Small Diameter Copper Tube Heat Exchanger Technology Development in China

International Copper Association
Frank Gao
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China Market

Small Diameter Copper Tube Heat Exchanger Technology Development in China

Future Research Direction
Market

Data Source: China IOL

- Market: ∑ 86 billion USD
- Residential Refrigeration: 4.6%, 19.7%, 23%
- Central AC: 4.16%, 43.8%, 51.2%
- Air Source Heat Pump: -15%, 1.9%, 2.2%
- Commercial Refrigeration: +11.4%, 6.4%, 7.4%
- X: Y/Y (%), Y: Sales in 2018 (Billion $), Z: %
RAC Production

2009-2018 RAC Annual Output in China

* Data Source: F-better
• Sales of RAC goes after sales of apartment in China domestic market
• In 2016, sales of apartment reached crest value
• In 2017, sales of RAC reached crest value in China domestic market (4% in 2018)

* Data Source: China IOL
## RAC Energy Efficiency Labelling

**GB 12021.3-2010**

**Non-inverter**

**EER**

<table>
<thead>
<tr>
<th>Model</th>
<th>Cooling capacity</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Window</td>
<td></td>
<td>3.30</td>
</tr>
<tr>
<td></td>
<td>CC ≤4500 W</td>
<td>3.60</td>
</tr>
<tr>
<td>Split</td>
<td>4500 W &lt;CC ≤7100 W</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>7100 W &lt;CC ≤14000 W</td>
<td>3.40</td>
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</table>
### RAC Energy Efficiency Labelling

**GB 21455-2013**

#### Inverter

<table>
<thead>
<tr>
<th>Model</th>
<th>Cooling capacity</th>
<th>SEER Grade</th>
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<tbody>
<tr>
<td></td>
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<td>1</td>
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<tr>
<td>Split</td>
<td>CC ≤ 4,500</td>
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<tr>
<td></td>
<td>4,500 &lt; CC ≤ 7,100</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td>7,100 &lt; CC ≤ 14,000</td>
<td>4.70</td>
</tr>
</tbody>
</table>

#### SEER

<table>
<thead>
<tr>
<th>Model</th>
<th>Cooling capacity</th>
<th>SEER Grade</th>
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<tbody>
<tr>
<td></td>
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<td>1</td>
</tr>
<tr>
<td>Split</td>
<td>CC ≤ 4,500</td>
<td>5.40</td>
</tr>
<tr>
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<td>4,500 &lt; CC ≤ 7,100</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td>7,100 &lt; CC ≤ 14,000</td>
<td>4.70</td>
</tr>
</tbody>
</table>

#### APF

<table>
<thead>
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<th>APF Grade</th>
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<tbody>
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</tr>
<tr>
<td>Split</td>
<td>CC ≤ 4,500</td>
<td>4.50</td>
</tr>
<tr>
<td></td>
<td>4,500 &lt; CC ≤ 7,100</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>7,100 &lt; CC ≤ 14,000</td>
<td>3.70</td>
</tr>
</tbody>
</table>
RAC Energy Efficiency Labelling

- Sales of grade 1 boomed in 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>G3 (10k)</th>
<th>G2 (10k)</th>
<th>Grade 1, highest EE (10k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>5245.8</td>
<td>941.4</td>
<td>810.8</td>
</tr>
<tr>
<td>2016</td>
<td>4804.1</td>
<td>917</td>
<td>327.5</td>
</tr>
<tr>
<td>2015</td>
<td>4775.5</td>
<td>1437.3</td>
<td>74.8</td>
</tr>
<tr>
<td>2014</td>
<td>5009.1</td>
<td>1976.9</td>
<td>17.1</td>
</tr>
<tr>
<td>2013</td>
<td>3857.2</td>
<td>1213.2</td>
<td>90.9</td>
</tr>
</tbody>
</table>

8.1 M, 11.6%

- Consumers’ awareness and running hours
- Manufacturers’ image & profit
- Governments’ energy conservation promotion via EE labelling
Inverter RAC Increased

- Inverter RAC became the mainstream of domestic market in 2017

![Graph showing domestic sales of inverter air-cons exceeding constant frequency air-con in 2017]
RAC Refrigerant Chase-out

Market share of refrigerants during 2015-2017

- **2015**: 8% R22, 50% R410a, 42% R32
- **2016**: 12% R22, 41% R410a, 48% R32
- **2017**: 16% R22, 44% R410a, 40% R32

Total refrigerant sales:
- **23 M** in 2015
- **62 M** in 2017
Tendency of RAC

- New refrigerant
- Higher EE
- More Inverter
- \( \leq 5 \text{mm Cu tube solution} \)

Higher EE
Compacter
Lower Cost
Content

China Market

*Small Diameter Copper Tube Heat Exchanger Technology*

Development in China

Future Research Direction
Brief Introduction

*Key Words:*
- Heat exchanger with copper tube aluminum fin
- $\leq 5\text{mm OD}$
- Microgroove™

Invest, and collaborate with manufacturers, universities and research institutes, to develop and promote the small diameter copper tube heat exchanger technology for HVAC applications.
Advantage

With the development of efficiency regulation in US in 2012, manufacturers began to use 5mm copper tube to replace aluminum fin-tube in condenser.

Some manufacturers develop 5mm copper tube heat exchanger to downsize RAC.

- **Downsize**: 15%
- **Refrigerant Reduce**: 20%
- **High Efficiency**: 10%
- **Cost saving**: 20%

Less refrigerant will be used in 5mm copper tube compared to 9.52mm and 7.94mm copper tube in heat exchanger.

Reduce cost is basic driver to use 5mm copper tube.

Use similar process.
Work

- **Platform Establishment**
  - Establish project team
  - Establish technology platform of air-con and refrigeration industry to guide the industrial development

- **5mm R&D**
  - Develop high efficient 5mm diameter inner-grooved copper tube
  - Develop fin for 5mm diameter copper tube system
  - Optimize 5mm diameter copper tube system

- **Commercial Popularization**
  - Assure commercial availability of high quality equipment for mechanical tube expansion of small diameter copper tube

- **Simulation Software Development**
  - Develop and validate software for heat exchanger and system design with small diameter copper tube

- **Smaller tube R&D**
  - Develop smaller tube heat exchanger technology
Collaborative Partners

- institutes
- government
- copper manufacturers
- air-con manufacturers
- commercial refrigeration manufacturers
- tube fabricator
- supplier
Products

Room Air-con (RAC)

Commercial Air-Con (CAC)

Commercial Refrigeration (CR)
Market Situation

✓ According to market study, it’s estimated that the penetration of RAC production with 5mm copper tube heat exchanger has reached **22.6%** of the market share.

* Data Source: F-better
Content

China Market

Small Diameter Copper Tube Heat Exchanger Technology

*Development in China*

Future Research Direction
Development in China

Historical Achievements

- Tube & Correlations (5mm/4mm)
- New Fin Design & Correlations (5mm/4mm)
- Software (Heat Exchanger & System)
- Team & Experience & Expert
Development in China

**Tube & Correlations (5mm/4mm)**

![Tube Image]

<table>
<thead>
<tr>
<th>5mm/4mm Tube</th>
<th>3mm Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Drop Correlation</td>
<td>Pressure Drop Correlation</td>
</tr>
<tr>
<td>$\Delta P_{\text{corr}} = (0 + 2.023x^{0.50})^{2} \Delta F$</td>
<td>$\Delta P_{\text{corr}} = (0 + 1.585x^{0.28})^{2} \Delta F$</td>
</tr>
<tr>
<td>$f_\ell = 2f_\ell (U/D) \sqrt{\frac{\gamma \Delta P}{\rho \chi}}$</td>
<td>$f_\ell = 2f_\ell (U/D) \sqrt{\frac{\gamma \Delta P}{\rho \chi}}$</td>
</tr>
<tr>
<td>$f_\ell = 0.0139 / \sqrt{Re^{0.22}}$</td>
<td>$f_\ell = 0.046 / \sqrt{Re^{0.22}}$</td>
</tr>
<tr>
<td>$Re = \frac{C_{D} \cdot D}{\mu}$</td>
<td>$Re = \frac{C_{D} \cdot D}{\mu}$</td>
</tr>
<tr>
<td>$X = \frac{1}{x} \left( \frac{P_{\text{in}} - P_{\text{out}}}{P_{\text{in}} - P_{\text{out}}} \right)$</td>
<td>$X = \frac{1}{x} \left( \frac{P_{\text{in}} - P_{\text{out}}}{P_{\text{in}} - P_{\text{out}}} \right)$</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat Transfer Correlation</th>
<th>Heat Transfer Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{h}} = 0.0120 \cdot 35 + 0.06 \left( \frac{\Delta P}{\mu} \right) \left( \frac{D}{L} \right) \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right)$</td>
<td>$N_{\text{h}} = 0.022 \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right) \left( \frac{D}{L} \right) \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right)$</td>
</tr>
<tr>
<td>$N_{\text{h}} = 0.0725 \cdot \frac{1}{\gamma} \frac{1}{\mu} \frac{1}{\phi} \frac{1}{P_{\text{in}}/P_{\text{out}}}$</td>
<td>$N_{\text{h}} = 0.022 \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right) \left( \frac{D}{L} \right) \left( \frac{P_{\text{in}}}{P_{\text{out}}} \right)$</td>
</tr>
<tr>
<td>$\Phi = 1.1 + 1.0 \frac{C_{D}}{C_{L}} \left( 1 - \frac{C_{D}}{C_{L}} \right)$</td>
<td>$\Phi = 1.1 + 1.0 \frac{C_{D}}{C_{L}} \left( 1 - \frac{C_{D}}{C_{L}} \right)$</td>
</tr>
<tr>
<td>$P_{\text{in}} = \frac{D}{L} (P_{\text{in}} - P_{\text{out}})$</td>
<td>$P_{\text{in}} = \frac{D}{L} (P_{\text{in}} - P_{\text{out}})$</td>
</tr>
<tr>
<td>$P_{\text{in}} = \frac{D}{L} (P_{\text{in}} - P_{\text{out}})$</td>
<td>$P_{\text{in}} = \frac{D}{L} (P_{\text{in}} - P_{\text{out}})$</td>
</tr>
</tbody>
</table>

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![Additional Image]
New Fin Design & Correlations (5mm/4mm)

The basic forms of the correlations are:

$$N u = j \cdot Re \cdot Pr^{1.3} \cdot \phi$$

$$\phi = C_1 \cdot Re^{C_2} \cdot \phi$$

where $C_1, C_2, C_3$ and $C_4$ depend on the physical dimensions of the heat exchanger.

The final equations for the $f$ factor are given as follows:

$$f = 0.0899 \cdot \frac{\rho_{\text{air}}}{\rho_{\text{Cu}}} \left( \frac{\mu_{\text{air}}}{\mu_{\text{Cu}}} \right)^{0.2} \left( \frac{P}{D_1} \right)^{0.5} \left( \frac{P}{D_2} \right)^{0.2}.$$
Development in China

Software (Heat Exchanger & System)
Team & Experience & Expert

Founder

Council Members

System manufacturers

Members

HX manufacturers

Equipment manufacturers

Components manufacturers

Including the whole heat exchanger industry chain
**Cooperation Case-Commercial Refrigeration**

<table>
<thead>
<tr>
<th>Performance</th>
<th>Refrigerant Charge</th>
<th>Noise</th>
<th>Heat Exchanger Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal</td>
<td>26%</td>
<td>0.6dB</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Explanation:**
- **Refrigerant Charge:** The new 5mm condenser has a 26% reduction in refrigerant charge compared to the original 9.52mm condenser.
- **Noise:** The new condenser reduces noise by 0.6dB.
- **Heat Exchanger Price:** The price of the new 5mm condenser is 20% lower than the original 9.52mm condenser.

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**Original 9.52mm Condenser**

**New 5mm Condenser**
Another story in China

Cu tube Cu fin ; humid environment, fungi ; Higher EE
China Market

Small Diameter Copper Tube Heat Exchanger Technology Development in China

*Future Research Direction*
Future Research Direction

Energy Efficiency

• Based on the new energy efficiency evaluation, develop the copper heat exchanger technology to improve the energy efficiency.

• Best hole pitch and row pitch ratio
Future Research Direction

**Comfort**

- Develop the heat exchanger with different diameter copper tube and other technologies to improve the comfort of users
- **Strong heating capacity**
Future Research Direction

**New refrigerant**

- GWP (Global Warming Potential) is an index of the greenhouse effect of a substance. GWP is within the 100-year time frame, and the greenhouse effect of various greenhouse gases corresponds to the same effect of carbon dioxide quality. Carbon dioxide is used as a reference gas.

- **Kigali Amendment**: On October 15, 2016, the 28th Conference of the Parties to the Montreal Protocol held in Kigali, the capital of Rwanda, reached consensus on historic limits for greenhouse gas HFCs. (HFCs) Amendments - The Kigali Amendment will take effect on January 1, 2019, when at least 20 countries sign amendments. This agreement is another landmark environmental document following the "Paris Agreement" on climate change, which has aroused strong repercussions from the international community. It is expected that 88% of HFC emissions will be reduced, which will prevent the global warming of 0.5 degrees by the end of the century.

- HFC-32, HFC-404a, HFC-407c, HFC-410A, HFC-134a, HCFC-125 are included in the phase-out schedule.

<table>
<thead>
<tr>
<th>Refrigerants</th>
<th>Molecular formula</th>
<th>Life span (years)</th>
<th>ODP</th>
<th>GWP(100 years)</th>
<th>Safety classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-32</td>
<td>CH2F7</td>
<td>5.6</td>
<td>0</td>
<td>675</td>
<td>A2L</td>
</tr>
<tr>
<td>HFC-404a</td>
<td>R125/143a/134a (44/52/4) mass fraction%</td>
<td>-</td>
<td>0</td>
<td>3780</td>
<td>A1</td>
</tr>
<tr>
<td>HFC-407c</td>
<td>R32/125/134a (23/25/52) mass fraction%</td>
<td>-</td>
<td>0</td>
<td>1650</td>
<td>A1</td>
</tr>
<tr>
<td>HFC-410A</td>
<td>R32/125 (50/50) mass fraction%</td>
<td>-</td>
<td>0</td>
<td>1980</td>
<td>A1</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>CH2FCF3</td>
<td>14.6</td>
<td>0</td>
<td>1430</td>
<td>A1</td>
</tr>
<tr>
<td>HCFC-125</td>
<td>CHF2CF3</td>
<td>32.6</td>
<td>0</td>
<td>3500</td>
<td>A1</td>
</tr>
</tbody>
</table>
Future Research Direction

New refrigerant

- Combine with small diameter copper tube heat exchanger technology and other copper based technologies to improve the efficiency of the new refrigerant system.
# Development in China

**Smaller Copper Tube**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Air-con</th>
<th>Capacity (W)</th>
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<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>Cooling</td>
<td>ODU</td>
<td>2330</td>
</tr>
<tr>
<td></td>
<td>IDU</td>
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<tr>
<td>Heating</td>
<td>ODU</td>
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<td></td>
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<td>2283</td>
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</tbody>
</table>

![Material Cost](image.png)
Thank you!

For more information please contact
frank.gao@copperalliance.asia