Visualization of the Refrigerant Flow at the Capillary Tube Inlet of a Household Refrigeration System

L. Bardoulet, S. Martínez Ballester, A. Pisano, JM. Bordes and JM. Corberán
Capillary Tube in Household Refrigerators

- Capillary tube with suction to liquid heat exchanger (CT-SLHX)
- Complex phenomena can take place due to simultaneous heat transfer and expansion
  - Re-condensation
  - Reverse heat transfer
Negative effects of these phenomena

- Hysteresis
- Oscillations
- Noise
- Effectiveness loss

Solutions to negative effects

- Noise
- Oscillations

Is there actually subcooled condition?

All the solutions avoid the risk of bubbles at the capillary tube inlet.

Boeng and Melo (2012) concluded that even with a certain subcooling of 5 K, the inlet was two-phase flow.

- They evaluated numerically that the vapor quality at the capillary tube inlet ranged between 2-12%.
- This fact would mean a considerable gap for efficiency improvement

Objective

- To deepen in the actual conditions at the condenser outlet and cap. tube inlet.
Experimental Set Up

- **Analyzed System**
  - Two compartment Refrigerator/ Freezer
  - 330 liters
  - Vacuum panels
  - **High efficiency system** → Low cooling capacity
    - A+++ → 0.48 kWh/day → 30/25 W (average pow. 20W)!
    - Cooling capacities 70/60 W
  - R600a
  - No-Frost fin and tube evaporator
  - Natural draft tube and wire condenser
  - Variable speed compressor
    - 7 cm³ hermetic reciprocating
  - Non adiabatic capillary tube
    - D=0.65 mm
    - Total Length= 2.44 m
Test Bench

- Objectives:
  - Visualize flow conditions at condenser outlet
  - Visualize flow conditions at capillary tube inlet
    - For different filter arrangements
    - For different capillary tube locations within filter
  - Measuring temperature along condenser wall
  - Measuring temperature at capillary tube inlet
Tests conditions:
- Ambient temperature at 25 °C
- Empty cabinets and closed doors
- System and electronics working as it is

Tests Matrix

<table>
<thead>
<tr>
<th>Filter orientation</th>
<th>Flow direction</th>
<th>Capillary tube position inside the filter</th>
<th>Test #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>From the top to the bottom</td>
<td>Top</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>Vertical</td>
<td>From the bottom to the top</td>
<td>Top</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>5</td>
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<tr>
<td></td>
<td></td>
<td>Low</td>
<td>6</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Horizontal</td>
<td>Top</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>9</td>
</tr>
</tbody>
</table>
Temperature profile analysis

- **T1-T6 → Two-phase flow area**
  - Are T1-T6 lower than Tsat(Pcond) due to longitudinal heat conduction?

- **T7 and T8 → Subcooling area**
  - However, by increasing the charge 5g the subcooling changed less than 1K!
    - Is the filter operating as liquid receiver? or incomplete condensation?
Clearly there are **two phases**: the filter is constantly filled by a mixture of vapor and liquid.

The capillary **draws in both vapor and liquid** forming a vortex with an unstable interface due to the droplets.

When the capillary is moved inside the filter the interface follows the inlet section.

- Thus, the filter is not operating as liquid receiver.
Vertical Filter – Upward Flow

- Same presence of two phases as in downward flow: the filter is constantly filled by a mixture of vapor and liquid
- Abrupt interruption of the interface due to bubbles which come from condenser
- Capillary tube draws in both liquid and vapor **regardless position of capillary tube** within filter
- Same presence of two phases as in vertical filter: the filter is constantly filled by a mixture of vapor and liquid
- The interface can be now considered practically motionless due to absence of droplets or bubbles
- The capillary draws in a mixture of liquid and vapor but now the vortex is really small
- No changes occur when the capillary tube is moved along the filter
A test bench was designed in order to visualize the refrigerant flow condition at the capillary tube inlet of low capacity refrigerator system.

The analysis of the temperature profile leads to the next considerations:

- A certain subcooling looks to be present at the condenser outlet.

Visualizations of the refrigerant flow at the capillary tube inlet showed:

- Regardless the orientation of the filter and the capillary tube position within it, the capillary tube is always drawing in a mixture of liquid and vapor.
  - It demonstrates that filter is not operating as a liquid receiver.

It is confirmed that inlet is two-phase flow, but still cannot be assured that quality is larger than 0:

- It could be a non-equilibrium mixture.
- If experimentally confirmed that quality is larger than 0, there is a gap for efficiency increase.

Why?

- High efficiency and low capacity systems.
- Balance of capillary tube and compressor.

Further works have been planned in order to:

- Evaluate experimentally the actual conditions and quality of the refrigerant at the condenser outlet.
Thank you for your kind attention!

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