Q&A

Thirty Questions with Answers about Economical, Eco-friendly Copper Tubes for Air Conditioner Applications

Core Benefits

1. What are the major benefits of economical, eco-friendly copper tubes?

Energy efficiency. Reducing the diameter of copper tubes in coils provides an economical path to energy efficiency for air-conditioning and refrigeration (ACR) products. System energy efficiency could also be improved by using a larger number of conventional tubes but then a penalty would be paid in terms of the increased weight of tube material and fin material as well as 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 and consequently easier 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 that 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 (CTAF) or copper tubes and copper fins (CTCF) 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 difficult to improve upon the exceptional durability of copper tubes for ACR applications.

Familiarity Tube suppliers, OEMs, mechanical-systems engineers and HVAC contractors all enjoy a high level of familiarity with copper tubes and aluminum fin (CTAF) technology. Up and down the value chain, the materials and processes are well understood. The fabrication, assembly, installation, service, repair and recyclability are not substantially changed in the migration from conventional copper tubes to economical, eco-friendly copper tubes.

Energy Efficiency

2. Are small diameter tubes necessary for increasing the energy efficiency of air conditioners?

No. The system energy efficiency can also be achieved with conventional tubes (such as 3/8 inch diameter tubes) simply by using more tubes and thereby increasing the surface area available for heat transfer. Nevertheless, a penalty is paid in terms of the increased weight of tube material and fin material as well as increased refrigerant volume. In general, if larger diameter tubes are used then a larger coil size is necessary to achieve the same performance and energy efficiency that could more achieved in a more compact system with smaller diameter tubes.

3. Why are OEMs suddenly interested in economical, eco-friendly tubes for ACR coils?

In the past, energy and electricity were considered cheap and abundant. Efficiency was not an important criterion in the design of air conditioners. Energy efficiency can be achieved at a lower material cost with smaller diameter tubes. Overall system size can be reduced by using small diameter tubes. Smaller tube diameters result in reduced usage of tube materials, fin materials and refrigerants, contributing to overall reduction in system cost. Also, smaller diameter tubes can operate at higher pressures.

4. Will there still be a role for conventional-diameter copper tubes in ACR coils?

Yes, there are many designs of air conditioners and refrigeration systems and so there will always be a place for coils based on conventional tube diameters. Nevertheless, economical, eco-friendly copper tubes will become the *de facto* standard for most applications within a few years.

5. What is the history of copper tubes with aluminum fins?

Condenser coils with round copper tubes and aluminum fins have been a winning combination for ACR coils for many years. Manufacturers enjoy the assembly advantages provided by these components while technicians find it easy to join and repair copper tubing in the field. More importantly, this well established technology has a proven record of durability in the field resulting in a high level of customer satisfaction.

6. Is demand rising for economical, eco-friendly copper tubes?

Demands for lower costs, energy-efficiency and less damage to the environment recently have moved the copper tube industry toward economical, eco-friendly tubes. The advantages of smaller diameter tubes include higher heat transfer, less refrigerant and space-savings. All result in cost savings. Overall performance can be increased even as refrigerant charge in the system is reduced. The recyclability of copper contributes to sustainability.

Heat-Transfer Efficiency

7. What is the main advantage of small diameter tubes for the design of air conditioner coils?
Smaller diameter tubes allow for more effective heat transfer.

8. What is meant by "more effective" heat transfer?
The same or better performance can be achieved with less tube and fin material. In other words, more heat can be dissipated with less material. Less tube, more heat! Technically speaking, a coil made with smaller diameter tubes can be designed with a higher "heat-transfer coefficient" compared to a coil made with larger diameter tubes.

9. What determines the heat transfer coefficient of a coil?
The overall heat transfer coefficient has many parts including 1) the convection of the fluid inside the tube to the tube wall; 2) conduction through the tube wall and 3) dissipation through the fins. Among other things, the first part is a function of the flow stream inside the tube as well as the thermal conductivity of the fluid and the tube geometry. As an approximation, the first part is inversely proportional to the diameter of the tube. In other words, a smaller diameter tube transfers heat more efficiently than a large diameter tube.

10. Why do small-diameter tubes dissipate heat more efficiently?
The human body provides an example of the benefits of small diameter and even microscopic tubes. Heat flows into extremely 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 the blood vessels, a modest reduction in diameter from the conventional tube diameter markedly increases cooling rates.

11. What theory explains the improved heat transfer of smaller tubes?
Heat-transfer engineers talk about the "convective cooling of fluids in turbulent flow" as described by, for example, the Dittus–Boelter heat-transfer correlation. Briefly, the differential flow-stream volumes are closer on average to the tube wall as the diameter of the tube decreases. In other words, convective heat-transfer from the flow stream (refrigerant) to the tube wall is more efficient for flow streams that are closer to the tube wall.

Surface Area

12. Does this have to do with the surface-to-volume ratio?
Yes. It has to do with scaling. It is well known from experience that small bodies are easier to cool than large bodies. Elephants need large ears to keep cool. The surface-to-volume ratio *increases* as tube radius *decreases*.

13. How do surface area and volume vary with tube diameter?
The enclosed-volume of a tube increases in proportion to the square of the radius ($V = \pi R^2 L$) Meanwhile, the surface area scales in direct proportion to the radius ($A = 2\pi RL$).

INCREASE DIAMETER
If one doubles the tube diameter then the surface area doubles while the volume increases fourfold.

CONSTANT AREA
If one halves the diameter and doubles the length then the surface area remains the same while the tube encloses half the volume.

CONSTANT VOLUME
If one halves the diameter and quadruples the length then the enclosed volume remains the same while the surface area doubles.

14. What is the advantage of increasing the surface-to-volume ratio?
Convective heat-transfer from the flow stream (refrigerant) is more efficient with the flow stream closer to the tube wall.

<u>Enhanced Inner Surface</u>

15. Is there another way to increase the surface-to-volume ratio?
Yes. The surface area can be increased by rifling or grooving the inside surface of the tube. The increase in surface area is more pronounced in small diameter tubes since more surface area is available to groove. Furthermore, 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 enhancement can significantly increase performance.

16. What effect does surface enhancement have on the boundary layer?
The “boundary layer” is an important characteristic of fluid flow and it has a major effect on heat transfer as well. Surface enhancement increases turbulence and reduces the thickness of the boundary layer. The result is more effective heat transfer. Note also that smaller diameter tubes also contribute to the turbulence, which improves in heat transfer.

Pressure Drop

17. What tradeoffs are involved in reducing tube diameter?
The refrigerant "pressure drop" increases for smaller diameter tubes. More work is required to circulate the refrigerant through a given length of tube when the pressure drop is high.

18. What can be done to offset the refrigerant pressure drop?
The 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.

19. How is the total length of tube affected by the tube diameter?
More tubes of shorter length are required to offset the internal pressure drop and the total tube length may be longer. Nonetheless, more effective heat transfer offsets any weight increase that is due to greater total tube length. The inherent strength of smaller diameter tubes can be used to advantage.

Refrigerants

20. What effect does refrigerant type have on tube diameter selection?
Small diameter tubes are more desirable as operating pressures increase. Higher pressures typically are required to condense new refrigerants (e.g., R410a or R744) compared to refrigerants that being phased out (e.g., R22). 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.

Tube Design

21. What are typical tube wall thicknesses for economical, eco-friendly copper tubes?
Tube walls thickness is typically less for smaller diameter tubes compared to conventional (3/8 inch diameter, or 9.52 mm) tubes. Wall thickness is typically 0.32 mm (or 320 micrometers) for a 7 mm tube; and 0.20 mm (or 200 micrometers) for 5 mm tubes and 4 mm tubes. A conventional tube typically has a wall thickness of 0.36 mm (360 micrometers).

22. How is tube weight calculated?
The total length of tubing finally is determined by the whole system design, which is influenced by such factors as 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.

23. What is the typical weight savings for tube materials when using economical, eco-friendly copper tubes?
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.

24. What percent savings in tube materials can be realized using economical, eco-friendly copper tubes?
In the same design study, the tube weight was reduced by 31 percent and 46 percent when copper tube diameters were downsized from 3/8 inch to 7 mm and from 3/8 inch to 5 mm, respectively.

Fin Design

25. What fin designs are suitable for economical, eco-friendly copper tubes?
A variety of fin designs have been developed for use with small-diameter copper tubes. A white paper titled "Development of a Small-Diameter Tube Heat Exchanger: Fin Design and Performance Research" compares the performance of slotted fin and louvred fin designs as various fin dimensions are varied. Simulations were used to the optimize performance of fin designs. Contact ICA for more information.

26. What fin materials are suitable for coils with small diameter tubes?
Fins could be made from aluminum or copper. In either case, less fin material is required for coils with small diameter copper tubes compared to larger diameter tubes. Since less fin material is required, copper fins are an attractive alternative fin material, providing advantages with regard to corrosion resistance and antimicrobial properties.

27. What are the typical fin weights for coils with small diameter copper tubes?
In one design study for functionally equivalent 5-kW HVAC heat exchangers, the weight of the fin materials in the coils was 3.55 kg, 2.61 kg and 1.55 kg for tube diameters of 9.52 mm, 7 mm and 5 mm, respectively.

Ease of Manufacture

28. What is the status of the development of air conditioners with small diameter copper tubes among OEMs?
The migration to small-diameter copper tubes is inevitable because of their inherent advantages. The small-diameter tube project in China involves manufacturers who

together account for more than 80 percent of HVAC production of approximately 75 million units. Several OEMs in North America are already marketing residential air-conditioner products with economical, eco-friendly copper tubes.

29. What new equipment is required to produce economical, eco-friendly copper tubing for air-conditioning applications?

Copper tubes are most widely produced using the cast and roll process. Copper ingots are cast into mother tubes and these tubes are drawn to a final shape. The tubes next are annealed and then they are enhanced to improve heat transfer performance (e.g., provided with an inner surface texture). The production of small diameter copper tubes requires only the addition of a few drawing steps to existing equipment. For example, one or two additional drawing passes should suffice to achieve 5-mm tubes.

30. What new production methods are required to manufacture air-conditioning products with economical, eco-friendly copper tubes?

Existing air-conditioner coils comprised of round copper tubes and aluminum fins (CTAF coils) typically are mechanically assembled using tube expansion. Small-diameter copper tubes also can be assembled using tube expansion with only modifications to the expansion tube.

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