RESEARCHING SMART COOLING SYSTEMS AND INTELLIGENT THERMAL MANAGEMENT IN AUTOMOBILE ENGINES

Oybek Daminov, Associate Professor
Yangibayev A.I. (senior lecturer)
Ramazonov B.U. Assistant teacher
Zafar Arabov, Master Student

Introduction

The fundamental mechanical architecture of automotive cooling systems has remained largely unchanged for decades. Traditional thermal management relies on a mechanical water pump driven by an accessory belt connected to the engine crankshaft, paired with a simple wax-pellet thermostat. While this design is robust, it is inherently inefficient because the cooling performance is strictly tied to engine RPM rather than the actual thermal load. This rigid dependency frequently leads to overcooling during low-stress cruising or insufficient cooling during heavy load at low speeds. In modern internal combustion engines (ICE) and hybrid electric vehicles (HEV), where optimizing energy efficiency and minimizing parasitic losses are paramount, these legacy systems act as a significant barrier to performance. This study explores the paradigm shift toward Intelligent Thermal Management (ITM) systems that decouple cooling mechanisms from engine speed.

The Flaws of Mechanical Cooling

Thermal management is a delicate balancing act. An internal combustion engine converts fuel into mechanical energy, but approximately 30% to 40% of this energy is lost as waste heat. If an engine runs too hot, it risks catastrophic metallurgical failure, oil degradation, and severe knocking. Conversely—and this is the issue with traditional belt-driven pumps—if the engine is overcooled, the internal fluids become more viscous. Higher oil viscosity exponentially increases internal mechanical friction, forcing the engine to burn more fuel simply to overcome its own internal resistance, thereby increasing greenhouse gas emissions.

Transitioning to Intelligent Thermal Management

To eliminate these parasitic losses, modern automotive engineering replaces mechanical pumps with variable-speed electric water pumps and smart multi-way valves. This architecture allows for a completely decoupled cooling strategy. AI-driven frameworks and advanced multidimensional Electronic Control Units (ECUs) constantly analyze real-time data, including ambient air temperature, engine load, vehicle speed, and cabin climate demands. Using adaptive fuzzy PID controllers, the system can dynamically dictate the exact flow rate of coolant required at any given millisecond. Experimental data highlights that shedding the constant drag of mechanical pumps and optimizing electric fan usage can cut the cooling system's total power consumption by up to 26.1%.

Dual-Loop Architectures and Targeted Cooling

The advantages of ITM are most evident in the deployment of dual-loop (or multi-loop) cooling architectures, which are becoming standard in high-performance and hybrid vehicles. A dual-loop system physically separates the coolant circuits. The primary high-temperature loop is dedicated to the engine block, intentionally maintaining it at a hotter, more efficient temperature (typically around 95°C to 105°C) to thin the engine oil and minimize friction.

Simultaneously, a secondary low-temperature loop serves heat-sensitive auxiliary components. Elements such as the turbocharger charge-air cooler, transmission fluid cooler, and power electronics (in hybrids) require much cooler environments to function optimally. By actively managing these distinct thermal zones, intelligent cooling systems prevent energy waste, significantly reduce fuel consumption, and ensure that every sub-system operates within its ideal thermodynamic window.

Alongside software innovations, the physical hardware of engine cooling has evolved. High-performance internal combustion engines and hybrid electric vehicles increasingly utilize dual-loop cooling systems. Unlike traditional single-loop architectures, a dual-loop system features a high-temperature circuit dedicated exclusively to the engine block and cylinder head, and a low-temperature circuit designated for auxiliary components such as the turbocharger intercooler, transmission fluid cooler, and, in hybrids, the power electronics and battery packs.

This separation allows for highly targeted thermal management. The engine block can be maintained at a hotter, more efficient temperature (often around 95°C - 105°C) to reduce oil viscosity and friction, while the cylinder head and charge-air coolers are kept cooler to prevent engine knock (detonation) and increase intake air density. Furthermore, novel approaches to heat dissipation are being tested to replace energy-intensive mechanical fans.

As the automotive sector continues to optimize internal combustion and hybrid technologies leading into the next decade, intelligent thermal management will remain a cornerstone of sustainable vehicle design.

References

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