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# INTERCOOLER 101

## Things To Know About Cooling The Intake Charge

BY PAUL HUIZENGA

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Cosmology, the "big picture" branch of astronomy, tells us that one possible final state of the universe is "heat death," when everything everywhere is at the same temperature and energy state, making it impossible to sustain motion or even life itself. In the intervening 100 billion years, though (give or take a century), the flow of heat from one point to another makes a lot of interesting stuff possible, like getting your boat trailer up a grade, or beating the guy in the other lane at the drag strip.

While diesels are more efficient at turning heat into useful work than other piston engines, the majority still gets thrown overboard through the cooling system and out the tailpipe. Some of that heat (and pressure) gets captured by the turbocharger and put to work cramming more air in the front end of the system. The process inevitably wastes some energy heating up the intake air, which is where the intercooler comes in—taking that hot, thin air and thickening it up, and hastening the heat death of the universe in the process.

So what do you get in exchange for slightly sooner cosmological doom? Better performance, less stress on the engine, and greater efficiency. Even though late-model factory diesels are sporting OEM intercoolers big enough to seat four at Applebee's, like every other stock part, they're the result of a

thousand different trade-offs between cost, packaging, ease of manufacture and performance. Like every other stock part, there's a vast array of aftermarket upgrades available to get around those compromises. Getting it right, though, is more complicated than just picking the biggest one and hoping for the best. To get some guidance, we talked to several leading aftermarket intercooler suppliers to find out what's important and what's just a lot of hot air.

When it comes to performance parts, the first question we always ask is whether an upgrade is really worth doing—spending time and money on hardware that doesn't give you some tangible reward is basically just buying jewelry for your truck. If that's what you're into, there's nothing wrong with that. But an aftermarket intercooler represents a pretty substantial chunk of cash, so if you're after more power, you better be getting it. "Most stock intercoolers are well designed and constructed.

Factory-equipped vehicles are made with parts that have been engineered to work on a stock or programmed vehicle for the lowest cost possible. That is the way of the OEM," says Spearco's Tyler Tanaka.

"When the performance standards are raised, stock parts are generally pushed outside their design parameters and efficiency ranges." Jason Bruce of Advanced Flow Engineering adds, "When you use the truck for towing or high-load appli-



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**1.** When you're upgrading your intercooler, don't overlook the importance of the plumbing that goes with it. Smooth, large-radius curves and properly designed transitions keep total pressure loss to a minimum. Tight kinks and too many bends can lead to flow restrictions that dwarf those caused by the intercooler itself.



**2.** An intercooler upgrade is somewhere between the plug-and-play simplicity of a tuner and the in-it-to-your-elbows commitment of a turbo or injector swap. Hand tools will suffice, and in most situations you won't have to crack open the air conditioner loop to do it. At a minimum, you should have an extra pair of hands available to help wrestle the core into position, though.

cations, a performance intercooler becomes necessary. Generally speaking, a stock truck can benefit from an intercooler upgrade, but the gains aren't as noticeable until other components like exhaust, intake and a programmer are used."

Like an upsized exhaust or beefed-up fuel system, an aftermarket intercooler is really a way to support more power from other modifications, removing the bottleneck of an overworked stock 'cooler. If your diesel isn't challenging the flow and heat rejection capabilities of what you've already got, putting a bigger intercooler up front won't make it any better. On the other hand, once you've turned up the wick by adding more fuel and boost, an upgrade is almost mandatory, and for more reasons than most people realize.



**3.** Physical size isn't the only factor that determines an intercooler's performance. End tank design plays a huge role in how effectively flow gets directed across the core, and how much pressure loss the system has. In some cases, a smaller, well-designed intercooler will actually outperform a huge core with tanks added as an afterthought.



**4.** All other things being equal, a dark-colored intercooler will radiate heat more effectively than bare aluminum. Don't just break out the rattle can—you'll end up insulating it instead of picking up performance. Specialized heat transfer coatings are available for the serious DIY'er, but most of us will just leave a shiny intercooler the way it came—the better to show it off.

## COOLER IN, COOLER OUT

It's a given that cold, dense air makes more power, so it's no surprise an intercooler that drops intake air temperatures will help performance. But there's far more to it than that, because a diesel's output is tied directly to how much fuel you feed it, and is limited by peak exhaust gas temperature.

An upgraded intercooler fights that battle on multiple fronts. More air through the engine obviously means more fuel gets used in the combustion chamber instead of burning in the exhaust and roasting the turbine wheel, but there's another benefit in the almost one-to-one correlation between lower-intake air temperatures and EGT reduction.



5. Since the A/C condenser, intercooler and radiator are all fighting for the same ambient air flow, managing external pressure drop is just as important as what goes on inside the core. Per Sparco, at a road speed of 60 mph, the "face velocity" of the air across an intercooler may be only 10 mph or even less. Pay attention to what's blocking air from reaching and leaving the heat exchanger stack, or even the biggest intercooler won't do its job.



5. "Bar and plate" intercooler cores alternate layers of corrugated aluminum sheet to channel pressurized and ambient air. The intake air passages are smooth-walled to minimize flow restrictions, while the vanes for outside air are lowered to exchange as much heat as possible in the slower-moving ambient air stream.

CJ Baker of Banks Engineering says, "Excessive exhaust gas temperature, above 1,300 degrees, can't be sustained in a diesel without eventual engine and/or turbocharger failure. Lowering intake temperature results in an almost-equal reduction in exhaust temperature." Tanaka agrees, saying, "As a general rule, for every degree of intake temperature reduction, it will reduce the EGT by the same amount."

It just makes sense that starting with colder air leads to lower temperatures on the other end of the line, and in many sit-

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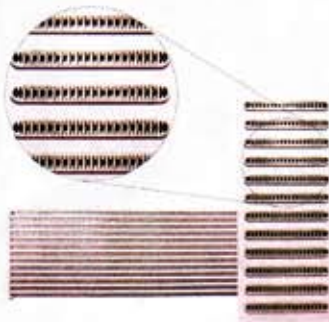
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6. "Tube and fin" cores carry pressurized air through extruded aluminum tubes that have internal dividers and fins to offer increased surface area for heat exchange. On the ambient air side, louvered, corrugated aluminum sheet bridges the space between tubes. Because tube-type cores need a header panel on either end to connect to the end tanks, they are slightly less deep than a bar-and-plate intercooler of the same overall size, but they also tend to be a little lighter.



7. Regardless of core type, both cast and fabricated end tanks are typically TIG-welded to the core. The cores themselves are assembled using either a vacuum or controlled-atmosphere brazing process, where the entire assembly is clamped together temporarily with brazing material applied to all the surfaces to be joined, then heated to fuse it all together.

uations where fueling, (and by extension, power), is limited by EGT, a better intercooler can be the key that unlocks a whole new level of performance without any other changes. "If EGTs never build to the point where the computer tuner limits fuel delivery, all of the additional power is always available," concludes diesel guru Gale Banks.

## SIZE MATTERS

Once you've determined that you can benefit from an intercooler swap, the next obvious question is, "How big?" A look at what the OEMs are using provides a hint that size does indeed matter. In the aftermarket arms race, it seems the only practical limit is what you can shoehorn between the headlights. The

## ALL WET

Air-to-water intercoolers, as seen on factory supercharged gas engines like those in the Ford Shelby GT500 and Lightning, are usually there because packaging problems prevent the designers from using a lighter, simpler air-to-air system. For day-to-day use in diesel trucks, air-to-air systems are the way to go. Wet intercoolers have one ace up the sleeve for drag racing and pulling—stuff the coolant tank full of ice, and you can pull the intake air down below ambient temperature, though only for a few seconds at a time. In normal use, a separate radiator is used to pull heat out of the coolant before returning it to the intercooler core. The stacked losses of going from air to water, then back to air again, though, mean that a wet intercooler will never be as efficient as an air-to-air system.

A more practical way for daily-driven diesels to get the same benefit in racing situations is an intercooler sprayer system using nitrous oxide or carbon dioxide directed at the outside of the core. Efficiency improvements of as much as 50 percent are possible, right up until the bottle runs out. Nitrous exits the sprayer at -127 degrees F, compared to -109 for CO<sub>2</sub>, which somewhat offsets its greater cost-per-pound. Nitrous will set you back \$40-to-\$60 for a fill on a 10-pound-capacity bottle, while carbon dioxide is closer to \$2 a pound. The bottles aren't interchangeable, but with the right adapters a sprayer system can utilize either one. Hooked up to a momentary button, WOT switch, or even a timer, it's a practical way to increase power and drop EGT during an all-out run.



drawbacks to a monster barn-door core? "On a bone-stock diesel, a high-performance intercooler can be too big," states aFe's Jason Bruce. "This is why intercoolers are generally later in the performance purchasing tree."

A small stock turbo can struggle to react to changes in load when asked to pressurize a lot of extra intercooler volume, and this may lead to lag. Start throwing more fuel on the fire, as with an aftermarket programmer or bigger injectors, and the situation becomes very different. Once you have enough exhaust energy, Brian Roth from BD Diesel Performance points out, "A well-designed intercooler will reduce the flow restrictions present in a stock application, which will actually improve turbo response throughout the operating range."

An important factor in intercooler sizing are the face dimensions—in other words, how many square inches of surface area the core provides. Thickness also plays a role. All other factors being equal, a thicker core will offer more internal volume and surface area for heat transfer, and lower pressure drop from flow restriction, but there's a hidden downside to the added core depth.

To do its job, the intercooler has to pass heat from the intake stream to the outside world, and ambient air isn't being pushed through the core at hundreds of cubic feet per minute and 30-plus psi like it is on the inside. It has to make do with whatever flow can be had from ram air pressure when the truck is moving, and the draw from the radiator fans when it's not.

Stacked in front of a truck's A/C condenser and radiator, even a thin core is going to see surprisingly low actual air-flow. Spearco typically assumes only a 10-mph intercooler "face velocity" on a vehicle traveling at 60 mph. Core dimensions, therefore, are limited by the physical space available and by factors like how much the ambient air flow is restricted by

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**8.** Ideally, intercooler cores should be 100-percent leak-free, but very small pinholes (0.05 cfm or less) are considered within spec, since the hose clamp connections at the tanks typically leak more than that.

the depth of the core itself, and obstructions to flow in front of and behind it like the bumper and radiator support. A well-engineered intercooler kit with better ducting and a small core can easily outperform a bigger yet carelessly designed setup in the real world.

### CORE VALUES

Speaking of the core, there are two main methods of intercooler core construction. The type favored by OEMs, (and some aftermarket manufacturers), uses extruded aluminum tubes, connected to a header plate on either end, and separated by corrugated fins to transfer heat to the ambient air-flow. The other option is a "bar and plate" design that alternates layers of corrugated aluminum channels for pressurized and ambient air.

Both designs have pros and cons: Tube-type intercoolers tend to be lighter for a given size, but give up a little core depth for any overall package thickness because of the way the tubes are assembled to the headers, while bar and plate cores are heavier but can typically withstand extreme boost pressure better.

BD's Brian Roth points out, "An extruded tube is constructed as a single piece, which allows for superior strength properties with the use of any brazing materials for the actual air flow tube. Because of this, there is no joint to fail, and at higher temperatures, there is no brazing material to weaken, (along the length of the tube)." Jason Bruce from aFe counters saying, "The tube design is inexpensive to make, but doesn't offer the flow capability or the ability to handle high boost pressures that the bar and plate does."

Another area that differentiates the two core philosophies is end tank construction. In many OEM applications, the header on a tube-type core makes it possible to use tanks made from molded composite or plastic material, with a crimp-type seal. This is nearly identical to the well-proven methods used to build car radiators, but it's not something you'll see on any aftermarket intercooler.

Instead, fabricated aluminum, or in some cases, custom-designed alloy castings, are used for strength. "One of the major



**9.** You might not realize how much stress is being exerted on an intercooler, but on a big core like this, at 30 psi there's more than a ton of force trying to push the end tanks in opposite directions. Combine that with exposure to the elements, (not to mention the occasional hailstorm, gravel truck or road alligator), and you'll understand that material quality and workmanship are extremely important.

issues with the OE and some aftermarket intercoolers is the end tanks burst under high pressures," Bruce cautions. Pushing 30 psi across a 3-inch-wide by 36-inch-tall intercooler core means that there's more than 3,000 pounds of force trying to tear off the end tanks off boost.

Once again, both approaches to tank construction have their benefits and drawbacks. It's expensive to tool up to make a casting, but once they are being made in large numbers, the per-unit cost of a high-quality part goes down because there's less labor involved. Fabricated tanks require skilled welders to create, but because they're made one at a time, it's easier and less expensive to do custom designs or perform R&D to look for improvements.

With either method of construction, tank design is critical to the overall performance of an intercooler. Per Gale Banks, "Within some factory charge-air coolers, the air flow inside is so poor that some cooling passages don't even get used." Roth adds, "A well-designed tank spreads the flow throughout the cooling tubes, withstands higher pressures without bulging or cracking, and fits into the space available without modifications." Some manufacturers even go as far as putting internal aerodynamic features into their end tanks to direct flow.

"On the Bladerunner, we have designed our end tanks with directional blades that help maximize the flow throughout the entire core area as well as strengthen the tank for high-boost applications," says Bruce from aFe. Whatever the design, the important thing to look for is a balance between core face size, large, well-designed end tanks, and proper placement of the inlet and outlet locations.

## LOST IN TRANSLATION

Pressure drop across an intercooler is inevitable. The immutable laws of physics say that when you cool a gas, you lower its pressure. An intercooler that doesn't have at least a little pressure drop isn't doing its job. However, that doesn't mean that losses from flow restrictions get a free ride. Spearco says that ideally the total drop across an intercooler from inlet to outlet should be 1 psi or less.

There's not much that you, as the consumer, can do to determine what the performance of a particular intercooler will be without actually testing it. Assuming it meets the general requirements listed above, you can have confidence it's in the ballpark. One often-overlooked area where the average Joe can find real advantage is in the plumbing between the turbo, intercooler and intake manifold.

According to Spearco, a properly sized 90-degree, mandrel-bent tube may have a loss as low as 0.15 psi, while a tight-radius casting might be as high as 0.3 or 0.4, and straight tubing is essentially "free." Take a close look at how many bends, kinks and couplers a particular intercooler uses, and how they're made—a system that looks like a Windows screensaver can easily triple the total flow restriction of an otherwise-efficient piece.

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