Copper Development Association Inc.
Copper Alliance

Less Is More: Why Smaller Diameter Copper Tubes are More Efficient

The Advantages of Lighter Weight, Smaller Diameter Copper Tubes

In the past, energy and electricity were considered cheap and abundant. Efficiency was not an important design criterion in the design of appliances for heating, cooling, and refrigeration. Suffice it to say that is no longer the case.

The California Building Standards Commission created Title 24 in 1978 to ensure that building construction, system design, and installation achieve higher energy efficiency. Many jurisdictions worldwide are adopting the International Energy Conservation Code (IECC) of the International Code Council (ICC). As a further aid in developing energy efficiency standards, minimum energy performance standards (MEPS) have been defined for various energy-using devices. A MEPS effectively limits a product's maximum energy to perform a specified task.

These regulations and others motivate OEMs to improve their products' energy efficiency. For refrigeration, air-conditioning, and heat pumps (RACHP), which are based on the vapor compression cycle (VCC), it is possible to improve the overall system efficiency by improving the heat transfer efficiency of the heat exchangers in these systems. The highest efficiency is obtained when the refrigerant exits a heat exchanger at a temperature close to the ambient. That is true whether the heat exchanger functions as a condenser or an evaporator. A higher heat transfer rate corresponds to a higher system efficiency in both cases.

A higher heat transfer rate could be obtained by increasing the size of heat exchangers. Twice as much cooling could be accomplished by using two heat exchangers where before there was one. While it is possible also to improve heat transfer by building bigger heat exchangers, there is a more economical way: Reduce the tube diameter.

Equipment manufacturers can achieve energy efficiency at a lower material cost while reducing overall system size with smaller diameter tubes. Smaller tube diameters result in reduced usage of tube materials, fin materials, and refrigerants, contributing to the overall reduction in system cost. Also, smaller diameter tubes can operate at higher pressures.

Let’s take a closer look at why that is possible.

The Quest for Low HTCs

The local heat transfer coefficient (HTC) characterizes the heat transfer rate. The HTC is often represented by the Greek letter alpha (α) in the technical literature.

While it may seem counter-intuitive that the HTC could be increased by decreasing the tube diameter, the idea is backed up by everyday experiences. For example, it is well known that smaller bodies are easier to cool. The explanation has to do with how the surface area and volume increase with the “scale factor." The surface area is the number of square units needed to cover all surfaces of a three-dimensional figure. It is proportional to the scale factor squared. For any pair of similar three-dimensional figures, the volume equals the volume of the original figure times the scale factor cubed.

Hence, as the scale factor increases, the surface-to-volume ratio decreases. Conversely, as the scale factor decreases, the surface-to-volume ratio increases. The human body provides an excellent example of the advantages of small-diameter tubes. Heat flows into microscopically small tubes close to the skin surface and is distributed over a larger cooling surface area. Although copper tubes will never be as small as blood vessels, a modest reduction in diameter from the conventional tube diameter markedly increases cooling rates.

To summarize, smaller-diameter copper tubes provide more surface area through which heat can pass from the refrigerant to the ambient for a condenser and from the ambient to the refrigerant for an evaporator.

Equipment manufacturers can achieve energy efficiency at a lower material cost while reducing overall system size with smaller diameter tubes. Smaller tube diameters lessen the usage of tube materials, fin materials, and refrigerants, contributing to the overall reduction in system cost. Also, smaller diameter tubes can operate at higher pressures.

The Role of Microfins

Another way to increase the surface-to-volume ratio is by rifling or grooving the inside surface of the tube. (Mathematically, the "fractal dimension" of the surface increases to some non-integer number between two and three.) The increase in surface area is more pronounced in smaller diameter tubes since more surface area is available to groove. More importantly, the enhanced surface helps to mix the refrigerant and homogenize the refrigerant temperature across any tube section, resulting in more efficient convective heat transfer. Typically, such surface enhancements can significantly increase performance.

What about Pressure Drop?

The "pressure drop" of the refrigerant inside the tube increases as the tube diameter decreases. The pressure drop is the resistance to the flow of refrigerant. As the resistance increases, more force is needed to keep the refrigerant flowing through the tubes. More force means more work is required to circulate the refrigerant through a given tube length. Depending on the system requirements, increased pressure drops could be managed with bigger compressors, but there is a simpler solution. Since the smaller diameter tubes have higher HTCs, the length of the circuit can be reduced. In other words, to offset higher pressure drops, coils can be designed with shorter tube lengths, and the tube circuitry can be configured with fewer tubes per branch and more branches per coil.

Tube Wall Thickness

According to basic stress analysis for tubes and pipes, the burst pressure of a tube increases as the tube diameter decreases. Therefore, the tube wall thickness can be reduced without risking material failures. In other words, if smaller diameter tubes are used, less tube wall thickness would be required to support the same internal pressures.

The reduced tube wall thickness pays big dividends in materials savings.

Tube wall thickness is typically less for smaller diameter tubes (7 mm or 5 mm) compared to conventional tubes (3/8 in., or 9.52 mm). Typically, wall thickness is 0.36 mm for a conventional tube, 0.32 mm for a 7 mm tube, and as low as 0.20 mm for a 5 mm or a 4 mm tube. Exact thickness values would depend on the refrigerant type and operating pressure, but these wall thicknesses are typical.

Small-diameter tubes are more desirable as operating pressures increase. Higher pressures typically are required to condense low GWP refrigerants (such as R32 or R744) compared to refrigerants being phased out (e.g., R22 or R410A). Working pressure is directly proportional to wall thickness and inversely proportional to diameter. In other words, for tubes with the same thickness, smaller diameter tubes can withstand higher pressures than larger diameter tubes.

Weight Savings

Heat exchanger designers are often surprised at the weight savings possible using smaller-diameter copper tubes. Weight savings is a consequence of several factors:

- Total tube length
- Tube wall thickness
- Less fin material
- Less refrigerant

The total length of tubing is finally determined by the whole system design, which is influenced by fin design, refrigerant, pressure, and other operating parameters. Tube weight can be approximated by multiplying the surface area by the tube thickness to obtain the volume of the tube material and then multiplying this result by the density of copper to obtain tube weight. Surface enhancement is also a factor.

In one design study for functionally equivalent 5-kW HVAC heat exchangers, the weight of the tube materials in the coils was 3.09 kg, 2.12 kg, and 1.67 kg for tube diameters of 9.52 mm, 7 mm, and 5 mm, respectively. Expressed as percentages, tube weight was reduced by 31 percent when copper tube diameters were downsized from 9.52 mm to 7 mm and by 46 percent when decreased from 7 mm to 5 mm.

Similarly, in one design study for functionally equivalent 5-kW HVAC heat exchangers, the weight of the fin materials in the coils were 3.55 kg, 2.61 kg, and 1.55 kg for tube diameters of 9.52 mm, 7 mm, and 5 mm, respectively.

State-of-the-Art Applications

Coils with smaller diameter copper tubes have been developed for use with R-32, HFOs, and low-GWP refrigerant blends. Mildly flammable (A2L) refrigerants are being adopted globally, especially R-32, but it is not the final word on refrigerants. There are also microgroove coil applications for hydrocarbon refrigerants such as propane (R-290) and isobutane (R-600a). Microgroove tubes, employed in light commercial refrigeration, allow the same cooling capacity to be realized with fewer flammable refrigerants.

The approval of an increase in the charge limit for A3 (flammable) refrigerants to 500 grams from 150 grams in self-contained commercial refrigeration cabinets under International Electrotechnical Commission standard 60335-2-89 opens the door to the development of a broad range of atmospheric-friendly refrigeration equipment, especially when smaller-diameter copper tubes are used with propane as a refrigerant.

The migration to smaller-diameter copper tubes is inevitable because of their inherent advantages. OEMs of residential air conditioning have been using 5 mm copper tubes for over a decade, particularly in China, Japan, and South Korea. For residential AC appliances, 5 mm diameter copper tubes are the rule.

Several OEMs in North America are already marketing residential air-conditioner products with economical, eco-friendly copper tubes. Central air conditioners in the 1.5-ton to 15-ton capacity range have been made in the USA for over a decade. According to one OEM, finding the optimal mix of performance and product size is essential to being a competitive player in the HVAC market. Copper suppliers work with OEMs to facilitate the transition to smaller-diameter copper tubes.

Smaller diameter tubes are used in large heat exchangers for chiller and multifamily and commercial heat pumps. These can range in sizes of 20 tons and above. As mentioned above, considerations about refrigerant flow and pressure drops can be addressed by using more circuits. As the manufacturing technology evolves for using smaller tubes in larger RACHP systems, more of these systems will use 7 mm and 5 mm diameter copper tubes.

The migration to 5 mm tubes occurred rapidly in refrigeration applications. In anticipation of HFC phasedowns, OEMs of refrigerated display cabinets and bottle coolers began using 5 mm diameter copper tubes to meet the charge limitations placed on propane (R290) refrigerant.

OEMs of heat pumps using propane as a refrigerant have also adopted smaller-diameter copper tubes. In this application, 7 mm or quarter inch (6.25 mm) are not uncommon. As cold climate heat pumps are developed, more OEMs are taking advantage of the possible efficiency gains using 5 mm diameter copper tubes.

Core Benefits of Smaller Diameter Tubes

The core benefits of smaller-diameter copper tubes remain the same throughout the past decade. That's because the basic physical principles of heat exchangers have stayed the same. These benefits can be summarized as follows:

Energy efficiency. Reducing the diameter of copper tubes in coils provides an economical path to energy efficiency for RACHP products. System energy efficiency could also be improved by using a more significant number of conventional tubes. Still, a penalty would be paid in terms of the increased weight of
tube material and fin material and increased refrigerant volume.

Less material. Tube-diameter reduction results in more effective heat transfer and, consequently, smaller, lighter coils. Less tube and fin material could provide equivalent heat transfer or more heat transfer, or the same material could provide much more heat transfer. Smaller evaporator and condenser coils allow for smaller overall product dimensions, more accessible storage and transport, easier handling during installation, and a smaller footprint at the point of use.

Less refrigerant. A dramatic reduction in refrigerant volume is a further benefit of economical, eco-friendly copper tubes. The smaller internal volume of the coils means less refrigerant is necessary to charge the coil—the need for less refrigerant results in other design advantages, including a further reduction in overall system weight.

Durability. Coils made of copper tubes and aluminum fins, or copper tubes and copper fins, are durable and dependable. They set the industry standard for corrosion resistance and long, reliable service life. Advanced coatings and surface treatments continue to improve durability in the harshest environments. The industry has found it challenging to improve the exceptional durability of copper tubes for RACHP applications.

Familiarity. Tube suppliers, OEMs, mechanical systems engineers, and HVAC contractors are familiar with copper tubes and aluminum fin technology. Up and down the value chain, the materials and processes are well understood. The fabrication, assembly, installation, service, repair, and recyclability are substantially the same in migrating conventional copper tubes to economical, eco-friendly ones.

A Look Toward the Future

The magic of the VCC revolutionized our modern world. It ushered in the age of air conditioning, leading to significant demographic changes and creating industries dedicated to comfort. Simultaneously, refrigeration created a global cold chain, crossing national boundaries "from farm to fork" in ways never possible before.

Yet the story of the VCC has yet to be entirely written. The use of heat pumps for heating has barely begun, mainly because there has been no need. If necessity is the mother of invention, innovations in heat pump designs can be assured in the next few years.

To remain competitive in bringing new, energy-efficient RACHP products to market, mastery, and improvement of the technology of diameter copper tubes will also be necessary.