microgroove™ Update

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

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A BRIEF HISTORY OF MICROGROOVE

Whatever the industry, economic incentives favor continual improvements in efficiency. The same holds true for cooling and refrigeration. MicroGroove technology is an advance in coil design that has already reduced the consumption of energy and materials in many applications.

MicroGroove technology represents a major transformation in the design of heat exchanger coils. It is deeply influencing the design of appliances and commercial systems and will continue to do so for many years to come.

The story is still playing itself out in the research laboratories and marketplaces of the world. A brief history of the first years of development of MicroGroove technology is given here.

Efficiency Breakthrough

Conventional 3/8 inch copper tubes were so firmly entrenched in coil technology that for many decades there was little thought of changing them. Yet the efficiency of air conditioners depends on cooling the refrigerant temperature as quickly and as close as possible to the ambient outdoor temperature in the condenser; and raising its temperature as quickly and as near as possible to the ambient indoor temperature in the evaporator. And that depends on the efficiency of the coils more than anything else.

Fast forward to today. Environmental concerns prompted the phase out of refrigerants with high ozone depletion potential (ODP) and global warming potential (GWP) and, at the same time, demands for improvements in energy efficiency increased.

Manufacturers were forced to "break the mold" and completely redesign their products.

The Carrier Corporation was among the first of the large OEMs to embark on a complete redesign of its residential AC systems. This project was dubbed "Everest" because of the magnitude of this daunting task. As described in a 2006 article appearing in *Managing Automation*, hundreds of man-years of R&D were involved in the "Everest" project[1]. One key advance was to decrease the tube diameters to 7 mm. The new air conditioner designs subsequently garnered several awards for the Carrier Corporation.

Goodman went even further with the introduction of its SmartCoil technology in 2008. Today this technology remains central to the Goodman product lines and continues to be manufactured at plants in Texas and Arkansas. The SmartCoil is a 5 mm diameter inner-grooved tube that greatly increases the efficiency of the Goodman AC systems. (See the "In the Spotlight" section for more about the SmartCoil.)

The march to smaller diameter copper tubes had begun.

Mass Production

Meanwhile, a consortium to further develop the technology of smaller-diameter copper tubes was formed in China. The consortium is a model of industry cooperation. Major ACR manufacturing giants such as Chigo, Gree, Haier, Kelon and Midea collaborated with tube

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suppliers via the International Copper Association (ICA). Participating research institutions included the School of Energy and Power Engineering at Xian Jiao Tong University (XJTU) and the Institute of Refrigeration and Cryogenics at Shanghai Jiao Tong University (SJTU).

The consortium's initial focus was on the use of smaller diameter copper tubes in room air conditioners, including window units and ductless split systems. In the highly competitive business of home appliances, any improvement in efficiency or reduction in materials can be a major competitive advantage. The smaller diameter copper tubes offered major advantages in both respects.

The research included simulations of coil designs, laboratory measurements of tube properties, the development of software design tools and the construction of prototype designs as well as modifications of manufacturing equipment and processes.

Laboratory Confirmation

In a beautiful series of experiments, Professor Guoliang Ding and his colleagues and students at SJTU measured the local heat transfer coefficients (HTCs) inside the tubes and found that the HTCs were significantly increased by reducing the tube diameters[2, 3].

The results are as predicted by theoretical models pertaining to heat transfer. In a condenser tube, for example, the heat energy moves outward through the flowing refrigerant; and across the insulating boundary layer of the slowly moving refrigerant near the inside surface of the tubes. These results show how more heat can be transferred using less coil material by making the tubes smaller.

Inner Grooves

Furthermore, experiments show that even for tube diameters of 4-mm or less, inner grooves or "microfin" patterns can further improve the local heat transfer coefficients. The exact patterns of the inside tube surface enhancement remains a subject of intense research. Tube supplier members of the ICA have developed proprietary enhancements, which can bust up insulating boundary layers in condensers or speed up nucleation of vapor bubbles in evaporators. The most effective patterns are application specific.

ICA refers to the technologies associated with smaller diameter, inner-grooved copper tubes as MicroGroove™ technology, which is suggestive of a "micro" (small diameter) tube with "grooves" (i.e., surface enhancements or "microfins") on the inside surfaces of the tubes. The term can also be applied to coils, meaning such coils contain MicroGroove copper tubes.

Tube Circuitry and Fin Designs

The smaller cross sectional area of a MicroGroove tube affects the flow rate and pressure drop through the individual tubes. A smaller diameter tube results in a higher pressure drop for a given flow rate of refrigerant through the tube.

Pressure drops can be reduced by increasing the number of paths through the heat exchanger and shortening the length of each path. In other words, the tube circuitry can be adjusted to increase the overall flow rate through the coil. The search for an optimized circuitry is typically guided by a knowledge base, which focuses the simulation trials on designs that can be readily manufactured.

Fin optimization should not be overlooked in the design of new coils. The optimal fin design for smaller diameter tubes can be quite different than a fin design optimized for conventional tubes. Note that smaller diameter tubes have less "form drag" than larger diameter tubes. Hence, all other factors being equal, MicroGroove coils can be made more streamlined and more efficient than conventional coils with respect to outside-the-tube heat transfer. That is why it is important to reconsider and re-optimize fin designs when switching to smaller tubes. Conventional fin types may no longer be optimal.

The effect of tube circuitry and fin design on coil performance has been accurately modeled and optimal configurations can be identified using the latest coil-design software tools. When verified by building prototype coils and measuring actual performance in laboratory experiments, the results of such simulations today agree with actual coil performance to a high degree of accuracy, typically within one percent.

Nowadays, given accurate heat transfer coefficients, these simulations can speed up the process of optimizing the coil circuitry and fin designs. Several papers have been published on this topic by members of the research consortium[4-6] as well as in the trade media[7-8].

Manufacturing Methods

Manufacturers soon discovered also that familiar manufacturing techniques can be adapted for use with smaller diameter tubes. The equipment and techniques are modifications of the equipment used to manufacture coils with conventional tubes. Manufacturing processes include Fin Stamping, Tube Processing, Handling & Assembly, and Expansion.

Smaller diameter tubes require better control over the manufacturing tolerances for each of these steps. And the quality of the tube materials may also be more important for manufacturing processes involving smaller diameter tubes; equipment modifications and in some cases new equipment may be needed. Nevertheless, the processes and equipment will be familiar to coil makers.

The above equipment is illustrated and described in the MicroGroove webinar titled "The Manufacture of ACR Coils with Smaller Diameter Copper Tubes" hosted by *Appliance DESIGN* and the *ACHR News* March 2012. A recording of the webinar is now available on YouTube and in the slideshow and script can be downloaded from the "Webinar" section of microgroove.net.

Non-Shrinkage Tube Expander

In a typical coil manufacturing process, tubes are expanded by pushing a "bullet" that is slightly larger in diameter than the tube through the entire length of the tube. The purpose of the expander is to ensure that the tubes are in firm contact with the fins.

Tube expansion occurs with an increase in the circumference. For a constant volume of copper tube material, geometrical considerations demand that tube expansion be accompanied by a decrease in tube length or reduction in tube wall thickness. If the tube length is held constant then the material is made up by slightly decreasing the tube wall thickness. Otherwise it is made up by reducing the overall tube length.

For window type ACs and split units (ductless systems), OEMs have reported variations of tube lengths after the tube expansion step. The lack of control over the final lengths of tubes after the tube expansion step in some cases can disrupt later automated assembly steps, such as the attachment of return-bends to the open tube ends.

Several OEMs have solved this problem by using a non-shrinkage tube expander, which holds the tubes length constant during the expansion process, hence the term "non-shrinkage" tube expander. One type of non-shrinkage tube expander is made by the Zhongshan OMS Industrial Co., Ltd.

Not all OEMs are using a non-shrinkage tube expander. Some are finding other ways to expand the tubes and/or cope with the differences in tube lengths.

Looking Ahead

Who knows what will be the next big thing for MicroGroove smaller-diameter tubes? Will it be the growing use of heat pumps; variable refrigerant volumes; new synthetic refrigerants and natural refrigerants; the elimination of leaks from supermarkets; the development of energy-efficient cold display cases; the integration of hot-water systems with air-conditioning; "cold energy" storage; or the rise of zero net-energy homes?

Whatever the future brings, it is a good time to be in product development in the ACR industry. The next big thing in ACR might be made from small tubes. And it may come from your laboratory work bench. Will MicroGroove tubes be the key to your success? Join our discussion group on LinkedIn and let us know what you think[9].

REFERENCES

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[9] Join the MicroGroove Group on LinkedIn via www.microgroove.net.

NOTE: ASME-ATI-UIT-10 = The American Society of Mechanical Engineers (ASME), the Associazione Termotecnica Italiana (ATI), the Unione Italiana di Termofluidodinamica (UIT) and International Centre for Heat and Mass Transfer (ICHMT). Conference on Thermal and Environmental Issues in Energy Systems, Sorrento, Italy, May 2010.

NOTE: See "Technical Materials" box on the home page of microgroove.net for links to MicroGroove technical literature or go directly to www.microgroove.net/technical-literature.

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IN THE SPOTLIGHT

GOODMAN PIONEERS USE OF 5-MM TUBES IN CONDENSERS

Goodman announced its new SmartCoil™ technology in 2008. The coils were made of aluminum fins and 5-mm copper tubing. One of the team members involved in the development of SmartCoil products when the project began in 2007 was Rusty Tharp, who currently is the Director of Regulatory Affairs, Goodman Manufacturing Company, a member of the Daikin group.

"Many new manufacturing methods were pioneered in the development of the first coils with 5-mm copper tubes," explained Tharp. "Five millimeter copper tubes are now used by Goodman for central air conditioners in the 1.5 ton to 15 ton capacity range. Our copper supplier willingly worked with us to facilitate the transition to smaller diameter copper tubes. Finding the optimal mix of performance and product size is important to being a competitive player in the HVAC market, which is why Goodman has chosen 5-mm SmartCoil condenser coils as the foundation for our cooling products."

Condenser coils made from 5-mm diameter copper tubing are manufactured in Houston, Texas and Fayetteville, Tennessee. According to Tharp, the key benefits for the customer are reduced refrigerant volume, energy efficiency, compactness and ease of maintenance.

"Reduced refrigerant volume is good for HVAC products because, as a general rule, systems with lower refrigerant charges have lower failure rates," he explains. "The 5-mm diameter copper tubes allow for energy-efficient comfort products and reduce the size and weight of these products. Furthermore, SmartCoil condenser coils are easier for our customers to service in the event of a leak. Industry technicians are familiar with copper as compared to aluminum microchannel heat exchangers. The latter can be difficult, if not impossible, to repair in the field where conditions are less than optimal."

Tharp reports that pressure drop was controlled by appropriately choosing the number of refrigerant paths (circuits) in each condenser coil. "The aluminum fins themselves were obviously changed due to the design and spacing of the smaller-diameter copper tubes. Heat transfer was optimized by selection of appropriate aluminum fin enhancements," he says. "Goodman uses computer simulations in all of its product designs."

New hairpin benders, fin dies and expanders and their associated components were procured by Goodman to allow for volume production of the new coil designs. "Lacing long, small hairpins was initially a challenge and expanding such long coils with small diameter tubes without bending expander rods also presented several challenges," says Tharp. "Changing the sheet metal cabinetry and coil manifolding were among the most challenging aspects of converting designs from 3/8" diameter copper tubing to 5-mm SmartCoil copper tubing. These challenges were met successfully. We now have a manufacturing process that is reliable and flexible with regard to our product mix."

What does the future hold for even smaller-diameter copper tubes in appliance design and manufacturing? "If further improvements can be discovered with regard to optimization of heat transfer, less refrigerant use and more compact sized units, we plan to actively explore all options," says Tharp.