EXECUTIVE Report

Diesel Engine Makers Strive to Meet EPA, EU and Japanese Emissions Standards for Highway, Off-road and Locomotive Applications, Part I

New Low-Emission Engine Technologies Adopt CuproBraze Heat-Exchangers

Part I – Overview of Legislation and Review of On-Highway Emissions Standards

[Editor's Note: See *CuproBraze Executive Report* Number 59 for Part II, which will describe the new emissions standards for off-road equipment, locomotives and stationary power generators.]

Diesel engine manufacturers are facing a situation of historic, global proportions. Independently and collectively, nations around the world have passed legislation that requires OEMs to develop environmentally "clean" engines and related equipment. Manufacturers that fail to meet increasingly tougher new standards eventually will be prevented from selling their products in any market.

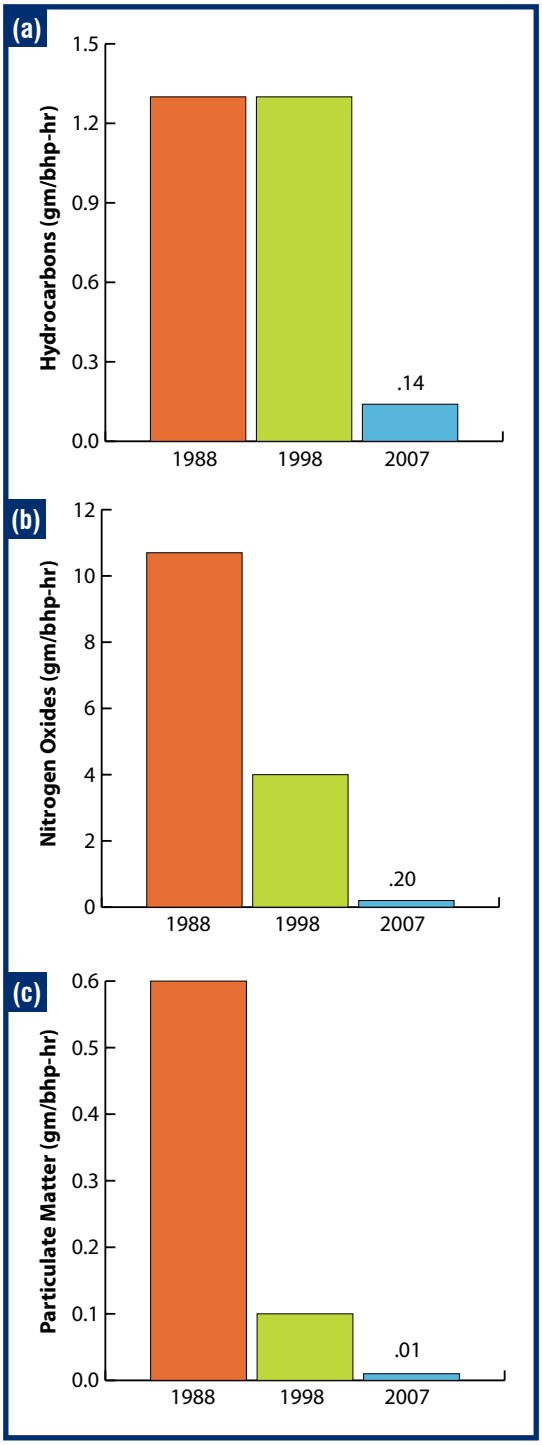
The impetus behind this movement is the fact that diesel engines are a significant source of emissions that cause health problems. A recent report titled "No Escape from Diesel Exhaust: How to Reduce Commuter Exposure" published by the Clean Air Task Force (www.catf.us) implicates diesel exhaust as a major source of noxious air pollutants. According to CATF, emissions from an estimated 13 million diesel engines in the U.S. alone are associated with respiratory illness, cancer, heart attacks and premature death. Its web site provides national, state, metropolitan area and local (county) estimates of the health impacts of diesel particulate matter.

Growing concerns about global warming are also bringing about increased regulation of fuel efficiencies. In 2007, the U.S. Supreme Court ruled that the Environmental Protection Agency (EPA) can lawfully regulate carbon dioxide emissions. Although the consequences are still to be determined, this decision eventually will spur the development of clean, fuel-efficient diesel engines in the U.S. and globally.

For at least a decade, various government agencies around the world have placed ever-stricter regulations on emissions from large diesel engines. These regulations have required engine makers to develop new engine technologies and dramatically reduce emissions of particulate matter (PM) and nitrogen oxides (NOx) from their products.

In the U.S., the EPA acknowledged the impact of diesel emissions on health many years ago and passed several tiers of rules gradually tightening emissions standards for various classes of diesel engines as detailed later in this article.

The European Union currently has six tiers of emissions standards for heavy duty



EPA's "HD2007" emissions standards apply to on-highway heavy-duty trucks. Compared to previous emissions standards, the HD2007 standards call for a dramatic reduction in a) non-methane hydrocarbons, b) oxides of nitrogen and c) particulate matter. The European Union and Japan have passed similarly stringent regulations.

trucks and buses, beginning with Tier I in 1992 and culminating in 2013 with Tier VI standards. For off-road engines, the EU has four levels of emissions standards, beginning in 1997 for Stage I and culminating in 2014 with Stage IV. European emission standards can be found online at http://ec.europa.eu/environment/air/transport/index.htm.

Japan's Ministry of Environment (MoE) also has established strict emissions regulations, including regulations for heavy duty trucks as well as off-road vehicles. These standards are described in reports available in English on the Ministry of the Environment (Government of Japan) web site (www.env.go.jp). For example, the Eighth Report on "Future Policy for Motor Vehicle Emission Reduction" is available online in English at www.env.go.jp/en/air/aq/mv/vehicle-8th.pdf.

China has been adopting emission standards since the 1990s through its State Environmental Protection Administration (SEPA), typically basing its standards on European regulations with built-in implementation delays. Russia also has adopted the EU emissions standards (Tier I-V and Stage I), according to specific implementation dates.

Advantage *Cu*proBraze

These changes affect all types of diesel engines. Because commercial vehicles and equipment tend to have large diesel engines, the new standards are especially applicable to heavy duty trucks, buses, mobile off-road equipment (for agriculture, construction and industry), locomotives and marine applications as well as stationary diesel engines for power generators and industrial compressors.

These stringent emissions regulations have impacted the industry beyond engine manufacturing and have prompted engine makers to re-examine basic premises about ancillary equipment such heat-exchangers.

As a new materials technology for heat exchangers, *Cu*proBraze is extremely attractive in heavy duty on-highway and off-road applications because it offers distinct advantages over aluminum. While aluminum is less dense than copper, copper is stronger per unit volume and has a higher thermal conductivity. Copper's thermal conductivity is 360 W/m-K compared to 260 W/m-K for aluminum. The result is that, for the same volume of heat exchanger, aluminum fins and copper fins provide about the same heat dissipation but the copper-fin heat exchanger provides a lower airside pressure drop with its associated benefits.

In other words, *Cu*proBraze provides greater cooling efficiency than aluminum. Such differences add up in the large-volume heat exchangers used to cool air charges as well as diesel engine blocks and engine oil in heavy duty on-highway and off-road applications. For mobile and stationary diesel applications, the advantages of cooling efficiency, heat exchanger size and durability are keys. The result is that more space is available for other uses. Coupling that advantage with increased

durability and high temperature resistance, it is easy to see why manufacturers are increasingly gravitating toward the *Cu*proBraze alternative.

Young Touchstone, a Wabtec Company (Jackson, Tennessee), is a leader in the development of *Cu*proBraze heat exchangers. Mike Sprenger, director of Sales & Marketing, says, "Diesel engines designed to meet the increasingly stringent emissions levels worldwide require more and more from cooling systems. These new diesel engine cooling systems reject more heat, operate at higher pressures and temperatures, have higher power densities, and operate in a variety of demanding applications. Young Touchstone's cooling systems with FLAT-ROUND® *Cu*proBraze technology can fulfill these needs for our global OEM customers with a low total-cost solution."

HD Emissions

Emissions standards for heavy duty (HD) trucks and buses were established and gradually tightened by the U.S. EPA for model years 1988 through 1998. Beginning in 2007, these limits were lowered further to historic levels. Known as the HD2007 standards, they included:

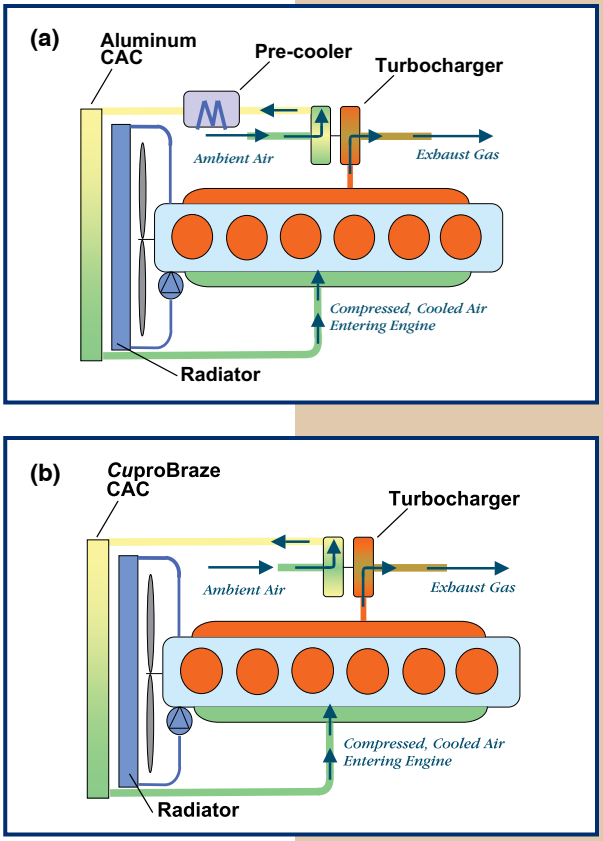
- Particulate matter (PM) is restricted to 0.01 g/bhp-hr [1]
- Nitrogen oxides (NOx) are restricted to 0.20 g/bhp-hr
- Non-methane hydrocarbons (NMHC) are restricted to 0.14 g/bhp-hr

To put these new numbers in perspective, by comparison the 1988 limits were 60 times higher for PM (at 6.0 g/bhp-hr) and more than 50 times higher for NOx (at 10.7 g/bhp-hr).

Effective in 2008, the Euro Tier V standard restricts NOx to 2.0 g/kWh (~ 1.5 g/bhp-hr) and restricts PM to 0.02 g/kWh (~ 0.015 g/bhp-hr). In 2013, the Euro Tier VI standard restricts NOx to 0.4 g/kWh (~ 0.3 g/bhp-hr) and PM to 0.01 g/kWh (~ 0.008 g/bhp-hr) [2, 3].

The 2009 Japanese JE05 standards will bring NOx down to 0.7 g/kWh (~ 0.52 g/bhp-hr) and PM to 0.01 g/kWh (~ 0.008 g/bhp-hr). A concise summary of emissions standards for heavy duty trucks and buses is provided by DieselNet at www.dieselnet.com/standards/us/hd.php.

The U.S. "HD2007" standards are potentially the most restrictive, but truck makers have at least another year to fully implement them. Although the PM emission standard took full effect in the 2007 heavy-duty engine model year, the NOx and NMHC standards will be phased in for diesel engines between 2007 and 2010. According to DieselNet, very few engines will meet the 0.20 g/bhp-hr NOx requirement before 2010 because most manufacturers will opt instead for a Family Emission Limit (FEL) for most of their engines [4].



In the near future, higher charge air temperatures will mandate the use of (a) a pre-cooler to cool the charge air before it reaches the temperature-challenged aluminum CAC; or (b) the conventional approach (no pre-cooler) with a copper-brass CAC.

*Cu*proBraze and HD

Because *Cu*proBraze radiators and charge air coolers provide greater cooling capacity than their aluminum counterparts, heavy-duty truck makers benefit from more available space under the hood. In some cases, aluminum-based systems require a stainless-steel pre-cooler to meet the more stringent emissions standards, which takes up additional space and adds cost to the cooling systems. The use of a pre-cooler also may be avoided because *Cu*proBraze CACs can operate at higher temperatures than aluminum CACs [5].

This huge *Cu*proBraze CAC is for a locomotive application. (Photograph courtesy of Young Touchstone.)

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.

Footnotes and References

1. European emission regulations for new heavy-duty diesel engines are commonly referred to as Euro I ... VI but sometimes Arabic numerals are also used (Euro 1 ... 6). Following the example of DieselNet, we will use Roman numerals when referencing standards for heavy-duty engines.
2. Since emission standards for both gasoline and diesel heavy-duty engines are expressed in terms of grams per brake-horsepower-hour (g/bhp-hr), conversion factors in terms of brake-horsepower-hour per mile (bhp-hr/mi) must be used to convert the emission data from engine certification testing to in-use gram per mile emission factors.
3. To compare Euro standards with U.S. EPA standards, it is necessary to convert brake horsepower to kilowatts; the values in parentheses are based on conversion factor of 1 bhp = 0.7457 kW.
4. Family emission limit (FEL) means an emission level declared by the manufacturer which serves in lieu of an emission standard for certification purposes in any of the averaging, trading, or banking programs.
5. For more about possible cost savings in this application, see *CuproBraze Executive Report* Number 50, "Brazed Copper-Brass Simplifies Charge Air Cooling System for Clean Diesel," available online at www.cuprobraze.com/lit_er.asp.

The higher temperature operation of clean diesel engines also shortens the useful life of aluminum CACs. Buses typically have a longer life cycle than HD trucks, so durability is especially important for these vehicles. Emissions reduction is equally vital for buses, which transport people, including schoolchildren, and frequently operate in population-dense urban settings. *Cu*proBraze is an extremely attractive option for clean diesel engines in buses. Buses also stand to benefit from the space-savings advantage of compact *Cu*proBraze heat exchangers, which leave more space available for passengers.

Close-up of a *Cu*proBraze CAC built for a locomotive application. Note that the copper fins and brass tubes have been painted. New emissions standards for locomotives will be discussed in Part II. (Photograph is courtesy of Young Touchstone.)

The elevated pressures and temperatures associated with new clean diesel engine technologies favor a transition from aluminum to copper and brass in heavy-duty truck and bus applications. Unfortunately, the adoption of brazed copper and brass in this marketplace has been slowed because OEMs and end-users are still accustomed to specifying aluminum radiators and charge air coolers in these applications.

*Cu*proBraze radiators and CACs are expected to capture a steadily increasing market share as OEMs and end-users realize that *Cu*proBraze heat exchangers offer superior cooling efficiency, durability and high temperature performance compared to the aluminum alternatives. Currently, SHAAZ in Russia is pioneering the use of *Cu*proBraze radiators and CACs in on-highway applications. In North America, Climex World (Monterrey, Mexico) is gearing up to provide *Cu*proBraze CACs and radiators as replacement parts for popular OEM heavy duty trucks.

A Turning Point

At this critical juncture, OEMs are working hard to create new generations of diesel engines to meet these stringent diesel emission standards, which will be implemented globally within the next decade.

Existing diesel emissions standards were covered in previous editions of *CuproBraze Executive Report* (Numbers 21 and 29), which are available online at www.cuprobraze.com/lit_er.asp. Since then, new standards have been introduced for locomotives and stationary power generators. Current standards are also summarized by DieselNet at www.dieselnet.com/standards along with references to the original rules. ■

Editor's Note: Part II will be presented in the next CuproBraze Executive Report (i.e., issue number 59). Part II will review timetables for the implementation of diesel emissions standards worldwide for off-road equipment as well as locomotives and stationary power generators. In parallel with this overview, updates will be provided on the development of CuproBraze heat exchangers for these applications.

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