microgroove™ Update

Attain High Energy Efficiency with Less Materials Using Smaller-Diameter, Inner-Grooved Copper Tubes

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PRESENTATIONS

UPCOMING EVENTS

CHILLVENTA 2018
Oct 16–18
Nuremberg, Germany

ATMOsphere Europe 2018
Nov 19–21
Lago di Garda, Italy

AHR Expo 2019
Jan 15–16
Atlanta, Georgia

ACREX 2019
Feb 28 – Mar 2
Bombay Exhibition Center, Mumbai, India

China Refrigeration 2019
Apr 9–11
Shanghai New International Expo Center, Shanghai, China

25th IIR International Congress of Refrigeration
Aug 24–30
Montreal, Canada

PUBLICATIONS

Nigel Cotton and Yoram Shabtay, "MicroGroove Contributes to the Success of Propane in Refrigeration Appliances," International Appliance Manufacturing, October 2017.
https://microgroove.net/sites/default/files/IAM-2017-MicroGroove-Article.pdf

Yoram Shabtay and Nigel Cotton, "Performance Testing of MicroGroove Heat Exchangers with Natural Refrigerants," ATMOsphere America 2018, Long Beach, California.
http://www.atmo.org/media.presentation.php?id=1380

MICROGROOVE SPANS THE GLOBE: THE AMERICAS

The supply chain for heat exchangers for ACR products includes copper producers, tube fabricators and coil makers. Copper production can be found throughout the world in the Americas, Africa, Asia and Australia. As for copper tube fabricators, the International Copper Association (ICA) counts as members all major tube fabricators, including four from Asia, four from Europe and six from the United States. Many of these companies are meeting the demand for inner-grooved smaller diameter copper tubes.

Coil makers number in the hundreds. They manufacture hundreds of millions of round-tube, plate-fin (RTPF) coils annually for various applications such as

- Coils for residential AC, including window units, ducted unitary systems and ductless split systems.
- Coils for commercial AC, including outdoor condensers, VRF systems and Packaged Terminal AC (PTAC) systems.
- Coils for light commercial refrigeration equipment, such as bottle coolers and refrigerated display cabinets.
- Large condenser coils for industrial process cooling, food processing, cold storage and supermarkets as well as various other refrigeration systems in the cold chain.

This six-vee (12 fans) condenser is made with 5 mm copper tubes. (Photograph Courtesy of Innovative Cooling & Equipment)

Coil manufacturing can be carried out internally in an OEM's own production facility. In this manner, the OEM can develop its own proprietary methods of coil manufacturing. In many instances, the OEM may also develop its own coil-making equipment. Either way, the OEM gains an edge over its competitors by not sharing its manufacturing know-how.

Tube fabricators typically are not captive to any one OEM and hence the same tube technology is available to many OEMs through one tube supplier. Different tube fabricators offer different tube configurations, particularly with respect to the tube alloys and internal enhancement. Coil makers may specialize in coils of a certain tube diameter or fin design. The optimal design of the fin dies can vary considerably, depending on the application.

This article surveys trends in the adoption of MicroGroove in three regions of the world including the Americas, Europe and Asia. Already MicroGroove is being adopted at an accelerated pace in every corner of the world.

MicroGroove was on display at the 2018 ATMOsphere America Conference. Smaller-diameter copper tubes allow for the safe and efficient use of R290 in eco-friendly refrigeration equipment, a major success for MicroGroove in the Americas.

THE AMERICAN WAY

The United States is widely regarded as a global leader in air-conditioning technology. It has been argued that air-conditioning made the Sun Belt more livable and thereby radically altered the demographics of the United States.

Invented by Willis Carrier in 1902, to alleviate the heat and humidity at a lithography and printing company in New York City, the air conditioner regularly appears at the top of "greatest inventions" lists, e.g., The Atlantic, September 19, 2017.

The history of air conditioning in America has been traced in several academic books including "Air-Conditioning America: Engineers and the Controlled Environment" by Gail Cooper (Johns Hopkins University Press, 1998) and "Cool Comfort: America's Romance with Air-Conditioning" by Marsha E. Ackerman (Smithsonian Press, 2002) as well as "Cool: How Air-Conditioning Changed Everything" by Salvatore Basile (Fordham University Press, 2014).

"Losing Our Cool: Uncomfortable Truths about Our Air-Conditioned World (and Finding New Ways to Get through the Summer)" by Stan Cox (The New Press, New York, 2010) explores some of the environmental aspects the subject.

MICROGROOVE IN AMERICA

The North American residential air conditioning market is largely dominated by unitary ducted AC systems. Unitary systems take advantage of the ductwork that also carries blown air from furnaces for heating. Blown air furnaces are largely an American phenomenon and hence also unitary air conditioners are chiefly sold in the United States.

Many of these unitary systems are made in North America. The regulatory pressures to increase the efficiency of these systems encouraged OEMs to experiment with smaller diameter copper tubes as well as aluminum microchannel tubes. Today, copper round-tube plate fin (RTPF) condensers and evaporators dominate the competition from microchannel heat exchangers (MCHXs) which have some disadvantages, including poor condensate drainage and refrigerant maldistribution. Especially for the outdoor evaporators of heat pumps, MicroGroove coils offer superior performance with respect to condensate drainage and thus frost prevention.

One of the first companies to adopt 5-mm diameter copper tubes for use in unitary systems was Goodman Manufacturing. The company announced its SmartCoil® technology ten years ago, in 2008, as described in an "In the Spotlight" column titled "Goodman Pioneers Use of 5-mm Tubes in Condensers." (See the January 2014 issue of the *MicroGroove Update* newsletter, Volume 4, Issue 1.) Goodman's success with its SmartCoil Technology is also described in an article titled "Building Better Appliances with Smaller-Diameter Copper Tubes" which appeared in the October 2013 issue of *International Appliance Manufacturing* magazine.

Goodman continues to use SmartCoil technology with smaller-diameter copper tubes in unitary ACs and heat pumps.

American OEMs are building their reputation on advanced technology both for advanced air-conditioning systems and the equipment used to make them. For decades, Burr OAK Tool in Sturgis, Michigan supplied AC manufacturers with the tube handling equipment necessary for the manufacture of RTPF coils.

This U.S.-based company continues to be a global leader in the supply of equipment for the manufacture of coils made with smaller diameter copper tubes as described in numerous articles, videos and webinars.

One of the largest coil makers in the world is now doing business as Modine Commercial and Industrial Systems (or "Modine CIS," formerly known as Luvata Heat Transfer Solutions). This company is the primary supplier of copper tube coils for many large OEMs in the United States, especially in the refrigeration sectors. Smaller diameter copper tubes are used in many of its product offerings.

Super Radiator Coils is a pioneer in the manufacture of heat exchangers made from smaller diameter copper tubes. A state-of-the-art wind tunnel is used to test the efficiency of these coils. The results of performance measurements by SRC on prototype MicroGroove Coils made with 5 mm copper tubes for use with R744 and R290 refrigerants were presented at ATMOsphere America Conferences in 2015 and 2016.

Optimized Thermal Systems (OTS) and the International Copper Association (ICA) collaborated on the OTS-ICA Educational Program, which motivated various OEMs look more closely at the benefits of using smaller diameter copper tubes. Examples include Friedrich, Sub-Zero and GE Appliances, who recently completed research projects with OTS.

The project with Sub-Zero was so successful that the company, a manufacturer of high-end residential refrigerators and freezers, is moving forward with plans to use smaller diameter copper tubes in its future product development. The results of the collaboration between Sub-Zero, OTS and ICA were presented at the Purdue Conferences in July 2018 (Paper 2582).

Another major trend in North America is the use of smaller diameter copper tubes with propane, also known as R290, which is a natural refrigerant with ultra-low Global Warning Potential. This story has been covered on numerous occasions and does not need repeating here. The reader is referred to an earlier issue of the *MicroGroove Udpate* for the story: "MicroGroove Gains Momentum in Refrigeration Applications for Supermarkets and Convenience Stores." Many OEMs of light commercial refrigeration equipment with manufacturing capacity in North America have already switched to R290 and MicroGroove coils in advance of the F-Gas phase out. Yoram Shabtay recently delivered a presentation on this topic at the 2018 ATMOsphere America conference in Long Beach, California.

Yoram Shabtay's presentation on using MicroGroove heat exchangers with natural refrigerants prompted a good discussion from the audience at 2018 ATMOsphere America conference in Long Beach, California.

In summary, North America and South America are hotbeds of activity for air-conditioners, heat exchangers and refrigeration equipment using smaller diameter copper tubes. There has been a great deal of activity in the supply chain as tube fabricators and coil makers prepare to meet the demand for MicroGroove heat exchangers.

Cu2Consulting has summarized changes among copper and copper alloy fabricators in a press release titled "US: Top changes in the copper and copper alloy fabricating competitive scenario" with special attention to copper tube fabricators.

The next articles in this series will survey trends in Europe and Asia, where MicroGroove continues to grow as the technology of choice for air-conditioning, refrigeration and heat pumps.

WEBINARS

Advantages of Small Diameter Copper Tube-Fin Heat Exchangers
Webinar #1 in the OTS-ICA Educational Outreach Program (EOP)

View Recorded Webinar #1

Construction of Small Diameter Copper Tube-Fin Heat Exchangers
Webinar #2 in the OTS-ICA EOP

View Recorded Webinar #2

Effective Design of Small Diameter Copper Tube-Fin Heat Exchangers
Webinar #3 in the OTS-ICA EOP

View Recorded Webinar #3

See the MicroGroove "Webinars" webpage
http://www.microgroove.net/webinars

Also see MicroGrooveTech YouTube channel for archive of past webinars
https://www.youtube.com/user/MicroGrooveTech

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.

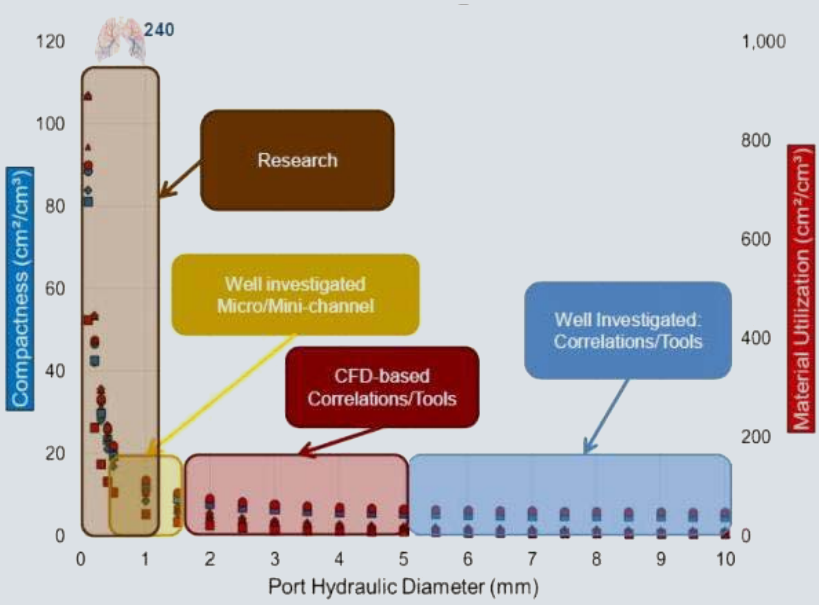
HVAC&R PLENARY

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.

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.

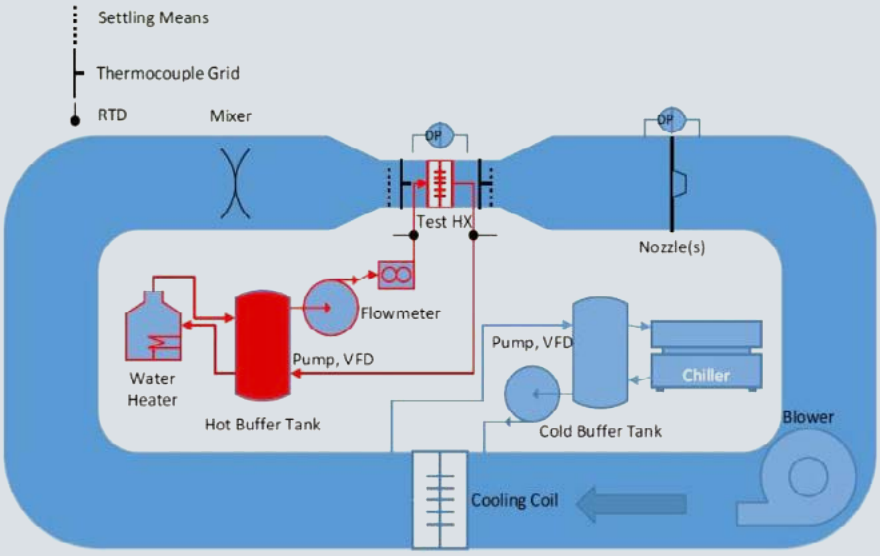
The optimization of such parameters as fin design, fin spacing, tube spacing, tube circuitry, and so forth can provide significant improvements in efficiency.

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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