# microgroove™ Update

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

Vol. 9, Issue 2 • Oct 2019

Join us on LinkedIn via microgroove.net

## PRESENTATIONS

### UPCOMING EVENTS

**ATMOsphere Europe 2019**
Oct 16-17
Airport Hotel Okęcie
Warsaw, Poland
(More info on "Events" page)

### WEBINARS

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

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

### PUBLICATIONS

Yoram Shabtay and Nigel Cotton, "Advantages of small diameter tubes in transcritical refrigeration cycles," ATMOsphere America 2019, Atlanta, Georgia. See Slideshow.

Yoram Shabtay and Nigel Cotton, "Sub-Zero, MTL Cool and LU-VE optimize MicroGroove copper tube coils for use with natural refrigerants," ATMOsphere Europe 2018, Lago di Garda, Italy. See Slideshow.

# MICROGROOVE COILS SPAN THE GLOBE: SMALLER DIAMETER COPPER TUBES THRIVE IN INDIA

South Asia is on the crossroads between Europe, Central Asia and Southeast Asia. As such, it is well located to supply heat exchangers for global ACR markets. India not only exports heat exchangers to Europe and Asia but also to North America, especially for refrigeration equipment.

Furthermore, the demand for heat exchangers domestically continues to grow. India is among the largest and fastest growing markets globally for room air conditioners (RACs) with about six million units sold in 2018. Increased infrastructural development, urbanization, higher standards of living and rising disposable income have all contributed to the heightened demand for air-conditioning.

India is a stronghold of MicroGroove know-how. Smaller diameter copper tubes increasingly are used in air conditioning and refrigeration applications in South Asia. A round tube, plate fin heat exchanger provides superior drainage and is easier to clean than a microchannel heat exchanger with serpentine fins sandwiched between ribbonlike multichannel tubes.

"A MicroGroove heat exchanger is made from smaller-diameter copper tubes," explains Avinash Khemka, Chief Manager at the International Copper Association India. "MicroGroove offers numerous advantages. MicroGroove is now emerging as the preferred alternative to microchannel."

This issue reviews the status of MicroGroove in India. It is one in a series of articles covering MicroGroove in the Americas, India, Asia and Europe. India merits separate coverage because of its large domestic market as well as its unique position as a global exporter of MicroGroove coils.

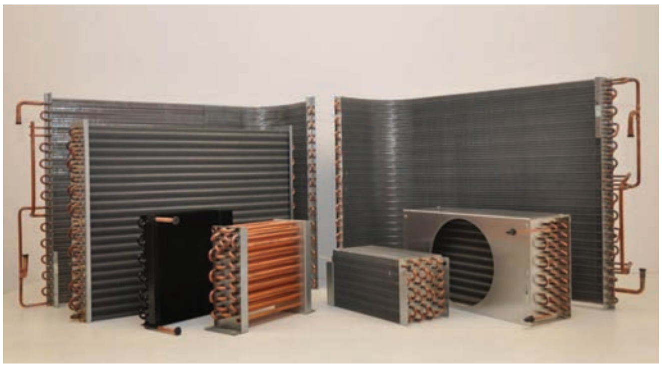

Avinash Khemka and Shankar Sapaliga at ACREX India.

## CORROSION RESISTANCE WINS MARKET SHARE

"MicroGroove usage continues to grow in India. It is a preferred tube for India because of its corrosion resistance," says Khemka. "It is true that a decade ago larger-diameter copper tubes began to lose market share to aluminium. Although a low point was reached in 2014, the corrosion resistance of copper prevailed and copper heat exchangers are now recapturing market share.

"The trend back toward copper has been dramatic in the last four years as end users of aluminium microchannel experienced many cases of failure and leakage. Now end users have an energy-efficient copper alternative. MicroGroove copper has emerged as an easy-to-maintain, reliable and durable option, well suited for the tropical climate of India," continues Khemka.

"The industry is rapidly switching to MicroGroove as a practical, economical, eco-friendly alternative to MicroChannel," Khemka emphasizes.

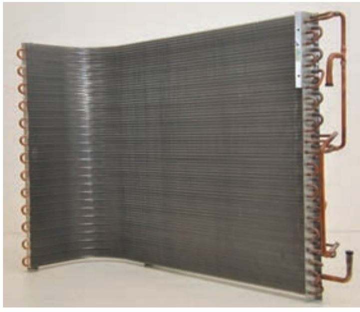


SPIROTECH Heat Exchangers was an early adopter of 5 mm copper tubes. The condensers shown here all use 5 mm copper tubes..

## STAR LABELING FOR ENERGY EFFICIENCY

Since the revision of Star Labeling by the Bureau of Energy Efficiency in 2018, AC manufacturers are specifying condensers and evaporators that transfer heat efficiently. Laboratory experiments show that heat transfer coefficients (HTCs) are highest for smaller diameter inner-grooved copper tubes compared to larger diameter tubes and smooth tubes. Higher HTCs result in more efficient RAC systems. These systems also use less material and less refrigerant.

MicroGroove coils made from smaller diameter inner-grooved copper tubes deliver an unprecedented combination of reliability and energy efficiency. They are more affordable than traditional designs because they use less material. Typical MicroGroove copper tube outer diameters are 7 mm, 6.35 mm (0.25 inch) and 5 mm.



5 mm bent condenser coil for 2.0 TR outdoor unit of a split room air conditioner Courtesy of SPIROTECH

5 mm condenser coil for 1.5 TR window room air conditioner. Courtesy of SPIROTECH.

## COIL MAKERS EXPAND PRODUCTION

Many coil manufacturers have added MicroGroove heat exchanger production lines to their plants or even built new facilities dedicated to the production of MicroGroove heat exchangers.

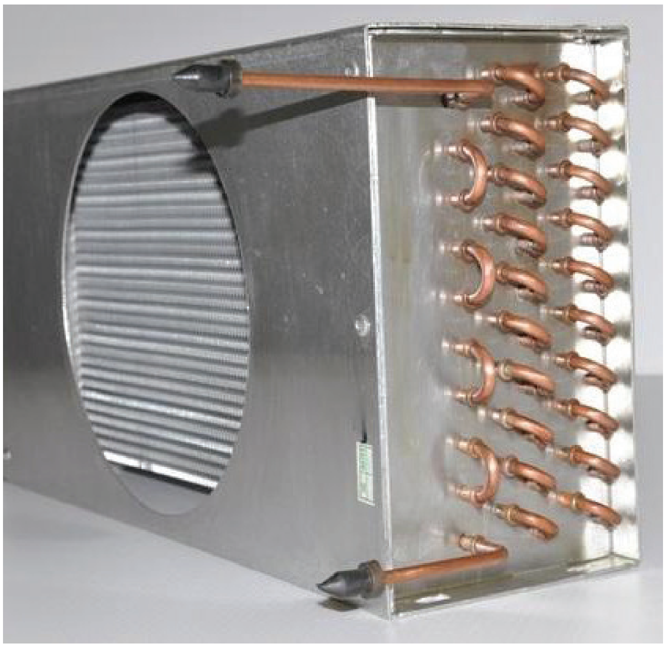
SPIROTECH Heat Exchangers (LU-VE Group) was among the first companies to adopt MicroGroove five years ago. Based in Bhiwadi, Rajasthan (about 60 km south of New Delhi), it makes MicroGroove heat exchangers for heat pumps, air conditioners and refrigeration systems, including MicroGroove heat exchangers for R744 systems. For more about SPIROTECH, see video "Presentation and Factory Tour," October 31, 2018.

Indus (www.indusair.com) is another company that has invested in the manufacture of MicroGroove coils. Another company, Danvita, was established recently in Mumbai by one of the directors of Indus (www.danvita.com).

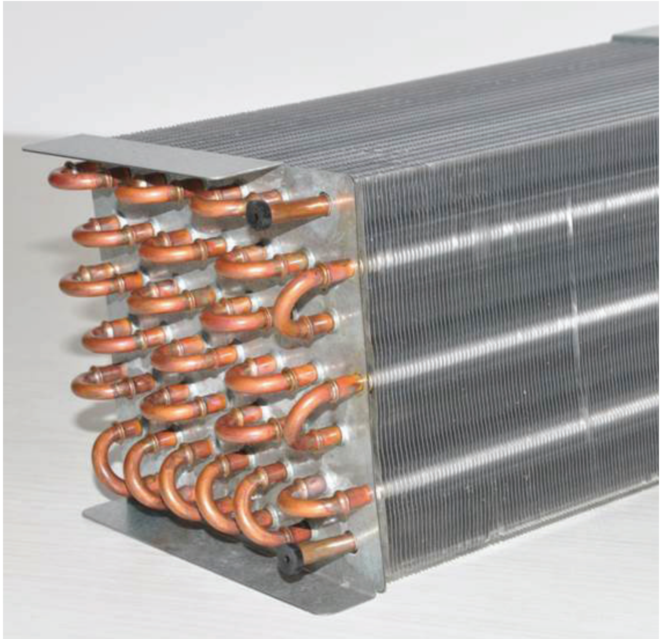
Danvita uses five millimeter "Micro Tube" copper tube coils that reduce refrigerant charge by one third compared to seven millimeter copper tube coils. According to the company, Micro Tube coils are a perfect substitute for multichannel heat exchangers because they are lighter, offer reduced refrigerant charge, and they are serviceable in the field.

Danvita's Quantum™ Fin design provides high system efficiency. With its use of CFD technology and in-depth knowledge of fluid flow, Danvita developed an innovative fin surface that provides heat transfer capacities much higher than other fin surfaces using the same footprint. Danvita serves commercial, industrial and residential HVAC and refrigeration markets as well the mobile HVAC industry and it is well equipped with the latest technologies.

The Amber Group India (www.ambergroupindia.com/heat-exchanger/) recently collaborated with the International Copper Association India and Optimized Thermal Systems (Beltsville, Maryland, USA, www.optimizedthermalsystems.com) to optimize Microgroove heat exchangers for an AC application that uses R32 as a refrigerant.



5 mm coil for condensing unit for $CO_2$ refrigerant. Courtesy of SPIROTECH.



5 mm condenser coil for a clothes dryer application.
Courtesy of SPIROTECH.

## ICA INDIA AT ACREX INDIA

The International Copper Association India (ICA India) actively promotes MicroGroove in India. (See https://copperindia.org/ for more information.) ICA India regularly exhibits at ACREX India under the MicroGroove banner. The reader is invited to view photographs from past ACREX Exhibitions uploaded into Flickr Albums. Also, ICA India contributes regular articles on MicroGroove in various HVAC-R magazine in India.

## THE SUN NEVER SETS ON MICROGROOVE

MicroGroove technology is being used in China, Korea, Vietnam, Japan and India; in several EU countries; and in the United States, Canada and Mexico. It is a breakthrough, "game-changing technology" in every sense of that phrase; and it is paving the way to more eco-friendly solutions for human comfort and the cold chain.

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

The International Copper Association India promotes MicroGroove Technology at ACREX India. Shown here are Shankar Sapaliga, Senior Consultant HVAC, and Avinash Khemka, Chief Manager HVAC.

# MICROGROOVE RETURNS TO INTERNATIONAL CONGRESS OF REFRIGERATION

Every four years, academia and industry gather for the International Congress of Refrigeration (ICR). MicroGroove exhibited at the ICR 2011 in Prague; ICR 2015 in Yokohama; and recently at ICR 2019 in Montreal.

The theme for the 25th IIR ICR was "Refrigeration for Human Health and Future Prosperity." Montreal is the city where the original Montreal Protocol on substances that deplete the ozone layer (such as CFCs and HCFCs) was signed in 1987. Many papers on low-GWP refrigerants were presented at ICR 2019. According to search results, at least 31 papers mention "Low GWP refrigerants" and at least 20 papers mention "R744." The next ICR will be held in Paris in 2023.

MicroGroove Technology was once again on display at the International Congress of Refrigeration. Harry Schmitz and Yoram Shabtay manned the booth in the exhibit hall to answer questions from the delegates in Montreal

## MOGA CASE STUDIES

"Optimization of copper-tube coils for energy-efficiency and charge reduction in heat pumps, air conditioners and refrigerators" reviewed five simulation studies using the Multi-Objective Genetic Algorithm (ID 854). The authors were Yoram Shabtay from Heat Transfer Technologies; Nigel Cotton and Hal Stillman from the International Copper Association; and Dennis Nasuta from Optimized Thermal Systems.

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 the optimal designs.

MOGA systematically varies the parameters of a coil design and simulates the performance for each selected set of parameters. Genetic Algorithm (GA) is a type of evolutionary algorithm. A population of possible solutions is evaluated in each iteration. In a Multi-Objective (MO) algorithm, the decision or selection is made from the resulting Pareto space *after* the search is complete. Heat exchanger designs that more closely meet the design objectives are selected from the resulting options.

Case studies included (1) heat-pump condensers to replace microchannel tubes with smaller diameter copper tubes; (2) a window air-conditioner condenser to improve system efficiency while reducing cost and refrigerant charge; (3) a refrigerator-freezer condenser to reduce hydrocarbon refrigerant charge; (4) the condenser of a packaged terminal AC system to minimize raw material costs and airside pressure drop while maintaining performance; and (5) an evaporator coil for a heat pump water heater to maximize capacity and minimize fan pumping power.

These diverse case studies demonstrate the advantages of smaller diameter copper tubes and the value of MOGA for design optimization. In most applications, MicroGroove heat exchangers can clearly outperform heat exchangers made from larger diameter copper tubes and performance can be comparable to microchannel heat exchangers.

## ANNUAL PERFORMANCE FACTOR

Tao Ren, Jiamin Shen, Guoming Wu from the Institute of Refrigeration and Cryogenics of Shanghai Jiao Tong University, Shanghai collaborated with Yongxin Zheng, Yifeng Gao, and Ji Song from the International Copper Association Shanghai Office, Shanghai on a paper titled "Fast predicting method for maximum APF of heat pump type air conditioner" (ID 722).

# Optimization of Copper-Tube Coils for Energy-efficiency and Charge Reduction in Heat Pumps, Air Conditioners and Refrigerators


**Yoram SHABTAY[a], Hal STILLMAN[b], Dennis NASUTA[c], Nigel COTTON[d]**

a. Heat Transfer Technologies LLC, Prospect Heights, Illinois
b. International Copper Association, Ltd., Washington, DC
c. Optimized Thermal Systems, Inc., Beltsville, Maryland
d. European Copper Institute, Brussels, 1150, Belgium


## Objective:

To optimize the design of a variety of heat exchangers using Multi-Objective Genetic Algorithms (MOGA).

## Introduction:

MOGA facilitates the optimization of heat exchanger performance using algorithms that mimic evolution in nature by carrying forward the traits of successful designs into future populations.

MOGA has proven effective in the optimization of MicroGroove heat exchangers for commercial and residential air-conditioners as well as refrigerators, heat pumps and hot-water heat pumps.

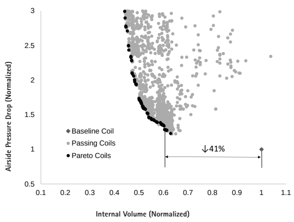



Figure 1: The best 5 mm design reduced internal tube volume by 41 percent.

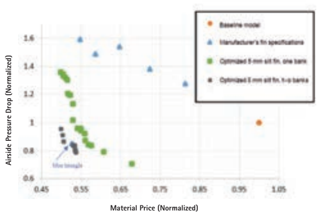



Figure 2: Low-cost PTAC condenser designs.

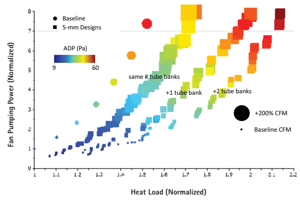



Figure 3: Performance of 5 mm designs normalized against the baseline 7.9 mm heat exchanger. Circles and squared of increasing area represent performance at higher flow rates.

## Results:

Five different optimization studies were performed by Optimized Thermal Systems in collaboration with the International Copper Association and five different manufacturers. In each case, copper tubes with diameters of five millimeters were specified and MOGA was used to optimize the configurations of heat-exchanger-geometry parameters.

### 1. Heat pump condenser.

The MOGA-optimized designs were similar to the baseline microchannel coil with regard to airside pressure drop and capacity.

### 2. Window AC condenser.

MOGA designs increased the efficiency of the heat exchanger while reducing materials usage and refrigerant charge. MOGA designs improved the COP by as much as 15% and reduced material usage by more than 60%.

### 3. Refrigerator-freezer condenser.

Hydrocarbon refrigerant charge was dramatically reduced in the 5 mm designs. MOGA designs reduced the internal tube volume up to 41% along with a 57% reduction in overall coil volume compared to the baseline 6.25 mm copper tube designs. (Fig. 1)

### 4. PTAC condenser.

Raw material costs and airside pressure drop were reduced while maintaining performance. MOGA designs provided as much as 50% savings in raw material costs while keeping the pressure drop close to the baseline. The best design reduced the overall internal volume by 62%. (Fig. 2)

### 5. HPWH evaporator.

MOGA was used to show that capacity could be doubled by increasing fan power; and that 5 mm designs delivered more capacity than the 7.9 mm baseline heat exchanger for a given fan power.(Fig. 3)

## Conclusions:

Heat exchangers can be optimized using simulation tools and a multi-objective genetic algorithm (MOGA). The examples here show how to realize performance objectives while meeting design constraints of actual applications. These and other applications demonstrate that charge reduction and efficiency gains can be achieved through the use of smaller-diameter copper tubes.


Kerry Song from the International Copper Association Shanghai Office delivered a presentation on a method for calculating the APF for a HPAC that uses 5 mm copper tubes.

The annual performance factor (APF) is the energy efficiency index for heat pump type air conditioners (HPAC). The paper presents a method to maximize the APF of an HPAC quickly. The method can be described in three steps: (1) a set of experimental data of air conditioner performance is obtained; (2) the APF optimization equations are deduced from the theoretical cycle of refrigeration; and finally (3) the experimental data are substituted into the APF optimization equations to calculate the best combinations of capacity and energy efficiency. The new method was applied to a real-world HPAC, specifically a smaller diameter copper tube system, demonstrating that the maximum APF can be obtained quickly while reducing the experimental work.

## THE MICROFIN ADVANTAGE

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.

At ICR 2019, laboratories around the globe reported on careful laboratory measurements of the effects of internal grooves, or microfins, on thermophysical properties of smaller diameter copper tubes. Typically tube suppliers offer surface enhancements inside the tube which improve the heat transfer coefficients when the tubes are used in evaporators and condensers. These effects can vary significantly depending on the refrigerant type, flow type (e.g., boiling or condensing), and flow rate.

One example of such research presented at the ICR 2019 is a paper titled "Condensation and evaporation of pure refrigerant flowing in small diameter micro-fin tubes" by M. Khairul Bashar *et alia* (ID 607). This excellent research was performed at a test facility established in Miyara and Kariya Laboratory at Saga University. A schematic shows the test section (total length is 852 mm), which consist of a horizontally installed tube, two headers, water channels, three sub-sections and total of 24 thermocouples on the tube wall for measuring wall temperature. The refrigerant flows inside the test tube, while the counter-current water flows through the water loop. Bashar *et alia* made measurements on four types of copper tubes: Type 1 was a Smooth tube with an outer diameter of 2.5 mm; and Types 2, 3 and 4 were Microfin tubes with outer diameters of 3.5 mm, 3.0 mm and 2.5 mm, respectively. The experiment yielded many data points related to tube performance. Among the many results, it was reported that during evaporation test, the heat transfer coefficient of the microfin tube (Type 4) is approximately 1.5 to 2.3 times greater than that of smooth tube (Type 1) at mass at a mass flux of 50 kilograms per meter squared per second. The authors acknowledged the Japan Copper Development Association (JCDA) is acknowledged for its financial support.

The Miraya and Kiriya Laboratory at Saga University was not the only laboratory performing research on smaller diameter inner-grooved copper tubes. Research on microfins in smaller diameter copper tubes was also conducted at the University of Padova. The paper titled "R1224yd(Z) Flow Boiling inside a Mini Microfin Tube" by Longo *et alia* (ID 404) includes a detailed review of research on mini microfin tubes in its introduction with references to many recent research papers.

An excerpt is as follows:

> More recently, microfin tubes with internal diameter smaller than 5 mm are becoming more and more popular because they can be used in the next generation of air conditioning and refrigeration systems, leading to more compact and more efficient

heat exchangers. Furthermore, the use of these mini microfin tubes may imply a relevant reduction of the refrigerant charge of the system, thus facing with the new stricter environmental regulations. For these reasons, large manufacturers are exploring the possible use of mini microfin tubes and there is a strong interest in understanding the heat transfer and pressure drop behaviors of these enhanced tubes. The literature about small diameter microfin tubes (i.e. inner diameter lower than 6 mm or so) is still poor if compared with larger tubes.

That said, numerous papers from the University of Padova present the detailed results of painstaking research on the heat transfer coefficients of smaller diameter copper tubes, including smooth and microfin tubes. The experiments described by Andrea Diani *et alia* (ID 224) were undertaken at the Heat Transfer in Micro-Geometries Laboratory at the University of Padova on a 4.0 mm OD horizontal microfin tube with 40 fins along the inner circumference. Each micro-fin is 0.12 mm high with an apex angle of 43 degrees. Tests are carried out for mass fluxes from 100 to 800 kilograms per meter squared per second. Noteworthy papers from the University of Padova are as follows:

**ID 225:** R513A condensation inside a small sized microfin tube, Diani *et alia.*

**ID 404:** R1224yd(Z) Flow Boiling inside a Mini Microfin Tube, Longo *et alia.*

**ID 408:** R1233zd(E) and R1234ze(Z) condensation inside a 4 mm horizontal smooth tube, Longo *et alia.*

**ID 1197:** Heat transfer mechanisms during refrigerant condensation when varying inclination, Azzolin *et alia.*

Similar research was performed at the Tokyo University of Marine Science and Technology (TUMSAT), Tokyo, Japan. One noteworthy TUMSAT paper is "Experiments on condensation heat transfer and visualization of flow pattern with R1234ze(E) inside horizontal 4 mm small-diameter microfin tubes" by Hirose *et alia* (**ID 1303**).

Flow visualization of the effects of microfins using 3D printed clear resin tubes with different geometries is described in two papers from the University of Illinois at Urbana-Champaign, Urbana, United States.

**ID 857:** Modified flow pattern maps for flow boiling in horizontal micro-finned tubes considering the effect of helix angle, Cheng-Min Yang and Pega Hrnjak.

**ID 858:** Analysis and quantification of generated bubbles in flow boiling through diabatic visualization, Cheng-Min Yang and Pega Hrnjak.

## NATURAL REFRIGERANTS

Several papers on trends in R744 refrigerant were presented at the conference. "Global market and policy trends for $CO_2$ in refrigeration" (**ID 1103**) by Klara Zolcer Skačanová from shecco describes the impressive growth of $CO_2$ transcritical systems worldwide from 2015 to 2018. In that time period, Europe reached 16,000 stores, or 14 percent of the food retail market for stores bigger than 400 square meters; Japan reached more than 3,530 stores; and the U.S. had the largest relative growth rate, growing from 52 to more than 370 stores. Skačanová also discusses $CO_2$ refrigeration system in small stores, industrial applications and ice rinks. One conclusion is that the "the speed of technology adoption will also be determined by the availability of technicians able to safely install and maintain the equipment."

"The advantages of natural working fluids" (**ID 1030**) by Armin Hafner of the Norwegian University of Science and Technology makes the case for natural working fluids such as carbon dioxide and propane. After a comprehensive review of current refrigerants, he shows how natural refrigerants are energy efficient and environmentally benign alternatives. One conclusion is that "the integration of expansion work recovery devices like ejectors allows today's $CO_2$ commercial refrigeration systems to outperform HFC units on annual energy consumption in any climate region."

Hafner was also the coauthor of more than a dozen other papers, including case studies from Jordan and India demonstrating the efficiency of $CO_2$ systems for supermarkets in very hot climates (**ID 787, ID 797** and **ID 1044**). He will be a keynote speaker at 2019 ATMO Europe in Warsaw.

## MICROGROOVE IN GAS COOLERS

Stefano Fillipini of the LU-VE Group presented the latest research on gas coolers with smaller diameter copper tubes in "High efficiency air cooled heat exchangers for $CO_2$ applications" (ID 326).

LU-VE has developed a $CO_2$ plant designed to be able to test condensers, gas coolers and unit coolers. According to the authors, a dedicated software program was developed in-house by LU-VE using LabView to monitor and acquire data. The maximum operating pressure is 120 bar, while the maximum temperature is 120 °C.

The authors describe some peculiarities of $CO_2$ gas coolers in this excerpt from the abstract.

> $CO_2$ is significantly different from all the other halogenated and non-halogenated fluids and it poses peculiar opportunities to heat exchanger designers: their discussion is the subject of this paper, underlining in particular innovative solutions and test laboratory to enhance the heat exchange efficiency and to improve the overall performance of the refrigeration plant.

In light of the most recent research and development on gas coolers, the LU-VE authors drew the following conclusion:

> The $CO_2$ gas cooler product can therefore be considered "proven technology" in the refrigeration field. This achievement was made possible because of the design strategy adopted by the LU-VE Group, consisting of the utilization of high performance heat transfer surfaces and of miniaturized geometries (small diameter tubes) even for large heat exchangers.

## CFD MODELING OF $CO_2$ GAS COOLER

A three-dimensional CFD model method for a fin-and-tube $CO_2$ gas cooler is proposed in the paper titled "Performance analysis of finned-tube $CO_2$ gas cooler with advanced CFD modelling development and simulation" by Zhang *et alia* (ID 835). According to the authors, the new model allows for the prediction of the airside local heat transfer coefficient and the effect of different operating conditions. The model is applied to a gas cooler made with smooth copper tubes with 7.9 mm outer diameter and 7.5 mm inner diameter.


The LU-VE Group now markets a $CO_2$ gas cooler that benefits from high air-side and refrigerant-side heat transfer coefficients (HTCs), compact designs, less materials usage and less refrigerant charge, using 5 mm diameter copper tubes rather than larger diameter copper tubes.

The CFD results suggest that the airside heat transfer coefficient and heat transfer rate increase with higher air inlet velocity; the refrigerant temperature drops dramatically at the beginning of heat exchanger pipes; and lower air inlet temperature results in lower refrigerant outlet temperature. Another conclusion is that higher velocity lowers the approach temperature and improves the performance of gas cooler.

The CFD research received support from GEA Searle and Research Councils UK (RCUK). The authors are from the University of South Wales and Brunel University London.

## CONCLUSION

Montreal played host to 850 participants from 45 countries. The quadrennial IIR ICR is a unique venue for sharing research with colleagues from around the world. Among the 534 oral presentations and 72 posters based on manuscripts, several papers on copper tubes, heat exchangers coils and systems are highlighted here. Global research shows that heat exchangers made with smaller diameter copper tubes offer higher performance and are suitable for next generation refrigerants. The HVACR industry will face many challenges in the next four years before the Paris Congress in 2023.

Perhaps the Montreal Congress will be looked back upon as a turning point in the history of refrigeration.