

Formulation design for long-life low-conductivity battery coolants

- Analysis of factors contributing to conductivity increase in low-conductivity battery coolants -

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In battery electric vehicles (BEVs), reliable thermal management is essential to ensure battery safety, durability, and stable performance under increasingly severe operating conditions such as rapid charging and high-power driving. Low-electrical-conductivity coolants have been introduced to mitigate the risk of abnormal heating caused by coolant leakage; however, their electrical conductivity tends to increase over time during actual use. The primary factors for this increase are oxidation of ethylene glycol and dissolution of ionic species from cooling system components. In low-conductivity coolant systems, where initial conductivity is intentionally minimized, even a small amount of ion leaching can have a significant impact on long-term electrical safety. Among various sources of ionic species, flux used in aluminum brazing is considered a dominant contributor because it contains fluoride and alkali metal components that can dissolve into the coolant. Furthermore, emerging regulations and increasing thermal loads in BEVs require more stringent control of long-term conductivity stability. Therefore, this study focuses on suppressing flux-derived ion dissolution and proposes a formulation design strategy for extending coolant service life.

To evaluate the suppression effects of additives, several aluminum corrosion inhibitors were investigated using a circulation test with automotive battery cooling system components. The effectiveness of each inhibitor was evaluated based on the conductivity evolution of the coolant, which reflects the degree of ion dissolution from flux and other components. Figure 1 shows the conductivity behavior during the circulation test. The combined use of aluminum corrosion inhibitors A and C significantly suppresses the increase in conductivity compared with the use of inhibitor C alone. In particular, the initial rapid increase in conductivity is moderated, and the subsequent re-increase observed after a certain period in the single-inhibitor system is effectively eliminated in the combined formulation. This result indicates that the combination of inhibitors A and C stabilizes coolant conductivity over an extended duration and contributes to longer coolant service life.

To clarify the mechanism behind this behavior, the retention behavior and reaction characteristics of each inhibitor were analyzed. Inhibitor C effectively interacts with flux-derived ions and contributes to ion dissolution suppression in the early stage. However, inhibitor C is gradually consumed through reactions with aluminum ions originating from flux and with dissolved species such as calcium ions leached from rubber components. As a result, its concentration in the coolant decreases, reducing its ability to maintain suppression performance over time. In contrast, inhibitor A does not form insoluble products with aluminum ions and remains dissolved in the coolant. Its high retention level throughout the test period suggests that inhibitor A maintains its active state in the liquid phase and provides sustained suppression of ion dissolution. In addition, the presence of inhibitor A appears to mitigate the rapid depletion of inhibitor C, thereby supporting the long-term effectiveness of the combined formulation.

These findings demonstrate that the combination of inhibitors A and C achieves both strong initial suppression and long-term stability through complementary mechanisms. Inhibitor C contributes primarily to early-stage flux-derived ion suppression, while inhibitor A maintains long-term functionality by remaining in solution and reducing excessive additive consumption. This indicates that controlling both additive reactivity and retention behavior is a key design factor for long-life low-conductivity coolant formulations. The proposed formulation design concept is not limited to initial corrosion protection, but also incorporates time-dependent interactions between additives and surrounding components. This approach is essential for realizing low-conductivity coolants that can maintain electrical safety over prolonged operation. The developed technology has been applied to battery cooling systems since 2025 and contributes to maintaining electrical safety and system reliability under high-load and high-temperature operating conditions.

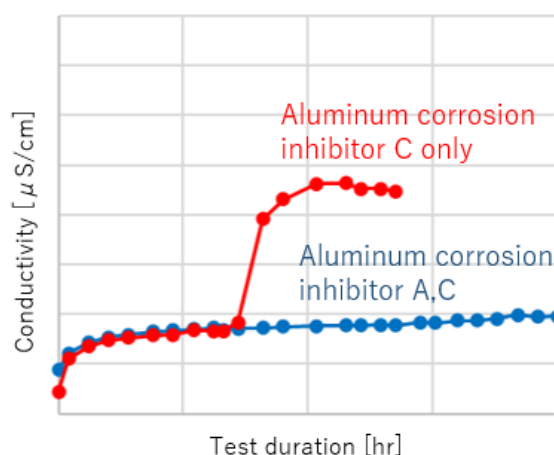


Fig.1 Effect of Aluminum Corrosion Inhibitors A and C on Flux Dissolution Suppression