Impact, Measurement, and Mitigation Strategies for Non-condensable in R134a and R1234yf EV Thermal Management Systems

Section I - Background, Impact & Key challenges of NCGs on Refrigerant based Thermal Management Systems

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The growing adoption of electric vehicles (EVs) has led to significant changes in the design and operation of traditional off-highway cooling systems, now incorporating advanced thermal management solutions for cooling batteries, power electronics, and fuel cells. Unlike internal combustion engine (ICE) vehicles, there is less temperature differential between EV components and the ambient conditions. To manage the heat generated by the battery packs and associated components during operation, along with maintaining thermal comfort, more robust and sophisticated thermal management systems with refrigerants-based cooling are essential to maintain battery performance, extend lifespan and ensure safety across diverse operating conditions.

This increase in demand for cooling EVs has also led to a need for more refrigerant in the system, often requiring larger or more efficient compressors, condensers, and evaporators. The growing size of AC systems, especially in high-performance EVs has intensified the focus on refrigerants with both better thermodynamic properties and lower environmental impact.

One such refrigerant that has gained widespread adoption is R1234yf (2,3,3,3-tetrafluoropropene), a low-GWP alternative to R134a. Historically, R134a (1,1,1,2-tetrafluoroethane) has been the most used refrigerant in mobile AC systems due to its favorable thermodynamic properties, efficiency, non-flammability and low ozone depletion potential (ODP). Despite the advancements, both R134a and R1234yf systems face challenges due to the presence of non-condensable gases (NCGs) which can degrade system performance.

Non-condensable gases, as the term implies, are unwanted contaminants (gases) that cannot condense within the refrigeration cycle, disrupting the normal heat exchange process, leading to many operational issues. Common sources of NCGs include leaks in the refrigerant circuit, improper evacuation and servicing procedures, and contamination during refrigerant charging. The most common NCG is air, but moisture (water vapor) can also pose significant problems. The impact of these gases is significant, as they reduce the system's efficiency, raise operating pressures, and increase the risk of premature component failure.

In EV thermal management systems, the presence of NCGs can manifest as increased compressor loading, higher discharge temperatures, and reduced cooling capacity.
At AKG, a key objective is to design and manufacture thermal management systems that are compatible with both refrigerants and improve their performance by minimizing the introduction of non-condensable gases, while incorporating effective methods, EOL (end-of-line) tools, and techniques to measure and remove them from the system.

What are some of the key challenges related to NCGs in both systems?

Both R134a and R1234yf are susceptible to performance degradation caused by NCGs. However, the way in which NCGs impact these two refrigerants may differ due to their unique thermodynamic properties.

In R134a systems, the benefit of higher operating pressure helps move or push the trapped air and moisture out. However, NCGs can elevate discharge temperatures, which in turn may lead to heat-related issues, such as compressor damage.
R1234yf typically operates at lower pressures than R134a, reduces the load on the compressor, potentially improving system efficiency, and can lead to reduced power consumption for the compressor, which – to customer's benefit- is especially important in electric vehicles (EVs) where minimizing energy use is crucial for range optimization. With lower pressures, the system may tolerate NCGs with less impact on compressors, however, there's less driving force to push the refrigerant (and the non-condensables) through the heat exchanger (condenser or evaporator). This can reduce the system's ability to release heat, especially if the NCG concentration is high, eventually leading to higher compressor loads.

In R134a systems, the higher operating pressure creates a significant pressure differential between the refrigerant circuit and the external environment, preventing unwanted air and moisture into the system. However, in R1234yf systems, the lower operating pressure means there is less pressure differential to resist the introduction of external air or moisture. Even minor leaks in components like seals, joints, or valves can allow ambient air (which contains oxygen and nitrogen) or moisture (water vapor) to infiltrate the refrigerant circuit. Moisture is particularly problematic because it can react with the refrigerant to form acids, which can damage system components or freeze within the system - blocking refrigerant flow.

In both systems, elevated pressures due to NCGs can cause refrigerant leaks. Trapped air or moisture can lead to higher-than-normal operating pressure conditions, adding extra stress on the system components, such as hoses, seals, valves, and joints (which if not designed to manage the increased pressure load over time) can cause leaks. Even small leaks can accumulate over time, significantly reducing the amount of refrigerant in the system. This, in turn, can lead to performance degradation, as the system struggles to operate with less refrigerant, further escalating issues like high discharge temperatures or insufficient cooling capacity. Also, releasing the refrigerant into the atmosphere.

As electric vehicles continue to advance, understanding and addressing these challenges will be critical to improving the energy efficiency, reliability, and sustainability of future EV thermal management systems. To mitigate the risk of non-condensable gases (NCGs), engineering teams at AKG continuously address several design challenges, particularly due to the lower operating pressures of R1234yf compared to R134a.

With proper component selection, heat exchanger design, advanced modeling, simulation & controls strategies along with efficient evacuation & charging procedures, training, system testing and validation, and real-time monitoring tools, we ensure that AKG's systems deliver enhanced reliability while maintaining thermal efficiency & long-term performance.

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