Mike Stubblefield

Coolant: What It Is and What It Does

This month's *How To* gives you some tips on maintaining the health of your liquid-cooling system. In this column I'm going to talk about coolant itself, that funny smelling liquid that circulates through all those labyrinthine passageways of your motor. Coolant is a fascinating chemical. Compared to plain old water, it has a higher boiling point—about 230 degrees—and a lower freezing point—about 40 degrees below zero. That's because coolant is about 95 percent ethylene glycol, which is a synthetic derivative of petroleum or natural gas.

But the other five percent of coolant solution is *really* astonishing. It's comprised of a complex group of additives known as *inhibitors*, without which a typical 50/50 coolant/water mixture would quickly destroy the cooling system. It's not the coolant that's the problem. It's the water. So, why not just dump straight coolant into your cooling system? Well, it would never boil over or freeze, but your engine would eventually melt down from overheating anyway. Coolant without water just doesn't conduct heat well enough. In other words, water is a necessary evil. That's why inhibitors are the most critical part of coolant, because water can do awful things to aluminum.

The effectiveness of a liquid-cooling system can be improved by raising the working temperature of the coolant. The introduction of ethylene glycol was originally based on its higher boiling point. However, experimentation proved that by pressurizing a cooling system to around 40 psi, water could be kept in its *liquid* state at the same temperature (around 286 degrees Fahrenheit) without boiling. So glycol came into popular usage primarily as an anti-freeze agent. (That's why it's popularly known as "antifreeze," not anti-boil.) To this day, some experts argue that more than 30 percent glycol is unnecessary since water possesses superior heat transfer ability. In fact, the higher the boiling point, the better does water compare with any other liquid coolant. Adding even a modest amount of water to glycol makes it a better heat conductor. Once the proportions reach 70 percent water to 30 percent glycol, heat transfer is virtually as good as with plain water, and resistance to freezing (or the slushing state that precedes it) is adequate anywhere except in regions of intense cold. If you live in a warm climate and want to experiment with the basic 50/50 recommended ratio, get yourself an inexpensive antifreeze tester at an automotive hardware store. This little device measures the relative effectiveness of ethylene glycol by indicating how low a temperature your coolant can withstand before freezing.

Modern liquid-cooled machines have pressurized systems because the higher the pressure, the higher the temperature at which water boils. At 7 psi above atmospheric (14.7 psi) the boiling point of water is raised from 212 to 233 degrees Fahrenheit. The greater efficiency of a high pressure system allows the radiator to be smaller, lighter and less expensive. A spring-loaded radiator cap prevents steam blow-off until the pressure within the system has risen to between 7 and 14 psi, depending on the system.

Now back to inhibitors. To understand just how critical inhibitors are to the long term effectiveness of coolant (indeed to the long life of your motor) you have to look at modern motorcycle engines. Compared to brass or iron, aluminum is a superior material for conducting and dissipating heat. Its excellent cooling characteristics, combined with light weight, have made it the material of choice for all contemporary motorcycle engines. Unfortunately, aluminum is also easily susceptible to corrosion, particularly to the types of mineral solids that are prevalent in ordinary tap water. Eventually, these mineral solids can clog the thin tubing of your (aluminum) radiator and, even worse, corrode the internal passages of your (aluminum) engine's cooling system. Obviously, tap water, with its high concentration of mineral solids, is out of the question as an additive for coolant.

And so is soft water. True, it's had all mineral solids removed, supposedly, but the manner in which they've been removed makes soft water just too suspect as a desirable additive for coolant. Water softeners trap mineral solids in a tank containing a resin bed. Once the resin grid becomes clogged by the solids it's supposed to be trapping, it is automatically cleansed by a salt water flushing system. Should a residue of salt remain in the resin, Murphy's Law decrees that it will find its way to your cooling system. And salt will wreck aluminum faster than you can say, "I need a new engine."

Which leaves *distilled* water. Distilled water is boiled until it vaporizes into steam, then condensed back to its liquid state. So you *know* you're getting nothing but pure H_2O. If you want to be sure you've eliminated the possibility of corrosion caused by minerals and/or salts, accept no substitutes. Use distilled water.

Okay, once you've eliminated the danger of those insidious corrosive solids, there are still other battles to be fought before you can win the war against corrosion. Even the most mineral free water contains one oxygen molecule for every two hydrogen molecules. Unless they're neutralized, these oxygen molecules will really do a number on aluminum.

This is where that other five percent of coolant comes into play. As aluminum corrodes, tiny molecular particles called *ions* are released from the walls of the cooling passages. Corrosion inhibitors bond with these ions to form a sealing compound on the surface of the aluminum itself. Once the surface is sealed, further ionization is blocked. Corrosion is stopped, *as long as enough inhibitors remain in the coolant solution*. Because these inhibitors form the sealing compound on a continuing basis, they get used up over a period of time and have to be replenished. In other words, the coolant must be routinely replaced.

Once you've taken steps to eliminate the possible danger of corrosion due to mineral solids, salts and oxygen, is that it? Not quite. There's still a chance that *electrolysis* may occur. The presence of liquid in conjunction with the various metals present may turn your cooling system into a primitive battery! True, the electrical current will be virtually insignificant but even a slight flow of electrons is sufficient to erode the surfaces of cooling passages. Once again, inhibitors are there to prevent electrolytic corrosion.

Now that you know all you ever wanted to know about coolant, turn to *How To* and find out how to put coolant to good use. ☐

SHOP TALK

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ineffective in siphoning off further heat downstream until it can be cooled off again. Yet water, and oil, are often routed straight from the radiator, or oil cooler, to the hottest area, the head, of many motors, before being circulated through cooler areas on the return trip to a heat exchanger. The ability of overheated coolant to carry off further heat after leaving the head is questionable, again, because it flies in the face of what we know about efficient heat transfer.

But enough theory. Let's take a trip through a typical modern liquid-cooled system. A pump pulls coolant from the bottom of the radiator and pushes it, usually through external plumbing, up into the water jackets which surround the cylinders. From there it moves up through the cast-in passages of the cylinders until it reaches the head, where it leaves the engine and is recirculated back into the radiator, where it is cooled for re-use. And so on.

Basically, that's all there is to it, but the cooling system has two built-in features that allow it to deal with the extremes of hot and cold. A temperature sensitive valve, the *thermostat*, integrated into the return lines between the cylinders and the radiator, ensures that the cooling system keeps the engine operating at the proper temperature. When the engine is cold, the thermostat stays shut, bypassing the radiator entirely and sending coolant back to the pump. The relatively small amount of water in the system quickly warms up, the engine reaches operating temperature and the thermostat opens, allowing coolant to flow through the radiator. Should frigid ambient air send coolant temperature plummeting, the thermostat will shut down once more until normal temperature is restored. Think of the thermostat as the brain of the cooling system.

But the thermostat can't do much for the cooling system in rush hour traffic and extremely hot weather. There must be some means of increasing air flow through the radiator to effectively dissipate excess heat carried off from the cylinder head. This is accomplished by a thermostatically activated electric fan situated immediately behind the radiator that turns on when coolant temperature soars and shuts off once normal temperature is restored.

The only other thing you need to know about your cooling system is that the stuff that circulates inside it, the coolant, is an esoteric blend of chemicals which perform several tasks vital to its proper function. And, of course, you need to know how to keep your cooling system working properly by changing the coolant. But that's another story which we will discuss next month. Stay cool. ☐

BE COOL

Coolant, what it is and what it does is the subject of this month's letter. Early caveman discovered that the more heat you used, the faster the work got done. That same thinking exists today because it is true. Water-cooling allows an engine to be built to tighter tolerances because it operates in a controlled environment, courtesy of your thermostat. Less slop equals more horsepower, more efficient burning and you get the added bonus of a quieter running engine with a water jacket surrounding it. Despite our best efforts, the average engine only produces about one third of it's potential. Nearly 2/3 of the energy in gasoline is converted to heat, light and sound, which exits through the exhaust pipe. Coolant is a fascinating chemical that is designed to help your engine run more efficient and keep it from freezing at the same time.

The introduction of ethylene glycol was originally based on its higher boiling point, some 230 degrees verses water's 212 degrees. As an added bonus its freezing point was about 40 below zero. (With the introduction of pressurized systems the anti-boil usage quickly became anti-freeze.) So why not use straight anti-freeze in your system? Your engine would never boil over or freeze, but it would melt down none the less.

> *Coolant is about 95% Ethylene Glycol, but it is the other 5% of the solution that is really astonishing.*

Water is an excellent conductor of heat. The ability of water to pick up the heat generated by an engine and move it to the radiator, then give off the heat to the air is just about unparalleled. Ethylene glycol without water simply doesn't conduct heat well enough to keep an engine cool. Thus adding water to the solution becomes a necessary evil. When you add water to an aluminum engine and radiator a host of other problems appear.

When adding water to reach the recommended 50/50 ratio, one has to be careful which type of water to select. Tap water has mineral solids, which can clog the small passages of your radiator and may corrode the internal passages of your engine. Not a good choice and neither is soft water. Water softeners remove most of the mineral particles by running them over a resin bed. Flushing it with a salt-water solution then cleans this bed. Murphy's Law clearly states that if there is any remote chance of salt water finding it's way into your cooling system, it will. Salt will wreck an aluminum engine faster than you can say "Rebuild." That pretty much leaves only one choice.

The only water you should ever use is distilled water. The problems don't end there. Water, better known as H_2O, is the problem itself. The "O" in H_2O represents one Oxygen molecule (the H_2 is two Hydrogen molecules). Oxygen will corrode aluminum by releasing tiny particles called *ions* when it comes in contact with any aluminum surface. This process is stopped when corrosion inhibitors are added to the anti-freeze. These inhibitors bond with the *ions* to form a sealing compound on the surface itself. Once the surface is sealed, further *ionization* or corrosion is blocked. Inhibitors make up about 5% of the solution in anti-freeze, but they do more than just bond with *ions*.

Any liquid mixed between two unlike metals leads to a condition known as *electrolysis*. This can turn your engine into a primitive battery, and even the tiniest current will produce a flow of electrons that will erode the surfaces of the cooling system. Once again inhibitors come to the rescue and prevent *electrolysis*. Corrosion is stopped only *as long as enough inhibitors remain in the cooling system*. They wear out and get used up over time so your coolant has to be routinely replaced. Check your manual for times/mileage requirements. Thanks to Mike Stubblefield for the basis for this article.

Ride Safe

COOLANT

HOTTER ENGINES = GREATER EFFICIENCY
RAISE BOILING POINT
PRESSURIZE SYSTEM

ETHYLENE GLYCOL - PETROLEUM / NATURAL GAS
BOILING POINT = 230° F
FREEZING POINT = -40° F
POOR HEAT TRANSFER

SOLUTION = MIX WITH DISTILLED WATER
TAP WATER - HIGH MINERAL CONTENT
SOFT WATER - POSSIBLE SALT RESIDUE

INHIBITORS

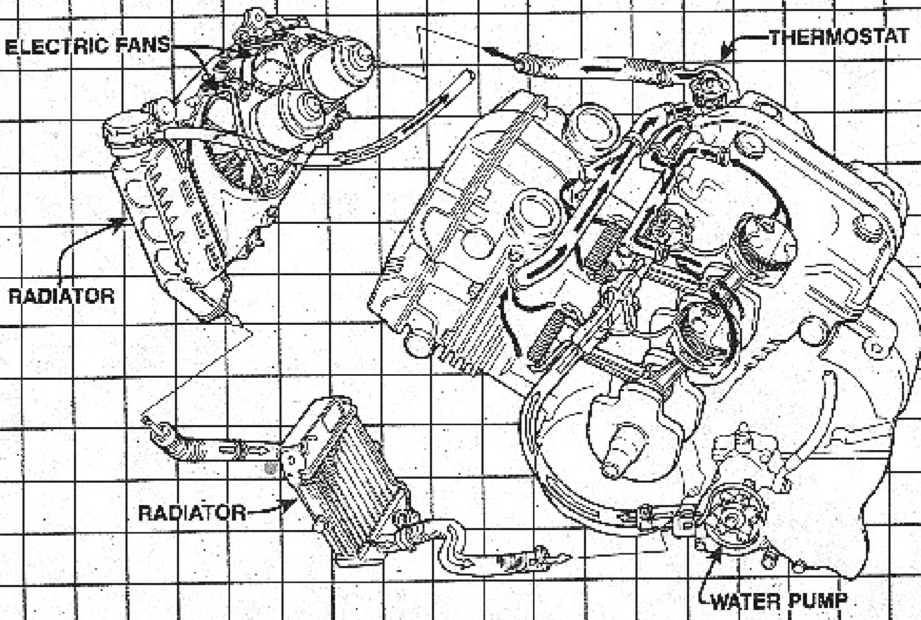
COAT & SEAL CYLINDER WALLS
PREVENT ELECTROLYSIS
WEARS OUT - CHANGE 3 YEARS

CAUTION - HIGHLY TOXIC

NON - BIODEGRADABLE
MAJOR CAUSE OF ANIMAL POISONINGS
WILL DAMAGE PAINT

Mike Stubblefield

How Cooling Systems Work



Air, oil, water. At least two of these media are used in the cooling systems of all motorcycle engines. Strictly speaking, all bikes are ultimately air-cooled because the waste heat they produce is exhausted into the outside air. But exhaust systems can't remove the intense heat generated deep within the hotter environs of internal combustion engines. Instead, water, oil, or both, must transport it to a *heat exchanger*, like cooling fins or a radiator, where it can be radiated into the passing air. The amount of heat that must be shed is considerable. Only about a third of all the calorific value of the fuel burned by the engine is actually converted into useful work. The remainder must exit through the cooling and exhaust systems.

The cooling system of a motorcycle is not limited just to obvious heat exchangers, like cooling fins, radiators and oil coolers. It actually includes every exposed surface of the motor from which waste heat can be radiated, from the sump to the crankcase to the cam covers. That's why high performance racing engines are often "bead blasted" (an industrial process using glass beads and compressed air to produce a rough finish) and then painted with a thin (under .015 inch) coat of black paint (like KalGard). Bead blasting maximizes the heat exchanging efficiency of the cases of hot running motors by increasing the surface area from which heat can be radiated into the air.

Still, most waste heat is shed by more efficient means. How that heat is transported to major heat exchangers is a fascinating story. Situated as they are at ground zero, the heads, cylinders, pistons, valves and guides take the heat more than any other components, so they must be able to shed heat quickly and effectively if they are to survive in a hostile environment like the combustion chamber. How do they do it? In air-cooled motors, these parts absorb the heat generated by each power stroke and then transfer it to cooler surrounding metal and thence outward to the cooling fins, which present a large surface area that can radiate heat into the passing air. In water-cooled engines, combustion chamber heat is also absorbed by cylinder walls, then is transferred into the surrounding "water jackets," through which flows a liquid solution known as "coolant." Coolant absorbs heat from the surrounding walls and carries it off to the radiator. The radiator is actually a grid-like network of thin copper or aluminum tubing through which the coolant must pass before it can take another lap through the engine. Why aluminum or copper? For the same reason your mother uses aluminum and copper cooking utensils in the kitchen: Both of these metals are good thermal conductors (copper is a slightly better conductor but is also heavier, hence aluminum has come into favor in modern radiators). And since these tiny tubes are themselves connected to thousands of paper-thin strips of metal surrounded by flowing fresh air, they are quite effective at lowering the temperature of the liquid inside. If you're confused by my use of such words as "absorb," "dissipate," "radiate," "transfer" or "transport" in discussing the movement of heat from one area to another, don't get caught up in the terminology. The important thing to note here is that *heat always moves from hotter to colder areas.* Heat transfer is most efficient when the surface giving up heat to the air is much hotter than the air—in other words, when the temperature gradient is steep. That's why cooling systems work.

You may recall that I mentioned oil as one of the three basic cooling agents. It's true. Oil is the means by which heat is conducted from the violent world of pumping pistons and spinning shafts into the surrounding metal. The valves, which absorb more than their fair share of heat, ride up and down the guides in a cooling layer of oil. This heat is transferred up the valve stems, through a thin film of oil and into the guides, from which it is dissipated into the head. Bearings, gears, camshafts—everything runs on a fine coat of oil which not only lubricates but cools. Without oil as the immediate cooling medium and transfer agent, none of these parts could survive, so in a very real sense, all motors are also oil-cooled. Then why not just add more oil and be done with it? Why even bother with external cooling fins or liquid cooling systems? Several reasons. First, an engine can only have so much oil flying around inside before it starts to get in the way of all those moving parts. Beyond that point, it does more harm than good. Second, oil already has too many jobs to perform, like lubricating, cleaning, fighting oil oxidation and corrosion, etc. And third, without belaboring you with a lot of thermodynamic theory, oil just isn't as good at transferring heat as water.

Air or liquid cooling? The choice has always involved engineering tradeoffs. Air, obviously, is lighter and more readily available than liquid (and the price is right). So what's the catch? To remove a given quantity of heat demands four times the weight and *four thousand* times the volume of air as water. Of course, air can be left behind as soon as it's been used; liquid-cooling requires the onboard storage of not only the coolant itself, but also the water jackets, cast-in passageways, external plumbing, pump, radiator, and thermostat necessary to contain and control it. All this paraphernalia will usually weigh more than mere cooling fins.

Width is another factor that is often just as important, if not more so, than weight and complexity in determining the correct cooling system design for a particular machine. The use of cooling fins necessitates cylinders with wider bore spacings than would be necessary with water jackets, so the crankshafts and the cases of air-cooled motors will, generally speaking, be longer, heavier and therefore less rigid than those in liquid-cooled engines of similar displacement and configuration. And to attain torsional rigidity comparable to cranks in liquid-cooled designs, they must be much heavier.

Despite the relative complexity of water cooling, it offers several other performance advantages over air-cooled designs. For instance, the troublesome "hot spots" that plague air-cooled motors (usually around the spark plug bosses and the backside of the cylinders) can be eliminated by liquid cooling. The result? More uniform operating temperatures, which allows much greater variety in engine configurations. But more importantly, a liquid-cooled powerplant expands and contracts uniformly so clearances can be tighter, which means less leakage, less wear, and a longer lasting engine. It's also much easier to dial in the carburetion for an engine with a consistent operating temperature. And because a liquid-cooled motor warms up quickly, choke circuits don't have to be as complex as those used with air-cooled designs. Finally, better cooling means higher horsepower, without any concomitant loss of reliability.

But though it's tempting to ascribe the sudden nascence of liquid-cooled engines to the horsepower wars, it would probably be more accurate to credit the government with their recent resurgence. Why? Because tight emissions regulations require hotter operating temperatures, a situation best handled by more efficient liquid-cooling. And ever stricter noise levels will necessitate a switch to liquid-cooling because water jackets are a far more effective sound barrier than cooling fins. In other words, you can look forward to a water-cooled wonderland in the future. Say bye-bye to dirty, noisy air-cooling.

And yet, it's tempting to speculate on what might have been. Though most popular engine designs have, until quite recently, been air-cooled, it's interesting to note that designers have never taken full advantage of the scope of available technology. For years, most aviation engines have incorporated close-pitched fins about 3mm apart, a close-fitting cowling and a forced draught fan to attain optimal cooling. Volkswagens, Porsches and a few other automotive motors of similar design (like the Citroen GSA used in Harley's Trihawk) have also utilized this method of forcing a controlled stream of moving air over the cooling fins.

And motorcycles? Despite the fact that bike motors reside in the turbulent wake behind the front wheel and the forks, designers have always been optimistic about the ability of an erratic airstream to do its job without the help of a device as elaborate as that used on even the commonest airplane engines. Interestingly, when heat has become an unavoidable problem, some manufacturers have finally resorted to plates across the ends of the fins to make the most of the available air supply (Suzuki's GT380 and GT550 triples and Yamaha's RD400 Daytona come readily to mind).

Another lamentable lapse in awareness of what works best and what doesn't has been the convention of constructing air-cooled cylinders with forward-facing exhaust ports, apparently because designers have always felt, and still do, that the hotter exhaust ports will thus benefit from the full blast of air hitting the front of the engine. Have you ever noticed that the exhaust headers of many motors feature baroque little finned collars presumably fitted in the vain hope that they will assist in cooling the exhaust headers. Do they work? Sure, they probably impede the flow of air over the cooling fins, ensuring an even hotter running engine. And the intake ports? Oh, they're supposed to make do with any (by now heated) air that miraculously manages to find its way to the backside of the cylinder. The only problem is that the air which is supposed to carry off the heat from the back of the engine is by now as hot as the intakes themselves.

The Better Way, falling back once more on the collective wisdom of aviation technology, would have been to reverse properly shrouded air-cooled cylinders so that the exhaust ports faced to the rear. Thus, thanks to a forced air supply contingent only upon a fan, instead of the dubious wake from the front wheel, the controlled stream of air ducted through the fins would be warmed only insignificantly as it passed by the intake ports and would still be relatively cool when it reached the hot exhaust ports (Remember what I said earlier about heat dissipating better into a cooler medium?).

But don't think that liquid-cooled systems have some kind of monopoly on logic. They don't. For instance, with the exception of Harley's Nova project, all liquid-cooled designs utilize a radiator illogically located in the same suspect place, right behind the front wheel. For some bikes, Gold Wings for instance, this location seems to work satisfactorily. For others—Ninjas come readily to mind—it's less than ideal.

Nor does it make sense to pump fresh, cool liquid to the hottest parts of the engine first. Once the coolant is heated to a certain temperature, it's going to be

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