EXECUTIVE Report

Thermal Conductivity of Copper Is Key to Efficiency in Air-To-Air-Cooler (ATAC) Applications

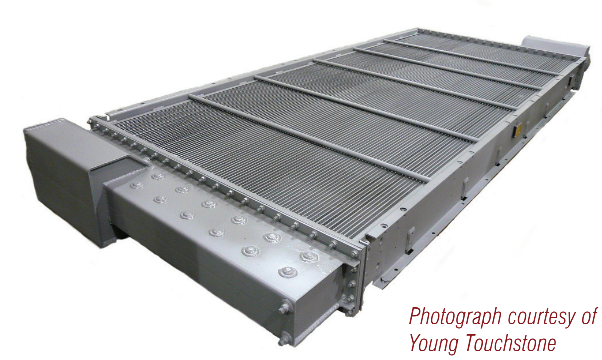
One type of charge-air cooler (CAC) is an air-to-air cooler (ATAC). These are also known as intercoolers as distinct from pre-coolers, which can be water-cooled. And ATACs are distinct from liquid-to-air coolers, which include radiators and various oil coolers.

An intercooler is typically situated between the turbo compressor and the combustion chamber of a diesel engine. Its purpose is to cool the "charges" of hot compressed air prior to their injection into the diesel combustion chambers. When the temperature decreases the density increases, allowing more oxygen to enter the engine and more fuel to be combusted per engine cycle.

ATACs in Locomotives

Huge ATACs are commonly employed in power generators and diesel locomotives. In these applications, the mechanical energy from the diesel engines is converted to electrical energy by an electric generator. Most modern diesel locomotives are diesel-electric locomotives, meaning that electricity is generated on-board and traction is delivered to the wheels via electric motors.

ATACs for a diesel-electric locomotive can weigh hundreds of kilograms. For the ATACs used in power plants and diesel electric locomotives, weight is not as much of a consideration as size and heat-transfer efficiency. Additionally, ATACs or CACs are employed in off-road diesel equipment, such as tractors and bulldozers. In this case, again, weight is not as important a consideration as size.



Photograph courtesy of Young Touchstone

*Cu*proBraze technology is rapidly being adopted for many types of locomotive heat-exchanger designs such as this charge-air cooler. The brass tubes and copper fins were brazed using *Cu*proBraze technology and then painted gray.

*Cu*proBraze technology has allowed for a revolution in the design of ATACs for locomotives as well as off-highway vehicles and even on-highway trucks.

Strictly in terms of the basic physical properties, the advantages of copper fins compared to aluminum fins are easy to understand. In this report, the effect of thermal conductivity, density and yield strength on ATAC designs will be examined. It's only slightly harder to appreciate the other advantages such as resistance to elevated temperatures, fatigue resistance and corrosion resistance.

Heat Transfer

Consider a metal conductor with a base area A of 10 mm^2 and a length L of 10 mm and a temperature difference ΔT of 100 Kelvin (i.e., 100 degrees Celsius) from one end to the other.

For this fixed geometry, assuming that no heat escapes from the sides, the heat Q that flows across this conductor will be proportional to the thermal conductivity k, according to the following equation.

$$Q = k\,(A/L)\Delta T = k\,(1\text{ mm})\,(100\text{ K})$$
$$Q = k\,(0.1\text{ m-K})$$

The "heat" or heat transfer is expressed in watts (W) and so thermal conductivity has the units of W/m-K. For copper, $k_{Cu} \approx 390$ W/m-K; for aluminum, $k_{Al} \approx 210$ W/m-K.

For a conductor of this particular size and for this temperature difference, the heat will be 39 watts if the conductor is made of copper; and only 21 watts if it is made of aluminum. Figure 1 illustrates this. The thermal conductivity is an inherent property of the materials and can only be changed by changing the materials (although its value does vary with temperature).

The International Copper Association, Ltd. (ICA)

The International Copper Association, Ltd. (ICA) is the leading organization for promoting the use of copper worldwide. The Association's 38 member companies represent about 80 percent of the world's refined copper output. ICA's mission is to promote the use of copper by communicating the unique attributes that make this sustainable element an essential contributor to the formation of life, to advances in science and technology, and to a higher standard of living worldwide.

For information about the *Cu*proBraze process or ICA's *Cu*proBraze consulting services, please contact the International Copper Association at: cuprobraze@copper.org. For European inquiries contact: ndc@eurocopper.org.

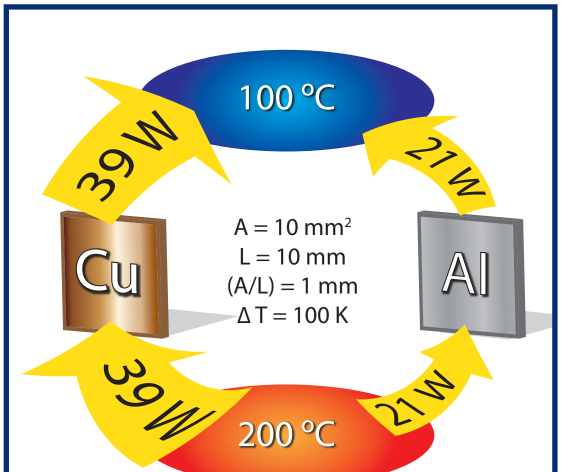


Figure 1

Copper clearly conducts more heat per unit volume than aluminum. For heat exchanger designs, this directly impacts what is sometimes called heat-transfer efficiency. For identical geometries, a copper element will remove more heat compared to aluminum. Valtra Inc. uses copper-and-brass charge air coolers in many of its tractor designs mainly because of this size advantage. The CAC fits better in the tractor because of its reduced size and the design affords better visibility to the operator.

Next, consider the density or weight of the materials. In the case of identical geometries, the copper conductor will weigh more than the aluminum component by a factor that is determined by the ratio of the densities.

$$\rho_{Cu}/\rho_{Al} = 8.9/2.7 \approx 3.3$$

So, for the same geometry the copper conductor transfers much more heat per unit volume but it is significantly heavier. If the base area of the copper conductor were reduced by the factor of k_{Al}/k_{Cu} then the copper conductor would conduct the same heat as the aluminum conductor. It would be much smaller but still weigh more by the following factor.

$$[k_{Al}/k_{Cu}]\ [\rho_{Cu}/\rho_{Al}] = [210/390]\ [8.9/2.7]$$

$$\text{weight factor} = 0.54 \times 3.3 \approx 1.8$$

Although the copper conductor still weighs more than the aluminum conductor, the smaller size of the copper conductor offers additional advantages. When convection is taken into account in real heat exchanger designs, the smaller size of the copper conductor will allow more air to circulate and allow for even greater heat transfer efficiency. This effect is known as the air-pressure drop. Its importance depends, of course, on the velocity of the air passing by the conductor. If the fins occupy more volume then it can be predicted that the air pressure drop will be greater since the air cannot easily pass through the heat exchanger. With copper, the fins can be made thinner and so the overall size of the heat exchanger can be reduced or the air pressure drop made less.

For off-road agricultural and construction equipment as well as locomotives and diesel power plants, air is blown through the heat exchanger by fans since the vehicle velocity is not significant. Additionally, construction and agricultural equipment is often exposed to dirt so wide fin spacing is desirable to avoid clogging and ease cleaning.

Simulations, Testing and Production

Simulations of ATAC performance with various software programs have been carried out, accounting for various fin design, fin spacing, tube thickness, tube materials and external air velocities as well as internal pressure and temperature and internal fins (or turbulators). Once prototypes are built, they also can be tested in wind tunnels prior to manufacturing in volume. Wind tunnel testing allows for an accurate determination of the heat-transfer efficiency of the whole design to a degree not possible with simulations.

Yield strengths at elevated temperatures, resistance to fatigue cracking, corrosion resistance and other aspects of durability and reliability can be tested under laboratory conditions. Ultimately, however, field testing is necessary to evaluate the performance of the ATACs in real world applications. Here, the whole system design can be evaluated for durability and reliability as well as thermal performance. ATACs made of copper-and-brass perform extremely well in harsh environments. This has been proven not only in the laboratory but also in extensive field tests.

Designers of *Cu*proBraze ATACs today benefit from years of accumulated design experience and field testing. As advanced technologies are developed for diesel engines and operating conditions become more demanding, copper and brass are becoming the materials of choice for ATACs. ■

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