Hydrofluoroolefins (HFOs) as Low GWP Refrigerants for Residential Heat Pump Water Heaters

Kashif Nawaz, Bo Shen, Ahmed Elatar, Van Baxter

Building Technologies Research and Integration Center, ORNL

nawazk@ornl.gov

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Content

- Background
- Potential alternative refrigerants
- ORNL Heat Pump Design Model (HPDM)
- Performance comparisons
- Summary
Acknowledgements

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• Dr. Omar Abdelaziz (ORNL)
Consequences of Global Warming

- Glacier retreat
- Severe weather
- Droughts and large scale fires

Alaska’s Pedersen Glacier as it looked in the 1920s-1930s (left) and as it looked when photographed in 2005 (right). About 40 percent of the world’s glaciers are shrinking, and their reduction in size worldwide has accelerated rapidly since the 1970s, according to the Worldwide Glacier Monitoring Service. Photo by USGS (Brock Molnia)
Next Generation Refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>GWP_{100}</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>R-22</td>
<td>1760</td>
</tr>
<tr>
<td>R-134a</td>
<td>1300</td>
</tr>
<tr>
<td>R-410A</td>
<td>1924</td>
</tr>
</tbody>
</table>

**Hydrofluoroolefins (HFOs)**
- Fluorinated propene isomers
  - R-1234yf (CF₃CF = CH₂)
  - R-1234ze (CF₃CH = CHF)
- GWP < 4
- Mildly flammable

**Natural Refrigerants**

Moving away from Chlorine (ODP) and Fluorine (GWP) inevitably leads to flammability.
Goals

Identify appropriate substitute for R-134a as HFCs will phase out:

- Demonstrate an environmentally friendly ENERGY STAR®-qualified residential HFO refrigerant-based-based HPWH
  - Low GWP, no direct environmental impact
  - No major modification of existing system
  - FHR and EF performance should be comparable
## Alternative Refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Composition (mass %)</th>
<th>at 45 F</th>
<th>at 155 F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$T_c$ (K)</td>
<td>$P_c$ (Mpa)</td>
</tr>
<tr>
<td>R134a</td>
<td>Pure</td>
<td>374.21</td>
<td>4.06</td>
</tr>
<tr>
<td>R1234yf</td>
<td>Pure</td>
<td>367.85</td>
<td>3.38</td>
</tr>
<tr>
<td>R1234ze</td>
<td>Pure</td>
<td>382.51</td>
<td>3.64</td>
</tr>
</tbody>
</table>
Component-Based Flexible Modeling Platform for HPWHs – ORNL Flex HPDM

Component-Based

Component models have standard interfaces to the solving framework, and generic connections to each other.

Automatically connect components into required system configuration by user input file.
Model Calibration with Experimental Data

- Matching the measured water stratification profile

Water Draw Pattern is based on Pre-2015 EF evaluation criteria
Design Parameters

• 46-gallon water tank
• Heat pump T-stat at the top: on at 115°F, off at 125°F.
• Electric element at the top: on at 110°F, off at 125°F.
• Two different heat loss factors from tank (0.90 and 0.95)
• Two different condenser coil wrap patterns (parallel, counter)
• Two different evaporator sizes and air flow rates (Evap 1 & 2)
• Two different condenser tube sizes (0.31, 0.5 in Nominal)
First Hour Rating (FHR)
## Performance Evaluation Criteria

<table>
<thead>
<tr>
<th>FHR greater or equal to (gals)</th>
<th>FHR less than (gals)</th>
<th>Draw pattern for 24-hr UEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>Point of use</td>
</tr>
<tr>
<td>20</td>
<td>55</td>
<td>Low usage</td>
</tr>
<tr>
<td>55</td>
<td>80</td>
<td>Medium usage</td>
</tr>
<tr>
<td>80</td>
<td>Max</td>
<td>High usage</td>
</tr>
</tbody>
</table>

### Medium usage draw pattern

<table>
<thead>
<tr>
<th>Draw Number</th>
<th>Time During Test (hh:mm)</th>
<th>Volume (gals/L)</th>
<th>Flow Rate (GPM/LPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:00</td>
<td>15.0 (56.8)</td>
<td>1.7 (6.5)</td>
</tr>
<tr>
<td>2</td>
<td>00:30</td>
<td>2.0 (7.6)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>3</td>
<td>01:40</td>
<td>9.0 (34.1)</td>
<td>1.7 (6.5)</td>
</tr>
<tr>
<td>4</td>
<td>10:30</td>
<td>9.0 (34.1)</td>
<td>1.7 (6.5)</td>
</tr>
<tr>
<td>5</td>
<td>11:30</td>
<td>5.0 (18.9)</td>
<td>1.7 (6.5)</td>
</tr>
<tr>
<td>6</td>
<td>12:00</td>
<td>1.0 (3.8)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>7</td>
<td>12:45</td>
<td>1.0 (3.8)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>8</td>
<td>12:50</td>
<td>1.0 (3.8)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>9</td>
<td>16:00</td>
<td>1.0 (3.8)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>10</td>
<td>16:15</td>
<td>2.0 (7.6)</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>11</td>
<td>16:45</td>
<td>2.0 (7.6)</td>
<td>1.7 (6.5)</td>
</tr>
<tr>
<td>12</td>
<td>17:00</td>
<td>7.0 (26.5)</td>
<td>1.7 (6.5)</td>
</tr>
</tbody>
</table>

Total Volume Drawn Per Day: 55 gallons (208 L)
Unified Energy Factor

- **R134a**
- **R1234yf**
- **R1234ze**
Coefficient of Performance

![Graph showing Coefficient of Performance (COP) for different refrigerants and conditions. The graph compares R134a, R1234yf, and R1234ze.](chart.png)
Average Supply Water Temperature

Average supply water temperature (°F)

- R134a
- R1234yf
- R1234ze
Heat Pump Run Time

- R134a
- R1234yf
- R1234ze
Total Charge in Both Heat Exchangers

- **R134a**
- **R1234yf**
- **R1234ze**

The graph shows the total charge in heat exchangers for different configurations. The x-axis represents various configurations, and the y-axis shows the total charge in heat exchangers in pounds (lbs). The configurations are labeled with codes that indicate the type and size of the heat exchangers.
Max. Condenser Sat. Temperature Drop

Saturation temperature drop (°F)

- R134a
- R1234yf
- R1234ze

90EF/Paral/1Evap/0.31IN
90EF/Paral/1Evap/0.5IN
90EF/Paral/2Evap/0.31IN
90EF/Paral/2Evap/0.5IN
95EF/Paral/1Evap/0.31IN
95EF/Paral/2Evap/0.5IN
95EF/Countl/1Evap/0.31IN
95EF/Countl/2Evap/0.31IN
95EF/Countl/2Evap/0.31IN
95EF/Countl/2Evap/0.5IN
95EF/Countl/2Evap/0.5IN
95EF/Countl/2Evap/0.5IN
Max Compressor Discharge Temperature

- R134a
- R1234yf
- R1234ze
Average Difference between Supply and Tank Bulk Water Temperature

Temperature difference (°F)

- R134a
- R1234yf
- R1234ze

Temperature differences for various scenarios are shown in the diagram. The differences are represented for different conditions and refrigerants, including R134a, R1234yf, and R1234ze.
Conclusions

• R-1234yf can be used as drop-in replacement for R-134a with approximately 2% lower energy factor, and slightly longer heat pump running time due to the reduced capacity.

• R-1234ze performance is comparable as well. However relatively longer HP runtime is disadvantages caused due to relatively lower volumetric capacity of the refrigerant.
Further Developments

Lab testing of the prototype HPWH will confirm the findings and will highlight any potential issues due to the relatively higher flammability of the HFO refrigerants.
Kashif Nawaz
nawazk@ornl.gov