Cooling Systems

Cooling System Modifications

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Thermal Efficiency

Before we go into what a cooling system does and how to modify it, you must first understand what the engine does. Plain and simple, an engine makes heat energy and turns it into mechanical energy. Any heat generated that does not get used to make power is wasted energy. How well an engine converts the heat it generates into mechanical energy is known as it's thermal efficiency.

The cooling system takes heat from the engine, heat that ideally could have made power, so the cooling system actually takes power from the engine. It is a necessary evil, without a cooling system, the engine will overheat and the internal parts will have a very short life.

A cooling system will also reduce the chances of detonation. With new cooling systems and coolants, it is possible to run today's engines hotter, which increases thermal efficiency. If you take less heat away from the engine, there will be more energy available to make power.

Any heat that is radiated off the engine, and out the exhaust system is also wasted heat energy that did not get used to make power, which reduces thermal efficiency. The average engine has only a 25-30% thermal efficiency, so 70-75% of the heat generated never gets used to make power. An average 250hp gasoline engine is actually burning enough fuel to make about 1000 hp, making it a very inefficient machine.

Cooling System Goals

Most people seem to think that all a cooling system needs to do is keep the engine from overheating. But what is not realized is that if the engine runs too cool, thermal efficiency is lost and power is reduced. Many will argue that an engine has more power when it is cold, but that is only due to the fact that the intake air is colder and denser, actual BSFC is higher. Remember that an engines whole job is to make heat and turn it into mechanical energy. Running the engine as hot as possible (limited by the detonation limit) will increase power and provide a lower BSFC.

If the coolant begins to boil, steam pockets will form and detonation will limit power (by forcing you to retard timing to less than optimum or run the engine cooler). Most of today's high output street motors using a water/ethylene glycol mixture will be limited to about 200° F before detonation becomes a problem (unless other steps are taken).

Another goal of modifying the cooling system is to even out the temperatures of the whole engine, which is not easy to do. All it takes is one hotter cylinder to run into detonation to limit the engines power. It only takes 1 cylinder to limit all of them. Most high performance engines are close to detonation to begin with, so a good cooling system is a must.

Nucleate Cooling Phase

As coolant flows through the system it absorbs heat from the engine parts that it comes in contact with. As it does this some of the coolant will boil and form tiny steam bubbles (absorbing a lot of heat in the process) on the internal engine surfaces. When these bubbles get larger they become a flow restriction and the flowing fluid pushes them away from the surface and that process starts over again.

The process is called the Nucleate Cooling Phase. When the coolant boiling point is too low or the flow rate is too slow, these bubbles can become too large and form steam pockets that insulate that surface from being cooled. This usually happens around the combustion chambers, the hottest parts of the engine. Once the steam pocket forms the surface will rise in temperature (even though the coolant is not overheating) and cause that part to overheat, which can cause detonation and / or other problems.

Types of Coolant

I'm sure that you've read or heard somewhere before that water is the best coolant. This is true as far as being able to absorb heat for a given flow rate, water does do that the best. Water also boils at a lower temperature than other coolants and can develop steam pockets easier, so it's not the best coolant in that respect. A water / ethylene glycol mixture will boil at a higher temp and resist steam pockets better than plain water, the down fall is that it has to have a higher flow rate, but that is easy to accomplish.

The 3rd common form of coolant is propylene glycol, which has the highest boiling point and can run higher than 250° F (average temperature as seen on a gauge) without forming steam pockets, but it must flow at more than twice the speed of a water / ethylene glycol mixture (which means major changes to most cooling systems).

System Pressure

The pressure in the block is higher than the radiator pressure; this is because the pump is building pressure due to the thermostat being a restriction. This pressure raises the boiling point of the coolant and reduces the chance of steam pockets, so never run with out a thermostat (or some form of restriction).

The radiator cap will usually hold 15-18 psi, if the radiator holds the system at 15 psi, the boiling point of plain water will be raised to 250° F. The water pump can then make an additional 40-45 psi in the engine and bring that boiling point close to 300° F. So as you can see, pressure is important.

Stock Cooling Systems

Most stock cooling systems pull coolant from the radiator and push it through the each bank of the block; it then goes up through holes in the head gasket(s) to the heads and out the front of the heads to a common exit point. This ok for a stock engine that has no problems with detonation, but the cooling is very uneven. The front cylinders will run coolest and the front combustion chambers will run the hottest.

Most stock pumps will also favor one bank. The stock pump used on a small-block Chevy for instance will always favor the passenger side bank. This means that cylinder 2, 4, 6 & 8 get more flow, so the 1, 3, 5, & 7 bank runs hotter.

With the center exhaust ports right next to each other, you can see that combustion chambers 3 and 5 will run the hottest, it is in these two cylinders that detonation will usually first start.

It seems a little backward to start the coolant at the block instead of the heads; it would make more sense to bring the coolest coolant to the hottest parts first. This type of reverse flow system has been tried with much success, but it is harder to get it working properly and not worth it for car companies to research when the stock system worked good enough on a stock engine.

Mechanical Water Pumps

As I said before, stock pumps rarely flow evenly between banks. On the small-block Chevy you can restrict 1/2 of the block inlet to the even cylinder bank to get more even flow, but the better solution is to use an aftermarket high volume pump that has worked out such problems.

Stock pumps have a stamped steel impeller and tend to cavitate easily when turned more than 6000 rpm, so overdriving the stock pump offers little to no advantages and can actually aggravate any cooling problems. Most aftermarket pumps will use a cast iron or an aluminum impeller that better resists cavitation. Weiand, Howard Stewart and Milidon make very good water pumps for most popular applications, which improve flow, resist cavitation better, and require less power to drive than stock pumps.

Electric Water Pumps

Many aftermarket companies offer electric water pumps. These pumps do not flow well or build sufficient pressure in the block. They are only good for limited drag racing use, and when used they need a high pressure cap to help prevent steam pockets. At best these pumps can flow 30 GPH and only build about 5 psi additional pressure in the block. An electric pump should never be considered on a street or any type of endurance engine.

Even a stock mechanical pump has less than 10hp parasitic power loss, so the advantages outweigh the disadvantages of an electric pump. Better aftermarket designs only take 5-7hp at ~6000 rpm, so there is not much to be gained by switching to an electric pump.

Coolant Flow

Different coolants require different minimum flow rates, but contrary to popular belief, you cannot make the coolant flow too fast. This rumor was started because people removed the thermostat to gain flow, because they had an over heating problem, and it only aggravated the problem. The real reason they ran into problems is that removing the thermostat also removes the restriction that builds pressure in the engine, so they gained flow, but reduced the boiling point of the coolant in the block.

Running a higher flow thermostat and a higher volume pump to maintain pressure, will give no such problems. If you think about it, making the coolant flow twice as fast will also make it flow though the engine twice as often, so there will be more even temperature across the engine.

There has been, and still is, the rumor that of the coolant flows too fast, it will not have time to pick up heat. That is nonsense, as long as there is coolant contact a surface, the rate of heat transfer will be the same. Coolant that flows twice as fast also flows through the block twice as often.

Basic Flow Modifications

Most stock systems on a V type engine will have a common outlet for both banks. The outlets of each bank flows directly at each other than must take a 90° turn to return to the radiator. If one side gets hotter (which is sure to happen) the pressure of that side will increase. The increased pressure will increase flow in the hotter bank and decrease flow in the cooler one. The faster moving coolant will cool the hot bank better and the slower moving coolant picks up more heat in the colder side. As you can see, the hot side is getting cooled and the cooler side is heating up. This happens until the banks reverse, the side that was cooler is now hotter and has more pressure. The cyclic flow will continue until the engine is shut off. Smokey Yunick was the first to do studies on the cyclic flow and traced the problem to the outlet. By tapping the front of the heads, and bringing the coolant together in a Y eliminated the cycling.

Radical Modifications

To truly equalize temperatures throughout the engine is not possible with today's technology, but we can improve the situation some. To get the best results you must start fresh and build totally custom cooling system.

The first step is to tap off the pump and put coolant to the back of the block so the coolant enters at both ends. This helps equalize the cylinder temperatures, but the heads will still be hotter toward the front.

To equalize the head temperatures you must tap outlets at the back of the heads so that all the coolant does not have to pass the front combustion chambers. To further equalize, you can tap inlets and outlets in the center of the block and heads also. At that point the coolant will be flowing basically from bottom to top and is about the best you will get without reversing the flow.

Reverse Flow Systems

As I said earlier, it makes sense to put the coolest coolant to the hottest parts first to bring the temperatures down as much as possible, the already heated coolant can help bring the temperatures of the coolest parts higher and make everything more even. To do this the coolant must flow in reverse (compared to most systems). The problem with reverse flow systems is that the pump tends to cavitate easier (even with a good aftermarket pump). To limit cavitation, a higher boiling point of the coolant helps and so does a higher system pressure.

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Cooling Fans

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Stock Clutch Fans

The stock clutch fan is often tossed in favor of an electric fan. In reality this may not be such a good idea. A factory clutch fan and shroud flows more air than just about any electric fan set up. I have seen many people go out and buy electric fans because they had over heating problems. Then find out the problem is worse. If your car is running hot, find out the cause, the fan is probably not it. A new fan clutch is a whole lot cheaper than an electric fan.

If the problem is a clogged, or too small radiator, buying a new fan is no solution. Bottom line here is that the factory did a lot of research and development on cooling systems and they use a belt driven clutch fan and shroud because it flows the most air. In turn, this allowed them to run slightly smaller radiators. I have no problem with using electric fans, but they do not move as much air as a stock clutch fan and shroud set up. Set up your whole cooling system with this in mind and you'll be fine, but just put one on your car and plan on loosing some cooling. If your cooling system was borderline adequate before, an electric fan might just push it over the limit. If you are having an over heating problem, don't even consider an electric fan until you find the problem.

Flex Fans

My opinion of flex fans is, they are next to worthless. They can be better than a solid (no clutch) stock fan, and that is the only good thing I have to say about them. They are noisy, and offer little to no benefit over the factory clutch fan. They claim to move a lot of air at low-speeds and flatten out at high speeds to cause little drag. The air hitting the blades is what flattens them out and that takes power to do, so they must have some drag. Maybe not a lot, but certainly more than a clutch fan that is near freewheeling.

I personally just do not like them. Flex fans are popular in certain race classes that require an engine driven fan due to the fact that they are light and can take very high rpm. They were popular for a while on the street, probably because they are so cheap and people always insist on buying the "race" parts for a street car.

It is very important to do research on these kinds of parts. Race cars do always use parts because they are the best, they are usually the best for what is allowed by the rules in that class. Some of the newer designs of flex fans have the blades curved toward the rotation, this looks like a better design because centrifugal force will assist in flattening out the blades and they should reduce drag over other types of flex fans. I have not had any experience with them, so I can't say for sure, but they appear to be a better design. Actual testing will tell for sure, but I have not personally tried one.

Electric Fans

Electric fans can offer some advantages. They are compact, which can really helps when there are space limitations. They are reliable and simple, so it can make for a clean neat installation. They may not move as much air as the stock set up, but if the cooling system is planned out well, they can flow enough to get the job done just fine.

Hotter running engines have better thermal efficiency, which means that heat losses are reduced and intern more heat is used to make power. If you can safely raise the operating temperature of the engine, you will have less heat to get rid of in the cooling system. If you have less heat to get rid of it means that you can use a cooling system with a smaller capacity. This is where electric fans work great, when the factory fan moves more air than you need, an electric fan with less flow can work just fine.

Another benefit of electric fans in the ability to control them however you want. My ECU for the injection system controls my fans and I can over ride that with a switch in the car to keep the fans on or shut them off if I want. Many aftermarket companies also make thermal switches to control fans.

When you add and electric fan, there is always the option of pushing or pulling air through the radiator. So which is best? For the most part, the pulling air through the radiator works better. It is not a question of the fan being more efficient as a puller, if the fan was totally sealed to the radiator so there was no leakage, the pusher would be the ticket, but even with a shroud, there is some leakage. A fan does not just flow air through itself straight. A fan spins and causes the air to spin as well. Centrifugal force throws air outward all along the fan as well, but the intake side of the fan is pretty much limited to the area of the fan. When the fan is in front of the radiator, a lot of air goes thrown out and never makes it through the radiator at all. So when you compare total air moved, with a pusher, less makes it through the radiator than the same fan as a puller. A shroud really helps with a pusher, so I recommend a shroud on all pusher fans.

Curving the blades toward the direction of rotation like the new flex fan designs might help electric fans as pushers. The curved blades could cup the air and limit the amount thrown outward by centrifugal force. This is just a theory though, some experimenting would tell for sure.

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