IN THE SPOTLIGHT

MICROGROOVE RESEARCH AT PURDUE HERRICK CONFERENCES

Every two years, industry and academia convene at Purdue University for the Herrick Conferences, which are comprised of three concurrent international conferences: Compressor Engineering, first held in 1972; Refrigeration and Air-conditioning, since 1984; and High Performance Building, since 2008. High-quality technical research papers are presented over the four days of the event as well as four plenary lectures.

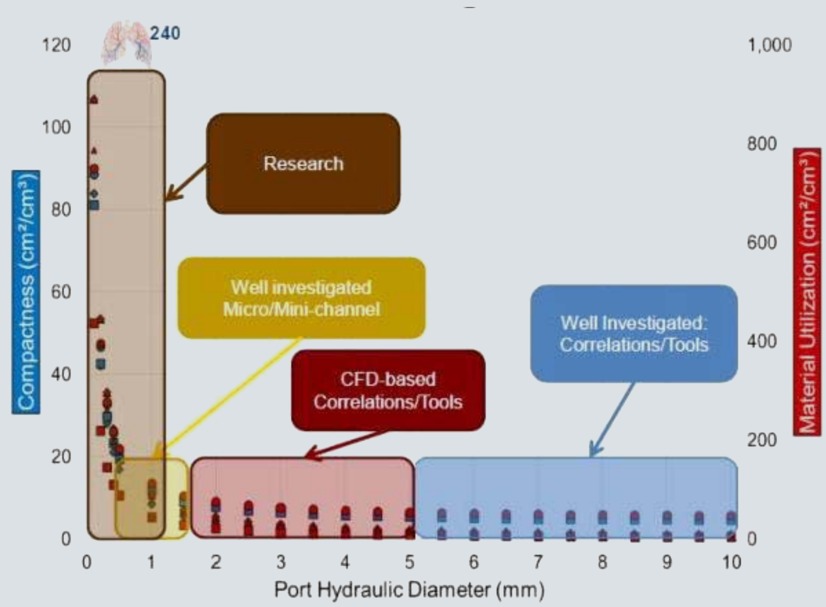
HVAC&R PLENARY

On the last day of the conferences, Reinhard Radermacher, who is the Minta Martin Professor and Director of Center for Environmental Energy Engineering (CEEE) consortium at the University of Maryland, delivered a plenary presentation titled "Thoughts on Emerging HVAC&R Technologies." (Download slideshow.)

The overarching theme was "It will NOT be business as usual."

Slide number 25 compared the state of research on heat exchanger tubes of various diameters. According to Radermacher, the correlations and tools for tube hydraulic diameters of 5-mm and greater are well investigated.

Radermacher further explained how the use of Multiple-Objective Genetic Algorithms (MOGA) in heat exchanger design frees the designers to do creative research rather than focusing on the tedious task of searching the design space for optimal designs.



Professor Reinhard Radermacher's plenary address included this "Heat Exchanger Roadmap" slide, indicating the state of research on tubes of various diameters. (Image used with permission.)

MICROGROOVE RESEARCH HIGHLIGHTS

The Seventeenth International Refrigeration and Air-Conditioning Conference included 41 sessions (R-01 through R-41) with hundreds of papers. PDF versions of all of these papers are now openly accessible and downloadable by searching for the paper number in the Conference Tool.

In the academic literature, MicroGroove tubes are commonly referred to as "microfin tubes" since "MicroGroove" is a trademark of the Copper Alliance. Research relating to MicroGroove includes laboratory experiments, theory and modeling, and design case studies. The most pertinent papers relating to MicroGroove are highlighted here.

Tube-Side Heat Transfer and Pressure Drops

There is no substitute for experimentally measuring heat-transfer coefficients and pressure drops for various tube sizes, refrigerant mixes and microfin geometries. Data from these experiments can then be used in simulation software to predict the performance of heat exchangers with high accuracy. As noted by Professor Radermacher in his plenary lecture, conventional models often do not apply to smaller diameter tubes and hence the need for careful experiments is essential.

Four papers on smaller-diameter copper tubes were presented in Session R-39: Heat Transfer in Microfin Tubes and Microchannels.

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The experiments from Tokyo University of Marine Science and Technology (TUMSAT) were especially intriguing because they showed the combined effects of flow rates and microfin geometry on heat transfer coefficients and pressure drops (Papers 2542 & 2511). As the refrigerant evaporates along the length of a tube, distinct flow types can be identified. Paper 2511 helps to understand how the optimal tube enhancements may be different for different flow rates and flow types. Paper 2469 from Padova University reported on R1233zd(E) and R245fa flow boiling heat transfer and pressure drop inside a microfin tube. An excellent paper from Nagasaki University and the Research Center for Next Generation Refrigerant Properties (NEXT-RP) at Kyushu University measured heat transfer and pressure drop of R1123/R32 flow in horizontal microfin tubes during condensation and evaporation (Paper 2164).

Two additional papers from Padova University (ID 2204 and ID 2205) examined the behavior of low-GWP refrigerants inside smaller diameter copper tubes for flow boiling and condensation, respectively. The refrigerants tested are reflective of the large number of papers dealing with new low-GWP refrigerants in general and HFO blends in particular. Indeed at least five papers were presented by authors from Chemours or Honeywell and at least eight papers were published with "R1234" in the title. Many presentations opened with an overview of the timetables for phasing out high-GWP refrigerants as mandated by the Kigali agreement and European F-Gas legislation.

Airside Computer Simulations

There are four measurements of vital importance in heat exchanger design. There is the refrigerant-side pressure drop and heat transfer inside the tube, which are functions of type of refrigerant, flow rates and internal tube enhancements. Then there are also the airside pressure drop and heat transfer on the outside, which are functions of air flow rates, fin and tube geometries and fin enhancements. Typically, this air-side performance is the most critical limiting factor in overall heat exchanger performance.

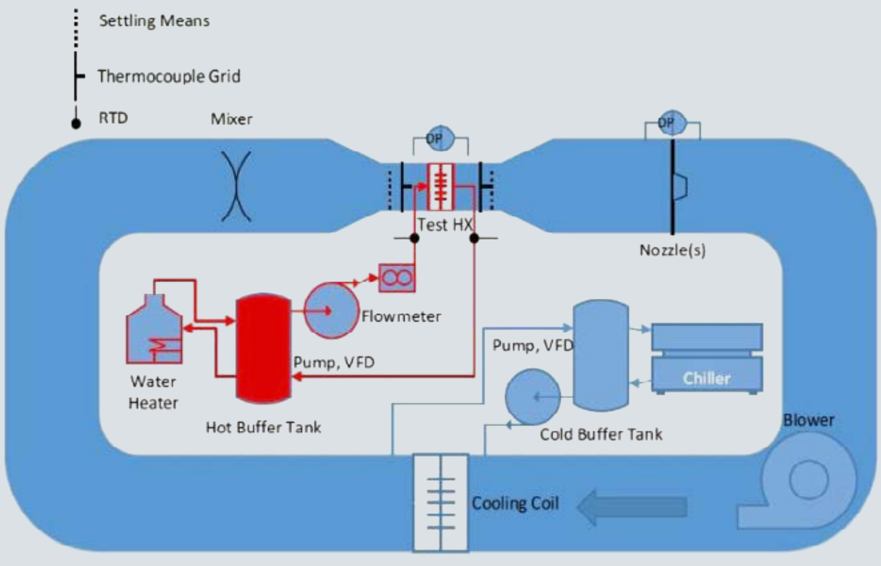
The optimization of such parameters as fin design, fin spacing, tube spacing, tube circuitry, and so forth can provide significant improvements in efficiency.

A research program conducted by Optimized Thermal Systems with support from the Copper Alliance developed new air-side correlations for fins with smaller-diameter tubes based on thousands of CFD simulations, and then validated these new correlations against experimental data.

CoilDesigner software from CEEE at the University of Maryland with customized versions marketed through OTS now includes such correlations, allowing designers to predict the performance of MicroGroove coils with good accuracy. The research underpinning these correlations is discussed in the Paper 2582 titled "Experimental Validation of CFD-Based Correlations for 5 mm Louver- and Slit-Fin Heat Exchangers: Lessons Learned," an OTS paper delivered in Session R-15: Air-Side Heat Transfer Characterization.

In the words of the authors:

> *"Several sample heat exchangers were acquired from manufacturers in China, India, and the US. These sample coils employed slit and louver fins with a range of fin densities and*



Here is a schematic of the heat exchanger test facility that was used to experimentally validate the MicroGroove correlations that are used in CoilDesigner software. Dennis Natusa from OTS presented a paper on this topic at the 2018 Purdue Conferences.

tube patterns. The major dimensions of these HXs are outlined in Table 3. All tested HXs had tubes with 5 mm nominal diameters."

The experimental findings were well-predicted by the new correlations and minor deviations between CFD predictions and experimental observations were attributed to manufacturing differences and the thermal contact resistances between fin and tube. Nonetheless, the authors concluded the paper as follows:

"This method of combining numerical exploration of the design space with limited experimental testing and validation can be used to rapidly develop new, comprehensive correlations in a cost-effective manner."

Readers and researchers interested in learning more about Multiple Objective Genetic Algorithms (MOGAs) in coil design will be interested two papers delivered in the Session R-08: Heat Exchanger Optimization.

ID 2598: "Tube-Fin Heat Exchanger Circuitry Optimization Using Integer Permutation Based Genetic Algorithm" (CEEE).

ID 2532: "Optimization of MicroGroove Copper Tube Coil Designs for Flammable Refrigerants" (Copper Alliance, OTS, Sub-Zero and HTT).

The latter paper showed how OTS applied MOGA to the optimization of new designs of MicroGroove heat exchangers for residential refrigeration products made by Sub-Zero. It was presented by Yoram Shabtay, President of Heat Transfer Technologies, who assisted in this application. The slideshow presentation, which is available for download from the "Technical Literature" webpage of microgroove.net, includes Sub-Zero's experimental verification of the MOGA results.

The domestic appliances product division of Liebherr manufactures refrigerators and freezers in four countries for private and commercial use. Mario Straub from Liebherr-Hausgeräte GmbH in Ochsenhausen, Germany, concluded in his paper on household refrigerators that R600a and R290 are still the best refrigerants for household refrigerators. (Paper 2129).

A paper from Embraco used simulations to demonstrate annual energy consumption savings up to 30 percent when a self-contained R-290 variable speed hermetic refrigeration unit is applied to a cabinet originally designed for an R-404A single speed compressor refrigeration unit. (Paper 2456).

EMERGING RESEARCH FRONTS

The above papers are very relevant to the application of MicroGroove tubes and coils in new products. Additional research covered a wide range of ancillary topics, including phase change materials (e.g., 2293), domestic refrigeration (e.g., Sessions R-05 and R-19), CO2 refrigeration cycles (e.g., Session R-23) and heat pumps (e.g., Sessions R-06, and R-41).

Papers on the additive manufacturing of heat exchangers garnered excitement and interest (e.g., 2478, 2306, and 2309). Some remarkable case studies included a refrigerated truck with adiabatic walls and solar panels on the truck roof (2151); and a cold storage system for spacecraft (2407)!

A topic of perennial interest is the defrosting of evaporator coils for residential heat pumps. Several papers were presented on this topic in Session R-12: Heat Exchanger Frost Impacts and Control. For example, Paper 2258 titled "Alternative Defrost Strategies for Residential Heat Pumps" was presented by Cara Martin of Optimized Thermal Systems and supported by the Electric Power Research Institute and the International Copper Association.

The antimicrobial benefits all-copper coils were compared with coils made from copper tubes with aluminum fins with and without ultraviolet irradiation in a paper titled "Comparison Study of Bio-Growth in Commercial AHU's Using Copper Heat Exchangers and Components" (Paper 2476). This research project was conducted John Hipchen of Exel Consulting in cooperation with Remington & Vernick Engineers and supported by the Copper Development Association.

One thing is certain about the state of research in HVAC&R as seen through the vast array of original papers presented at the Herrick Conferences: It will NOT be business as usual.

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