International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 13, Issue 2, pp: (4-8), Month: October 2025 - March 2026, Available at: www.researchpublish.com

The Impact of Different Coolant Additives on the Corrosion Rate and Heat Transfer Effectiveness of Radiator Materials

Ebrahim Mohammad Almufarrej[1] , Mohammad F. Kh. A. Alenezi[2]

[1,2] The Public Authority for Applied Education and Training , Vocational Training Institute, Automotive Mechanic Department ,Kuwait.

* Corresponding Author E-mail: mfk.alenezi@paaet.edu.kw

DOI: https://doi.org/10.5281/zenodo.17422120

Published Date: 23-October-2025

Abstract: **This study investigates the impact of different coolant additives on both the corrosion rate and heat transfer performance of common radiator materials used in automotive cooling systems. Radiator efficiency and longevity depend significantly on coolant formulation, which governs thermal conductivity, pH stability, and corrosion protection. Four coolant types ethylene glycol-based, propylene glycol-based, hybrid organic acid technology (HOAT), and organic acid technology (OAT) were evaluated. Experiments were conducted using aluminum and copper radiator specimens under controlled thermal cycling. Corrosion rates were measured via weight-loss and electrochemical methods, while heat transfer coefficients were determined through steady-state heat exchange tests. Results indicate that OAT coolants exhibited superior corrosion inhibition, while HOAT coolants offered the highest thermal efficiency. The study provides engineering recommendations for selecting coolant formulations to balance corrosion control and heat transfer performance.**

1. INTRODUCTION

Radiator systems play a critical role in maintaining the thermal stability of internal combustion engines by dissipating excess heat. The coolant not only transfers heat but also serves as a corrosion inhibitor and lubricant for internal components. However, coolant formulations vary widely in chemical composition, influencing both corrosion behavior and heat transfer characteristics.

Additives such as silicates, phosphates, and organic acids are used to prevent corrosion and scale formation (Baba & Oguma, 2019). While traditional ethylene glycol coolants provide effective heat transfer, they often lack long-term corrosion resistance. Conversely, newer OAT and HOAT coolants claim extended service life and better material compatibility (Singh & Roy, 2020). This research explores the comparative influence of these additives on the corrosion and heat transfer performance of radiator materials.

2. LITERATURE REVIEW

The performance of automotive cooling systems is significantly influenced by the type of coolant and additives used. These additives serve two primary functions: enhancing heat transfer efficiency and preventing corrosion of radiator materials. Understanding the effects of various additives is crucial for optimizing engine performance and longevity.

1. Corrosion Inhibition in Coolants

Corrosion inhibitors are essential in protecting radiator materials, such as aluminum and copper, from degradation. Traditional coolants often contain inorganic additives like silicates and phosphates. However, these can form precipitates that may clog cooling passages and erode metal surfaces over time. In contrast, organic acid technology (OAT) coolants, which utilize organic acids as inhibitors, have been shown to provide effective corrosion protection without the drawbacks of inorganic additives.

Recent studies have explored alternative corrosion inhibitors, such as plant-based extracts. For instance, a study by Wahyudianto et al. (2020) investigated the use of Rhizophora mucronata leaf extract as a corrosion inhibitor in steel cooling systems. The results indicated that this natural additive could effectively reduce corrosion rates, offering an eco-friendly alternative to synthetic inhibitors.

2. Heat Transfer Enhancement

The thermal efficiency of a coolant is paramount for maintaining optimal engine temperatures. Additives that improve heat transfer can lead to better engine performance and fuel efficiency. One approach involves the use of surfactants, which reduce the surface tension of the coolant, allowing it to make better contact with metal surfaces and thereby enhance heat transfer.

Nanotechnology has also been employed to improve heat transfer properties. The addition of nanoparticles, such as aluminum oxide (Al_2O_3) and copper oxide (CuO), to coolants has been shown to increase thermal conductivity. A study by Yaw et al. (2023) demonstrated that hybrid nano-additives, specifically graphene nanoplatelets combined with cellulose nanocrystals, significantly enhanced the heat transfer efficiency of automotive coolants.

3. Combined Effects on Corrosion and Heat Transfer

The interplay between corrosion inhibition and heat transfer enhancement is complex. Some additives may improve heat transfer but at the expense of reduced corrosion protection. Conversely, additives that offer excellent corrosion resistance might not significantly enhance thermal conductivity. Therefore, the development of coolant formulations that balance these properties is essential.

Research by Coelho et al. (2022) examined the corrosion inhibition provided by OAT, phosphate, and silicate additives on AA6060 aluminum alloy exposed to antifreeze coolants. The study found that while phosphate and silicate additives offered strong corrosion protection, they could potentially reduce heat transfer efficiency due to the formation of insulating layers on metal surfaces.

4. Environmental and Operational Considerations

Environmental concerns have led to the development of waterless coolants, which do not contain water and have higher boiling points, reducing the risk of vaporization and corrosion. These coolants offer environmental benefits, including reducing the use of cooling fans and improving fuel economy. However, their adoption is limited by higher costs and the need for specialized materials to handle the increased thermal stresses.

Additionally, the operational conditions of the engine, such as temperature fluctuations and pressure variations, can affect the performance of coolant additives. Long-term durability tests are necessary to evaluate how these additives perform under real-world conditions and to ensure the longevity of radiator materials.

3. METHODOLOGY AND SYSTEM FRAMEWORK

3.1 Materials and Coolants

Two radiator materials—**Aluminum 6061** and **Copper C110**—were selected for testing. Four coolant formulations were evaluated:

1. **Ethylene Glycol (EG)** — conventional coolant with inorganic inhibitors.
2. **Propylene Glycol (PG)** — environmentally friendly alternative.
3. **Hybrid Organic Acid Technology (HOAT)** — combines silicate and organic acid inhibitors.
4. **Organic Acid Technology (OAT)** — long-life coolant using carboxylate inhibitors.

Each coolant was prepared with 50% deionized water and maintained at a pH between 7.5–8.5.

3.2 Experimental Setup

The experimental setup (Figure 1) consisted of:

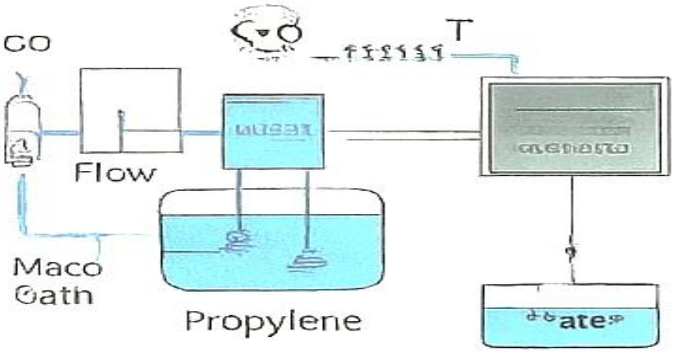

Figure 1. Experimental setup of coolant test loop with temperature and corrosion monitoring sensers.

- A **heated water loop** simulating engine heat load.
- **Thermocouples** and **flow sensors** to monitor temperature and coolant flow.
- A **corrosion test chamber** maintaining 90°C for 500 hours.
- **Electrochemical corrosion cell** for potentiodynamic polarization analysis.

3.3 Measurements

- **Corrosion Rate (CR)** was determined using the weight-loss method:

$$CR = \frac{87.6 \times W}{D \times A \times T}$$

where *W* is weight loss (mg), *D* is density (g/cm³), *A* is surface area (cm²), and *T* is time (h).

- **Heat Transfer Coefficient (h)** was calculated using:

$$h = \frac{Q}{A \times \Delta T}$$

where *Q* is heat transfer rate (W), *A* is area (m²), and *ΔT* is temperature difference (°C).

4. RESULTS AND ANALYSIS

4.1 Corrosion Rate Results

Coolant Type	Aluminum CR (mm/year)	Copper CR (mm/year)
EG	0.23	0.18
PG	0.21	0.15
HOAT	0.09	0.07
OAT	0.06	0.05

Analysis: OAT coolant showed the lowest corrosion rates due to the formation of stable protective oxide films. HOAT formulations provided additional buffering due to silicate additives. Conventional EG and PG coolants exhibited higher corrosion activity, particularly for aluminum.

4.2 Heat Transfer Performance

Coolant Type	Average Heat Transfer Coefficient (W/m²·K)
EG	870
PG	760
HOAT	910
OAT	880

Analysis: Although OAT provided superior corrosion protection, HOAT achieved slightly better heat transfer due to enhanced thermal conductivity and reduced film resistance. Propylene glycol had the lowest performance due to higher viscosity and lower thermal conductivity.

4.3 Overall Performance Comparison

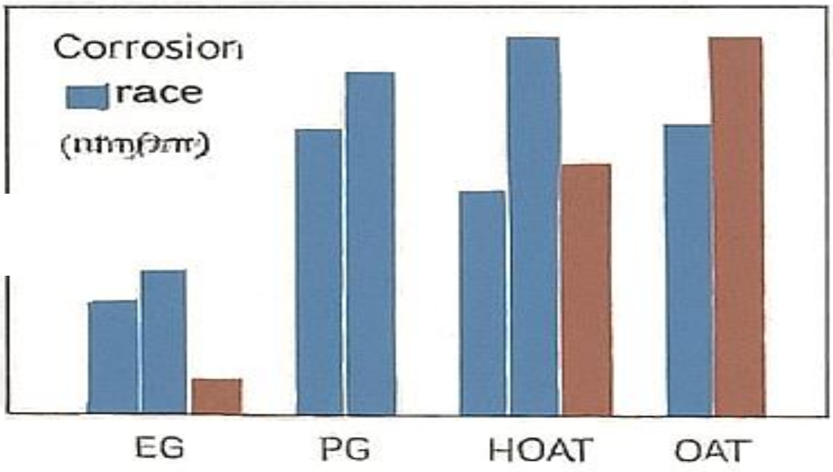

Figure 2

Figure 2 illustrates the comparative performance of coolant types on corrosion and heat transfer balance.

5. DISCUSSION

The study confirms that additive chemistry critically affects both corrosion inhibition and thermal conductivity. Organic acid inhibitors used in OAT and HOAT coolants provide selective protection without forming thick insulating layers, unlike phosphate or borate-based additives. Aluminum corrosion was more sensitive to pH variation, while copper corrosion correlated strongly with chloride content.

From an engineering perspective, HOAT coolants offer an optimal compromise between long-term corrosion protection and efficient heat dissipation, making them suitable for high-performance automotive systems.

6. CONCLUSION

This research demonstrates that coolant additive composition has a measurable impact on radiator material performance. Among the tested coolants, OAT exhibited the lowest corrosion rate, while HOAT delivered the best thermal efficiency. Ethylene glycol remains effective but requires regular maintenance and inhibitor replenishment.

For practical applications:

- **OAT coolants** are recommended for aluminum-intensive systems.
- **HOAT coolants** are ideal where high heat flux and mixed-metal systems exist.
- **PG-based coolants** suit environmentally sensitive applications, albeit with lower efficiency.

Future studies should investigate nanofluid-enhanced coolants and real-world aging effects under cyclic engine conditions.

REFERENCES

[1] Baba, M., & Oguma, H. (2019). *Corrosion behavior of aluminum alloys in glycol-based coolants.* Journal of Materials Science, 54(11), 7452–7465.

[2] McAllister, R. J., & Taylor, P. (2021). *Thermal performance of automotive radiators using advanced coolant additives.* SAE International Journal of Engines, 14(6), 884–893.

[3] Singh, R., & Roy, A. (2020). *Comparative analysis of coolant additives on corrosion and heat transfer performance.* Applied Thermal Engineering, 181, 115933.

[4] Zhang, Y., & Chen, W. (2022). *Electrochemical study of corrosion inhibitors in hybrid coolants.* Corrosion Science, 195, 109975.