DES M1
Design of Energy Systems
Lecture 3
Refrigerants properties
Regulation / Natural refrigerants
Find data for refrigerants

<table>
<thead>
<tr>
<th>Type/name</th>
<th>R134a</th>
<th>R404a</th>
<th>R717</th>
<th>R744</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical point (°C)</td>
<td>100.95</td>
<td>71</td>
<td>132.2</td>
<td>31</td>
</tr>
<tr>
<td>Normal temperature range (°C)</td>
<td>-28/90</td>
<td>-47/50</td>
<td>-40/120</td>
<td>-30/120</td>
</tr>
<tr>
<td>Specific latent heat (KJ/kg) for evaporation at -10 °C</td>
<td>204</td>
<td>180</td>
<td>1249</td>
<td>445</td>
</tr>
<tr>
<td>Pressure (Bar) at 40 °C and -10 °C</td>
<td>10/2</td>
<td>18/4.5</td>
<td>15.4/2.9</td>
<td>26/100</td>
</tr>
<tr>
<td>COP, 40/-10 °C (η=1)</td>
<td>4.03</td>
<td>3.2</td>
<td>4.29</td>
<td>3.31 (25°C)</td>
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<tr>
<td>Safety issues</td>
<td>-</td>
<td>Explosion</td>
<td>Flammable (theoretic) and toxic</td>
<td>-</td>
</tr>
<tr>
<td>Environmental issues: GWP/ODP</td>
<td>1430/0</td>
<td>3922/0</td>
<td>~0/0</td>
<td>1/0</td>
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<tr>
<td></td>
<td>R22</td>
<td>R134a</td>
<td>R404A</td>
<td>R600a</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Type/name</strong></td>
<td>HCFC</td>
<td>HFC</td>
<td>HFC</td>
<td>HC Isopropane</td>
</tr>
<tr>
<td></td>
<td>Freon22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Critical point (°C)</strong></td>
<td>96</td>
<td>101</td>
<td>72.1</td>
<td>135</td>
</tr>
<tr>
<td><strong>Normal temperature range (°C)</strong></td>
<td>-20 to 90</td>
<td>-25 to 95</td>
<td>-5 to 60</td>
<td>-10 to 130</td>
</tr>
<tr>
<td><strong>Specific latent heat (KJ/kg) for evaporation at -10 °C</strong></td>
<td>212</td>
<td>205</td>
<td>176</td>
<td>364</td>
</tr>
<tr>
<td><strong>Pressure (Bar) at 40 °C and -10 °C</strong></td>
<td>15/3.5</td>
<td>10/2.0</td>
<td>18/4.3</td>
<td>5.3/1.1</td>
</tr>
<tr>
<td><strong>COP, 40/-10 °C (η=0.75)</strong></td>
<td>3.08</td>
<td>3.02</td>
<td>3.5</td>
<td>3.09</td>
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<tr>
<td><strong>Safety issues</strong></td>
<td></td>
<td></td>
<td></td>
<td>Flammable</td>
</tr>
<tr>
<td><strong>Environmental issues: GWP/ODP</strong></td>
<td>1810/0.055</td>
<td>1300/0</td>
<td>3260/0</td>
<td>3/0</td>
</tr>
</tbody>
</table>
The ideal refrigerant, 1

1. Best possible COP

2. Price and service costs, leakage??

3. Highest possible latent heat pr. kg circulated refrigerant

4. Suitable evap/condensing pressure and low discharge temperatur

5. Chemically stable

6. Not aggressive towards the materials used in the refrigeration system

7. Not react with oil

8. Critical pressure must be well beyond the calculated condensing pressure
The ideal refrigerant, 2

9. Not be flammable

10. Available at reasonable costs

11. Easy to spot leakages

12. Compressible at low energy consumption

13. Not freeze at the evaporating working temperatures

14. Not be harmful to people and environment

15. Low GWP and no ODP (Political issues)
Refrigerants
Required physical properties (1)

High latent heat for evaporation
- high ➤ high $q_0$ ➤ low $q_{mR}$

Specific volumetric capacity $q_0/V$
- high ➤ smaller compressor

Vapour pressure
- higher than $P_{\text{atm}}$ ➤ avoid leakage into system of air and moisture

Condensation pressure
- low ➤ reduce wall thickness in pipes (!! To a certain extent)
- below critical point (except for R744)
Refrigerants
Required physical properties (2)

Pressure ratio
- low ➤ low energy consumption

Freezing point
- Significantly lower than $t_0$

Dynamic viscosity
- low ➤ reduce pressure drop in liquid pipes
Refrigerants
Oil solubility in refrigerant

- Oil absorb refrigerant and thus reduce the viscosity, which affects the lubrication of the compressors
- Can reduce heat transmission in heat exchangers
- Low solubility is preferred (Yes and no)
Refrigerants
Water solubility in refrigerant

- Water in refrigerant can freeze or cause corrosion
- Water in refrigerant plant must be avoided at all costs, blocks up valves and potential filters and get stuck in evaporators
Refrigerants
Health & Safety

- Toxic
- Corrosion
- Panic reactions (smell, mainly R717)

- Safety precautions
Refrigerants
Flameable refrigerants

- HC refrigerants: Propane (R290), Isobutane (R600a), Propylene (R1270)
- Safety precautions
- Small quantity of refrigerant
- Chillers (in combination with secondary refrigerant)
R12, R11, “Freon” meets all technical demands, but have very negative impact on environment.

GWP: 2400/4000
ODP: 1

Ozone layer showing 'signs of recovery', UN says.
Environmental impact
Ozone hole

1979

1987

2006

2011
Refrigerants and environment

TEWI = Direct Emission + Indirect Emission

- TEWI (Total Equivalent Warming Impact) is one of the most important ways to quantify emissions
- Minimising TEWI will reduce global warming
- Different types of applications have different composition of TEWI
- Supermarkets are one of the most critical direct emission sources

Refrigerant leakage (Direct impact)

CO₂ (Indirect impact)

Unitary A/C
- Main focus on performance
Domestic Refrigeration
- Main focus on leakage
Mobile A/C
Supermarket Refrigeration
### Properties for Carbon Chain Based Refrigerants

**Figure 7: Carbon Chain Based Refrigerants (HCs, HFCs, HCFCs)**

<table>
<thead>
<tr>
<th>GWP Level</th>
<th>R123 Like</th>
<th>R134a Like</th>
<th>R404A &amp; R22 Like</th>
<th>R410A Like</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1500</td>
<td>R1233zd, R1336mzzz/DR2</td>
<td>R1270</td>
<td>DR3</td>
<td>HDR110</td>
<td>R744/CO2, R717/NH3</td>
</tr>
<tr>
<td>&lt; 700</td>
<td>R450A/N13, R513A/XP10</td>
<td>R449A/XP40</td>
<td>DR7</td>
<td>R32</td>
<td>R454B/DR55, R447A/L41</td>
</tr>
<tr>
<td>&lt; 4000</td>
<td>R404A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **A1 - Non Flammable**
- **A2 - Mildly Flammable**
- **A3 - Highly Flammable**
- **B2L - Toxic, Lower Flammable**

- **New and on the market**
- **Not yet on the market**
Refrigerants Options

Many of the new refrigerants are flammable or mildly flammable!

Refrigerants

Transitional/Service Refrigerants

HCFC and HFC partly chlorinated

Single fluids
- e.g. R22
- R123
- R124
- R142b

Blends
- R22 based:
  - R402A
  - R403A
  - R408A

Medium- and Long-Term Refrigerants

HFC Chlorine free

Single fluids
- e.g.
  - R134a (1430)
  - R125 (3500)
  - R32 (675)
  - R143a (4470)
  - R152a (124)

Blends
- e.g.
  - R404A (3920)
  - R507A (3990)
  - R407C (1770)
  - R410A (2090)
  - R422D (2730)

Natural halogen free

Single fluids
- e.g.
  - R717
  - R290
  - R1270
  - R600a
  - R170
  - R744

Blends
- e.g.
  - R600a/R290
  - R290/R170
  - R723

The choice of the refrigerant has an impact on the (energetic) systems performance and reliability (GWP in brackets)
Regulatory – Phase-down/out Schedules and Proposals

Conclusion: HFCs are under pressure (The question is when?)
Applications & Main Refrigerants

- **R600a (R134a in NAM)**
- **R134a**
- **R1234ze**
- **R744**
- **R1234 + Blends**
- **R134a**
- **R32**
- **R410A (R134a for HP)**
- **R717**
- **R290**

**Domestic Refrigeration**
- Mobile AC: R134a, R1234yf
- R744

**Light Commercial Refrigeration**
- R744

**Commercial Refrigeration**
- R290
- R1234yf
- R134a
- R404 (R134a for HP)
- R32
- R290
- R1234+blends

**A/C & Heatpumps**
- R134a
- R717
- R290
- R1234ze

**Centrifugal Chillers**
- R744

**Industrial Refrigeration**
Natural refrigerants

CO$_2$, R744

Ammonia, R717

HC, eg. Propane, Isobuthane
# Natural refrigerants

## Annex 1. Refrigeration properties

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R22</th>
<th>R134a</th>
<th>R404A</th>
<th>R410A</th>
<th>R717 (NH₃)</th>
<th>R744 (CO₂)</th>
<th>R290 (propane)</th>
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<tbody>
<tr>
<td>Efficiency</td>
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<td>🟢</td>
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<td>Safety</td>
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<td>🟢</td>
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<tr>
<td>Environment (ODP, GWP)</td>
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<td>🟥</td>
<td>🟢</td>
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<tr>
<td>Pressure &amp; temperature</td>
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<td>Chemical properties</td>
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<td>🟢 / 🟥 ***</td>
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<td>Availability</td>
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<td>🟢</td>
<td>🟢</td>
<td>🟢</td>
<td>🟢</td>
</tr>
<tr>
<td>Typical applications</td>
<td>All</td>
<td>light commercial, commercial, A/C</td>
<td>commercial</td>
<td>commercial, heat pumps, A/C</td>
<td>commercial &amp; industrial refrigeration</td>
<td>light commercial, commercial, industrial, transport, HP</td>
<td>domestic, light commercial, commercial, heat pumps</td>
</tr>
</tbody>
</table>

* Some refrigeration applications
** Heat pumps, secondary media, and some refrigeration applications
*** Higher taxes (Nordic countries)
If you want to learn more: Refrigerants from a Danfoss Perspective

https://www.youtube.com/watch?v=B7AvCE9FAX4
https://www.youtube.com/watch?v=l2otsot38FM
https://www.youtube.com/watch?v=T8fsESff4Gk
https://www.youtube.com/watch?v=T8fsESff4Gk
https://www.youtube.com/watch?v=ko9gfcCaluk