Results of Multi-Objective Genetic Algorithm (MOGA) Optimization Studies with Small Diameter Copper Tubes

Sub-Zero Residential Refrigeration Study

Sub-Zero, a leading manufacturer of high-quality residential refrigerators and freezers, considered adopting small-diameter copper tubes (≤ 5mm) to reduce refrigerant charge, ahead of bans on high-GWP HFC refrigerants (see "Additional Information").

The company was initially motivated to meet the 57-gram "use conditions" for isobutene, a difficult task in the US due to the aforementioned bans on high-GWP HFC refrigerants. Sub-Zero explored the advantages of small-diameter tubes with outer diameters of 5 mm, causing engineers to approach Optimized Thermal Systems, Inc. (OTS) and the Copper Development Association, Inc. for assistance in using CoilDesigner®, a proprietary heat exchanger design and simulation software tool developed at the Center for Environmental Energy Engineering (CEEE) at the University of Maryland (UMD).

The team primarily sought to design a condenser coil that would match the performance of the existing (baseline) coil while decreasing the refrigerant charge. The secondary objectives included reducing the total footprint of the coil and the total mass of the tube-and-fin material.

Other design objectives also included:

- Heat rejection greater than or equal to the heat rejection of the baseline design
- Sub-cooling equal to or greater than sub-cooling of the baseline coil
- Saturation temperature drop kept within one degree of the baseline

The baseline condenser coil utilized quarter-inch copper tubing, flat plate fins and a low fin density. The condenser had two refrigerant circuits with each circuit serving an independent vapor compression cycle for the refrigerator and freezer compartments. The research team developed a CoilDesigner® model of the condenser and validated it against experimental data.

Before evaluating potential small diameter replacements, a study was conducted to evaluate the effect of refrigerant circuitry on the existing coil performance. Three operation modes were evaluated: the refrigerator circuit running, the freezer circuit running, and both circuits running. The heat load and refrigerant sub-cooling increased during single circuit operation by extending both refrigerant circuits to cover the entire face area of the coil instead of half of the face area.

The best circuitry design was selected from this initial review and used as the baseline reference for the optimization study, as detailed below.

Optimization Study

The optimization study was conducted to identify condenser designs that could reduce the internal volume and decrease the refrigerant charge. Five millimeter tube designs were evaluated and compared to the baseline design and significant reductions were found in internal tube volume. The best 5-mm design reduced the internal tube volume up to 41 percent when compared to the baseline, along with a 57 percent reduction in coil footprint.

Simulation Results

The simulations identified several new condenser designs with significant potential to reduce internal volume and maintain performance, thereby reducing total system charge. The designs' increased airside pressure drop can be accommodated by existing fan motors. The reduced footprint of the coils allows for a smaller enclosure.

This study signifies the potential to create high performance condenser coils for this application. The fan speed can be reduced through a high-performance condenser, resulting in a quieter refrigerator unit.

"R600a will play a key role in residential refrigeration systems for many years to come," said Andy Kireta, Vice President at the Copper Development Association Inc. "The Sub-Zero study has set a benchmark. It shows how small-diameter tubes and coils are well suited for use with isobutane."

Additional Information

Small-diameter tubes play an important role in developing high-quality residential refrigeration systems made with isobutene (R600a). Most products in this category use copper tubes with outer diameters of five-sixteenths inch (7.9mm) or one-quarter inch (6.35 mm). Small-diameter tubes measure less than the conventional three-eighths inch (9.525 mm).

International regulations limit the allowable refrigerant charge for isobutene because of its flammability. The limit on refrigerant charge is 150 grams in Europe and the United States. Formerly, the limit was 57 grams for residential applications in the U.S. In spite of the limit increase, there are many benefits to using smaller diameter copper tubes, namely the potential to reduce material and coil footprint.

Additionally, the International Electrotechnical Commission (IEC) approved an increase in the charge limit for A3 (flammable) refrigerants from 150 grams to 500 grams in self-contained commercial refrigeration cabinets under IEC standard 60335-2-89. Eagerly anticipated by commercial refrigeration equipment manufacturers, adoption of this new IEC standard is expected to comply with the phasing out of hydrofluorocarbon (HFC) refrigerants with high global warming potential (GWP).

Small-diameter tubes were vital in propane (R-290) and isobutene (R-600a) adoption when the commercial equipment charge limit was fixed at 150 grams (5.29 ounces). Nearly every major manufacturer of "reach in" cooler display cases began offering models with propane or isobutane as a refrigerant subject to the 150 gram use condition. With charge limits for numerous applications having increased to 500 grams, refrigeration equipment may have higher cooling capacities, especially with small-diameter tubes in the condensers and evaporators.