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Chances and Limitations of a Hybrid Refrigerant System for Vehicle Air Conditioning

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ABSTRACT

According to the motor vehicle directive of the European Community, as of January 2017 new cars will only be allowed to use air conditioning systems with refrigerants of GWP below 150. A moratorium to significantly extend this deadline is not to be expected considering the recent negotiation process on the EU F-Gas-Regulation. One option will be flammable refrigerants of the ASHRAE classification A3 or a future classification A2L. However they are subject to safety reservations when used in systems with direct evaporation. R744 requires for a wide use and a complete realization with development, industrialization and validation probably more time than the remaining available time horizon. Therefore an option shall be discussed, which is based on a hybrid solution with R744 and a flammable refrigerant and which may allow a sufficiently rapid implementation. The utilization of R744 refrigerant mixtures shall not be considered. Instead a small and compact refrigerant loop will be operated with A3 or A2L refrigerants. Compactness, leak tightness and significant reduced charge amounts already contribute to the enhanced safety. R744 will be used as a secondary refrigerant. Additional safety aspects arising from the use of R744 as secondary refrigerant and at the same time in the function as fire extinguishing medium. Efficiency, safety, time-to-market and scenarios for the possible full transition to R744 as a refrigerant will be discussed.

1. INTRODUCTION

Globally almost all passenger vehicles are equipped with an air-conditioning system. Besides passenger comfort other duties like battery or inverter cooling in hybrid or electric vehicles becoming important tasks for vehicle air-conditioning systems. Revised functionality like in heat pump mode for efficient heating helps electric vehicle to maintain a reasonable driving range. The refrigerant of choice has been for many years the HFC R134a. Due to the European Communities motor vehicle directive (EU 2006) refrigerants with a GWP higher than 150 are not allowed from January 1st 2017 in new passenger cars. Thus a replacement for R134a is needed. Proposed has been the HFO R1234yf which is the thermodynamic properties considered a reasonable retrofit replacement for R134a. Adaption of the cycle may be limited to modification of the expansion valve when replacing R134a by R1234yf. Recent announcement indicate that there is already a total of 120.000 vehicles with R1234yf air-conditioning systems alone in the German market. Even so R1234yf is announced to be a mildly flammable refrigerant with a future ASHRAE classification of A2L and the MSDS indicating it even as “extremely flammable” (DuPont 2010) certain car manufacturers were taken by surprise, when after an accident simulation with rupture of the refrigerant line and leaking of refrigerant and lubricant to the hot exhaust gas lines ignition took place and fire occurred (Wertenbach 2012). The flammability together with the highly toxic decomposition products caused a switch to restart the development of R744 air conditioning systems and a full stop on R1234yf technology at certain OEM. Even development of R744 systems including heat pump option has been ongoing during a decade from 1994 it is still a quite new and different technology in a motor vehicle. The time for development of this new technology is rather short with the deadline of January 1st 2017 approaching. The question is which options remain and if a transition path with a hybrid technology could be a helpful solution.

2. R744 TIME TO MARKET

Considering already an optimistic approach for a time to market scenario of R744 one can assume a restart of R744 MAC development to take place in the middle 2013. A first step is to build the basis of serial suppliers and in parallel to enhance the efficiency from a 2004 level to current R134a system level. NVH enhancement has been an issue with almost all MAC systems. Due to high pressure levels and rigidity of lines and hoses higher NVH problems can be anticipated from R744 systems and have been experienced in earlier vehicle applications. So an assumed general system development in parallel with the other two tasks till the end of 2014 might already be an optimistic approach. With the assumption of 18 months parallel serial project and process development and industrialization the first of tool samples may be available in the middle of 2016. With only another 18 months of validation the SOP and ramp-up may start early 2018 (Hesse 2013). It appears obvious (Figure 1) that there is a mismatch between a sound and even optimistic development planning and the time to match the regulation of the motor vehicle directive.

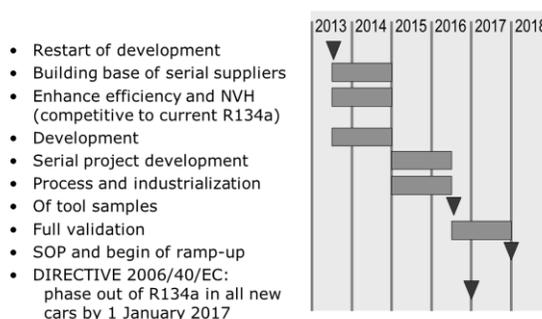


Figure 1: Assumed time schedule for R744 MAC development

The option to gain a moratorium on the directive is a political option and shall not be discussed here. Also it can be considered unlikely with the background of the recent F-Gas Regulation, which is rather stringent on the application of HFC in stationary applications (EU 2014).

3. Technical Options

Development of R744:

A significant time and risk is involved in the development of the R744 system especially when efficiency enhancement, NVH improvement and reliability testing will be included. While heat exchanger process and design development appears less critical, the main concern is with the compressor. Even with current technology NVH and reliability need significant attention and development time. For a new technology additional time will be required.

Flammables:

Even when R744 shall be the final technology, R1234yf could be considered as an interim fall back solution. This option would need the parallel development of R744 and R1234yf and thus significant resources. Further on it would require a solution how to handle the flammability risk in a safe and for all OEM acceptable manner. If the flammability risk can be handled than also other refrigerants such as R152a, R290 or hydrocarbon mixtures becoming options.

Suppression of the flammability risk:

Certain measures are commonly known to suppress the risk of flammability when applying flammable refrigerants. The system need to be separated from the passenger compartment. This leads to the need for a secondary refrigerant cycle. Typically one would consider applying the coolant, which is anyhow a part of the vehicles thermal management system. However, the additional heat transfer and the rather high viscosity will result in an efficiency disadvantage. The advantage of a secondary refrigerant system is the reduced refrigerant charge and the compactness of the system. Both are helpful for reduction of the risk. For full suppression of flammability a fire extinguishing system would be required, which allow to maintain safety even in case an accident or another incident causes a leak or refrigerant needs to become controlled discharged.

Secondary refrigerant systems:

Secondary refrigerant systems have been proposed for the application with flammable refrigerants in the past. Demonstration cars with secondary refrigerant systems have been shown and tested. New HVAC heat exchanger design, larger fluid lines, pumping power, and low evaporation temperature due to additional heat transfer are the drawbacks. The same problems apply in stationary applications. Here R744 has been used as a secondary refrigerant with phase change.

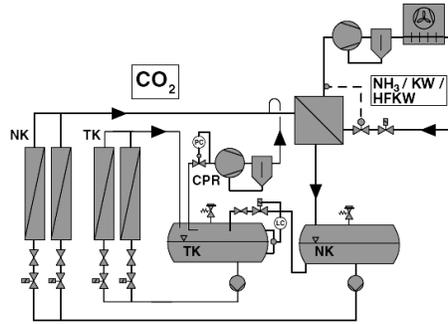


Figure 2: R744 (CO₂) as secondary refrigerant and cascade system (Bitzer 2010)

Hybrid System:

From the conclusions above a system can be derived, which consists out of a compact chiller with a minimum charge of a flammable refrigerant. The chiller is used to liquefy R744 in a subcritical stage. The R744 is used to transfer the cooling capacity to the HVAC and possibly other cooling sections in the vehicle as e.g. the battery of a hybrid car. R744 is known to be a fire extinguishing gas. Thus the secondary refrigerant loop can be assumed to be a reservoir for a fire extinguishing system of the vehicle.

4. Flammability Suppression

A key question to be clarified is if the flammability of the refrigerants can be suppressed by R744. It is known, that R744 is a good flame suppressant. Explosion limits have been investigated. Figure 3 shows the explosion limits of the system R170 (ethane), R744 and air (Askar 2012). Adding R744 as an inert gas can suppress the explosion.

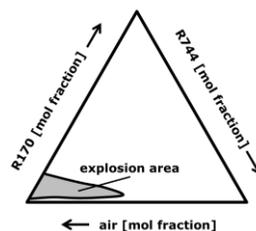


Figure 3: Explosion limits in of the system R170, R744 and air

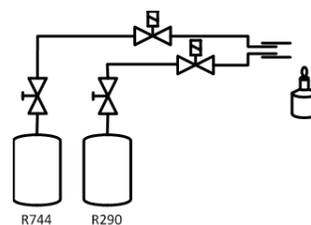


Figure 4: Flammability suppressant demonstrator

Additionally some tests for a first demonstration have been performed applying R290 (propane) and R744. The test set-up included two pressurized gas container of 200 cc, each with a solenoid valve for remote control. A single ignition source was used. The containers were charged with propane resp. carbon dioxide. Figure 4 shows the arrangement and Figure 5 shows the ignition source (a), propane being released (b) and propane and carbon dioxide being released from the containers at the same time (c). It clearly shows that R744 can suppress the flammability of R290.

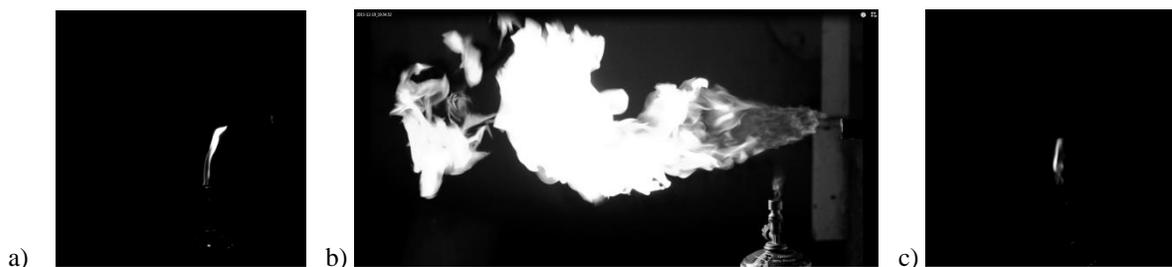


Figure 5: a) ignition source only, b) R290 blow-out, c) R744/R290 blow-out

6. Performance Comparison

For a first rough performance comparison a baseline cycle with R1234yf has been compared to three indirect systems. In the baseline cycle a suction line superheat of 10 K and a suction line pressure drop of 0,05 MPa were assumed. For the first indirect system R1234yf was considered with water glycol loops on both sides and with a temperature difference of 5 K between inlet and outlet and a change in evaporation resp. condensation temperature of 10 K compared to the direct system due to the additional heat transfer. The second indirect system was a combination of R1234yf as primary refrigerant, R744 as secondary refrigerant on the evaporator side and water glycol on the condenser side. With the enhanced heat transfer of R744 as secondary refrigerant only 5 K change of evaporation temperature was assumed. A final indirect system was the same system but with R290 (propane) as primary refrigerant. For both secondary refrigerant loops a pressure drop of 0,2 MPa was assumed. The power consumption reduces the total system COP accordingly.

Table 1: Comparison of secondary refrigerant options with a baseline system

refrigerant	R1234yf	R1234yf	R1234yf	R290
concept	direct	indirect	indirect	indirect
		warm side: water/glycol (temp. diff. 10K)		
		cold side: water glycol (temp. diff. 10K)	cold side: R744 (temp. diff. 5K)	
cooling capacity	5 kW	5 kW	5 kW	5 kW
suction line pressure drop	0,05 MPa	-	-	-
evaporation temp.	0 °C	-10 °C	-5 °C	-5 °C
condensation temp.	50 °C	60 °C	60 °C	60 °C
superheat	5 K	5 K	5 K	5 K
subcooling	5 K	5 K	5 K	5 K
suction line superheat	10 K	0 K	0 K	0 K
compr. efficiency	0,7	0,7	0,7	0,7
COP	2,34	1,62	1,85	1,99
volumetric cooling capacity	1420 kJ/m ³	1026 kJ/m ³	1268 kJ/m ³	1962 kJ/m ³
pressure drop sec. Loop	-	0,2 MPa	0,2 MPa	0,2 MPa
power secondary loop	-	300 W	160 W	160 W
COP total	2,34	1,48	1,75	1,87

The performance drop is clearly to identify. It is an almost 40% drop from R1234yf direct to R1234yf glycol. The drop is only half of it when R290 is used as the primary refrigerant and R744 as a secondary refrigerant on the evaporator loop.

7. CONCLUSIONS

The motor vehicle directive of the European Community requires the phase out of R134a in new vehicles. As flammable refrigerants in MAC are not an option for certain manufacturers and a sound development of R744 systems need probably more time than available, an indirect system based on R744 as secondary refrigerant might be a solution. Development of the most critical component, the compressor can be allowed more time. R744 can be utilized as fire suppressant when the flammable refrigerant is leaking out after an incident. Efficiency of an indirect system with R744 as evaporating secondary refrigerant is higher than with conventional water glycol loops. R290 becomes an option for such an indirect system and enhances the efficiency even further. Such an indirect system with a R744 secondary refrigerant might be a basis when at a later point of time the R744 transcritical direct evaporation system becomes introduced after final development and validation.

NOMENCLATURE

GWP: global warming potential
 HFC: hydro fluorocarbon
 HFO: hydro fluoroolefine
 MAC: mobile air-conditioning
 SOP: start of production

REFERENCES

- Askar, E., 2012, Experimentelle Bestimmung und Berechnung sicherheitstechnischer Kenngrößen ethylenoxidhaltiger Gasphasen, BAM-Dissertationsreihe Band 80, Berlin
- Bitzer, 2010, Bitzer Kältemittelreport, Bitzer Kühlmaschinenbau GmbH, Sindelfingen
- DuPont, 2010, Safety Data Sheet according to Regulation (EC) No. 1907/2006, Version 3.0, Revision Date 01.09.2010, Ref.130000043292
- EU, 2006, Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC
- EU, 2014, REGULATION (EU) No. .../2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006
- Hesse, U., 2013, Thermal Systems for Vehicle Thermal Management, Air Conditioning, Heat Recovery and Future Fuels, 5th International Conference on Sustainable Automotive Technologies, Ingolstadt
- Wertenbach J., 2012, Kältetagung des DKV, Würzburg, Nov.