R-466A
A Low GWP Non-Flammable Replacement for R-410A

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Trane Technologies
Outline

- Regulation Driving this Work
- Refrigerant Options to Replace R410A
- R466A Performance in
  - Scroll-based Air-cooled Chiller
  - Residential Split Systems
  - Rooftop System
- R466A Chemical Stability
- Conclusions
Concern that HFCs are contributing to climate change.

Regulatory pressure to reduce the use of HFCs.

- Kigali Agreement.
- European “F-Gas” Laws.
- EPA SNAP Rules
  - Being considered for adoption by California and other states.
- CARB:
  - R404A and R507 banned in commercial refrigeration beginning this year.
  - GWP < 750 in stationary air-conditioning beginning 2023 to 2025

Looking for “design compatible” nonflammable <750 GWP replacement for R410A
State HFC Action Update

Twelve States have taken legal action so far to phase down HFCs

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- Climate Alliance - 25 states (55% U.S. population / 60% U.S. GDP)
- Short Lived Climate Pollutant Challenge includes HFCs
- EPA SNAP 20/21
  - Commercial refrigeration
  - Chillers (2024)
  - Foams
- Pursuing restrictions on direct HVAC systems
- Codes allow A2Ls in all products
<table>
<thead>
<tr>
<th>name</th>
<th>Safety Class</th>
<th>R32</th>
<th>R125 A1</th>
<th>R1234yf A2L</th>
<th>R13I1 (CF₃I)</th>
<th>GWP (AR4)</th>
<th>GWP (AR5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A</td>
<td>A1</td>
<td>0.5</td>
<td>0.5</td>
<td>–</td>
<td>–</td>
<td>2088</td>
<td>1924</td>
</tr>
<tr>
<td>R32</td>
<td>A2L</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>675</td>
<td>677</td>
</tr>
<tr>
<td>R454B</td>
<td>A2L</td>
<td>0.689</td>
<td>–</td>
<td>0.311</td>
<td>–</td>
<td>465</td>
<td>467</td>
</tr>
<tr>
<td>R452B</td>
<td>A2L</td>
<td>0.67</td>
<td>0.07</td>
<td>0.26</td>
<td>–</td>
<td>698</td>
<td>676</td>
</tr>
<tr>
<td>R466A</td>
<td>A1</td>
<td>0.49</td>
<td>0.115</td>
<td>–</td>
<td>0.395</td>
<td>733</td>
<td>696</td>
</tr>
</tbody>
</table>

Take advantage of the flame suppressing ability of CF₃I (R13I1)
- Recently added to Std-34 as A1.

Investigated in 1990s as replacement for Halons and as component in low ODP refrigerant blends.
R466A Performance Compared to R410A Alternatives

- **Potential Alternatives:**
  - **R32**
  - **R454B**
  - **R452B**
  - **Variety of other blends**
  - **R466A**

- Class A2L: Assessed during AHRI’s AREP.
- **R466A**: New candidate.

**ASHRAE Standard 34-2019:**
- Class A2L = lower flammability
- Class A1 = non-flammable
R466A – Thermodynamics Comparison

- Using simple cycle model with “optimistic” assumption regarding matching $T_s$.

- Higher $P_c$ and $T_c$ modestly higher CDT.

- Narrower Sat Dome.

- Averaging of glide to match $T_s$.

- Modestly higher CDT.
## R410A Alternatives – Thermodynamics Comparison

<table>
<thead>
<tr>
<th>name</th>
<th>ΔCAP*</th>
<th>ΔCOP*</th>
<th>(Pc/Pe)*</th>
<th>mRt*</th>
<th>ΔCDT (R/K)</th>
<th>glide (R/K)</th>
<th>ρL*</th>
</tr>
</thead>
<tbody>
<tr>
<td>R410A</td>
<td>0</td>
<td>0</td>
<td>1.000</td>
<td>1.00</td>
<td>0 / 0</td>
<td>0.2 / 0.1</td>
<td>1.00</td>
</tr>
<tr>
<td>R32</td>
<td>+7.7%</td>
<td>+1.0%</td>
<td>1.005</td>
<td>0.67</td>
<td>+27 / +15</td>
<td>0.0 / 0.0</td>
<td>0.92</td>
</tr>
<tr>
<td>R454B</td>
<td>−3.9%</td>
<td>+1.6%</td>
<td>1.004</td>
<td>0.82</td>
<td>+10 / +5</td>
<td>2.2 / 1.2</td>
<td>0.95</td>
</tr>
<tr>
<td>R452B</td>
<td>−3.1%</td>
<td>+1.4%</td>
<td>1.003</td>
<td>0.84</td>
<td>+9 / +5</td>
<td>1.9 / 1.1</td>
<td>0.95</td>
</tr>
<tr>
<td>R466A</td>
<td>−2.6%</td>
<td>+0.9%</td>
<td>0.993</td>
<td>1.08</td>
<td>+12 / +7</td>
<td>2.7 / 1.5</td>
<td>1.18</td>
</tr>
</tbody>
</table>

- **Expect near-match to R410A.**
- **Consequence of employing heavy iodine atom.**
- **Consequence of employing narrower saturation dome.**
R466A Equipment Evaluations
Air-Cooled Water Chiller – Drop-in Test

- Nom capacity = 100 RT
  - 2 circuits
- Scroll Compressors
  - 2 compressors per circuit
- Microchannel Condensers
- BPHE Evaporator
- Flow control by EEV
- Ran only one circuit
  - Reduced amount of refrigerant needed
  - Cleaner data analysis

- Test Conditions:
  - TChWo: 44, 56, 68°F / 7, 13, 20°C
  - Tamb: 65..125°F / 18..52°C
Air-Cooled Water Chiller – Drop-in Test

- **CAP:** R466A ~ R452B
- **COP:** R466A ~ 3-4% ↓ than R452B
- **CDT:** R466A ↑ than R452B; R466A ↓↓ than R32

Residential Split System Heat Pump

- Nominal capacity = 10.5 kW (3 RT).
- Nominal COP = 3.5.
- Tests run with “Exp” and R466A in same unit ~1 year apart.
- Test procedure and test points per AHRI Std-210/240.
- Drop-in test – adjusted TXV to achieve target SH w/each refrigerant.
- Sensitivity to refrigerant charge studied.
Residential Split System Heat Pump

- **2017 w/ “R466A V1”**
  - SEER/R410A = 1.010
  - HSPF/R410A = 0.990

- **2018 w/ R466A Final**
  - SEER/R410A = 0.995
  - HSPF/R410A = 1.005
Rooftop Unit – Drop-in Test

- Nominal capacity = ~14 kW (4 RT).
- Nominal COP = 3.5.
- Test procedure per AHRI Std-210/240.
  - Tests executed by outside party.
  - Refrig circuit lightly instrumented.
- “A” and “B” test points plus outdoor air temperature sweep from 24°C .. 46°C (75°F .. 115°F).
- Adjusted TXV to achieve target SH w/each refrigerant. (Not done perfectly.)
- Adjusted refrigerant charge to achieve target SC w/each refrigerant. (Not done perfectly.)
Rooftop Unit – Drop-in Test

- Capacity w/R466A was 5% to 6% lower than w/R410A at A & B rating pts.
- COP w/R466A was 2% to 3% lower than w/R410A at A & B rating pts.
- Performance was lower than predicted by simple model, but within expectations of more conservative model.
**Refrigerant Charge – Summary**

<table>
<thead>
<tr>
<th></th>
<th>R466A vs R410A</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimate</strong></td>
<td>+15%</td>
<td>Based on ratio of liquid densities.</td>
</tr>
<tr>
<td><strong>Chiller</strong></td>
<td>+15%</td>
<td>Maximized COP at rating point, but relatively insensitive to charge.</td>
</tr>
<tr>
<td><strong>Residential</strong></td>
<td>+16%..+26%</td>
<td>Check sensitivity. Cooling okay with smaller charge. Heating helped by larger charge.</td>
</tr>
<tr>
<td><strong>RTU</strong></td>
<td>+7%</td>
<td>Matched subcooling at “A” (almost).</td>
</tr>
</tbody>
</table>

Refrigerant charge for R466A generally within expectations based on ratio of liquid densities (filling the condenser/subcooler and liquid lines).
R466A System Chemistry Evaluations
Refrigerant System Chemistry Overview

- SYSTEM chemistry deals with any chemical reactions that could take place in an HVAC&R system between refrigerants, lubricants, and construction materials of various system components (e.g., compressor, heat transfer coils, connecting tubing, expansion device).

- Two distinct refrigerant system chemistry evaluations
  - Chemical stability/compatibility testing (fluid stability)
  - Materials compatibility testing (stability of system components)

- ASHRAE Handbooks & Standards
  - Chapter 6 – Refrigerant System Chemistry
  - Chapter 12 – Lubricants in Refrigerant Systems
  - Chapter 7 – Control of Moisture and Other Contaminants in Refrigerant Systems
  - Standard 97 – Sealed tube stability test
  - Guideline 6 – Refrigerant Information Recommended For Product Development
Understanding Chemical Stability & Acceleration Factors

- Current approach to chemical stability is often times far too accelerated

Refrigerant + Hermetic Materials

Highly Accelerated Lab Tests

Accelerated Equipment Testing

Application Operational Conditions & Reliability

Highly Accelerated Chemical Reaction Rates

Equipment Reaction Rates

Challenge: Translating Accelerated Lab Tests to Equipment Operational Life
How to Avoid Burning the Turkey!!
HVAC Systems & Reaction Kinetics

- **Reaction Kinetics – not a novel concept**
  - Evaluation of chemical reaction mechanisms and their rates.
  - Relative stabilities of HFCs vs HCFCs & CFCs has allowed us to use high acceleration factors.

- **Basis of accelerated chemical testing**
  - Allow extrapolation between test temperatures/times.
  - First demonstrated in HVAC via the ability to test R-22 at temperatures beyond the traditional 175°C used to screen materials

- **Arrhenius determined 1st order chemical reactions double for every 18°F(10°C) increase in temperature**

  2 weeks @ 150°C ≈ 1 week @ 160°C
R466A System Chemistry

- R32 and R125 are known to have good chemical stability
- CF3I or R13I1 is the weak link, specifically the iodine bond
- Iodine bonds are among the weakest carbon-halogen bond strengths
- General halogen chemical stability follows:
  - Fluorine stronger than >Chlorine>Bromine>Iodine
  - There are exceptions to this rule depending on species on other bonds
Carbon Halogen Bond Strength Summary

[Bar chart showing bond dissociation energies (kJ/mol) at 298 K for various carbon halogen bonds, with different substitutions indicated by colors: CH₃-X (X=H,F,Cl,Br,I) and CF₃-X.]
ASHRAE 97 Sealed Glass Tube Stability Testing

R-466A Pre-Exposure

R-466A Post-Exposure
R-13I1 Breakdown Mechanism

Classic Halogen Reduction Reaction

R-12 + H-Donor Lubricant → R-22

Cl

F  F  F
C

F  F  F
Cl

H-Donor Lubricant

Chlorine Products
H-Cl or Chlorination of Lubricant

R-13I1 + H-Donor Lubricant → R-23

I

F  F  F
C

F  F  F
I

H-Donor Lubricant

Iodine Products
H-I or Iodization of Lubricant

Reaction Rate: Measuring the formation of R-23
Conclusions

- The performance of R466A has now been tested across a range of products and operating conditions. (Chiller, Residential Split Systems, RTU)
- In general, R466A is considered R410A “design compatible”
  - Classification as A1 (non-flammable) and capacity and efficiency is similar (+/-2%)
  - Design changes
    - Account for higher mass flow rate and impact on HXer pressure drops
    - Account for flow rate in selection of TXV
    - Refrigerant charge will be larger because of higher liquid density
- Chemical stability and materials compatibility is still an open issue, but progress is being made to understand the needed changes

R466A is R410A “design compatible” solution
Its nonflammable classification will allow its quick adoption
Chemical stability & materials compatibility acceptance in progress
Men Continue to Argue…
Nature Acts

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