R1234yf Flow Boiling Heat Transfer Inside a 3.4 mm ID Microfin Tube

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OUTLINE

- Introduction
- Experimental set up
- Mini microfin tube
- Experimental results
- R1234yf vs. R134a
- Conclusions
Environmental issues

The 1988 is the year in which the TIME magazine does not celebrate “The man of the Year” on its cover but suggests the “Planet of the Year: Endangered Earth”.

OZONE DEPLETION → MONTREAL PROTOCOL - PHASE-OUT of CFC

What’s next... Global Warming...

F-gas European regulation – Since 2011 - the use of a refrigerant with GWP greater than 150 is banned for air conditioning systems for new vehicle models.

...no more R134a!
Introduction: HFO

**R1234yf** - 2,3,3,3-Tetrafluoropropene is a hydrofluoroolefin – HFO.

With ODP=0 and GWP<1

Normal Boiling Temperature around 4 K lower than that of R134a.

**R1234ze(E)** - 1,3,3,3-Tetrafluoropropene is a hydrofluoroolefin – HFO.

With ODP=0 and GWP<1

Normal Boiling Temperature around 7 K lower than that of R134a.
Introduction: microfin tubes

Interesting heat transfer enhancement (80-180%)

Relatively small increase in pressure drop (20-40%)

Small diameter microfin tubes

Compact heat exchangers - Refrigerant charge reduction

Applications

• Single phase flow
• Condensation and Evaporation for Refrigeration, Heat Pumps, Air Conditioning equipment
• Evaporation for electronic thermal management
Motivations and Objectives

• Analyze the heat transfer capabilities of the mini microfin tubes during flow boiling heat transfer.

• Determine the heat transfer and fluid flow properties of the new low-GWP refrigerants.

• Develop reliable models for the use of these new low-GWP refrigerants inside these new enhanced tubes.
Experimental setup

This experimental test rig permits pressure drop measurements and either condensation or flow boiling heat transfer measurements to be performed.

Maximum pressure: 2 MPa.

Refrigerants: R134a, R1234ze, R1234yf.
Experimental setup

[Diagram of experimental setup]

**LEGEND**

- **M** Coriolis Mass Flowmeter
- **p** Pressure Transducer
- **Δp** Diff. Pressure Transducer
- **T** T-type Thermocouple
- **V** Volumetric Flowmeter
- **ΔT** T-type Thermopile
- **i** Electrical Current
- **ΔV** Electric Potential

- Red: Hot water
- Blue: Cold water
- Black: Refrigerant
Mini Microfin Tube

Parameter | Value
--- | ---
Fin tip diameter | 3.4 mm
Number of fins | 40
Fin height | 0.12 mm
Helix angle | 18°
Apex angle | 43°
Heated length | 300 mm
Δp length | 410 mm
Inlet quality

\[ q_{pc} = \dot{m}_{w,pc} \cdot c_{p,w} \cdot (t_{w,pc,\text{out}} - t_{w,pc,\text{in}}) = \dot{m}_{\text{ref}} \cdot (h_{vs} - h_{TS,\text{in}}) \]

\[ x_{in} = \frac{h_{TS,\text{in}} - h_{L}}{h_{V} - h_{L}} \]

Two phase heat transfer coefficient

\[ HTC = \frac{q_{TS}}{A_{D} \cdot (t_{\text{wall}} - t_{\text{sat}})} \]

\[ q_{TS} = P_{EL} - q_{\text{loss}} \]
Operating test conditions

- Working fluid: R1234yf
- Mass velocity: 190, 375, 565, 755 kg m$^{-2}$ s$^{-1}$
- Heat flux: 10, 25, 50 kW m$^{-2}$
- Saturation temperature: 30 °C
- Vapour quality change: 0.04-0.41
- Heat transfer coefficient: mean ±2.5%, max ±3.8%
- Quality: ±0.035
Experimental Results

R1234yf $t_{sat} = 30 \, ^\circ C$

$HF = 10 \, kW \, m^{-2}$

$HTC \ [W \, m^{-2} \, K^{-1}]$

$X_{mean} \ [-]$

$G=190$

$G=375$

$G=565$

$G=755$
Experimental Results

![Graph showing experimental results for R1234yf flow boiling heat transfer inside a 3.4 mm ID microfin tube. The graph plots HTC [W m⁻² K⁻¹] against \( x_{mean} \) [-] for different values of HF (10, 25, 50) at a specific saturation temperature and mass flow rate.]
Experimental Results

R1234yf
$t_{sat} = 30 \, ^\circ C$
$G = 755 \, \text{kg m}^{-2} \, \text{s}^{-1}$

$HTC [\text{W m}^{-2} \, \text{K}^{-1}]$

$\chi_{mean} [-]$

$HF=10$
$HF=25$
$HF=50$
Experimental Results

$R1234yf$
$t_{sat} = 30 \degree\text{C}$
$HF = 10 \text{ kW m}^{-2}$

$(\Delta p/L)_f \times 10^5 \text{ [Pa m}^{-1}]$

- $G=190$
- $G=375$
- $G=565$
- $G=755$

$x_{mean} [-]$

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R1234yf Flow Boiling Heat Transfer Inside a 3.4 mm ID Microfin Tube
R1234yf vs. R134a

<table>
<thead>
<tr>
<th>Property</th>
<th>R134a</th>
<th>R1234yf</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ [kg m$^{-3}$]</td>
<td>37.5</td>
<td>43.7</td>
</tr>
<tr>
<td>$\lambda$ [W m$^{-1}$ K$^{-1}$]</td>
<td>0.079</td>
<td>0.062</td>
</tr>
<tr>
<td>$\mu$ [$\mu$Pa s]</td>
<td>183</td>
<td>145</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>R134a</th>
<th>R1234yf</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{\text{sat}}$ [bar]</td>
<td>7.70</td>
<td>7.84</td>
</tr>
<tr>
<td>$p_{\text{red}}$ [-]</td>
<td>0.19</td>
<td>0.23</td>
</tr>
<tr>
<td>$h_{\text{LV}}$ [kJ kg$^{-1}$]</td>
<td>173</td>
<td>141</td>
</tr>
</tbody>
</table>
R1234yf vs. R134a

$\Delta p/L$ [bar m$^{-1}$] vs. $x_{\text{mean}}$ [-]

$H_F = 10$ kW m$^{-2}$
The two-phase heat transfer behavior of R1234yf during flow boiling inside a 3.4 mm ID microfin tube has been studied.

The effects of heat flux (HF=10 – 50 kW m⁻²), mass velocity (G=190 – 755 kg m⁻² s⁻¹), vapor quality (x=0.2 – 1) have been presented.

R1234yf shows slightly lower heat transfer coefficients and almost the same pressure drops as compared to R134a, at the same operating test conditions.

The mini microfin tube technology shows interesting heat transfer capabilities and large charge minimization possibility.
Thank you for your attention

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# Instrument accuracy

<table>
<thead>
<tr>
<th>Transducer</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-type thermocouples</td>
<td>± 0.05 K</td>
</tr>
<tr>
<td>T-type thermopiles</td>
<td>± 0.03 K</td>
</tr>
<tr>
<td>Electric power</td>
<td>± 0.13% of the reading</td>
</tr>
<tr>
<td>Coriolis mass flow meter</td>
<td>± 0.10% of the reading</td>
</tr>
<tr>
<td>Magnetic volumetric flowmeters</td>
<td>± 0.25% of the reading</td>
</tr>
<tr>
<td>Differential pressure transducer</td>
<td>± 25 Pa</td>
</tr>
<tr>
<td>Absolute pressure transducer</td>
<td>± 1950 Pa</td>
</tr>
</tbody>
</table>
Experimental Results

Dimensionless gas velocity

\[ J_G = \frac{G \cdot X}{\sqrt{g \cdot D \cdot \rho_G \left( \rho_L - \rho_G \right)^{0.5}}} \]

Martinelli parameter

\[ X_{\text{tt}} = \left( \frac{1 - x}{x} \right)^{0.9} \left( \frac{\rho_G}{\rho_L} \right)^{0.5} \left( \frac{\eta_L}{\eta_G} \right)^{0.1} \]
Enhancement Factor

Smooth Gungor Winterton model

Microfin - Present data
R134a
Penalty Factor

Microfin - R134a