Evaluation of Natural Refrigerants for HVAC Systems in Railway Vehicles

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eurammon
refrigerants delivered by mother nature

Agenda

- **Introduction**
- Comparison of Technologies and Refrigerants
- Railway-specific requirements for risk analysis for refrigerants
- Summary and Outlook

Introduction – Parameter of typical Rail HVAC System

- Mixed air system, Direct evaporation, single-channel system
- Cooling Capacity: 12 kW bis 60 kW (80 kW)
- Heating Capacity: 10 kW bis 60 kW
- Height: 220 mm to 1200 mm
- Length: up to 5500 mm
- Weight: 450 kg to 1300 kg
- Refrigerants EU: R134a / R407C / R729 / R744

- **Life span:** 30 years with ca. 6000 h/a operation
- Versions: Compact systems, Split systems, cabinet systems
- Arrangement: Roof area, Underfloor, Cabinet inside the vehicle

- Always compromise of:
  - ↘ Weight
  - ↓ Space envelope
  - ↗ Performance / Operational limit
  - ↘ Energy consumption
  - ↓ Invest. costs

Introduction – F-Gas Regulation and Consequences

Regulation – present and prospective

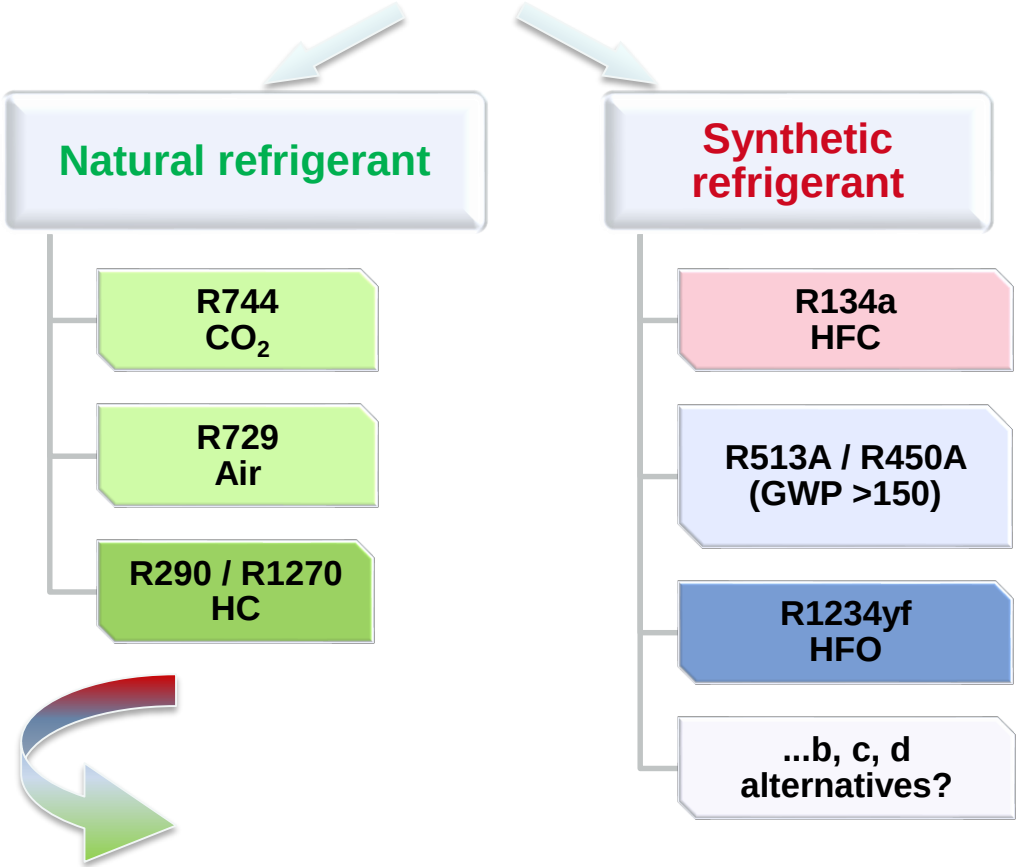
2015

- Since 2015 valid F-Gas Regulation EG/517/2014. Replacement of EG/842/2006
- No ban of fluoridate refrigerant, but Phase-Down lead to Practical Phase-out to HFC's (shortfall of these refrigerants on market)
- Increased Requires to Natural Refrigerants are already asked from Customers and Operators as Options or strong demands currently from: *DB, SBB, ÖBB, NSB*

2020

- Starting by 2020 (!): Operators ask on strong demands new Car-HVAC -Concepts exclusive natural Refrigerants (DB,…)
- **Prospective Steps or Rules are to expect in respect of the Environment-Protection…..**

Quo vadis – on refrigerant?



Which technology will be the future?

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General Comparison of Technologies and Refrigerants

Vapor-Compression Process

HFC, HFO Refrigerants & Blends

- Compact units
- Hermetic systems
- Various methods for capacity control
- Accepted COP
- Large component base
- Long-term availability
- Breakdown products in atmosphere
- HFO
  flammable
  MAK value 200 ppm
- Price level of refrigerants

Natural Refrigerants – R744, HC, H_2O

- CO_2
- Operating pressure
- COP in cooling mode (worst vs. HFC)
- Heat pump operation
- Additional Safety features required
- Limited component base

- R290 / R1270
- Explosive
- COP in cooling mode comparable vs. HFC, Heat pump operation better than HFC
- Medium component base

- H_2O
- Not available for Railway sector

Gas-Compression Process

Natural Refrigerant - Air

- Serial application in the ICE3 of Deutsche Bahn (BR403/406)
- Easy Maintenance and Repair
- Low COP < 1, Consequences for Energy consumption and On-board power supply
- Very limited component base
- Price level of components (TM, HX)

Future-proof
Always available

Other Processes

Absorption

- attractive for waste heat applications
- Dimensions and Weight
- Efficiency

Thermoelectric effect
Magnetocaloric effect
Thermoacoustic effect

- Low efficiency
- Basic research

Potential of Refrigerants to Rolling Stock Applications 1/2

	Attribute	Ecology	Thermo-dynamic	Chemistry	Physiology	Commercial aspects to HVAC business
Criteria Details	preferred attribute ->	low GWP- value (<10) ODP = 0	high specific cooling power at low pressure level	stable azeotrop behaviour in cooling circuit, no environmental risk at release	no risk on toxication, or other health risk	availability, price level, distribution net, restrictions by law
Refrigerant	R-134a (HFKW)	GWP = 1430 ODP = 0 ⊖			MAK=1000	Availability critical – no long term solution, wide range on applications at railway, synth. Refrigerant – cat. A1
	R-1234yf (HFO)	GWP = 5 ODP = 0	comparable to R-134a	at temperature > 250°C → toxic HF-generation, persistent Tri-Fluor Acid in atmosphere ⊖	MAK = 200 ⊖	Replacement of R-134a e.g. automotive industry, ongoing discussion about environmental impact of TFA generation to air /ground-water impact to future law open synth. Refrigerant – cat. A2L – mildly flammable
	R-290 (Propane)	GWP = 5 ODP = 0 ⊕	comparable to R-134a, Heat pump appl. up to -20°C ⊕	⊕	MAK=1000 ⊕	Strong increasing application in stationary business, stable price level to expect, risk assessment at acceptable level is ongoing; natural refrigerant – cat. A3 – flammable, explosive
	R-729 (Air)	GWP = 0 ODP = 0 ⊕	Small heat capacity, low COP ⊖	⊕	⊕	Standard application on air craft; Highest invest cost, high energy consumption (Peak) natural refrigerant – cat. A1
	R-744 (CO2)	GWP = 1 ODP = 0 ⊕	Max. pressure up to 140 bar ⊖	⊕	MAK=5000 ⊕	Higher invest cost; high pressure level, maintenance modification due to pressure level; natural refrigerant – cat. A1

Potential of Refrigerants to Rolling Stock Applications 2/2

Refrig-erant	System weight Space Envelope	Energy efficiency COP Heating Cooling	Complexity Serviceability	GWP Sustainability Lifespan	Flamm-ability Toxicity	Train Suitability	Expected safety level for operation	Total system costs	Rating – Σ
R134a	0	0 0	0 0	- - - -	0 0	0	0	0	**-4**
R1234yf	0	0 0	0 -	0 -	- -	0	0	0	**-4**
R290 (Propane)	0	+ 0	0 -	0 0	- - 0	0	0	0	**-2**
R729 (Air)	- -	+ - -	- +	0 0	+ +	0	0	- -	**-3**
R744 (CO_2)	-	+ -	- -	0 0	+ 0	0	0	-	**-3**

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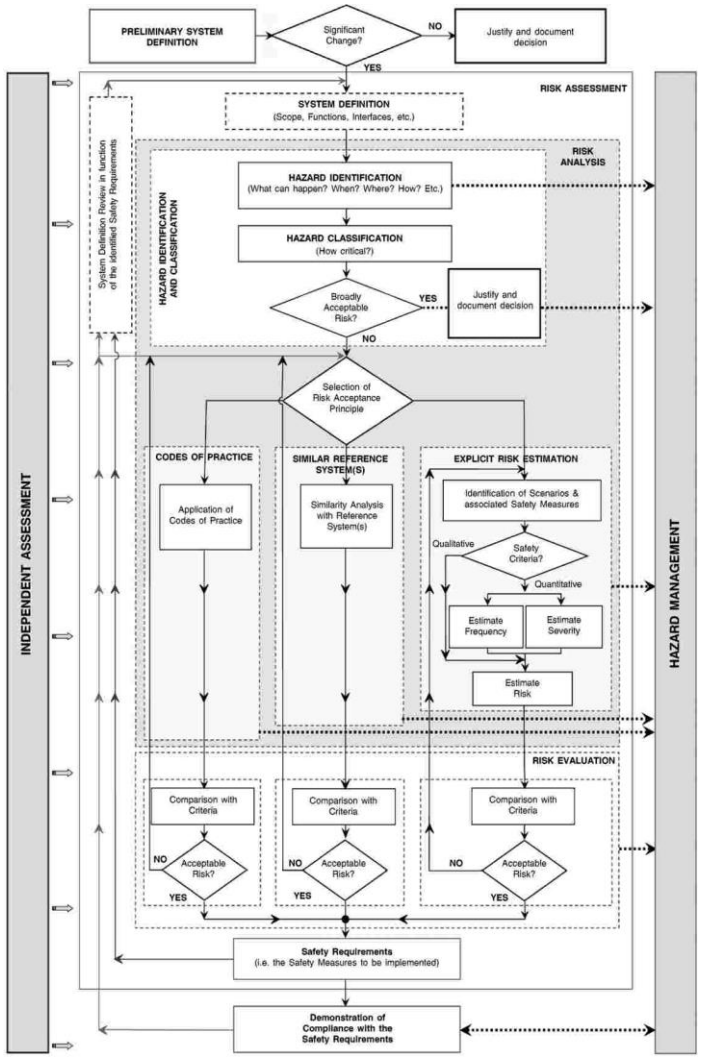
Risk Analysis – Application for HVAC Rail System

- ✓ No Refrigerant shows ideal properties
- ✓ The property "flammability" of the refrigerant does not "a priori" represent an exclusion criterion
- ✓ Risks in rail operations have to be analyzed and mitigated according to CSM guideline EU/402/2013 by
  - Application of regulations/standards and/or
  - Consideration of similarities to reference systems and/or
  - Risk analysis

- 🎯 TARGET: Acceptable Risk Level – comparable Safety Level as today
- 🎯 Assessment according to the railway-specific safety standard
  → EN 50126-1: Railway Applications -The Specification and Demonstration of Reliability, Availability, Maintainability and Safety

Risk Analysis – Application for HVAC Rail System



Introduction of change
Documentation recommended

Description of Modifications

Check of Safety relevance

Non safety relevant

Check of Significance

Non significant

Definition of System

Determination of Hazards

Application of Codes of Practice

Comparison to reference system

Explicit Risk Estimation

Risk evaluation and final assessment

Safety assessment report by AsBo

Management of Hazards

In-house safety method

- System definition
- Risk assessment
- Risk control

Documentation mandatory

Risk Analysis – Application for HVAC Rail System

Identification of risks in the life cycle for **in-service operation, standstill, maintenance** and **repair** as well as for **accidents** and **foreseeable misuse**:

- Assessment of the severity of an accident for people and infrastructure
- Frequency of the event

Additional for CO_2 and flammable refrigerants

- Leak types and frequencies
- Concentration as a function of the type of leak, the location and the ventilation

Additional for flammable refrigerants

- Ignition source analysis and Evaluation

Risk Analysis – Application for HVAC Rail System

- Determination of risks and frequencies in operation including foreseeable misuse during life cycle
- Validation of actual risks from operational experience
- Grouping of cases into an acceptance criterion

Akzeptanzkriterium Vorgeschlagen

			Häufigkeit / Anlage / Jahr	<--Bahnklima-anlagen						
Frequency of event	häufig	Frequent	$>10^{-3}$	N.A.	N.A.	unerwünscht	untragbar	untragbar	untragbar	untragbar
	wahrscheinlich	Probable	$\leq 10^{-3}$	N.A.	N.A.	tolerabel	unerwünscht	untragbar	untragbar	untragbar
	gelegentlich	Occasional	$\leq 10^{-4}$	N.A.	N.A.	tolerabel	unerwünscht	unerwünscht	untragbar	untragbar
	gering, selten	Remote, rare	$\leq 10^{-5}$	N.A.	N.A.	vernachlässigbar	tolerabel	unerwünscht	unerwünscht	untragbar
	unwahrscheinlich	Improbable	$\leq 10^{-6}$	N.A.	N.A.	vernachlässigbar	vernachlässigbar	tolerabel	unerwünscht	untragbar
	sehr unwahrscheinlich	very unlikely	$\leq 10^{-7}$	N.A.	N.A.	vernachlässigbar	vernachlässigbar	vernachlässigbar	tolerabel	unerwünscht
	nahezu unmöglich	Almost impossible	$\leq 10^{-8}$	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HAZOP Severity Ranking Scale -->				**0**	**4**	**5**	**6**	**7**	**8**	**9**
Values and key wording under evaluation by refrigeration industry				**No damage / injury**	**Minor** (minor injuries; treatment on site)	**Marginal** (several light injuries)	**Critical** (several injuries or few severe injuries)	**Catastrophic** (several severe injuries or less than three fatalities)		
Risiko-Akzeptanzkriterien nach EN 50126-1, Tabelle C.9					un-wesentlich	unbedeutend S5	geringfügig S4	kritisch S3	katastrophal S2	katastrophal S1
				Severity of event						

vernachlässigbar	Das Risiko ist ohne Zustimmung der Bahnunternehmen akzeptabel
tolerabel	Das Risiko kann unter der Voraussetzung angemessener Kontrollen (z. 8. Instandhaltungsverfahren oder -regeln) und mit Zustimmung der verantwortlichen Bahnunternehmen toleriert und akzeptiert werden.
unerwünscht	Das Risiko darf nur dann akzeptiert werden, wenn eine Minderung nicht durchführbar ist und die Zustimmung des Bahnunternehmens oder der zuständigen Sicherheitsbehörde vorliegt.

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Summary and Outlook

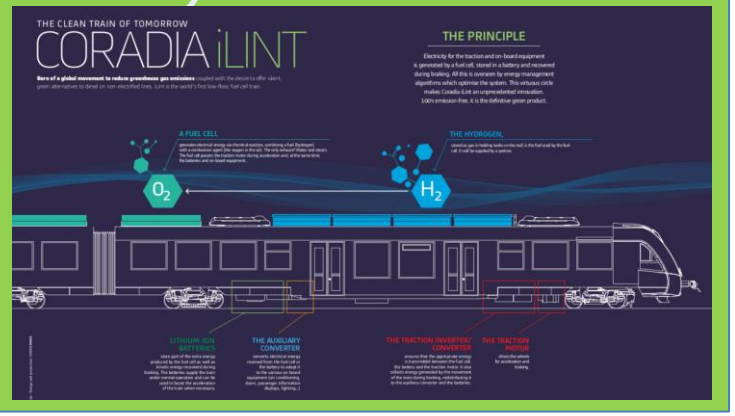
Criteria refrigerant	Weight	Dimensions	Energy consumption	Application
R134a (with HP)	100	100	100	All type of trains All climatic zones
R1234yf (with HP)	100 – 105	100 - 105	100	All type of trains All climatic zones
R290 (with HP)	100 – 105	100 - 105	70 – 100	All type of trains All climatic zones
CO_2* (with HP)	120 – 130	100 – 120 dimen. HX	80 – 120	Except Metro Except hot/very hot zones
Air cycle* (with HP)	100 – 110	100 -120 dimen. HX / piping	105 – 130	All type of trains All climatic zones

Summary and Outlook

- ✓ **F-gas regulation also effecting the rail sector**
- ✓ **Synthetic refrigerants** (established and new up-coming refrigerants) offer solutions today - R1234yf seems uncertain for rail operators in the long term (risks with regard to environmental impact and toxicity)
- ✓ **Natural refrigerants** not yet in ongoing projects / commercial service
- ✓ CO_2 and AIR available, but not optimal due to costs, weight, energy efficiency on-board electrical system, single source with suppliers and flexibility
- ✓ HC: Proof of the same level of safety when using flammable refrigerants as with state of art systems
- ✓ In the future stronger differentiation into the different refrigerants / technologies depending on the end customer and operating conditions

Summary and Outlook

- **Flammable substances are no longer excluded a priori**
  - Hydrogen as an source for fuel cells in rail operations
  - Li-Ion batteries as an energy source for battery-powered trains in rail operations
  - Use of HFO / HC in discussion
  - HC established in stationary refrigeration and A/C technology
- **Hydrocarbons enable**
  - Thermodynamically comparable process such as HFC / HFO (pressure level, technology → existing experience can be used)
  - Comparable system design / application limits
  - Maintaining the current electrical system architecture (installation space, weight, technology)
  - Same security can be achieved as with conventional systems



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