AUTOMOTIVE AIR CONDITIONING TECHNOLOGY SCENARIO AND IMPACT OF CURRENT REGULATIONS

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Introduction

In response to the Montreal Protocol, new vehicles with air conditioning (AC) have been equipped with systems using HFC-134a with some R-407C use in buses. By the year 2000, the transition to HFC-134a was complete in all developed countries and in 2007 in developing countries.

Beginning with the 2013 year as consequence of European MAC Directive and U.S. EPA regulations the transition to lower GWP (Global Warning Potential) refrigerant started and currently nearly all light duty vehicles in Europe and many in the United States and in some other countries are delivered with R-1234yf mobile air conditioners.

The R-1234yf has been finally identified as main R-134a replacement. R-744 is also an alternative even if in 2017 few premium models have started using the refrigerant R-744 while on electrified vehicles (battery and plug in electric vehicle) R-744 is again under evaluation for being used in heat pumps. The transition to R-1234yf for heavy duty and delivery vans is also occurring but with a lower speed.

The current systems are of direct expansion type while indirect expansion (secondary loop) systems are starting to appear on electrified vehicles that require specific thermal management system and battery refrigeration.

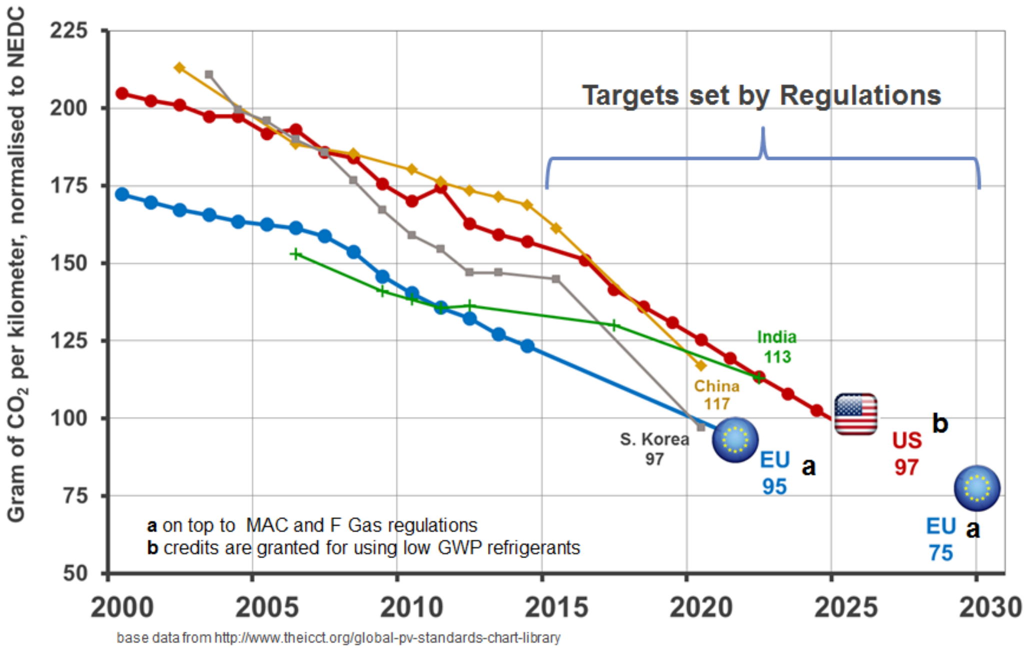
Refrigerant counterfeiting is still an even more relevant issue in non-European countries, even if the relative cost of HFC-134a is low, i.e. 5 US$/lb or 11 US$/kg (or even less). The counterfeit risk will become even more relevant in case of more expensive refrigerants (e.g. R-1234yf), and may reduce the expected environmental benefit.

The progressive diffusion of electrified vehicles in the main automotive markets is leading to the progressive diffusion of electric air conditioning likely with heat pump function and both for passenger compartment and battery thermal management.

Global CO2 and GHG (Green House Gas) Scenario

The European Union and the United States already have in place regulations n CO2 or GHG (green House Gas) emissions that influence mobile air conditioning design while the other countries with a high density of road vehicles are rapidly moving in the same direction (for example Brazil, Inovar Auto, 2012).

This drives to more efficient on-board systems including MACs and to the replacement of high GWP fluid with lower GWP substances. Meanwhile the same regulations are leading to a progressive diffusion of hybrid vehicles in the short-medium term (3 – 10 years) that in the medium-long term (5 -15 years) will be further integrated with fully electric vehicles.



Automotive Global CO2 regulations

These vehicles require highly efficient mobile air conditioning to minimise the impact on the pure electric range and, as additional evolution, able to operate also as heat pump. These challenges will be met by developing and adopting technical solutions that will have to represent the best trade-off among economic and environmental sustainability issues.

In this framework, the thermal systems and especially the MAC systems have a relevant role and will likely undergo a deep change where the system integration will represent a relevant evolution guideline.

It is expected that the passenger cars and light duty vehicle domain will rapidly move toward downsized turbocharged engines often coupled with different levels of hybridization to make the overall powertrain more efficient and to reduce CO2 emissions, with effects on MACs as described below.

The adoption of improved components (compressor and heat exchangers) and the introduction of internal heat exchangers as well as improved control strategies allowed a significant increase of system efficiencies.

New sealing concepts and improved hose materials have also been developed to reduce refrigerant direct emissions and to reduce the frequency of required maintenance or service.

Road Transport Electrification and Mobile Air Conditioning

The diffusion of vehicles able to carry out part of their mission with the combustion engine off (e.g. Stop & Start, extended Stop & Start and hybrids) asks for new solutions for the air conditioning system to guarantee the summer and winter thermal comfort in all the operational conditions.

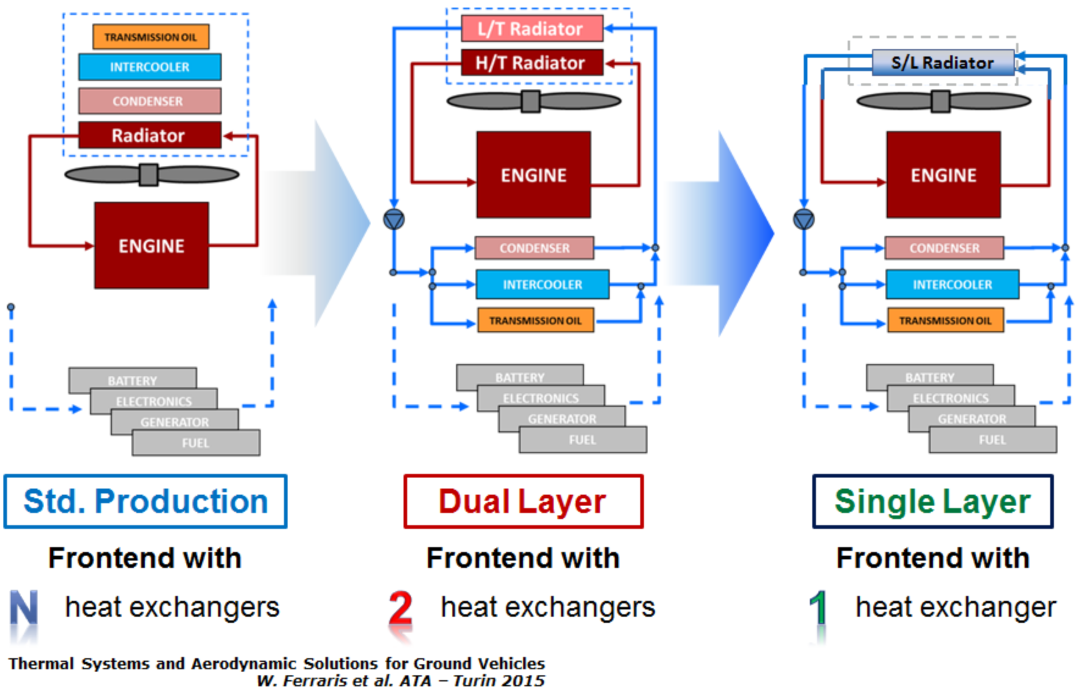
The major part of these vehicles will have 12 V to 48 V electric energy sources and only part of them will have higher voltage network (e.g. up to 350 V), while all will have an additional on-board electric energy storage unit with a capacity ranging from 0.2 kWh (low voltage) up to 5 kWh (high voltage).

This implies that only a small portion of the future vehicles will have an electric compressor while a large part will be equipped with mechanically driven compressors as today due to energy balance and cost, so measures will be adopted to maintain the required comfort and guarantee the safety performance (i.e. de-fogging), as for example:

- Cooling energy storage unit based on phase change materials
- Secondary loop system taking benefit from its thermal inertia to store cooling power
- Secondary electric compressor, downsizing the main one

The increase of on-board electric power and the diffusion of turbocharged engine together with the need to at least maintain the aerodynamic drag will presumably lead to a low temperature cooling loop integrating charge air cooler, air conditioning condenser, power electronics and generator in case of hybrid powertrain.

In synthesis, the evolution will produce a deeper integration of the on-board thermal systems and the air conditioning will become part of it. For Plug-in Hybrids (PHEV) and Battery-driven electric vehicles (BEV), vehicle air conditioning systems for cooling as well as heat pump systems for heating have to have very high-energy efficiency to minimize the impact on the vehicle driving range. MAC systems, when operating as heat pump with HFC-refrigerants currently used, can take benefit of the on-board outdoor heat sources (battery, power electronics, etc.) to enhance their effectiveness in case of very low ambient temperatures partially compensating for their low efficiency and capacity. This can be achieved adopting a secondary loop that by collecting the heat from the on-board electronics can raise the temperature of the heat source.



Example of Passenger Car Thermal Systems Evolution

In this framework, dual loop systems (with liquid cooled condensers and liquid heated evaporators) offer the highest flexibility level and at the same time allow the OEM to minimize the refrigerant charge, the leak rate, and the risk of dispersion in case of an accident. However, these secondary loop systems do increase the vehicle mass due to the additional coolant and components, which might adversely affect vehicle fuel economy at all times of vehicle usage. For some applications, the MAC system will be also used for battery thermal control as well as power electronics (i.e. cooling and heating).

New Refrigeration Systems

The need to progressively increase the energy efficiency requires the exploitation of all available waste energies, heat included. The application of heat driven refrigeration systems (e.g. adsorption, absorption, etc.) can be foreseen for the heavy duty vehicle domain (e.g. trucks, and coaches) which often operate at near constant speed (highway) and where the weight and packaging constraints are less severe than in the passenger cars field.

The adoption of a Rankine Cycle to convert part of the combustion waste heat of a thermal engine into mechanical or electric energy could allow manufacturers to increase dramatically the vehicle energy efficiency.

These systems are under investigation for diesel heavy-duty truck application in Europe and US and for gasoline light trucks in US. As working fluid, the Rankine cycle can use water, ethanol or a mixture of both, or an organic fluid like HFC-245fa, hydrocarbons, or carbon dioxide. The fluid HFC-245fa has good properties for the application but has a GWP of 1050, higher than the threshold of the MAC Directive in Europe. Studies are ongoing to evaluate the application of fluids with similar properties but with a lower GWP, as for example the HCFC-1233zd and HFC-1336mzz.

Conclusion

In developed countries, the transition to low GWP refrigerants is almost completed and, aftera long and complex analysis at the end R-1234yf is largely preferred options. Meanwhile, the increasing mobility electrification leading to a relevant change of the on board thermal systems leaves the door open to options to system configuration and refrigerant enabling the implementation of efficient heat pumps. In this framework, the R-744(CO_2) remains one of the options.