

A historical perspective on liquid cooling media

Abstract

Liquid cooling media have played a critical role in the development of modern machinery, engines, and industrial systems for over two centuries. This white paper provides a historical overview of the evolution of liquid cooling media, tracing the journey from early water-based systems through the introduction of alcohol and glycol antifreezes, to today's advanced formulations. It explores the expansion of liquid cooling across key industries including automotive, industrial manufacturing, electronics, aerospace, and renewable energy. The technological breakthroughs and challenges faced along the way are highlighted. The paper also examines how growing environmental and safety regulations have shaped the development of safer, more sustainable cooling fluids. Recent trends toward improved efficiency, integration with smart systems, and emerging applications are discussed, emphasizing the ongoing innovation in this vital field. This historical context provides engineers and industry professionals with a broad understanding of how liquid cooling media have evolved and the factors driving future advancements.

1. Introduction

From the earliest steam engines to today's electric vehicles and high-performance data centers, managing heat has been a constant engineering challenge. Whether in engines, power plants, industrial processes, or electronics, thermal control is essential for performance, safety, and longevity. Among the many methods developed over time, the use of liquid cooling media stands out as one of the most versatile and widely adopted solutions.

Liquid cooling media in this context is commonly pure water or water-based mixtures and they have enabled generations of technological progress. As engineering demands have increased, so too have the expectations placed on cooling systems: better thermal performance, longer service life, chemical stability, environmental safety, and material compatibility. These demands have shaped the development and selection of cooling media for over a century.

This paper presents a historical overview of liquid cooling media, tracing their evolution from simple water-based systems to more complex and specialized fluids. It

provides engineers and technical professionals with a broad understanding of how liquid cooling practices have developed, which solutions have been used and why, and what challenges have emerged over time.

By examining this progression, we also highlight patterns: how certain problems such as corrosion, toxicity, freezing risks, and environmental impact, have driven innovation. Understanding these historical trends offers valuable insight as the industry now faces a new wave of demands: higher power densities, greater sustainability, and the need for smarter, safer cooling systems.

In this context, the history of liquid cooling media is not just a retrospective, it also helps illuminate the path forward.

2. The origins of liquid cooling

The origins of liquid cooling stretch back to the 18th century, when the Industrial Revolution brought about dramatic changes in how energy was produced, converted, and controlled. As machines became larger and more complex, they generated increasing amounts of heat that needed to

be managed effectively to prevent mechanical failure and performance loss.

Water: The first cooling medium

By the late 1700s, early steam engines began incorporating condensers, which used cooling water to convert exhaust steam back into liquid form. This was arguably the first formal use of water as a cooling medium, not just to prevent overheating, but as part of the energy cycle itself. These developments were essential to the wide-scale adoption of steam power throughout the 19th century.

In the late 1800s, as internal combustion engines emerged and began replacing steam engines in vehicles and machinery, water remained the default coolant. In early automobiles, stationary engines, and generators, simple gravity-fed systems circulated water through engine blocks and radiators. These designs lacked pumps or pressure regulation, but they marked the beginning of modern liquid cooling principles.

The arrival of heat exchangers

A heat exchanger is a device that transfers heat from one fluid to another without direct contact, and this concept began to take shape in the late 19th century. Early versions were used in steam engine condensers and chemical processing plants. By the early 20th century, more sophisticated designs such as shell-and-tube and plate heat exchangers began appearing, especially in industrial settings. These systems enabled more efficient, compact, and controlled cooling, and soon became central components in both industrial and automotive cooling systems.

Early challenges and limitations

Despite its advantages, water presented clear limitations. It could freeze in cold climates, leading to cracked engine blocks or burst pipes, and it corroded metal components over time. These issues were particularly problematic in early

automotive systems of the early 1900s [1], as cars became more common in regions with varied weather conditions.

Attempts to address these issues with basic additives led to the exploration of other cooling liquids setting the stage for the introduction of alcohol- and glycol-based antifreeze solutions in the decades to come.

A foundation for innovation

Throughout the 19th and early 20th centuries, water remained the cornerstone of liquid cooling. Its use laid the foundation for the development of radiators, circulation systems, and heat exchangers, all of which enabled greater control over engine temperatures and system reliability. These developments not only supported the rapid progress of industrial machinery but also became essential to the rise of the automobile industry, which would soon drive new demands for better and more adaptable cooling solutions.

In retrospect, the history of liquid cooling did not begin with synthetic fluids or advanced chemistries, but with the widespread, practical use of water, a simple medium that supported the mechanical age and opened the door for the next wave of innovation.

3. The rise of antifreeze: Alcohol to glycol

As liquid cooling systems became more widespread in the early 20th century, engineers began encountering serious problems related to cold temperatures. In colder climates, water-based cooling systems froze easily, leading to cracked radiators, ruptured engine blocks, and immobilized machinery. This posed a significant barrier to the reliability and year-round use of vehicles and equipment.

Alcohol: The first generation of antifreeze

In the 1910s and 1920s, a practical workaround emerged in the form of alcohol-based antifreeze, most commonly methanol and ethanol. These substances

were added to water to lower its freezing point, making the coolant usable during winter. Early automotive manuals often recommended drivers drain the radiator in cold weather or mix alcohol with water during winter months.

While simple and effective to a point, alcohol had several drawbacks:

- It had a low boiling point, meaning it evaporated easily.
- It was flammable, posing a safety risk.
- It offered little or no corrosion protection, which shortened the lifespan of cooling system components.

As engine designs became more advanced and vehicles more powerful, these limitations became harder to ignore.

The shift to glycol-based solutions

A major turning point came in the 1920s and 1930s with the introduction of ethylene glycol as a coolant additive. Unlike alcohols, ethylene glycol had a higher boiling point, lower volatility, and could be used in sealed systems with less evaporation loss. It also mixed easily with water and allowed flexible concentration ratios to meet a variety of temperature requirements.

Although pure ethylene glycol is flammable, it is significantly less flammable than alcohols like methanol or ethanol and poses less of a fire risk in the diluted mixtures commonly used in cooling systems. In practice, this made it a safer and more stable option, particularly in high-temperature engines and enclosed systems.

By the 1940s, especially during World War II, ethylene glycol-based antifreeze had largely replaced alcohol in military and industrial vehicles. After the war, it became the standard for civilian automobiles as well. Glycol offered year-round protection and better reliability, marking a significant advance in liquid cooling media.

Beyond freeze protection: Inhibitors and system compatibility

As the use of glycol-based antifreeze became mainstream, attention shifted to long-term system compatibility. Engineers found that glycol solutions, while chemically stable, could still cause corrosion, scaling, or degradation of seals and materials if not properly formulated. This led to the development of additive packages with corrosion inhibitors, pH stabilizers, and anti-foaming agents, that could be tailored to specific engine types or system requirements.

These refinements throughout the mid to late 20th century transformed liquid cooling from a simple maintenance item to a more engineered component of mechanical systems. Antifreeze had evolved from a seasonal fix into a year-round necessity, integrated into the very design of engines, radiators, and heat exchangers.

A lasting impact

The rise of antifreeze enabled the expansion of liquid-cooled systems into harsher environments, more powerful engines, and more sensitive applications. It allowed vehicles and industrial equipment to operate reliably across a broader temperature range, and laid the groundwork for modern, closed-loop cooling systems.

At the same time, glycol-based fluids introduced new challenges, including toxicity [2], environmental concerns, and long-term stability issues that would later inspire the search for safer, more sustainable, and better-performing alternatives.

4. Expansion across industries

As liquid cooling media evolved from simple water to more advanced antifreeze solutions, their use expanded rapidly across a wide range of industries throughout the 20th century. The growing complexity and power density of machines, combined with the increasing demands of industrialization

and modernization, meant that effective thermal management was no longer a niche concern but a critical component for success.

Automotive industry: The driving force

The automotive sector was one of the earliest and most influential adopters of liquid cooling technologies. From the early 1900s, as cars transitioned from luxury novelties to mass-market products, reliable engine cooling became essential. The introduction of glycol-based antifreeze in the mid-20th century allowed vehicles to operate reliably in diverse climates, from frigid winters to hot summers.

Radiators, pumps, and thermostats became standard components in liquid cooling circuits, supporting higher engine outputs and longer operating hours. Cooling system design also evolved to optimize fuel efficiency and emissions, foreshadowing the increasingly sophisticated thermal management seen in today's vehicles including hybrid and electric models.

Industrial manufacturing and power generation

Beyond transportation, liquid cooling played a critical role in industrial manufacturing and power generation throughout the 20th century. Large engines, turbines, compressors, and chemical reactors generated substantial heat that required controlled removal to maintain operational safety and efficiency.

Heat exchangers, often using water-glycol mixtures, were installed in factories, refineries, and power plants to regulate temperatures and recover energy. These systems became more complex with the introduction of closed-loop cooling circuits and corrosion-resistant materials, enabling plants to run continuously and safely under demanding conditions.

Cooling the digital age

With the rise of electronics and computing in the mid to late 20th century, liquid cooling found new applications. Early computer mainframes generated enough heat to require active cooling, and as semiconductor devices became more powerful, managing thermal loads became an industry challenge.

Although air cooling remained dominant for decades, the limitations of air as a coolant led to the exploration of liquid cooling for electronics, particularly in high-performance computing and later in data centers. Today, specialized water-glycol mixtures and dielectric fluids are used in cold plates, immersion cooling, and other advanced methods to ensure stable operation of critical digital infrastructure.

Aerospace and military applications

Aerospace and military systems presented unique challenges for liquid cooling due to space constraints, extreme operating conditions, and the need for reliability. Since the mid-20th century, specialized liquid cooling systems have been employed in aircraft engines, missile guidance electronics, and naval vessels.

The use of tailored coolant formulations and compact heat exchangers allowed these systems to maintain performance while minimizing weight and volume, critical factors in aviation and defense applications.

Renewable energy and emerging fields

More recently, liquid cooling has begun to play a vital role in renewable energy technologies, such as solar thermal plants and geothermal systems. These applications often use water or water-glycol mixtures for heat transfer and storage, balancing efficiency with environmental considerations.

Emerging technologies like electric vehicle battery cooling and high-density power electronics also rely on liquid cooling media tailored to specific thermal and chemical requirements — continuing the

tradition of innovation that has characterized this field for over two centuries.

5. Changing priorities: Environment, safety, and efficiency

As liquid cooling technologies matured throughout the 20th century, growing awareness of environmental impacts and user safety began to shape the industry's priorities. What started as a primarily technical challenge, removing heat effectively, soon expanded to include concerns about the chemicals used in cooling media, their toxicity, disposal, and long-term sustainability.

Environmental awareness and regulation

By the 1970s and 1980s, increasing environmental consciousness around the world led to more stringent regulations governing the production, use, and disposal of chemical substances, including those found in antifreeze and cooling fluids.

Ethylene glycol, while highly effective, posed toxicity risks to humans and wildlife if leaked or improperly disposed of [3]. Governments introduced guidelines and laws requiring manufacturers to limit hazardous substances, improve labeling, and develop safer alternatives. For example:

- In the United States, the Clean Water Act and later environmental protection regulations mandated stricter controls on coolant discharge and spill prevention.
- In the European Union, directives like the REACH regulation pushed for evaluation and reduction of hazardous chemicals in industrial products.

These regulatory pressures encouraged research into less toxic, biodegradable fluids, such as propylene glycol and organic acid technology (OAT)-based formulations, which offered improved environmental profiles.

Worker and user safety

Alongside environmental concerns, workplace safety regulations compelled manufacturers to reconsider the toxicity and handling risks of cooling media. Early alcohol-based antifreeze posed flammability hazards and health risks through inhalation or skin contact. Even ethylene glycol, despite its widespread adoption, required careful handling due to its toxicity.

Over time, safety standards evolved to include mandatory Material Safety Data Sheets (MSDS), better packaging, and clearer usage instructions to protect users and technicians. Additionally, new coolant formulations aimed to reduce corrosiveness and chemical volatility, improving system safety and longevity.

Energy efficiency and sustainability

More recently, global emphasis on energy efficiency and sustainable development has impacted liquid cooling media selection and system design. As industries seek to reduce carbon footprints and operate more economically, the thermal efficiency and lifecycle environmental impact of cooling fluids are scrutinized more than ever.

Innovations have focused on:

- Developing fluids with better thermal conductivity and heat capacity to improve system efficiency.
- Designing cooling systems compatible with longer-lasting, less polluting fluids to reduce waste and maintenance.
- Integrating closed-loop and recovery systems that minimize coolant loss and environmental release.

These changes reflect a broader shift from viewing liquid cooling media purely as functional components to seeing them as integral elements of responsible, forward-looking engineering.

The industry's ongoing challenge

Despite these advances, challenges remain. Balancing performance, cost, safety, and environmental impact continues to drive research and innovation. Emerging concerns about microplastics, chemical biodegradability, and circular economy principles are beginning to influence new product development strategies.

Understanding this regulatory and cultural evolution is crucial for engineers and decision-makers who must navigate a complex landscape of technical requirements and societal expectations, an environment where liquid cooling media are no longer just coolants, but important players in sustainability.

6. Recent history and emerging trends

In recent decades, liquid cooling technology has entered a dynamic phase of innovation, driven by rapid advancements in engineering, stricter environmental regulations, and emerging industry needs. The quest for better-performing, safer, and more sustainable cooling media continues to accelerate, positioning liquid cooling at the forefront of modern industrial and technological development.

Advances in coolant formulations

Building on decades of experience, recent coolant formulations have become highly specialized. Modern antifreeze and heat transfer fluids often combine glycol-based mixtures with advanced additive packages that enhance corrosion protection, thermal stability, and system longevity.

Moreover, new organic acid technology (OAT) and hybrid organic acid technology (HOAT) formulations provide longer-lasting corrosion inhibitors and reduced environmental impact. These innovations extend coolant service life from a few years to sometimes a decade or more, reducing maintenance costs and waste.

Focus on environment and human health

Regulatory frameworks continue to evolve, encouraging the industry to reduce or eliminate hazardous components, improve biodegradability, and ensure safe disposal. There is increasing interest in non-toxic, biodegradable coolants and alternatives to traditional glycols.

At the same time, ongoing research is investigating natural fluids and liquids enhanced with nanoparticles to improve thermal conductivity, potentially offering breakthroughs in efficiency while maintaining environmental safety.

Integration with advanced cooling systems

Modern applications increasingly demand integration of liquid cooling with smart control systems and energy recovery technologies. For instance, in data centers and electric vehicle battery cooling, precise thermal management optimizes performance and extends lifespan while minimizing energy use.

Similarly, in industrial plants, closed-loop cooling systems with real-time monitoring improve efficiency, detect leaks early, and adapt coolant properties dynamically. These developments underscore how liquid cooling media and systems are becoming more interconnected and intelligent.

Emerging applications and market drivers

Several emerging fields are pushing the boundaries of liquid cooling:

- Electric vehicles (EVs) require highly efficient thermal management for batteries and power electronics, often relying on advanced coolant chemistries tailored for electrical insulation and thermal performance.
- Renewable energy technologies, such as concentrated solar power and geothermal, demand robust fluids capable of handling extreme temperature cycles with minimal degradation.

- High-performance computing and AI data centers increasingly adopt liquid cooling to meet the heat dissipation demands of dense processing units.

These trends highlight a future in which liquid cooling media must continuously adapt to evolving technical challenges and sustainability goals.

7. The future of liquid cooling media

As industries face mounting challenges, from stricter environmental regulations to increasingly demanding technical requirements, the future of liquid cooling media will be shaped by innovation, sustainability, and adaptability.

Innovation driven by performance and sustainability

The next generation of cooling fluids is expected to emphasize higher thermal efficiency, longer service life, and environmental compatibility. Research is actively exploring bio-based coolants, advanced synthetic fluids, and nanotechnology-enhanced [4] media that promise to improve heat transfer while reducing ecological footprints.

Circular economy and regulatory pressures

Growing focus on the circular economy will encourage manufacturers to develop fluids that are easier to recycle, regenerate, or safely dispose of. Compliance with evolving regulations worldwide will push the industry toward non-toxic, biodegradable, and low-impact solutions, supporting global sustainability goals.

Integration with smart systems and digitalization

The future of liquid cooling media is tightly linked to advancements in smart monitoring, predictive maintenance, and system optimization. Fluids may be engineered to work synergistically with sensors and control algorithms that

optimize coolant properties dynamically, maximizing efficiency and safety.

Emerging industry needs

New applications will continue to arise in sectors such as electric mobility, renewable energy, advanced electronics, and high-performance computing. Each of these demands tailored cooling solutions that balance thermal management, chemical compatibility, and environmental responsibility.

Conclusion

The evolution of liquid cooling media from simple water-based systems to today's complex formulations highlights a remarkable journey of innovation and adaptation. As we look forward, the convergence of technology, regulation, and sustainability will continue to drive transformative advances — paving the way for the next generation of cooling media that meet the demands of a rapidly changing world.

8. References

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