;78:109980.
10. A review on thermal runaway warning technology for lithium-ion batteries. *Renewable and Sustainable Energy Reviews*. 2024;206:114882.
11. Mechanism and control strategies of lithium-ion battery safety: A review. *Small Methods*. 2024. <https://doi.org/10.1002/smtd.202400029>.
12. World Bank. Uzbekistan Country Climate and Development Report. Washington, DC: World Bank Group; 2023.
13. World Bank. Uzbekistan Climate Risk Country Profile. Climate Change Knowledge Portal.
14. Agency of Hydrometeorological Service of the Republic of Uzbekistan. Climatic Characteristics of July and Weather Forecast. 2025. [In Russian].
15. Agency of Hydrometeorological Service of the Republic of Uzbekistan. June and the Summer of 2026. 2026. [In Russian].
16. National Statistics Committee of the Republic of Uzbekistan. How Many Electric Vehicles Are Registered in Uzbekistan? 11 December 2025. [In Russian].