Design and Numerical Parametric Study of Fractal Heat Exchanger

Paper 2381

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Introduction

Heat exchanger

- Fin-and-tube heat exchanger (>5 mm)
  - $j=0.009$, $f=0.035$ at $Re=400$, $OD=10.7$ mm (Joardar and Jacobi, 2008)

- Microchannel heat exchanger (1 ≤ mm)
  - $j=0.025$, $f=0.28$ at $Re=400$ (Joardar and Jacobi, 2005)

- Bare-tube heat exchanger (0.5~5 mm)
  - $j=0.035$, $f=0.1$ at $Re=400$, $OD=0.8$ mm (Bacellar et al., 2016)

Fractal channels

- Intrinsic advantage of minimized flow resistance and strong heat transfer capability over serpentine and parallel channels (Chen and Cheng, 2002, Wang et al., 2010, Yu et al., 2012).

- No application in liquid-to-gas heat exchangers
Fractal Heat Exchanger Design

Figure 1(a): HCHX-tube structure

Figure 1(b): HCHX-staggered pattern

Figure 2: HCHX schematic (staggered) and simulation domain

Figure 3: Baseline BTHX (staggered)
# CFD Modeling

<table>
<thead>
<tr>
<th>Type</th>
<th>Parameter</th>
<th>Unit</th>
<th>BTHX</th>
<th>HCHX</th>
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<tbody>
<tr>
<td>Constant</td>
<td>$P_i$</td>
<td>[mm]</td>
<td>1.5 $D$</td>
<td>1.5$D_1$</td>
</tr>
<tr>
<td>Constant</td>
<td>$P_t$</td>
<td>[mm]</td>
<td>1.5 $D$</td>
<td>1.5$D_1$</td>
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<td>Variable</td>
<td>DR=$D_1/D_2$</td>
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<td>-</td>
<td>0.7</td>
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<tr>
<td>Variable</td>
<td>$D$ or $D_1$</td>
<td>[mm]</td>
<td>1, 2, 3</td>
<td>1, 2, 3</td>
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<tr>
<td>Variable</td>
<td>$V_a$</td>
<td>[m/s]</td>
<td>0.5, 2, 3.5</td>
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<td>Variable</td>
<td>$\theta$</td>
<td>[deg]</td>
<td>-</td>
<td>30, 45, 60</td>
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<tr>
<td>Variable</td>
<td>LR=$l_1/l_2$</td>
<td></td>
<td>-</td>
<td>1.414, 1.732</td>
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</table>

- $T_{air,in} = 300K$
- $T_{wall} = 350K$

**Figure 4:** BTHX computational domain

**Figure 5:** HCHX computational domain (left) and bottom view (right)
Heat Transfer Area

**Figure 6:** Air-side heat transfer area improvement compared with bare tube heat exchanger

LR = $L_1 / L_2$
Heat Transfer Coefficient

- Air velocity↑, diameter↓, bifurcation angle↑ and length ratio
- Preferred: smaller diameter and larger bifurcation angle

**Figure 7:** Heat transfer coefficient comparison (LR=1.414)

**Figure 8:** Heat transfer coefficient comparison (LR=1.732)
Pressure Drop

- Air velocity↑, diameter↓, bifurcation angle↑ and length ratio↓
- Preferred: larger diameter, smaller bifurcation angle and larger length ratio

**Figure 11:** Heat exchanger air-side pressure drop comparison (LR=1.414)

**Figure 12:** Heat exchanger air-side pressure drop comparison (LR=1.732)
$hA_{\text{air}}$ Value

- Air velocity $\uparrow$, diameter $\uparrow$, bifurcation angle $\downarrow$, and length ratio $\uparrow$
- Preferred: larger diameter, smaller bifurcation angle and larger length ratio

**Figure 15:** $hA$ value (LR=1.414, angle=30°)

**Figure 16:** $hA$ value (LR=1.414, angle=45°)

**Figure 17:** $hA$ value (LR=1.414, angle=60°)

**Figure 18:** $hA$ value (LR=1.732, angle=30°)

**Figure 19:** $hA$ value (LR=1.732, angle=45°)

**Figure 20:** $hA$ value (LR=1.732, angle=60°)
Conclusions

- A novel finless fractal heat exchanger design was proposed.
- A parametric study was conducted, thermal and hydraulic performances were analyzed.
- Parameters were studied including air velocity (1~3 m/s), tube diameter (1, 2, 3 mm), bifurcation angle (30, 45, 60°) and length ratio (1.414, 1.732).

<table>
<thead>
<tr>
<th></th>
<th>Air velocity</th>
<th>Tube diameter</th>
<th>Bifurcation angle</th>
<th>Length ratio</th>
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<tr>
<td>HTC</td>
<td>↑</td>
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<td>↑</td>
<td>↑</td>
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<tr>
<td>hA</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
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Future Work

- Design optimization
- Prototype manufacturing
- HX performance tests
ACKNOWLEDGEMENT

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Thank you
Backup Slides
HTC Percentage Improvement

- Air velocity↑, diameter↑ and bifurcation angle↑ and length ratio
- Preferred: larger diameter and larger bifurcation angle

![Graphs showing heat transfer coefficient improvement](image)

**Figure 9:** Heat transfer coefficient improvement compared with BTHX (LR=1.414)

**Figure 10:** Heat transfer coefficient improvement compared with BTHX (LR=1.732)
Pressure Drop Percentage Penalty

- Air velocity, diameter↓, bifurcation angle↑ and length ratio↓
- Preferred: larger diameter and smaller bifurcation angle with larger length ratio

Figure 13: Heat exchanger air-side pressure drop improvement compared with BTHX (LR=1.414)

Figure 14: Heat exchanger air-side pressure drop improvement compared with BTHX (LR=1.732)
**hA Value Percentage Improvement**

- Air velocity↑, diameter↑, bifurcation angle↑ and length ratio↓
- Preferred: larger diameter, larger bifurcation angle and smaller length ratio

**Figure 21:** hA improvement compared with BTHX (LR=1.414)

**Figure 22:** hA improvement compared with BTHX (LR=1.732)