EXECUTIVE *Report*

Over-the-highway trucking has become such a large industry that it's easy to forget just how much modern civilization relies on off-highway diesel engines. They are essential to reducing human misery and increasing prosperity on a global scale.

Nonroad Diesel Engine Makers Face Tough New Emissions Standards

Nonroad diesel engines are employed in literally thousands of applications. The smallest engines may be just a few horsepower (hp). At the other extreme, for mining equipment, locomotives, ships and power plants, diesel engines of 6000 hp, i.e., about 4.5 megawatts (MW) are not unusual. Even larger 10,000 hp (7.5 MW) engines are available from some manufacturers. A power plant with ten or twenty of these engines could generate enough electricity for a midsize city.

Nonroad diesel engines are used in farming, construction and industrial applications. Large engines are used to drive the farm equipment that cultivates and harvests crops; and the construction equipment that clears the land for buildings and roads. Smaller engines are used in countless other applications. Worldwide engine production of nonroad diesel engines used for farming, construction and industrial is about 10.3 million units per year and there are about 90 million units in operation. Production of engines 750 hp and greater is about 13,500 units per year in North America; and worldwide production including North America is 20,000 units per year [Ref. 1].

Unfortunately, although the larger nonroad diesel engines account for only a small fraction of all mobile engines, they produce a disproportionately large portion of the total emissions from mobile sources, including over-the-highway heavy-duty (HD) trucks, cars and light trucks. The EPA estimates that nonroad diesel engines currently account for about 44 percent of diesel PM emissions and about 12 percent of NOx emissions from mobile sources nationwide and in some urban areas the percentage is greater [Ref. 2].

Not surprisingly, environmentalists have gained support for tough new emissions standards for nonroad diesel engines, similar to those already set for over-the-highway diesel engines. Regulatory agencies around the world are enforcing stringent rules aimed at reducing the sulphur content of nonroad, locomotive, and marine (NRLM) diesel fuel and encouraging OEMs to build clean nonroad diesel engines.

The companies most likely to succeed in this regulatory climate will be those who can meet these new emissions standards at competitive prices.

Setting the Standard

A new proposal from the U.S. Environmental Protection Agency (EPA) describes Tier 4 emissions standards for nonroad diesel engines [Ref. 3]. These new nonroad diesel engines standards are similar to the EPA's HD2007 standards [Ref. 4] and in harmony with the nonroad diesel standards of the European Union (EU) and other parts of the world [Ref. 5].

Today's nonroad engines already produce 70 percent less NOx emissions and 90 percent less PM emissions compared to engines built prior to 1987, thanks to engine makers striving to meet Tier 1, 2 and 3 emissions standards [Ref. 6]. The Tier 4 standards aim to reduce emissions another 80 to 90 percent. Table 1 compares Tier 3 and Tier 4 nonroad emissions standards for select midsize diesel engines.

These new emissions standards are just the latest in a series of events aimed at motivating diesel engine makers into building cleaner diesel engines. They come as no surprise to diesel engine makers; yet they provide exact targets that need to be met, so engine makers can plan accordingly.

Heterogenous Combustion

Although the targets are clearly set, it is not clear which technologies are best suited for meeting the standards. The technologies under evaluation typically require engine systems that operate at higher temperatures compared to past designs. Significant research and development is already underway by engine makers to meet the HD2007 emissions standards. According to the EPA's latest remarks on feasibility, in-cylinder NOx control is being achieved through a number of heterogenous combustion technologies [Ref. 7]. New technologies such as fuel injection timing retard, fuel injection rate control, charge-air cooling, exhaust gas recirculation and cooled EGR have proven effective in controlling engine-out NOx to levels consistent with the proposed standards. In addition, NOx adsorbers probably also will be needed to meet the emissions standards.

HEX Design Trends

Most of the heterogeneous combustion technologies call for an increase in the operating temperatures and cooling performance of heat exchangers (HEXs), including liquid-to-air types (radiators) and air-to-air types (charge air coolers).

As previously described [Ref. 8], *Cu*proBraze heat exchangers are well suited for operation at higher temperatures than the alternatives. Aluminum radiators and CACs especially are temperature challenged above 200 °C. The same considerations apply to nonroad diesel engines. Since a low velocity places a premium on the airflow through the heat exchangers, there is a need to provide even better cooling performance for an off-highway engine than for a HD on-highway engine.

Conventional, soldered copper-brass heat exchangers already are preferred over aluminum for nonroad applications, because they can withstand harsh environments and operating conditions better than their aluminum counterparts. Farm and construction equipment especially must tolerate large amounts of dirt and debris, vibrations and regular cleaning. In these applications, durability is more important than weight. Brass tubes resist cyclic stress and corrosion better than their aluminum counterparts.

Serpentine Fins

Conventional radiators for nonroad diesel engines commonly are made from plates of copper rather than serpentine copper fins. The plates provide an extremely rugged structure but they are more time-consuming to assemble. For the same reasons, louvered fins are rarely used in nonroad applications.

The *Cu*proBraze process can provide the same result using serpentine fins of a relatively heavy gage thickness. Assembly and production of heat exchangers is simpler using serpentine fins rather than plates. The *Cu*proBraze process provides a durable bond between the tubes and the fins and reduces assembly time.

Ready Today

Already, the *Cu*proBraze process has proven itself in the high volume production of HD radiators and copper-brass charge air coolers. The flexible manufacturing process is ideal for nonroad diesel engine makers.

Prototypes can be fabricated for testing and evaluation and high volume production can be ramped up on time for the scheduled implementation of the new emissions standards.

While diesel engines makers face many challenges in the years ahead, in meeting both the highway and nonroad diesel emission standards, they also have a whole new technology for heat-exchanger design and production. This new technology will help them achieve greater cooling performance in the same footprint, avoiding the drastic redesign of their families of engines and equipment. ■

Table 1 — Highlights of Nonroad Diesel Emissions Standards for Select Engines*

	PM	NOx	HC	NOx + HC
	[g/kW-hr]	[g/kW-hr]	[g/kW-hr]	[g/kW-hr]
Tier 3 (2006-2008)	0.20	-	-	4.0
Tier 4 (2011-2014)	0.02	0.40	0.19	-
% Reduction	90% drop	-	-	84% drop

* The Tier 3 values presented in this table apply to engines from 130 to 560 kW. Some Tier 4 emissions standards for smaller nonroad diesel engines take effect as early as 2008. Separate EPA rules apply to marine engines and locomotives. Engines used in underground mining or in underground mining equipment are regulated by the Mining Safety and Health Administration (MSHA). All units are in grams per kilowatt-hour (g/ kW-hr). HC = hydrocarbons other than methane.

The International Copper Association, Ltd. (ICA)

is the leading organization for the promotion of the use of copper worldwide. The Association's twenty-nine members represent about 80 percent of the world's refined copper output, and its six associate members are among the world's largest copper and copper alloy fabricators. ICA is responsible for guiding policy, strategy and funding of international initiatives and promotional activities. With headquarters in New York City, ICA operates in 28 worldwide locations through a network of regional offices and copper development associations.

For additional information about the *Cu*proBraze process or ICA's *Cu*proBraze consulting services, please contact the International Copper Association at Alea@copper.org.

REFERENCES

1. Data provided by Tom Rhein, The Rhein Report, Rhein Associates, Inc. www.rheinreport.com.

2. EPA news release April 15, 2003. Also see American Trucking Association (ATA) Information Center, "On the Road to Clean Air," December 2000. According to the ATA, mobile nonroad diesel engines account for 28 percent of the NOx and 50.3 percent of the PM from all mobile sources. www.truckline.com/infocenter/topics/environ/air/clean air.html

3. Federal Register: May 23, 2003 (Volume 68, Number 100) [Proposed Rules] [Pages 28327-28603] or www.epa.gov/nonroad/index.htm#links, "Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel"

4. Federal Register: (January 18, 2001) Volume 66, Number 12, [Final Rule] [Pages 5001-5193]. "Heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements." (This document is commonly referred to as HD2007.)

5. See www.dieselnet.com/standards/eu/offroad.html (and /… /us/offroad.html).

6. See 40 CFR 89.112. Code of Federal Regulations, Title 40 (Protection of the Environment), Part 89 (Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines), § 89.112 (Oxides of nitrogen, carbon monoxide, hydrocarbon, and particulate matter exhaust emission standards). The Electronic Code of Federal Regulations (e-CFR) database is available from the Government Printing Office (GPO). http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr1068_00.html

7. Draft Regulatory Impact Analysis (EPA420-R-03-008, April 2003) Chapter 4: Technologies and Test Procedures for Low-Emission Engines. (www.epa.gov/nonroad/index.htm#links); See also "Highway Diesel Progress Review," (EPA420-R-02-016), June 2002. (www.epa.gov/air/caaac/dieselreview.pdf).

8. International Copper Association, CuproBraze Executive Report, No. 21, "High-Temperature Strength of Charge Air Coolers is Crucial for Clean Diesel Engines."

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