microgroove™ Update

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

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PRESENTATIONS

TECHNICAL PAPERS

Purdue Conferences

1. "Investigation of application of suction-line heat exchanger in R290 air conditioner with small diameter tube" by Tao Ren *et al.*
2. "Influence of oil on heat transfer characteristics of R410A flow-boiling in conventional and small size microfin tubes" by Haitao Hu *et al.*
3. "New Copper-based Heat Exchangers for Alternative Refrigerants," Yoram Shabtay *et al.*

NEW WHITE PAPER

"Smaller Diameter-Copper Tubes Support Manufacturing and Design: A report from the 2014 Purdue Conference," By Nigel Cotton, International Appliance Manufacturing, October 2014.

www.appliancedesign.com/articles/94226-smaller-diameter-copper-tubes-support-manufacturing-and-design

NEW BROCHURE

"MicroGroove Technology for Heat Pumps: Questions and Answers," Four Page Color Brochure, download from www.microgroove.net/heat-pumps.

"All-Copper Heat Exchangers: Economical, Eco-friendly & Hygienic," Four Page Color Brochure, download from www.microgroove.net/antimicrobial-copper.

MICROGROOVE WEBINARS

A new webinar in the MicroGroove webinar series is being planned for January 2015.

(More info on "Webinars" page)

LABORATORY EXPERIMENTS AND COMPUTER SIMULATIONS ESTABLISH FIRM FOUNDATION FOR NEW DESIGNS AND APPLICATIONS

Here is a brief synopsis of select research relating to laboratory experiments, simulations, heat exchanger design and the manufacture of components and systems using smaller diameter copper tubes. Only the highlights of select papers from the 2014 Purdue Conferences are presented here. Interested readers can refer to the conference website for a listing of all the papers presented and to download original papers [1]

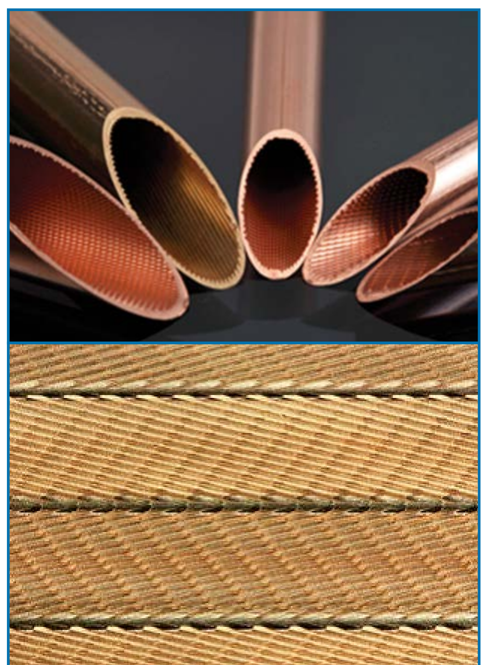
LABORATORY EXPERIMENTS ON SMALL TUBES

One fundamental area of experimental research involves the measurement of heat transfer coefficients (HTCs) and pressure drops for various sizes of copper tubes. There was no lack of such papers this year, with researchers investigating the behavior of new refrigerants and the effects of tube size, inner-groove geometry, mixtures and oil contamination.

Simone Mancin from the University of Padova described extensive experiments measuring boiling heat transfer with R1234yf as the refrigerant. The copper tube was inner-grooved with an inner diameter of only 3.4 mm at the microfin tip. (See paper 2460.)

Chieko Kondou from Kyushu University described measurements of HTCs and pressure drops on fluorinated olefins (R1234ze), including mixtures with R744 and R32 for air conditioning systems as well as comparisons between R1234ze(E) and the isomer R1234ze(Z) at higher temperatures for industrial heat pump applications. Detailed measurements for both condensation and evaporation are presented in the two papers, which should be consulted for a full examination of the results. (See paper 2337 and 2333, respectively.)

Haitao Hu from the Institute of Refrigeration and Cryogenics at Shanghai Jiao Tong University described experiments in which oil contamination actually increases the boiling HTCs. The results obtained were expressed in terms of an enhancement factor (EF) which compares the HTCs with oil and without oil at various oil concentrations. (See paper 2347.)



HTCs are increased using MicroGroove tubes. (See Paper 2570.)

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Laboratory Experiments and ...
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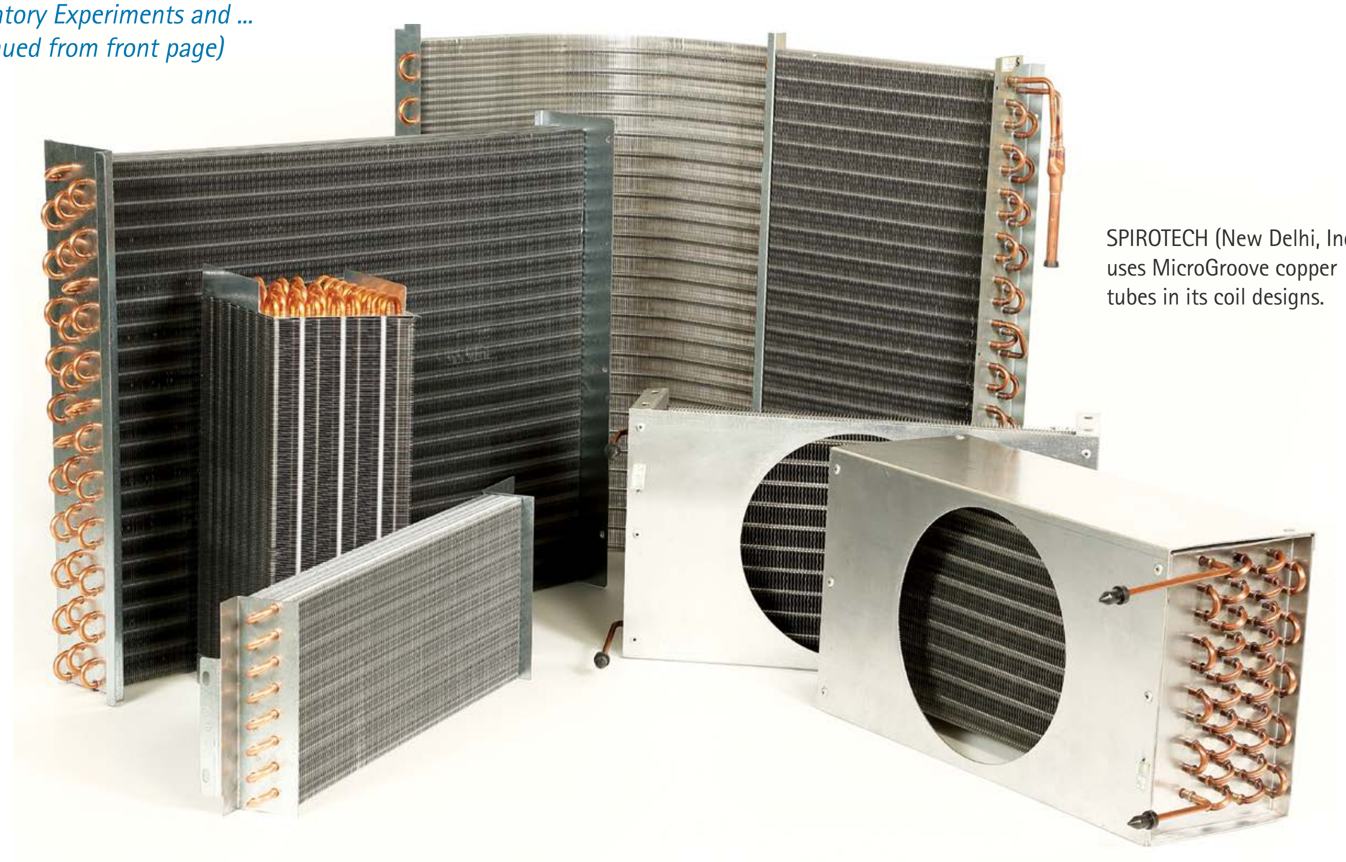

SPIROTECH (New Delhi, India) uses MicroGroove copper tubes in its coil designs.

Sangmu Lee from Mitsubishi Electric Corporation, Japan presented fascinating research on the heat transfer characteristics of a smaller diameter copper tube with non-uniform inner grooves. In other words, the microfins are of different heights, which has important effects on the performance of the tubes, considering the manufacturing process. (See paper 2283.)

The above papers on the measurement of heat transfer coefficients provide a link between theoretical product designs and the actual behavior of refrigerants in tubes. The goal is to obtain enough accurate data on the two-phase flow of various refrigerants through smaller-diameter copper tubes with various designs of inside-the-tube surface enhancements, or inner grooves.

MODELS AND COMPUTER SIMULATIONS

CFD software today can save a lot of time and help to get products to market faster. That is why the above experimentally measured values of HTCs and pressure drops are so vital. Several recent papers on the subject of simulations and correlations are noteworthy.

A paper presented by Santiago Martinez-Ballester of the Institute for Energy Engineering, Universitat Politècnica de València, Spain described a methodology for validating correlations. For simplicity, a smooth copper tube with a conventional diameter was used for this discussion. One conclusion is that the model was more sensitive to the air velocity than air temperature, subcooling and compressor speed.

At the other end of the scale of tube sizes, researchers from the University of Maryland simulated finned and finless copper tube heat exchangers with tube outer diameters ranging from 2 mm to 5 mm. According to Vikaunt Aute from the Center for Environmental Energy Engineering, experiments are needed to validate the correlations presented in this paper. Nonetheless, they can be used instead of CFD for the design and optimization of air-to-refrigerant heat exchangers, thereby saving computational time. (See paper 2240.)

In another intriguing simulation from the University of Maryland, investigators sought to measure how uncertainties about refrigerant properties translate into uncertainties in the simulation of heat transfer coefficients. Among other things, it was found that the uncertainties about the liquid heat conductivity translated into the largest uncertainty in simulation of heat transfer coefficients. (See paper 2204.)

DESIGN INNOVATIONS

The use of low-GWP refrigerants is an underlying theme of much of the current research. Manufacturers must work with the tradeoffs inherent in the current generation of eco-friendly refrigerants.

Yoram Shabtay of Heat Transfer Technologies examined copper RTPF heat exchangers for use with alternative refrigerants such as R290 (propane) and R744 (CO_2) as well as R32 and R32-HFO blends. He pointed out that smaller diameter copper tubes are now the norm in heat exchanger design and comparisons with alternatives should include results for 5-mm copper tubes and not larger diameter copper tubes from the past. He also described how high-strength copper-alloy tube (CuFe2P) in small diameters or in copper microchannel tubes could be integrated with advanced compact heat-exchanger

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designs to meet the needs of higher pressure, more compact, R744 (CO_2) refrigeration systems. He concluded his presentation with a discussion of Life Cycle Climate Performance (LCCP). An all-copper heat exchanger can provide higher efficiency over product life cycles and consequently may be the best choice for compact heat exchangers when LCCP is taken account. (See paper 2570.)

Professor Guoliang Ding of the Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, explained why a suction line heat exchanger (SLHX) increases efficiency. An SLHX was installed in a 2600 W air conditioner made with smaller diameter copper tubes and propane (R290) as a refrigerant. The SLHX increased the cooling capacity by 5.3 percent and the COP by 4.5 percent; and the refrigerant charge was reduced by six percent. (See paper 2231.)

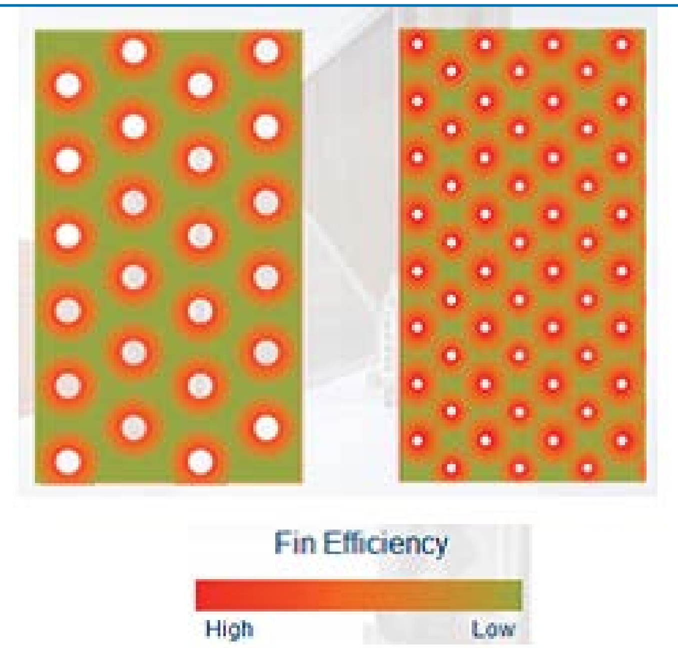
Another way to increase heat transfer through the copper tubes in an evaporator may be through pulse width modulation. While there exists a vast body of research on the pulsating flow of liquids, experiments described by Ke Tang from Zhejiang University in Hangzhou, China may be the first performed on a refrigerant. In this case, the refrigerant was R134a and the pulsating flow was generated by a solenoid valve in the evaporator. Limited data has been obtained to date but more is expected. (See paper 2585.)

Research from Pusan National University in South Korea focused on optimizing the tube circuitry for a condenser rated at 3,500 W and made with 7 mm copper tubes with wall thickness of 2.5 mm. There are numerous approaches to optimize tube circuitry. Here, an intuitive method with physical meaning was considered as it related to the pumping power and the heat transfer performance of the heat exchanger. (See paper 2396.)

Optimal circuitry may depend on the refrigerant flow rate. In a paper by researchers at Purdue University, a new interleaved circuitry was compared with active refrigerant flow control for different cases of maldistribution of refrigerant in an evaporator. The study focused on two circuits of an 8-circuit evaporator for a 3-ton (10.6 kW) R404a walk-in cooler refrigeration system (WCRS). The results show that interleaved circuitry recovers less of the performance losses than equalization of the exit superheats but its implementation would cost less. This research was supported financially by the California Energy Commission. (See paper 2396.)

When the ambient temperature is very high, condenser performance can be boosted by applying water as a deluge, spray or mist cooling. Research conducted at the CEEE at University of Maryland was presented by Sahil Popli. Visualization was accomplished by inserting boroscopes into these paths. The results showed that deluge cooling was most effective, wetting up to 85 percent of the fin area. (See paper 2143.)

An algebraic treatment of frosting was described by Christian Hermes from the University of Paraná, Brazil. The analysis yielded some useful guidelines for the design of tube-fin evaporator coils running under frosting conditions. In such light-commercial refrigerators, tube diameters are typically 10 mm for the frosted tube-fin evaporator coils. Geometric factors and operating parameters influence not only the heat and mass transfer rates but also the frost growth and densification. (See paper 2109.)



Smaller diameter copper tubes allow for more efficient heat transfer outside the tube. (See Paper 2570.)

Chad Bowers of Creative Thermal Solutions reported on extensive series of tests on six different sizes of fittings designed to connect tubes between 6.35 mm and 28.5 mm. These fittings were subject to a stringent series of accelerated tests, including mechanical fatigue tests, pressure testing, freeze-thaw cycles, vibrations and more. The new fittings are designed to reduce incidents of leaks due to unskilled use of open air flame brazing. (See paper 2564.)

PRACTICAL APPLICATIONS

The ultimate validation of experiments and modeling occurs when new products succeed in the marketplace. The competition is fierce and product development cycles are getting shorter. The research results and new technologies as described above are used to make products safe, economical and energy efficient. A sampling of new product designs and product categories follows.

More and more, the vapor-compression refrigeration cycle is being used for heating. An outstanding example is the development of a heat pump tumble dryer as described by Cenk Onan, Yildiz Technical University, Turkey. Copper tubes with diameters as small as 6 mm were tested in this R744 application. Not surprisingly, the best moisture extraction rates and COPs were obtained with the smaller tube diameters (See paper 2360.)

Practically every aspect of the design of a small-sized split-type heat pump system was outlined in a presentation by Tomoyuki Haikawa

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Laboratory Experiments and ...
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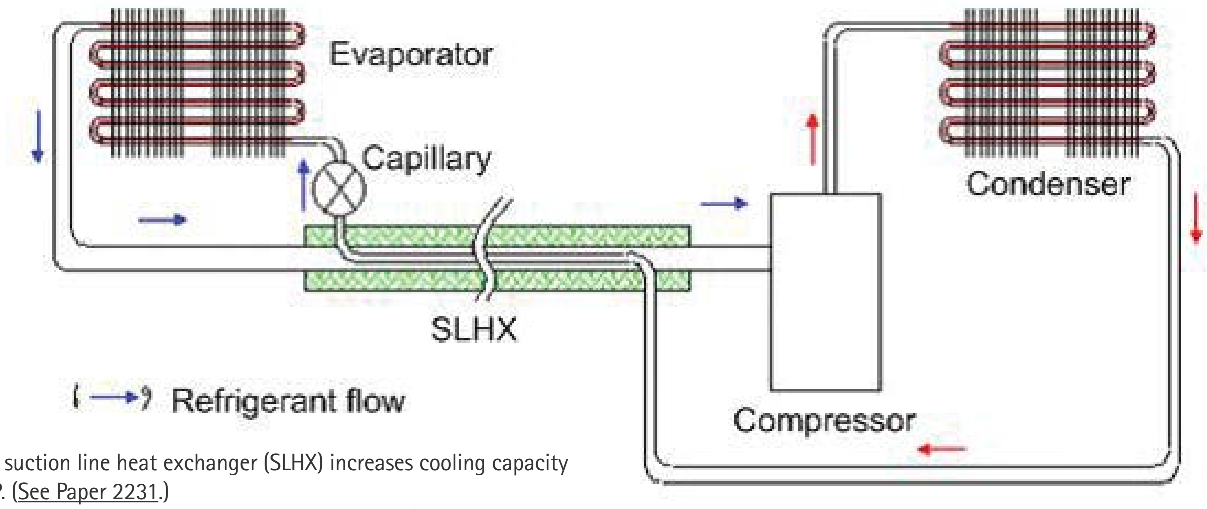

The use of a suction line heat exchanger (SLHX) increases cooling capacity and the COP. (See Paper 2231.)

from Daikin who asserted that R32 refrigerant performed better than other low-GWP alternatives to R410a. The system under research had a nominal cooling capacity of 4.0 kW, and the indoor unit and outdoor unit were joined with 5 m length connection. (See paper 2345.)

There were several papers dedicated to beverage display coolers, including one on transcritical R744 systems, which are well on the way to market acceptance. Stefan Elbel of Creative Thermal Solutions described a promising design of a glass door cooler that uses low-cost components such as round-tube-plate-fins heat exchangers for the gas cooler and evaporator, a capillary tube and a fixed-speed compressor. (See paper 2192).

Meanwhile, Yadira Padilla Fuentes, also of Creative Thermal Solutions, described a beverage cooler design that uses propane as a refrigerant (See paper 2458.)

Marcel van Beek from Re/genT in the Netherlands analyzed ways to reduce energy consumption of bottle coolers, including the use of phase change materials (PCMs) along with two evaporators. (See paper 2457.)

EFFICIENT USE OF ENERGY AND MATERIALS

The above synopses give various snapshots of select areas of research with special emphasis on research relating to the use of smaller diameter copper tubes in heat exchangers for HVACR systems. The quality and scope of recent research has been remarkable. Some of the papers described here can serve as good starting points to delve deeper and learn more about the latest developments.

The limitations of available refrigerants have forced the industry to carefully weigh design options and adopt innovations that will lead to more efficient use of energy and materials.

MicroGroove Technology is a game changer. As manufacturers seek to improve system performance they can revisit their faithful friend, tried-and-true copper, and reconsider the tube diameters, internal enhancements and coil designs. As is often the case in the supply chain, a single basic innovation can lead to hundreds of product innovations.

For an overview of MicroGroove technology, the interested reader is referred to the article "Building Better Appliances with Smaller-Diameter Copper Tubes" [2].

MicroGroove tubes represent the shape of things to come in appliance design.

References

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2. Nigel D. Cotton, Bob Weed and Wenson Zheng, *International Appliance Manufacturing*, 2013 edition, page 33.

View Online at http://digital.bnpmedia.com/publication/?i=176977&p=34; or download reprint from www.microgroove.net/sites/default/files/iam_microgroove.pdf.

TABLE OF RESEARCH PAPERS

SESSIONS	PAPER ID*	TITLE	AFFILIATIONS
HTC and PRESSURE DROP			
R-25: Flow & Pool Boiling	**2460**	R1234yf Flow Boiling Heat Transfer Inside a 3.4 mm ID Microfin Tube	University of Padova, Italy; Universidade Federal de Santa Catarina, Brasil
R-12: Refrigerant Heat Transfer & Pressure Drop	**2337**	Condensation and Evaporation of R744/ R32/R1234ze(E) Flow in Horizontal Microfin Tubes	Kyushu University, Fukuoka, Japan
	2333	Condensation and Evaporation of R134a, R1234ze(E) and R1234ze(Z) Flow in Horizontal Microfin Tubes at Higher Temperature	Kyushu University, Fukuoka, Japan
R-35: Refrigerant & Lubricant Design & Analysis II	**2347**	Influence of Oil on Heat Transfer Characteristics of R410A Flow Boiling in Conventional and Small Size Microfin Tubes	Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, China; Key Lab of HVAC, Beijing University of Civil Engineering and Architecture, Beijing, China; and International Copper Association Shanghai Office, Shanghai, China
R-09: Gas Cooling & Condensing Heat Transfer	**2283**	Heat Transfer Characteristics of the Non-uniform Grooved Tube considering Tube Expansion	Mitsubishi Electric Corporation, Japan
SIMULATIONS			
R-15: Air-side Heat Transfer, Fouling & Frosting	**2240**	CFD-Based Correlation Development for Air Side Performance of Finned and Finless Tube Heat Exchangers with Small Diameter Tubes	Center for Environmental Energy Engineering, University of Maryland, College Park
R-09: Gas Cooling & Condensing Heat Transfer	**2227**	A Discussion about the Methodology to Validate the Correlations of Heat Transfer Coefficients and Pressure Drop during the Condensation in a Finned-Tube Heat Exchanger	Institute for Energy Engineering, Universitat Politècnica de València, Spain; Thermal and Fluid Engineering Department, Technical University of Cartagena, Spain
R-12: Refrigerant Heat Transfer & Pressure Drop	**2204**	Uncertainty Analysis on Prediction of Heat Transfer Coefficient and Pressure Drop in Heat Exchangers Due to Refrigerant Property Prediction Error	University of Maryland, College Park
DESIGN CONSIDERATIONS			
Keynote Address	**Mark McLinden**	"Optimizing the Selection of Low-GWP Refrigerants: Limits, Possibilities and Tradeoffs."	Applied Chemicals Division of the National Institute of Standards and Technology
R-19: Heat Exchanger Analysis	**2570**	New Copper-based Heat Exchangers for Alternative Refrigerants	Heat Transfer Technologies, USA; Metal Scope, USA; Ohio University, Athens, Ohio; International Copper Association
R-08: Vapor Compression Cycle Enhancements I	**2231**	Investigation of Application of Suction Line Heat Exchanger in R290 Air Conditioner with Small Diameter Copper Tube	Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University; International Copper Association, Shanghai Office

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Table of Research Papers
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SESSIONS	PAPER ID*	TITLE	AFFILIATIONS
DESIGN CONSIDERATIONS			
R-03: Transient Heat Exchanger Modeling	**2585**	Effect of Pulsation Width Modulation (PWM) on the Performance of an Evaporator	University of Illinois at Urbana-Champaign; Creative Thermal Solutions, Urbana; Zhejiang University, Hangzhou, China
R-06: Heat Exchanger Flow Distribution Effects & Analysis	**2396**	Determination of Refrigerant Path Number for Fin-tube Condenser Considering Heat Transfer Performance and Pumping Power	Pusan National University, South Korea
	2180	Interleaved Circuitry And Hybrid Control As Means To Reduce The Effects Of Flow Maldistribution	Purdue University, West Lafayette, Indiana; California Energy Commission
R-15: Air-side Heat Transfer, Fouling & Frosting	**2143**	Visualization of Evaporatively Cooled Heat Exchanger Wetted Fin Area	Center for Environmental Energy Engineering, University of Maryland, College Park
	2109	Thermodynamic Optimization of Tube-Fin Evaporators Operating under Frosting Conditions	Laboratory of Thermodynamics and Thermophysics, Federal University of Paraná, Brazil
R-33: Refrigerant & Material Safety & Reliability	**2564**	Design of Accelerated Fatigue Tests for Flame Free Refrigeration Fittings	Cerro Flow Products; Creative Thermal Solutions
PRACTICAL APPLICATIONS			
R-27: Supermarket & Beverage Refrigeration Systems	**2457**	Reducing Display Bottle Cooler Energy Consumption Using PCM As Active Thermal Storage	Re/genT, The Netherlands
	2458	Extremely Low Refrigerant Charge Beverage Display Cooler Technology Using Propane	Creative Thermal Solutions; University of Illinois at Urbana-Champaign
	2192	Successful Design, Implementation, And Validation of Transcritical R744 Technology for Beverage Display Coolers	Creative Thermal Solutions; University of Illinois at Urbana-Champaign
R-07: Heat Pumps I	**2345**	Evaluation of Performance of Heat Pump System using R32 and HFO Mixed Refrigerant	Air-conditioning Manufacturing Division, Product Development Group, Shiga. Japan
R-18: Heat Pumps III	**2360**	The Effects of Fin Spacing and Tube Outer Diameter of Evaporator on System Performance in Heat Pump Tumble Dryers	Yildiz Technical University, Turkey

***To view or download papers, search for four digit paper ID from this webpage:**
https://www.conftool.com/2014Purdue/sessions.php

THE COLD CHAIN IN CHINA

The establishment of the cold chain in China has deep implications both for China and for the rest of the world.

An excellent article titled "The Price of Cold: What Do Chinese Dumplings Have to Do with Global Warming?" by Nicola Twilley appeared in *The New York Times Magazine* this past summer [1]. http://nyti.ms/1umKYpN

Twilley reports that, in 2010, the 12th Five-Year National Plan prioritized the expansion of refrigerated and frozen capacity. Tax breaks, subsidies and preferential access to land have favored the development of the cold chain. Market demand is up, too, as evidenced by the increase in ownership of domestic refrigerators in urban families from seven percent to 95 percent between 1995 and 2007 [1].

Twilley thoughtfully describes the economic aspects of the cold chain in China and provides cultural insights as well. It is noteworthy that she is preparing a book on the cold chain and has been interviewed online by several media outlets [2-5]. The takeaway from these interviews is that the cold chain by its very nature is made up of several complex and highly segmented industries.

Coupling government support with market demand, it is not surprising that the activity in the cold chain is really heating up. And yet there is profit to be made by entrepreneurs and corporations prepared to take on the challenges. According to a May 2014 press release [6], Roland Berger Strategy Consultants predicts the growth of Chinese cold chain logistics into a 470 billion yuan industry at rate averaging 25 percent per annum until 2017. Its development in the four aspects of products, customer channels, logistics providers and service coverage will generate new growth hotspots and new challenges. All types of industry participants must gain an understanding of how the industry is changing, to meet those challenges and seize opportunities.

The editors of the *ASHRAE Journal* also have taken note of the phenomenal expansion of cold chain logistics in China with an article titled "Energy Efficiency is China's New Proverb" [7]. The article describes important product innovations from China Refrigeration 2014 held in Beijing and also looks ahead to China Refrigeration 2015, which will be held in Shanghai.

MICROGROOVE IN CHINA

Regular readers of the *MicroGroove Update eNews* already know that MicroGroove is no stranger to China. In fact, the technology was largely developed in China by a technology consortium consisting of major appliance manufacturers, universities and Copper Alliance members, including the International Copper Association through its Shanghai office.

China appears to be moving toward the use of R-32 as a refrigerant. As described by Yoram Shabtay at the Purdue Conferences (see paper 2570 in the main article in this issue), R-32 is an HFC with zero ODP and relatively low GWP compared to refrigerants currently in use. Although an HFC, R-32 has a GWP of only 675, which is considerably lower than R410A's GWP of 2,088. Hence R-32 and blends of R-32 with HFOs are candidates for the replacement of R410A and other refrigerants that are being phased out.

Propane is another refrigerant that can be used for either air conditioning or refrigeration applications. Also, CO2 is also a candidate refrigerant for use in China. Not surprisingly, the Eleventh IIR Gustav Lorentzen Conference (GLC) was held in this summer in Hangzhou, 180 km southwest of Shanghai [8]. The Hangzhou Hi-Tech Zone is a center for the refrigeration and air-conditioning industry and has maintained double-digit growth for the past 20 years in a row. Among the presentations at the GLC were two papers from the Lu-Ve Group, including one on propane and one on CO2 [9,10].

AN ESTABLISHED TECHNOLOGY

The smaller diameters of MicroGroove tubes have the benefit of reducing the amount of refrigerant needed to obtain a given cooling capacity. Also, smaller diameter tubes allow for the higher operating pressures of alternatives without having to increase the tube wall thickness.

The need for refrigeration systems that could operate at higher efficiencies stimulated the industry consortium in China to develop technologies for making and using MicroGroove copper tubes. Realizing the importance of this development, the Copper Alliance began promoting the new technology to global audiences in 2010 and has exhibited every year at the AHR Expo and China Refrigeration Expo ever since 2011.

By now, the manufacturing techniques for producing heat exchangers for residential appliances as well as commercial-sized condensers and other refrigeration equipment are well established. The Copper Alliance has developed software to

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IN THE SPOTLIGHT (continued)

aid in the development of heat exchangers for application-specific refrigeration equipment.

While companies in the Americas, Europe and Japan are also conducting important research on heat exchanger coils and refrigeration systems, China continues at the forefront of research, considering the huge stakes for participants in the establishment of the cold chain in China.

The history of the development of refrigeration as well as the highly segmented product-specific demands of the food industry is a fascinating story. The story is just beginning to unfold anew in China at a whole new order of magnitude.

References

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10. S. Filippini, U. Merlo and M. Romano (LU-VE Group), "Latest development of air cooled heat exchangers for CO2 applications," The Eleventh IIR Gustav Lorentzen Conference on Natural Refrigerants, Paper 18 (2014).

2015 EVENT SCHEDULE

Noteworthy Conferences and Exhibitions

January

AHR Expo 2015 — Booth 1156
Jan 26 2015 - Jan 28 2015
McCormick Place, Chicago
http://ahr15.mapyourshow.com/6_0/exhibitor/exhibitor-details.cfm?ExhID=10457AHR

February

ATMOsphere Asia 2015
Feb 3 2015 - Feb 5 2015
Shin-Maru Conference Square, Tokyo, Japan
http://www.atmo.org/events.details.php?eventid=27

March

ACREX India 2015
Feb 27 2015 - Mar 1 2015
Bangalore, India
http://www.acrex.in/

ATMOsphere Europe 2015
Mar 16 2015 - Mar 17 2015
Crowne Plaza Le Palace Hotel, Brussels
http://www.atmo.org/events.details.php?eventid=26

April

China Refrigeration
Apr 8 2015 - Apr 10 2015
Shanghai, China
http://www.cr-expo.com/EN/index.asp

5th IIR International Conference CO2 and Ammonia Refrigeration Technologies
April 16-18, 2015
Ohrid, Republic of Macedonia
http://www.mf.edu.mk/web_ohrid2015/ohrid-2015.html

August

IIR International Congresses of Refrigeration, ICR
Aug 16 2015 - Aug 22 2015
PACIFICO YOKOHAMA, Yokohama, Japan
http://www.icr2015.org/