Applications with Low Global Warming Potential / Flammable Refrigerants

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Content

- Refrigerants in a historic perspective & our journey from **Montreal**, via **Kyoto** to **Kigali** and ahead
- Are there sustainable synthetic refrigerants?
- Most relevant natural working fluids
- Heat pumps and refrigeration systems applying hydrocarbons
- Mandatory information to end-user is key
- +How smart loans could **accelerate phase-in** of units with natural working fluids

Refrigerant journey until now

- 18.. -> 1930 mainly natural working fluids are applied
- 1930 – 1989 massive lobbying and introduction of 'safe' synthetic working fluids, mainly CFCs and HCFCs
- 1987 **Montréal Protocol**: [ODP] Globally ratified within 2 years only!
  → lobbying triggered the introduction of HFCs
  → initiated the revival of CO_2 as working fluid by Prof. Gustav Lorentzen
- 1997 **Kyoto Protocol**: [GWP] took 7 years, US didn't join, China & India ++ were exempted from reduction commitments
- 2006 → **EU F-gas directive**, updated 2014 (phase down steps based on GWP)
- 2015 Paris agreement + 2016 **Kigali amendment** to the Montréal Protocol
  → massive lobbying pushes the introduction of ultra low GWP HFCs

Is 'F-gas churning' to the best for society and environment ?

Next generation of synthetic refrigerants?

State of the ‘art’:

The use of F-gasses in the past decades has a sever impact on humans and the environment:

- Depletion of the ozone layer (CFCs)
- Global warming (CFCs, HCFs, HFCs)
- Poisonous decomposition products (PFAS*)
- Acidification of our wates by TFA (unsaturated HFCs)

What are sustainable working fluids?

*PFAS
(Per- and polyfluorinated alkyl substances), also known as the **Forever Chemicals.**
Large chemical family of over 9,000 highly persistent chemicals that don't occur in nature.

Sustainable working fluids?

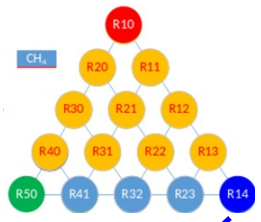
- McLINDEN [NIST] intensive screenings to **identify suitable refrigerants**
- Used **PubChem database** (Kim *et al.*, 2016), i.e. more than 60 000 000 chemicals
- **Cycle calculations** (simple performance)→ fluids with low COP and/or volumetric capacity were screened out.
- The **final result** was a list of **27 fluids**; these comprised **hydrocarbons**, HFCs, HFOs, **CO_2, ammonia**, and a total of five compounds with oxygen, nitrogen and/or sulfur.

Second Conclusion:

…While a **drop-in replacement** refrigerant requiring no changes to equipment design is appealing, **the properties of low-GWP fluids** will generally be different than the fluid they are replacing. Recognizing and **adapting to these differences will be required** to maximize the safety, efficiency, and reliability of new systems….

Source: Mark O. McLINDEN National Institute of Standards and Technology, Boulder, USA

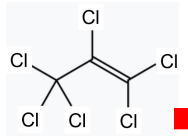
Sustainable working fluids?



Carbon tetrachloride

Methane

Carbon tetrafluoride

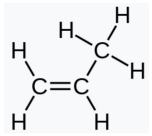


Hexachloro-propylene

Ozone Depletion !

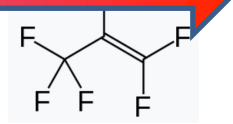
C3H6

Propene (propylene)



R1270

Hexafluoro-propylene



Source: Alexander Cohr Pachai

ultra low GWP

Summary of Latest scientific results*,:**

- **R-1234yf → transforms mainly to HF and TFA**
- **R-1234ze → ?**
  - **Hansen et al.*** discovered lately that in a unimolecular photolysis channel R-23 (→10%) is formed from CF_3CHO** (<- interm. breakdown product)
  - More scientific experiments are underway

- **Definition of GWP values**
  - **LCA based GWP values are nee**
    - **including manufacturing &**
    - **decomposition**

* https://ecostandard.org/wp-content/uploads/2021/05/ECOS-briefing-on-HFO-production-and-degradation_final.pdf
** https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated
*** https://www.green-cooling-initiative.org/news-media/news/news-detail/2021/05/11/green-cooling-summit-2021-germany-opts-for-a-rapid-hfc-phase-down

Way forward for a real green development

We all need to focus on

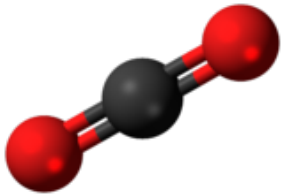
Natural Working Fluids

You and your customers will face no risk to invest and apply into technologies being on the **phase out agenda** in the near future

Safe & sustainable investment

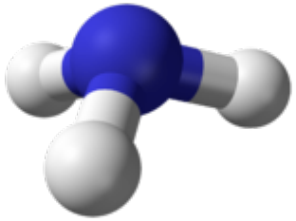
Most relevant natural working fluids

Carbon Dioxide / CO_2 / R744



- Hot water heat pumps
- Commercial- / low temp. industrial refrigeration
- Heat pump chillers

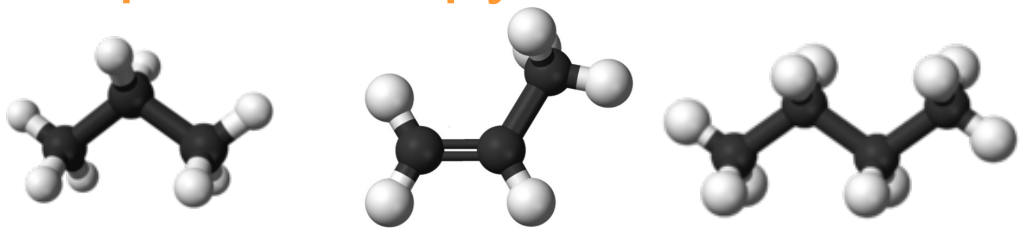
Ammonia NH_3 / R717



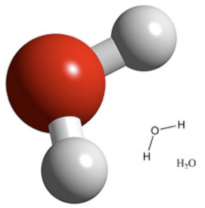
- Industrial refrigeration and heat pumps

Hydrocarbons

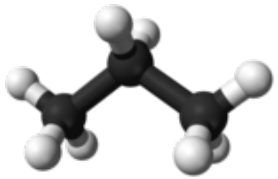
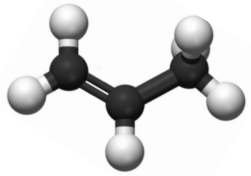
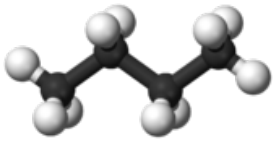
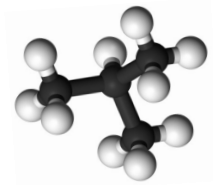
(Propane, Propylene, Butane, etc.) / R290, R1270 / R600



+ Water H_2O / R718



Hydrocarbons

	Evaporation temps:	Cooling / heating capacities:
Propane R290: 	MT: -19 °C → +2 °C	MT: 5 kW → 450 kW
	AC: +3 °C → +10 °C	AC: 10 kW → 1000 kW
	PC: +11 °C → +22 °C	PC: 10 kW → 1200 kW
	HP: 0 °C → +40 °C	HP: 10 kW → 1200 kW
Propylene R1270: 	LT: -35 °C → -20 °C	LT: 5 kW → 150 kW
	MT: -19 °C → +2 °C	MT: 5 kW → 450 kW
Butane R600:  n-butane  Isobutane (R600a)	LT: -25 °C → -10 °C	LT: (domestic) fridge
	HP: +40°C → +70 °C	HP: 100 kW →1000+ kW

Currently (2021) in the market

Applications with Hydrocarbons

- Available products in the EU market
- Indoor and outdoor installations
- Chilling, Heating and domestic hot water
- Integrated safety concepts
- Requirements
- Explosion protection measures
- Charge levels:

<150 g (500 g)	<1’000 g	<4’940 g
• no restrictions	• Restrictions for indoor installations	• Ventilated cabinets

Source: enerblue.it, hautec.eu, alpha-innotec.de, teko.de, skadec.de

Applications with Hydrocarbons

Pharma / LT (piston compressors)

2 x 77 kW (outlet temp. -34°C)

6 kg (R1270) per circuit

Meat factory / MT (screw compressors)

2 x 515 kW (outlet temp. -8°C)

25 kg (R290) per circuit

Ref: https://www.green-cooling-initiative.org/fileadmin/user_upload/26_Keynote_Schadt.pdf

Applications with Hydrocarbons

Shopping Mall / AC (screw compressors)

2 x 1.200 kW (outlet temp. +8°C)

40 kg (R290) per circuit

Production / PC (piston compressors)

1 x 600 kW (outlet temp. +12°C)

12 kg (R290) per circuit

Ref: https://www.green-cooling-initiative.org/fileadmin/user_upload/26_Keynote_Schadt.pdf

Applications with Hydrocarbons

University / AC (compact chiller)

3 x 52 kW (outlet temp. +8°C)

1,9 kg (R290) per circuit

Railway station / AC (piston compr.)

2 x 260 kW (outlet temp. +6°C)

4,5 kg (R290) per circuit

Ref: https://www.green-cooling-initiative.org/fileadmin/user_upload/26_Keynote_Schadt.pdf

End user awareness

Key factors for a successful and global fast phase-in of green cooling units applying Natural Working Fluids:

- **Training** and **knowledge transfer**
  - **Understanding** that green cooling/heating is not at all possible with non-natural working fluids
- **End-user awareness**: inform what kind of equipment they are ordering and become responsible for:
  - Look into Material Safety Data Sheet [MSDS] of working fluid
  - Seasonal energy demand and total GWP of the working fluid, including production & end of life

How to accelerate phase-in of green cooling units applying Natural Working Fluids globally?

World Bank, Multilateral funds, national governments and funding programs should support end-users (investors) to cover additional first costs for cooling units applying natural working fluids with affordable loans following the unit. So, the **end-users (operators) can return the debt during the operational phase.**

Investment in green cooling/heating is often 'killed' by slightly higher capital expenditures (CapEx) for new energy efficient NWF systems.

However, these units give significant operation expense (OPEX) savings for the operator.

Conclusion

- **All vital cooling and heat pump devices can be made available, energy / cost efficient, and environmental benign with natural working fluids**
- **Flammability of working fluids can be handled properly by following norms and standards**
  - in case of certain restrictions: CO_2 is a nonflammable natural alternative
- It must become **mandatory and requested by end-users (legislation) that other environmental impacts than Global Warming Potential (GWP) values** of working fluids, i.e. from by-products during production and degradation **are made public by the supplier of a cooling / heat pump unit**.

Take home massage:

- **Food is valuable** and essential for humankind
  → safe and reliable refrigeration equipment is needed to reduce food loss
- **Safety at work / home** important for responsible companies
  – Nobody should become **sick due to refrigerants**
  – Natural refrigerants are a **safe choice**
- **Environmental impact** of major importance
  – Only **natural working fluids will survive** towards 2050
  – Great **energy efficiency improvements** can be achieved

→ Let's cooperate

THANK YOU FOR YOUR ATTENTION
Questions are welcome?

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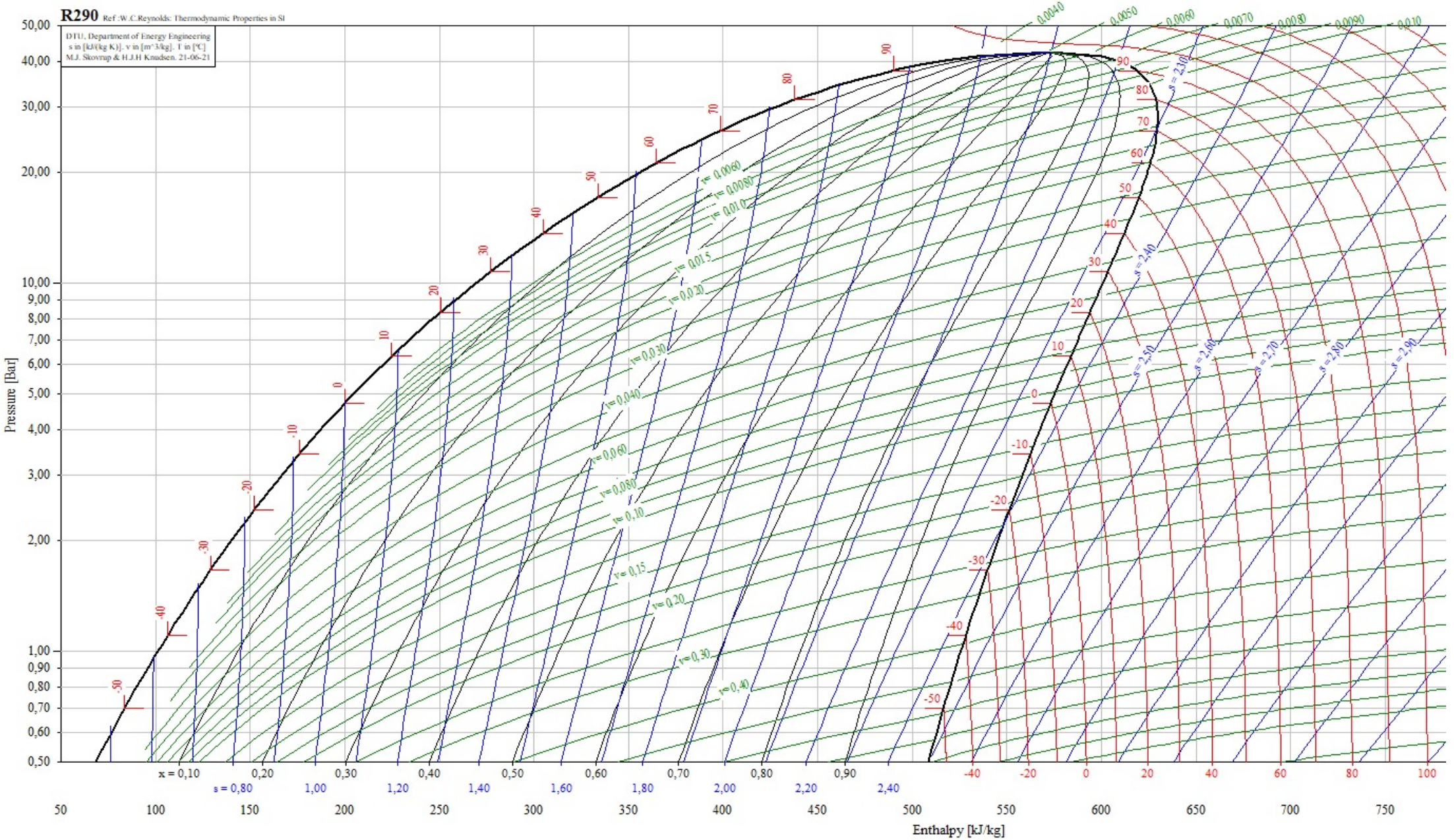
R290 Ref :W.C.Reynolds: Thermodynamic Properties in SI
DTU, Department of Energy Engineering
s in [kJ/(kg K)], v in [m^3/kg], T in [°C]
M.J. Skovrup & H.J.H Knudsen. 21-06-21
Pressure [Bar]
Enthalpy [kJ/kg]
x = 0,10
s = 0,80

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