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The BillaVista Tech Garage

The Cooling Bible Featuring Griffin Thermal Products

By Bill "BillaVista" Ansell
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Introduction

The cooling system – deceptively simple yet devilishly complicated. Like many things – your rig's cooling systems is one of those things that seems simple, that most people think they understand, but which, behind the scenes, is actually a lot of fairly complicated stuff working together in a fine balance. Or not working together well – which is often the problem.

In reality, "under the hood", cooling systems contain a lot of pretty sophisticated engineering – laws of thermodynamics, pressure, turbulent and boundary-layer flow, aerodynamics, etc.

As a result, because cooling seems simple, even though it isn't, a LOT of misinformation and tenacious long-lasting myths exist surrounding it.

So, let me get this out there – designing a complete cooling system is no easy task – especially if it's for a high-performance rig that's run hard. It takes a lot of know-how. So what are you to do?

Well, the easy and obvious answer is to enlist the help of true professionals, like Griffin Thermal Products. You call them up, explain what kind of vehicle you have and what you want to do with it, and they will design, build, and supply what you need.

These guys really know their stuff – they do everything from OEM, racing, off-road, & high performance, to industrial, locomotives, and aircraft.

So if you have the means, and you just want results – skip to the end of this article, ogle the pretty pictures, then simply call them up and order your own.

But – you don't necessarily have to engineer your system to build something that works. As much as there is rumour and myth – there are also many tried and true approaches, many well-tested components, and many rules of thumb that DO work. The trick is – telling them apart.

So, for those interested in a little more technical detail than just whom to call, that's what this article will attempt to do – sort the myth from the truth and present some solid tech to help you down the road of putting your own high-performance cooling system together. At the very least, it will help you have a more productive and meaningful conversation with the experts at Griffin when you do call them to order what you need.

Contents

Physics and Chemistry

In this article I'm going to forgo too much detail in terms of physics, equations, and laws of thermodynamics - they get pretty complicated pretty quickly and will bog most of us down. Having said that, there are a few basic "laws" we should just remind ourselves of - because they crop up time and again and keeping them in mind will help keep us from making mistakes or falling prey to those ever-present myths that surround cooling systems.

1) Metal, engine components, fluids and gasses all expand when heated.

2) Heat rises - hot fluid will rise in a system and cooler fluid will descend.

3) Air or vapour is lighter (less dense) than liquid and will rise to the top of any closed system.

4) Liquids are incompressible.

5) Substances can change state between liquid and gas (vapour). Boiling water (a liquid) turning into steam (gas) is an example of this. When exactly this change of state occurs, depends on the temperature and

pressure of the liquid. The greater the pressure a liquid is under, the higher the temperature it boils at (turns from liquid to vapour).

6) Heat spontaneously transfers from hotter objects to cooler objects. The rate at which this transfer occurs depends primarily on the difference in temperature between the two (the delta-T). When the difference is great, the transfer occurs extremely rapidly. As the temperature difference decreases - the rate of heat transfer decreases exponentially. This fact is an expression of Newton's Law of Cooling and understanding it is critical to dispelling one of the greatest and most-often quoted myths surrounding cooling systems. A good example of this law can be seen when quenching a red-hot piece of steel in a bucket of water. At first, the temperature difference (delta-T) between the red-hot steel and the water is huge - therefore the initial heat transfer occurs at a great rate - the steel initially cools very fast - almost instantaneously. However, after this initial cooling, the delta-T is much smaller, so the remaining cooling occurs much more slowly. If you removed the steel after a second or two - it has cooled a lot - but it will still be warm. To continue cooling the steel to the temp. of the water, you have to leave it in there quite a bit longer - because as it cools - the **rate** of cooling continually decreases as well. In short - initial cooling is fast, but subsequent cooling occurs more and more slowly until cooling that last little bit takes a long, long time. Remember this - we'll come back to it.

Cooling System Basics

A vehicle's cooling system is designed to do one thing - maintain the engine at the proper operating temperature. Note that I didn't say the purpose is just to "cool the engine". This is one of the first and most often overlooked aspects of a cooling system (which isn't helped by the name). Yes, it's possible to "overcool" an engine, and doing so can be almost as damaging as allowing it to overheat. This is because all engines are designed to operate most effectively and reliably at a certain temperature. This normal operating temperature takes into account internal clearances, oil viscosity (which varies with temperature), and combustion efficiency (which affects power, economy, and emissions). Too hot, and critical clearances are lost, oil breaks down, pre-ignition occurs, metal composition is changed, parts start to weld together and severe damage occurs. Too cold and combustion is incomplete, power production is reduced, emissions are excessive, economy suffers, and oil never reaches the proper temperature and therefore viscosity and is therefore too thick to provide proper lubrication - especially between critical surfaces like main and rod bearings.

To be fair - the majority of the work the cooling system must perform is to remove from the engine heat produced by combustion - but a good cooling system must also be designed to allow the engine to come up to proper operating temperature as quickly as possible and then keep it there.

Power makes heat. The more power the engine creates, the more heat it creates. As wonderful as they are - spark-ignition internal combustion engines are actually pretty damn inefficient beasts. A typical engine will loose more than 30% of the power it produces to heat production. That's a LOT of heat! Peak combustion chamber surface temperatures can exceed 500°F and the temperature of the combustion itself can exceed 3000°F. In fact, if you were to run an engine without a cooling system, even for only a short time, the temperatures produced could quickly melt the piston and fuse it to the cylinder. Clearly then, cooling is very important in order to keep this and other component failures from happening.

But that's not all - even in a working engine with a cooling system, well before total component melt down occurs, if the cooling system isn't up to scratch, excessive heat in and around the combustion chamber will cause pre-ignition and detonation - both of which have major negative affects on power production, efficiency, and longevity of the engine and can cause plenty of damage of their own.

The reason I'm pointing this out is two-fold: First - so you have a good appreciation for how much the cooling system does (and therefore why it's worth investing the time and money into getting it right). Secondly, so you understand that, just because your engine isn't blowing steam out the rad cap or melting pistons - doesn't mean that it's working optimally and couldn't use some improvement. Same goes for the guy down the street (or on the internet)- who's advice you're considering taking - just because he says "I just plugged the steam ports and haven't had any problems" doesn't mean his cooling system works well or that it won't cause problems down the road.

Pump Performance Curve and Total System Pressure Drop

Fluid flows because of pressure. It naturally flows from regions of high pressure to regions of low pressure. This basic theory explains everything from how airplanes fly to weather patterns. When fluid flows through a pipe, like a garden hose, there is friction between the fluid and the inside walls of the pipe. This friction creates pressure drop. Pressure is what causes the fluid to flow. If the pressure drops to zero before the end of the pipe, the fluid will not come out the end - it will just stop as if a valve was closed. Therefore, in order for fluid to flow through the pipe, the pump must be able to generate enough pressure to overcome, or equal, the total pressure drop in the pipe.

Take our garden hose as an example. Say we have it hooked up to a 10 PSI pump, it is 20' long, and has a sprinkler on the discharge end. When we open the tap, a certain flow will come out the sprinkler. The pump creates pressure, and that pressure causes the water to flow towards a region of low pressure - in this case ambient atmospheric pressure outside the sprinkler. If we add a 100' length to the hose we add a whole bunch of friction and therefore increase the pressure drop in the hose. If the pump still continues to produce only 10 PSI we will get reduced flow and therefore reduced output out the sprinkler. Ultimately, if we add enough hose, the pump's output pressure will no longer be able to overcome the total pressure drop and nothing will come out the end. If we connected a hose 5 miles long to the tap on our 10 PSI pump, nothing would come out the end.

If it helps, we can think of the total system pressure drop as "backpressure" against the pump - backpressure against which the pump must pump in order to create flow.

Now, these same rules apply equally to a complex series of pipes, tubes, passageways, manifolds, and restrictions as they do to a simple single pipe. Pump outlet pressure must equal total system pressure drop for flow to occur. Pump outlet pressure is referred to as "head". Therefore head must equal backpressure. Simple enough, right?

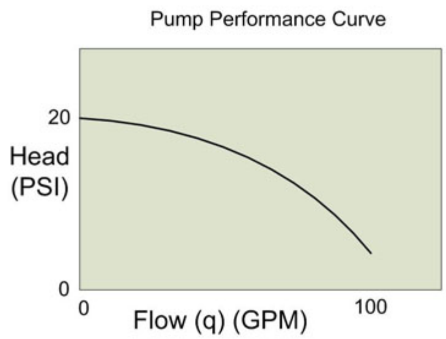
In the case of our cooling system, it is just that - a complex series of pipes, tubes, passageways, manifolds, and restrictions. All the various components induce some pressure drop in the system - some large, some not so large, but they all add up and the pump must be able to overcome the total. In addition, the cooling circuit is a closed system, meaning the output from the pump returns to become the inlet to the pump - the fluid flows in a circular route so that if the pump's head cannot overcome the backpressure, flow stops and there is nothing returning to the pump for it to continue pumping.

An automotive water pump is a centrifugal, non-fixed-displacement, vane-type pump. The pump creates the pressure and flow required to circulate the coolant. The pump must produce enough pressure at its outlet to overcome the restrictions in the cooling system. In other words, the coolant passages in the rad and engine create a certain amount of backpressure. The pump must be able to generate sufficient head in order to pump the coolant.

Now, pressure and flow are directly related. Depending on its design, construction, and specifications a pump will produce a certain head for a given flow. Stated differently, a pump will be able to produce a certain flow rate for a given amount of backpressure (or resistance in the system).

As we mentioned, in pump specification terms, the pressure a pump creates at its outlet is called "head". For centrifugal automotive water pumps, as head goes up, flow goes down. This makes sense - all we're saying is - the greater the resistance to flow in the system, the greater the head the pump must produce, and the less flow the pump will create.

If you draw a graph of any particular pump's performance in this regard, it is called the "characteristic performance curve" of the pump, or sometimes just the "performance curve". Here is a completely hypothetical example curve, just to illustrate the point. The values are not intended to be representative of typical or actual pump performance.



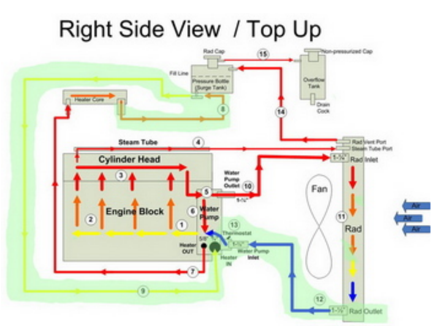
As you can see, the pump creates maximum head at zero flow. This makes sense - if we block the pump outlet (zero flow) the pump will create its maximum pressure. Alternatively, we can say the the pump is able to flow the most when the head (or the backpressure of the plumbing system) is the least.

The pump will always operate somewhere on its performance curve. Therefore, if backpressure due to restrictions in the cooling system goes up (total pressure drop increases), pump head must go up and therefore pump flow goes down. This is important to keep in mind as we generally want to maximize flow for the most efficient cooling (assuming we have the required airflow to match high coolant flow).

True cooling system engineering would include mapping pressure drop throughout the system, because this pressure drop affects more than just flow. As we shall discuss momentarily, pressure is also important in determining the boiling point of the coolant and in maintaining consistent and complete contact in the block and cylinder head passageways between the coolant and the hot engine parts.

In addition, since pressure drop is least at the pump outlet and increases through the system restriction to a maximum at the pump return, this means actual system pressure is greatest at the pump outlet and least at the pump inlet. Knowledge of system pressure at certain points is an important consideration in determining optimum location of certain components like the rad cap, steam vents, and surge tanks, as we shall soon see.

Since measuring and mapping pressure drop throughout the system is beyond the capability of most enthusiasts, for design and plumbing consideration, generally the cooling system is simply divided into the "high pressure" side and the "low pressure" side.



The areas where restriction are high are said to be the "high pressure" side of the system, and areas where restriction to flow are low are said to be the "low pressure" side of the system. Essentially, the low pressure side is the area after the heater and rad core up until the return (or inlet) side of the water pump.

In this pic the low-pressure side is shaded in green, everywhere else is considered the high pressure side.

In general, the radiator tank after the core and the return line to the pump, along with the return line from the heater are the low pressure side.

Don't worry about all the other details in this pic at this time, we'll cover them in good time.

Cooling System Components

The following are the basic components of any cooling system and so this section applies to any vehicle or any engine. Following this we'll have a look at some more specific GM Gen III/IV V8 ("LS") cooling system tech.

Water Pump

The water pump is a centrifugal-type non-fixed-displacement pump that circulates the coolant through the block and heads where it collects heat from the engine, and then through the radiator where it is cooled by air flowing through the rad.

The simple rule with water pumps is - the higher the flow the better. The reason for this will become clear later (and don't ever listen to anyone who says a water pump can flow too much and not let the coolant cool down in the radiator - pure myth. But I'm getting ahead of myself).

Coolant

The coolant is the liquid lifeblood of the system. Its job is to absorb the heat from the engine, and then give-up this heat in the radiator as air flows over the vanes attached to the tubes that carry the coolant. Coolant must also condition and lubricate the seals in the water pump and, in all but the most rigorously maintained race vehicles, inhibit corrosion in the many passages of the cooling system. Finally, in vehicles run in colder climates, the coolant must not freeze.

An entire separate article could be written around the debate over coolant types and brands. Rather than get into all that here, let's just stick to the basics.

Heat (or heat energy) is measure in units called British Thermal Units (or BTUs). A BTU is the amount of energy required to raise 1 pound of water 1°F.

Without knowing anything about thermodynamics, it's obvious that the best coolant is one that can absorb and give off the most heat energy per degree of temperature change it experiences - in other words it should be able to absorb and carry away a lot of heat energy without getting too hot itself. This property is called "specific heat". A liquid's specific heat is the number of BTUs it takes to raise the temperature of one pound of that liquid 1° F. In other words, the higher a liquid's specific heat, the more heat energy it can absorb per degree of temperature rise. We want the coolant to absorb a lot of heat energy while suffering the lowest temperature rise possible - that way the coolant can carry away the most heat without getting too hot itself and boiling. If the coolant boils it becomes a vapour (gas) and is now useless to us.

It turns out that plain old distilled water has the highest specific heat of all liquids commonly used for coolant. Water has a specific heat of 1 - meaning one pound of water can absorb 1 BTU for a temperature increase of 1° F.

A 50/50 Ethylene Glycol / water mix has a specific heat of 0.5, meaning it takes only 0.5 BTUs to raise the temperature of 1 pound Ethylene Glycol / water mix 1° F.

A 50/50 Propylene Glycol / water mix has a specific heat of only 0.3.

Therefore, it takes twice as much heat to raise a pound of water 1° F than a 50/50 Ethylene Glycol mix; and over three times as much heat to raise a pound of water 1° F than a 50/50 Propylene Glycol mix.

Ultimately, what this means is that straight water can carry away 50% more heat than 50/50 Ethylene Glycol mix and 70% more heat than 50/50 Propylene Glycol mix per degree per unit volume.

Of course, how much heat a liquid can absorb without boiling is also a function of the pressure acting on that that liquid. The boiling point, also called "vapour point" is that temperature where a particular liquid turns to vapour - which we don't want.

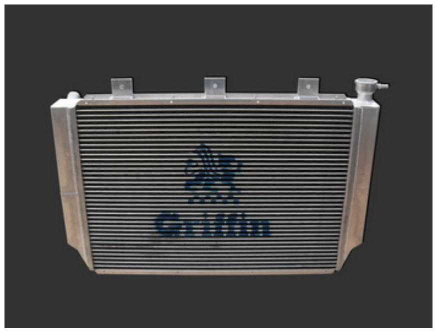
Now - the more pressure a liquid is under, the higher its boiling point. This is precisely why cooling systems are pressurized. In the case of water, our most efficient coolant, we all know that at atmospheric pressure it boils at 100°C or 212° F. However, if we pressurize the water, its boiling point increases as follows:

Pressure (PSI)	Boiling Point (° F)
0 PSI	212° F
10 PSI	239° F
20 PSI	259° F
30 PSI	273° F
40 PSI	286° F
50 PSI	297° F

We can see from the chart that, if we were running straight water, un-pressurized, it would boil at 212° F - which is no good as this is perilously close to the designed normal operating temperature of many modern engines. However, if we pressurized that water to even only 10 PSI, it wouldn't boil until 239° F. Many modern vehicle cooling systems are pressurized to 14-18 PSI, high performance systems to 22-24 PSI, and racing systems to 29-31 PSI. At the extreme end of the scale, Formula 1 race cars pressurize the coolant to as much as 50psi and have engine operating temps of about 265° F.

Now, at atmospheric pressure, both Ethylene Glycol and Propylene Glycol have higher vapour points than water, and this trend continues at higher pressures. That means they will not boil until they reach higher temperatures which in turn means a) that they can continue absorbing and transferring heat at temperatures higher than water is capable of and b) that they provide a greater safety margin against coolant boiling. Commercial coolant mixtures also have a lower freezing point than water and contain additive and conditioning packages to lubricate and inhibit corrosion in the cooling system.

Ultimately, which coolant to use will depend on your circumstances. For most, the benefits of an Ethylene Glycol mix or perhaps even a Propylene Glycol mix outweigh its lower efficiency. Of course, rather than run the normal OEM-recommended 50/50 mix, one can always custom tailor a mix to gain some of the advantages of a coolant mix while retaining as much of the efficiency of straight water as possible (e.g. a 75% water / 25% Ethylene Glycol mix). If you do - be sure to check that the vapour point and freezing point of the custom mix meets your system's needs. This is normally indicated in a little table on the bottle. However, for those running vehicles at the top edge of performance that see rigorous regular maintenance and are never subject to freezing temperatures - straight distilled water is undoubtedly the most effective liquid to use for coolant. Many folks who do run straight water will also add a small bottle of seal conditioner / corrosion inhibitor, such as Prestone Super Anti-Rust, to keep the water pump happy.



Radiator

The heart of the system, a high-quality, appropriately-sized radiator is the single most important component in the cooling system.

We'll look at how to spec a radiator, who makes the best, and what the best features are, in great detail later in the article.

The short story is: Get the biggest aluminum radiator from Griffin Thermal Products that you can possibly fit!

Fan(s) and Shrouds

Of course, a radiator is no use without a fan or two to pull air through it.

By far the best fans are electrical "puller" fans - and the best of those are made by SPAL.

Electric fans offer superior control, flow, mounting flexibility, and a host of other options not available from mechanically driven fans. In recent years, the popularity of front-wheel-drive cars with their transversely mounted engines that obviously must use an electric fan has led to major advances in electric fan performance and computer control that older mechanical fans can't match.

The only real choice for a performance cooling system is a "puller" fan - one that is mounted behind the radiator (in relation to the airflow) and sucks the air through the radiator. They are far more efficient than "pusher" style fans that mount in front of the radiator and push air through it.

All fans should be shrouded. Without a shroud your valuable airflow is dramatically reduced and all manner of complicated aerodynamics can go on, essentially leaving your expensive performance rad and fan combo stifled and unable to do its job before it had a chance.

Radiator Cap

The radiator cap is the "pressure relief valve" of the cooling system. It consists of a pressure-sensitive spring-loaded seal assembly that seals the cooling system from the atmosphere and thereby allows it to build the all-important pressure we were just talking about. In addition to raising the vapour point of whatever coolant is used, system pressure is vital for keeping coolant in contact with the metal surfaces of the cylinder heads and block. Consistent contact between the coolant and the engine passageways, particularly in the block and heads, is vital to prevent localized boiling or steam pockets in the combustion chamber areas of the cylinder heads.

Also, block pressure must be adequate to ensure uniform coolant distribution from the front to the rear of the engine. Low pressure can often result in insufficient cooling around the rear cylinders - which is why certain engine problems always show up first in the rear cylinders.

Steam pockets or localized coolant boiling can occur when excessive heat is generated (because of a lean condition, excessive ignition advance, or faulty cooling system) causing the coolant to reach its vapour point and spontaneously change state from liquid to gas - in other words - boil. This is sometimes referred to as "flashing to steam". The problem usually occurs first in the combustion chamber area because it is the hottest region. When this happens - a vicious cycle begins - cylinder head hot spots cause steam pockets - steam

pockets tend to "stick" in the highest area (the head) - steam cannot contribute to cooling and displaces much needed coolant - the excessively hot cylinder head experiences detonation and/or pre-ignition - which in turn creates excessive heat which causes hot spots and localized coolant boiling and steam pockets to form and so on.

Adequate system pressure (along with a properly functioning cooling system and properly tuned engine) helps ensure that the coolant's boiling point is sufficiently high that the formation of steam does not occur and the cycle cannot begin.

Keeping the coolant under pressure also helps to prevent cavitation in the water pump.

The pressure in the cooling system comes from two sources. The first is from the action of the water pump pumping the coolant through the restricted passageways and plumbing of the cooling system.

Secondly, since the cooling system is a closed and sealed system and liquids are both incompressible and expand when heated, pressure in the system results from the normal expansion of the coolant in the system as it heats up. Normally 12-17 PSI pressure is created when the coolant expands as a result of going from ambient temperature to normal engine operating temperature.

The radiator cap serves to regulate maximum system pressure. A properly functioning cooling system in good working order will not normally generate excessive pressure. But under certain conditions like excessive heat generation or component degradation/failure system pressure can build well beyond normal. If this pressure were allowed to build unchecked, eventually component damage would occur - including hoses blowing off, seals being blown, and damage to the pump and radiator and any other component not able to withstand the elevated internal pressure.

To avoid this, a radiator cap (safety valve) is installed that is designed to open at a certain pressure. A calibrated spring normally holds a seal in place that keeps the system sealed and pressurized. However, if system pressure builds beyond the opening pressure of the cap, the spring force is overcome, the seal retracts from its seat, and the system is opened to atmosphere. When this happens, excess pressure and fluid volume is allowed to bleed off in a controlled manner to a recovery tank, through a small fitting located just above the seal seat.

The rad cap also serves as the point of entry for filling the system with coolant and for bleeding the air out. The rad cap must be installed at the highest point of the system. Often this is on the radiator itself, but when this is not possible due to the position of the radiator (i.e. the top of the rad is not the highest point in the system), the rad cap may instead be installed on a pressurized surge tank, as we shall soon see.

As we previously discussed, because pressure drop increases as the coolant flows from the pump, through the system, and back to the pump, system pressure is not equal everywhere. This is an important consideration in rad cap location. The rad cap operates on the system pressure at its location. If it were located in the highest pressure portion of the system (the pump outlet or radiator inlet), it would regulate system pressure based on that highest pressure, meaning pressure elsewhere (for example, in the back of the cylinder heads) would be something less than the rating on the rad cap. This could mean pressure in the critical engine passageways could be as much as 10 PSI or more lower than the rad cap pressure rating - which is not good for cooling performance. It's also difficult to accurately measure system pressure at all locations, so you probably wouldn't even know how low the pressure was in the cylinder heads with the rad cap installed in the high pressure side of the system. In other words, with this arrangement, you may install a 20 PSI rad cap and expect coolant boiling point to be 259° F, but actual pressure in the heads, where boiling would occur first, would be less - perhaps only 10 PSI, and therefore actual coolant boiling point would only be 239° F - some 20° F less than you think! For this reason, the rad cap must be located on the low-pressure side of the system - either on the appropriate rad tank or on a remote-mounted surge tank.

Regardless of the location, the best advice is to run the highest rated cap the design and construction of the system will allow. For the dedicated seeking ultimate cooling performance, this may take some messy and risky trial and error - most often the result of a cap rated too high is a blown hose, but it could also lead to a cracked radiator. Some common values are:

Stock: 14-18PSI
High performance: 22-24 PSI
Racing: 29-31 PSI.

The rad cap also has a spring-loaded valve that can open to allow coolant entry back into the engine - described below in the section on "overflow tanks".

Thermostat

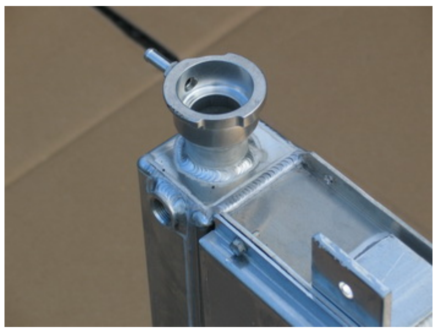
The thermostat is the "brains" of the cooling system. Recall how we said that the job of the "cooling" system was actually to regulate or control the temperature of the engine to keep it as close as possible to the designed normal operating temperature at all times? It is the thermostat that accomplishes this.

The thermostat is located in an area between the engine and the radiator. The classic small-block Chevy V8 located the thermostat on the "outlet" side of the motor, in the intake manifold. When cold, the thermostat was closed, and this prevented flow of coolant to the radiator. When the engine warmed up, the thermostat opened and coolant was allowed to flow to the radiator and back to the engine. The newer third- and fourth-gen GM V8's locate the thermostat on the "inlet" side of the motor - specifically in the inlet housing of the water pump. With this design, when cold, coolant is pumped through the rad, but is prevented from returning to the engine until the temperature of the thermostat has been reached, at which point the thermostat opens and the cooled coolant returns to the engine.

Similar to a rad cap, a thermostat contains a spring-loaded sealing mechanism - but instead of reacting to pressure, it reacts to heat. Most thermostats do this with what is called a "wax motor". The wax motor is a cylinder containing a wax pellet that acts directly on the thermostat piston. As the wax heats up, and expands, it forces the piston to open the seal and allow coolant to pass.

The Gen III/IV inlet thermostat location is designed to eliminate the following conditions / problems:

1. With the older outlet design, an air pocket could be created under the thermostat after the thermostat was installed following maintenance or service to the cooling system. Since the coolant was prevented from reaching the thermostat's wax motor, the thermostat didn't open and allow cooling to begin until the air pocket had gotten hot enough to cause it - which would happen much later than for coolant, and often too late to prevent overheating and component damage. This excessive heat would be bad for any engine, but can be especially damaging for aluminum components. Elimination of this air pocket is one of the reasons why old-school racers would drill a small bleed hole in the thermostat's flange.
2. The second problem is thermal shock that may occur at the radiator when hot coolant is released by the thermostat when the ambient temperature is near freezing. This sudden release of very hot coolant to a very cold radiator could cause thermal stress cracking in the radiator.
3. Because the old-style thermostats were located at the top of the engine where coolant temperatures are highest, and because any vapour or trapped air always seeks the highest point in a system and therefore could get trapped beneath the thermostat, this design can lead to unwanted thermal cycling as the area of the thermostat heats and cools causing the thermostat to repeatedly open and close. The newer inlet location design was designed to eliminate this potential thermal cycling problem.



Overflow Tank

All systems, regardless of whether they also use a pressurized "surge tank" or not, must use an overflow tank.

Also known as an overflow catch tank, overflow bottle, catch can, expansion tank, or recovery tank the overflow tank has a simple installation and job. It merely connects to the "dry", outside, non pressurized area immediately below the rad cap but above the rad cap seal, so that in the event the rad cap opens due to overtemp/overpressurization, the hot coolant and gas that is expelled is collected safely.

This pic illustrates the filler neck on my Griffin rad, where you can clearly see the outlet to the overflow tank above (or "on the dry side") of the rad cap seal seat.

The overflow tank is not to be confused with a surge tank or coolant recirculation tank - though they do appear similar.

The overflow tank serves no function in the normal operation of the coolant system. It only comes into play if there is an overpressurization and the rad cap opens, and then it only serves as a safe, environmentally responsible collection point for expelled coolant.

If the system pressure reaches the cap's pressure rating, the cap's spring is compressed, forcing the valve open and allowing coolant to escape through the overflow tube to the overflow tank. After such an event, as the system cools it contracts, creating vacuum that opens the other spring-loaded valve, in the rad cap, allowing coolant in the overflow tank to be sucked back into the radiator.

The overflow bottle can be distinguished from the surge tank / recirculation tank in that:

- It is not pressurized
- It has no pressure cap. It may have a non-sealing cap to allow inspection, or no cap at all.
- It has only one line running to it - from the fitting located directly above the rad cap seal seat.
- It will often have a drain cock or valve installed in the bottom for manual draining (which wouldn't be present on a surge tank).

The differences between the two will also become more clear once we get to the section on plumbing.

Surge Tank

The surge tank is a completely different animal from the overflow tank. It is an integral part of the cooling system through which coolant continually flows.

The surge tank also goes by many other names, adding to the common confusion between it and the overflow tank. You may see it referred to as a recirculating expansion tank, pressure tank, recirculation tank, coolant expansion fill tank, de-aeration tank, and others.

A surge tank serves two purposes. First it allows for "remote mounting" of the rad cap in situations where the top of the radiator is not the highest point in the system. Secondly, it serves as a de-aeration chamber, allowing for continual and effective removal of any vapour (air or vaporized coolant / steam) in the system.

How it does this we will examine in detail in the section on plumbing. For now, understand that, unlike the overflow tank, the surge tank is plumbed "inline" in the cooling system and therefore has coolant continually circulating through it, and is therefore a pressurized component of the system.

Surge tanks may come in many different forms. The one pictured above is a "Corvette style" tank, and the one pictured to the left is a generic aftermarket one.

Regardless of its exact form, a surge tank can be distinguished from an overflow tank by the fact that:

- It is a pressurized component.
- It has the distinctive filler neck opening at the top for mounting the rad cap.
- It will often have more than one inlet port (but not always).
- It will not have a drain cock or valve installed in the bottom for draining.
- It will have an outlet port so that coolant can flow / circulate through it.
- It still requires an overflow tank.

It is also important to note that the surge tank does not take the place of the overflow tank - it is used in addition to the overflow tank. This can be seen in both the examples above where you can clearly see the fitting in the filler neck (the overflow tube) that connects to the overflow tank - exactly the same way it does when the filler neck / rad cap are mounted directly to the radiator.

Temperature Gauge

Of course, it's important that you be able to monitor the performance of your cooling system, so a high quality gauge is a must.

Not being an article on gauges and instrumentation, I won't go into all the details of selecting gauges here, except the following important considerations.

From my aviation experience, it is a good idea to have the normal operating condition of all gauges appear at a consistent location on the gauge, normally at the 12 o' clock position. This way, a quick glance is all that is required to verify that all "temperatures and pressures are in the green" (meaning all OK).

Different gauges have different temperatures at the 12 o' clock position, as can be seen from the accompanying photographs.

Depending on the designed operating temperature of your engine, when selecting a gauge, along with other considerations you should consider selecting a gauge that displays the correct operating temperature at the 12 o' clock position. The gauges pictured here appear in order from coolest to warmest in terms of the temp indicated at the 12 o' clock position; in order 180° F, 200° F, and 230° F.

This leads me to the other point. We often talk, as I have done here, as if the temperature on the gauge were the temperature of the engine, but this isn't entirely accurate.

What the gauge reads is the temperature of the water, or coolant, at the position of the sensor or sending unit - it's even marked right there on the gauge "WATER TEMP".

This can be an important consideration when selecting where to mount the sensor or sending unit. We must also understand the distinction between this water temp and the actual temp of the engine.

Coolant temperatures do not accurately reflect actual metal temperatures in the engine. The metal can be several hundred degrees hotter than the adjacent coolant. This means, depending on the gauge sending unit location, coolant temperatures may read "normal" while the actual temp of the cylinder heads, for example, may be excessive. Therefore, the location of the gauge's sending unit or sensor must be chosen carefully - somewhere in the cylinder head is often a good choice.

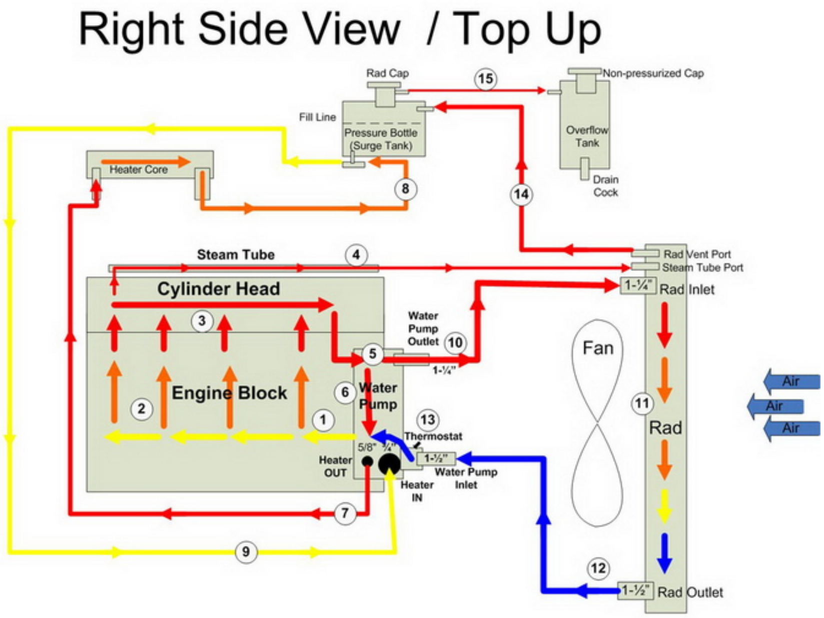
Assuming the gauge sending unit is properly located, an engine typically runs most efficiently when the coolant temperature is kept around 200° F. This comes back to maintaining the proper operating temperature again. At this temperature, the combustion chamber is warm enough to completely vaporize the fuel mixture for improved combustion, and the oil's viscosity is at the right point so that it can properly lubricate the engine and present minimal parasitic drag. An engine that is too cold is no good! Do not try to design your cooling system so that your engine runs all day at 160°F!

For most "normal" engines, 250°F is about the greatest water temp indication you should tolerate. Beyond this and the engine should be shut down or allowed to idle until it cools down. Incidentally, this is another advantage to electric fans. Because an electric fan can continue to run when the engine is not running, and because hot coolant will rise and be replaced by cooler coolant, and because the rad inlet is at the top and the engine inlet at the bottom - coolant will circulate and you can actually cool the engine even when it isn't running.

LS Cooling Systems

While the previous information is applicable to virtually any cooling system, this section will deal with the specifics of the cooling systems on third and fourth generation GM V8 engines, and in particular my Turnkey Engine Supply LS2.

The following illustration is a diagrammatic representation of a generic "LS" cooling system, complete with heater.



Starting at the water pump and following the numbers in sequence, here's the flow of the system:

1. The water pump pumps coolant out of the lower two ports on its back side and into the block.
2. Coolant circulates through the engine block...
3. ... and through the cylinder heads.
4. Special LS-specific "steam tubes" or "engine vent lines" are installed on top of the cylinder heads. As vapour or steam will always seek the highest point, any steam pockets created by local hot spots, particularly in the cylinder head exhaust valve area, will migrate up and into the steam tubes which will carry them and a small amount of coolant away and either into a port located at the top of the rad (as shown here) and from there to the surge tank, or directly to the surge tank (depending on application) where the steam is separated from the coolant.
5. Coolant returning from the cylinder heads enters the two upper round ports on the left and right back sides of the pump
6. Some coolant circulates through the water pump's bypass circuit and is again pumped back through the engine. This keeps the circuit flowing when the thermostat is closed.
7. Hot coolant exits the smaller, rear "heater out" port of the thermostat housing on the water pump. This takes it to the heater core. The port is 5/8" ".
8. After exiting the heater core, coolant returning from the heater passes through the surge tank to keep coolant circulating through that tank.
9. After passing through the heater core and then the surge tank, coolant re-enters the engine via the larger, front 3/4" "heater in" port of the thermostat housing on the water pump.
10. Hot coolant exiting from the engine that doesn't follow the pump's internal bypass circuit exits the water pump via the top 1-1/4" port and enters the top of the radiator.
11. Hot coolant flows across and down through the radiator, cooling as it goes.
12. Cooled coolant exits the radiator via the lower 1-1/2" outlet and returns to the inlet side of the water pump.
13. Returning coolant is blocked from re-entering the water pump inlet if the thermostat is closed. When the coolant on the inside (engine side) of the thermostat reaches the temperature of the thermostat (e.g. 190° F) the thermostat opens and the cool coolant enters the water pump inlet to be circulated through the engine again, starting over at #1.
14. A radiator bleed or vent port located at the top of the radiator connects to the surge tank. Any air or steam in the system, especially that coming from the engine's steam tubes, will naturally seek the highest point and will therefore exit the radiator via this port and travel to the surge tank. At the surge tank, coolant and steam enter and the steam or air is separated from the coolant. The lighter steam / air collects and remains in the surge tank at the highest point, just below the rad cap, to be eliminated first in the event the rad cap purges. The cooler, denser coolant goes to the bottom of the surge tank where it is collected by the flow returning from the heater core and circulated back through the system.
15. In the event of a system over-pressure condition, the rad cap opens and burps excess coolant and steam out of the system to be collected by the overflow tank.

As can be seen, the surge tank is an important and very useful component of the system. Following are a few more details on the use of a surge tank:

One of the prime reasons for mounting a pressurized surge tank in the cooling system is the flexibility it gives in the mounting location of the rad cap. Because it is the pressure relief valve of the system, the rad cap:

1. Must always be located at the highest point of the cooling system - otherwise it will be impossible to get a complete fill of coolant and air will be trapped in the system. Also, when the rad cap is the highest point in the system, steam and air will naturally migrate to the area just below the cap. In the event the cap vents due to excessive pressure, the steam and air will be purged first.
2. Should be on the low pressure side of the system - otherwise the high pressure created by the water pump running at high RPM can tend to unseat the cap and blow coolant out, leading to overheating.
3. Should be located in an area of low coolant velocity so that the any steam or air can separate from the coolant, even at high RPM.

The surge tank provides the ideal environment for satisfying all three of these requirements, and provides a low velocity, low-pressure environment for de-aeration of the coolant.

When plumbing a surge tank:

- The bottom of the tank is connected to the inlet side of the water pump with a 1/2" or 3/4" line. In the systems shown above the heater return port is used for this purpose.
- A 1/4" to 3/8" vent or "bleed" line from the side of the surge tank is connected to the engine's steam ports (if it has them) or from the highest point of the low pressure side of the radiator. That is - if connected to the radiator, the bleed line to the surge tank must originate at the top of the radiator tank that doesn't have the normal radiator inlet from the water pump. This is because coolant velocity and pressure are high at that location which would force high velocity, high pressure coolant through the line to the surge tank, defeating the purpose of the surge tank's low pressure, low velocity environment for deaeration. The bleed line allows continual circulation of some coolant through the surge tank.
- The surge tank must be large enough to allow the air to separate as the coolant flows through it. Air in the system will then migrate to the area just below the radiator cap, again so that it will be forced out first if system pressure exceeds the radiator cap's rating.
- The surge tank should be filled to a level just below the inlet ports, as shown in the system diagram above.

The continual de-aeration that a surge tank provides can be a huge benefit to your overall cooling system. We already discussed all the bad things that happen when steam or air are trapped in the cooling system. In addition to those, consider that 2% air in the system results in 8% less heat transfer, but 4% air results in a whopping 38% less!! The continual de-aeration of the coolant may be enough advantage to allow you to run a smaller, easier-to-fit radiator with a surge tank than the size you would have to run with only an overflow tank, for instance.

If your engine doesn't have steam ports, and the rad is lower than the top of the engine, the bleed line to the surge tank must come from the highest point on the engine because this is where steam and air will naturally gravitate and get trapped. A fitting on the water pump in the same passage as the outlet to the radiator can be a reasonable compromise.

If you add a surge tank to a system that already has a rad cap on the radiator, you need to permanently seal the radiator rad cap location, or at least install on the rad a cap with a rating significantly higher than the surge tank cap will have, so that the radiator mounted cap will not open before the surge tank cap.

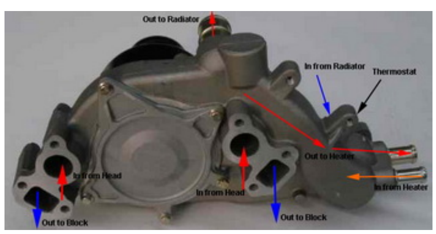
Now, here's a close look at some of the other components in the "LS" cooling system:

Here's the water pump mounted to the front of the engine.

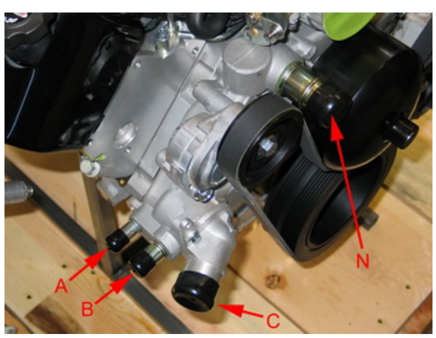
This particular example is a 2002 Camaro LS1 water pump mounted to my Turn Key Engine Supply LS2.

The pump is a belt-driven, cast aluminum unit of centrifugal non-fixed-displacement design with a double-shrouded impeller to improve pumping efficiency and total pump output.

The pump incorporates a crossover / bypass circuit as described above, 1.25" outlet, 1.5" inlet, and integrated thermostat housing with heater outlet (5/8") and inlet (3/4") ports, located on the engine side of the thermostat just inside the radiator inlet.



Back side of the water pump showing coolant flow path.

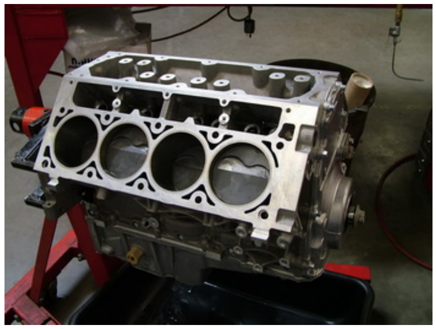


A = Water pump outlet to heater core, 5/8".

B = Water pump inlet from heater core, 3/4".

C = Water pump inlet / thermostat housing (in to engine from radiator), 1-1/2".

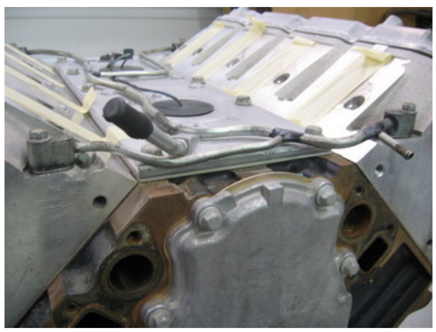
N = Water pump outlet (out to radiator, from engine), 1-1/4".



Coolant passages in the block.

Note the block has siamesed bores. This means there are no water passages between the cylinder bores. A lot of development went into the design of the Gen IV water jacket to get good heat rejection without the need for water between the bores.

Coolant passages in the cylinder head.



This picture illustrates the LS "steam tubes", also known as "coolant vent lines" or "engine bleed lines".

You can see that the lines originate at ports in the front and rear of the left and right cylinder heads.

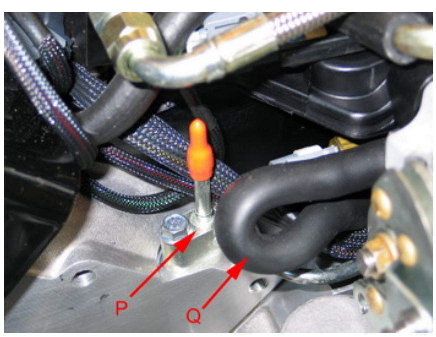
This picture is of a car engine, the truck engines had steam tubes originating only from the front of both heads.

Most stock "LS" engines had these steam lines routed to the top low pressure side of the rad, although some applications ran them directly to the surge tank.

I hope by now that you can see why simply capping the steam ports at the cylinder heads is a really bad idea as this will allow steam to get trapped exactly where it can do the most damage.

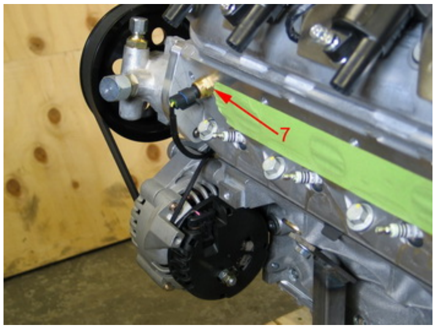
You may also read where folks run the steam lines back into the low pressure side of the cooling system - sometimes by putting a fitting on the thermostat housing, and sometimes by plumbing them directly back into the heater core return port. I imagine that the hope is that any steam pockets will then go back into the general cooling system flow with the hope that they would eventually migrate back to the area below the rad cap, wherever it may be. I have to be honest - this strategy makes no sense to me at all and is not supported by the laws of thermodynamics. It seems to me that doing this is asking for the steam to just re-circulate until it gets trapped somewhere at the highest point of the system - possibly in the steam line itself before it turns down to go to the low water pump inlet.

Regardless, the best strategy is to plumb the LS steam tubes either to the high point of the low pressure side of the rad or directly to a surge tank.



P = steam tube outlet at front of my LS2 right cylinder head. This must be plumbed either directly to a surge tank, or to a port at the top low-pressure side of the radiator tank (not the side with the radiator inlet).

LS1 thermostat located in the integral thermostat / pump inlet housing. This particular thermostat is rated at 180°F.

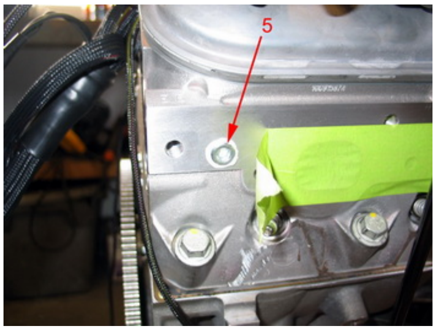


7 = Coolant Temperature Sensor (CTS).

The CTS monitors engine temperature and tells the Engine Control Module (ECM) when the engine has reached or exceeded normal operating temperature.

CTS data is used in a wide range of functions, from telling the ECM when to use cold start-up enrichment mode to turning on the electric radiator cooling fans to fuel/spark adjustments and engine over-temp protection.

The coolant temperature sensor provides important fueling information to the ECM when the engine is below its normal operating temperature. Cold engines require more fuel to operate so the ECM uses the CTS information to enrich the air/fuel mixture in much the same way an automatic choke did on carbureted engines. Depending upon how cold the engine is, the ECM will increase the base pulse width values obtained from its main fuel table and then gradually taper off the increase as the engine warms up. The CTS is also used for several other temperature-dependent functions including: the modification of idle speed, IAC motor position, and spark advance as well as detecting engine overheat situations.



5 = 1/4" NPT port for electrical water temperature gauge.

This port is a 12mm x 1.5mm metric fitting on the stock LS2, but on the Turn Key engine it is 1/4" NPT to match 99.9% of the gauges out there. This means that you don't have to try and make adapters or take the head off just to drill and tap for a gauge sender.

Recall what we were saying about the difference between the temp sensed by and indicated on the gauge, and the actual operating temperature of the engine. Combine this with the information above on the role of the CTS, and we see that it makes good sense to locate the gauge sensor (rear of right cylinder head) where it will get similar readings as the CTS (front of left cylinder head) so that we can see essentially the same data as the ECM does. Then, with some knowledge of the ECM's programming (which will be based on the designed operating temp of the engine) we can easily make informed decisions about the data displayed on the gauge.

For example, on my engine, when engine temperature (as read by the CTS) reaches 235°F, the ECM goes into "limp home" mode where it limits rpm to 2000.

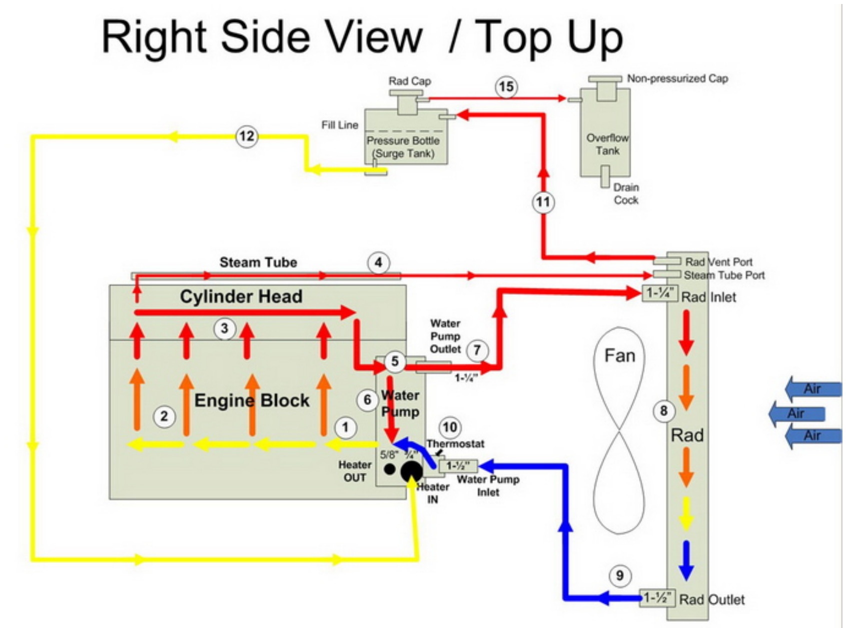
Overall shot of my LS2 showing all the coolant inlets and outlets.

LS Cooling System Plumbing Variations

Now that we've seen the design and components of the standard "LS" cooling system, let's have a look at a few possible variations based on swapping an "LS" motor into a non-oem vehicle.

No Heater

Many engine-swap applications, be they hot-rods or off-road rigs, delete the heater core. The following diagram illustrates a cooling system where the heater has been deleted but a stock-like surge tank setup is maintained.



The system flow is as follows:

1. The water pump pumps coolant out of the lower two ports on its back side and into the block.
2. Coolant circulates through the engine block...
3. ... and through the cylinder heads.
4. The steam tubes carry steam and a small amount of coolant into a port located at the top of the rad (as shown here) and from there to the surge tank, where the steam is separated from the coolant.
5. Coolant returning from the cylinder heads enters the two upper round ports on the left and right back sides of the pump
6. Some coolant circulates through the water pump's bypass circuit and is again pumped back through the engine. This keeps the circuit flowing when the thermostat is closed.
7. Hot coolant exiting from the engine that doesn't follow the pump's internal bypass circuit exits the water pump via the top 1-1/4" port and enters the top of the radiator.
8. Hot coolant flows across and down through the radiator, cooling as it goes.
9. Cooled coolant exits the radiator via the lower 1-1/2" outlet and returns to the inlet side of the water pump.
10. Returning coolant is blocked from re-entering the water pump inlet if the thermostat is closed. When the coolant on the inside (engine side) of the thermostat reaches the temperature of the thermostat (e.g. 190° F) the thermostat opens and the cool coolant enters the water pump inlet to be circulated through the engine again, starting over at #1.
11. A radiator bleed or vent port located at the top of the radiator connects to the surge tank. Any air or steam in the system, especially that coming from the engine's steam tubes, will naturally seek the highest point and will therefore exit the radiator via this port and travel to the surge tank. At the surge tank, coolant and steam enter and the steam or air is separated from the coolant. The lighter steam / air collects and remains in the surge tank at the highest point, just below the rad cap, to be eliminated first in the event the rad cap purges. The cooler, denser coolant goes to the bottom of the surge tank where it is collected by the flow returning from the heater core and circulated back through the system.
12. After passing through the surge tank, coolant re-enters the engine via the larger, front 3/4 " "heater in" port of the thermostat housing on the water pump. The "heater out" port is blocked off.
13. In the event of a system over-pressure condition, the rad cap opens and burps excess coolant and steam out of the system to be collected by the overflow tank.

Aftermarket Surge Tank

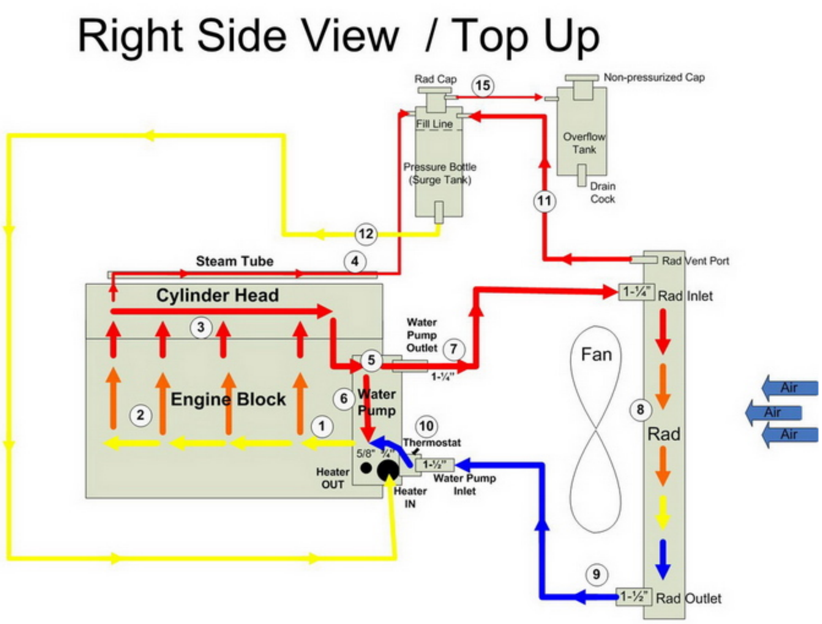
Unlike the above system, this setup not only deletes the heater, but also uses an aftermarket surge tank.

The "Corvette style" surge tanks that we have pictured so far are not very common.

Much more common are aftermarket type surge tanks that have a single large lower return port (usually 1/2" NPT or AN -10) and one or more smaller (1/4" or 3/8") upper inlet ports, such as this one from Canton...

... or this one from Afco.

The following diagram assumes an aftermarket surge tank with two inlet ports. If a dual-inlet surge tank were not available, a similar system could be run but the engine steam tubes would have to be run to the rad, and the rad vent port run to the single surge tank inlet.



In this system:

1. The water pump pumps coolant out of the lower two ports on its back side and into the block.
2. Coolant circulates through the engine block...
3. ... and through the cylinder heads.
4. The steam tubes carry steam and a small amount of coolant directly to the surge tank where the steam is separated from the coolant.
5. Coolant returning from the cylinder heads enters the two upper round ports on the left and right back sides of the pump
6. Some coolant circulates through the water pump's bypass circuit and is again pumped back through the engine. This keeps the circuit flowing when the thermostat is closed.
7. Hot coolant exiting from the engine that doesn't follow the pump's internal bypass circuit exits the water pump via the top 1-1/4" port and enters the top of the radiator.

8. Hot coolant flows across and down through the radiator, cooling as it goes.
9. Cooled coolant exits the radiator via the lower 1-1/2" outlet and returns to the inlet side of the water pump.
10. Returning coolant is blocked from re-entering the water pump inlet if the thermostat is closed. When the coolant on the inside (engine side) of the thermostat reaches the temperature of the thermostat (e.g. 190° F) the thermostat opens and the cool coolant enters the water pump inlet to be circulated through the engine again, starting over at #1.
11. A radiator bleed or vent port located at the top of the radiator connects to the surge tank. Any air or steam in the system, will naturally seek the highest point and will therefore exit the radiator via this port and travel to the surge tank. At the surge tank, coolant and steam enter and the steam or air is separated from the coolant. The lighter steam / air collects and remains in the surge tank at the highest point, just below the rad cap, to be eliminated first in the event the rad cap purges.
12. The coolant at the bottom of the surge tank re-enters the engine via the larger, front 3/4 " "heater in" port of the thermostat housing on the water pump. The "heater out" port is blocked off.
13. In the event of a system over-pressure condition, the rad cap opens and burps excess coolant and steam out of the system to be collected by the overflow tank.

Old School - Overflow Tank Only

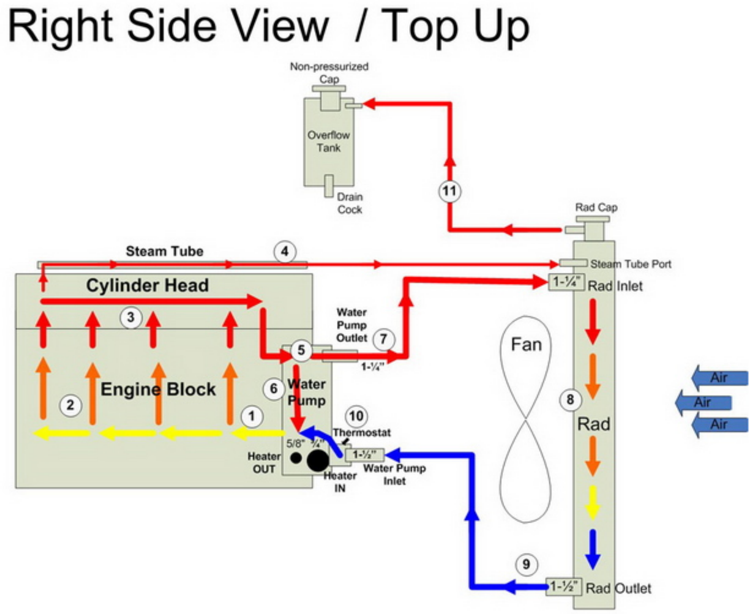
Though it eliminates the advantages of the surge tank, depending on the capabilities of the rest of your cooling system, it is possible to run a system with just an old-school overflow tank. Of course, this requires that the rad cap be mounted on the rad and that the rad be the highest point in the system. It also demands that the rest of the cooling system be capable enough that the advantages of the surge tank design can be safely done away with. However, with a good enough system, and especially a big enough rad and good enough airflow, eliminating the surge tank can save you some space (as their is no need to find a place to mount the surge tank), save a little plumbing, save a little weight, and simplify the system a little.

There are a huge number of overflow tanks available from the aftermarket.

This one from Canton incorporates a sight-tube for checking the coolant level in the tank, as well as a non-pressurized cap.

This one from Moroso has neither a sight-tube, nor a cap.

The following is the simplest of all systems we shall look at, and there is a certain beauty in simplicity. It deletes the heater and the surge tank. However, it forgoes the continual de-aeration capabilities of the surge tank and requires that the rad-mounted rad cap be the highest point in the system. Note however, that the steam tubes are still correctly plumbed to the radiator. Of course, never plumb the steam tubes directly to an overflow tank!!



In this system:

1. The water pump pumps coolant out of the lower two ports on its back side and into the block.
2. Coolant circulates through the engine block...
3. ... and through the cylinder heads.
4. The steam tubes carry steam and a small amount of coolant to the top of the radiator where the steam is separated from the coolant and collects just beneath the rad cap seal.
5. Coolant returning from the cylinder heads enters the two upper round ports on the left and right back sides of the pump
6. Some coolant circulates through the water pump's bypass circuit and is again pumped back through the engine. This keeps the circuit flowing when the thermostat is closed.
7. Hot coolant exiting from the engine that doesn't follow the pump's internal bypass circuit exits the water pump via the top 1-1/4" port and enters the top of the radiator.
8. Hot coolant flows across and down through the radiator, cooling as it goes.
9. Cooled coolant exits the radiator via the lower 1-1/2" outlet and returns to the inlet side of the water pump.
10. Returning coolant is blocked from re-entering the water pump inlet if the thermostat is closed. When the coolant on the inside (engine side) of the thermostat reaches the temperature of the thermostat (e.g. 190° F) the thermostat opens and the cool coolant enters the water pump inlet to be circulated through the engine again, starting over at #1. Both the "heater in" and "heater out" ports are plugged.
11. In the event of a system over-pressure condition, the rad cap opens and burps excess coolant and steam out of the system to be collected by the overflow tank.

Blocking the LS Heater Ports

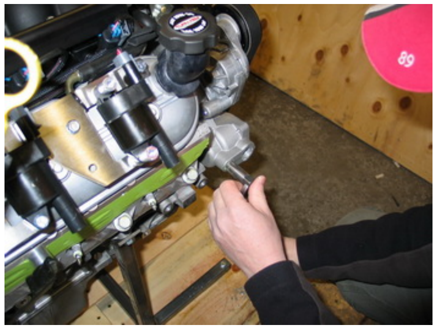
In many of the systems I've illustrated, as in many custom engine transplants, the heater is deleted and the heater ports blocked off. Here's how to block off the LS heater ports.

Unbolt and remove the engine inlet/thermostat housing and thermostat.

Firmly grasp the heater hose fittings with vise grips, twist, and remove from the housing. They are only pressed in and this will cause no damage.

Using a 1/2" NPT tap for the larger "in" port (shown) and a 3/8" NPT tap for the smaller "out" port, carefully tap the ports.

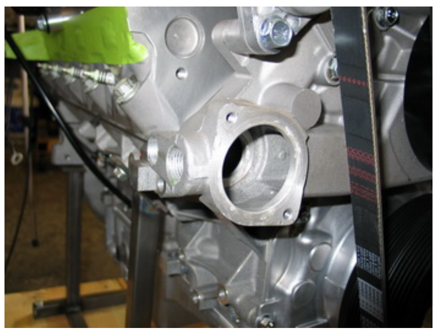
You do not need to drill the ports to size prior to tapping.



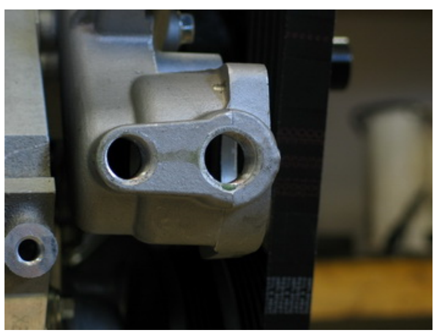
Be sure to follow all the normal good practices of tapping a hole - lubrication, back out the tap to clear the chips, etc.

You don't want to screw it up and have to buy a whole new water pump!

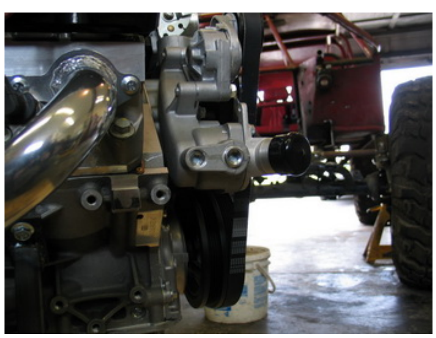
The chips will collect in the pump housing.



And can easily be vacuumed out when you're finished.



Threads cut.



NPT plugs installed with PTFE sealing tape.

How to Build a Killer Cooling System

OK, so now we know all the basics - what the parts are, what they do, how the system flows and is plumbed, what pressure does for us, etc. Now - what distinguishes a good, capable cooling system from a lousy, inadequate one? How do you begin to design or build a cooling system for your rig?

The quick answer is, you should maximize:

1. The flow of the coolant - the higher the better. More flow will always equal more cooling. Do this with a high-flow water pump, large hoses and passageways, large radius bends, and keeping the passageways as free of restrictions and blockages as possible.
2. The flow of air through the rad - quality, high CFM fans (like those from SPAL), properly shrouded, as well as appropriate bodywork/ducting to ensure air flows through the rad and not around it. Don't lean the rad way back, as air will flow over rather than through it.
3. The surface area of the radiator - use the biggest you can possibly fit. More details on rad tech to come shortly but again, short story is - buy an aluminum one from Griffin!
4. The percentage of water in the coolant - for cooling, as we have discussed, water is best - use as high as a percentage as you can get away with (without freezing, boiling, or corroding the system)
5. Pressure. Use the highest rated rad cap you can without blowing a hose or cracking the rad or some other component. More pressure equals higher vapour point (boiling point) which not only means less chance of steam pockets or boil-over, but also that the coolant can continue carrying away heat at temps beyond which lower pressure systems would have maxed out.
6. Turbulence. Turbulent (or rough) flow of coolant through the rad ensures that as much hot coolant as possible is exposed to the cooling surfaces of the tubes. If flow is too smooth (laminar), only a thin outer layer of coolant is cooled in the rad and an undisturbed, hot core of coolant goes uncooled. That's uncool! Griffin have some super-trick ways of ensuring turbulent flow in their high performance rads.

Here are Griffin's "10 Commandments for Maximum Cooling". I agree with them all (I'm sure they'd be relieved to hear that ;-) as they apply to most normal, street-driven vehicles. For race or other high-performance vehicles the only exceptions I would take are with regards to the the pressure of the rad cap and the percentage of Ethylene Glycol or Propylene Glycol in the coolant, as we have discussed.

1. Thou shall make room for an adequate cooling system in the design of your engine compartment.
First things first. When planning your performance vehicle, remember that you're building it to drive, not to sit and steam. Plan adequate space for the cooling system including the radiator, fan, shroud, over flow tank and mounting brackets. Talk with a cooling specialist to help you size the system for your vehicle, engine and driving habits. Consider the investment compared to the total cost of the car.

2. Thou shall shroud thy radiator when using a fan.
Fans move air through the radiator assisting in cooling the engine. A fan without a shroud is better than no fan. But, consider this. At idle or cruising speeds, you need the entire cooling system working at its optimum. An unshrouded fan is moving air through only the portion of the radiator equal to the surface area of the fan. For example, on a '32 Ford, the area of a 15.50" fan is about 189 sq. in.; the core of the radiator is approximately 371 sq. in. This means that almost 49% of the unshrouded radiator is not receiving any benefits of the fan. Shrouding your radiator lets the fan pull air through the entire core.

3. Thou shall use an electric fan.
Rule of thumb. Only choose a mechanical fan over an electric fan if it's your farm tractor. An electric fan is preferred because when you need a fan the most (at idle or cruising speeds) an electric fan is delivering maximum air independent of engine RPMs. Fans that move 2000-2300 CFMs are worth the investment. Preference should be given to a "pull" vs. a "push" fan. Mounted on the engine side of the radiator, a pull fan does not interfere with air flow at highway speeds. All shrouded fans should be on the engine side of the radiator.

4. Thou shall consider airflow or how a radiator cools.
Without adequate air flow, a radiator is just a reservoir for hot water. Coolant transfers heat to the tubes; the tubes transfer heat to the fins; air moving through the fins dissipates the heat from the radiator. You need sufficient openings to the radiator that channel adequate air to the entire surface area of the radiator. You must have a radiator design that allows the air to pass effectively through the radiator (wider and taller is better than thicker). You must consider how the heat will be evacuated from the engine compartment.

5. Thou shall use the proper water pump pulley ratio.
To obtain the maximum operating efficiency rate for your water pump at highway speeds, you should overdrive the pump by 30-35%. Check your pulley selection. Most after market pulleys are a 1:1 ratio. For a 30-35% overdrive, the crank pulley should be approximately 7 7/8" and the water pump pulley approximately 5 3/4". This overdrive provides proper coolant flow from the engine and through the radiator.

6. Thou shall consider the effects of the pressure cap.
The higher rated the pressure cap, the hotter the water has to get to boil. One pound of pressure raises the boiling temperature 3°F. A 16-pound cap raises the boiling point to 268°F. If your engine is designed to run at 200°F, a 14-16-pound cap should be sufficient. Running a higher pressure cap to prevent boil over is putting a band aid on another problem that needs to be fixed. Higher operating pressure places additional stress on the entire engine system and increases the potential of hoses bursting and possible injury.

7. Thou shall understand the operating temperatures of today's modern engines.
All engines have "normal" operating temperatures. Running engine temperatures well above or below recommended temperatures could cause damage. Most of today's engines operate in the 180°-210°F range. Pollution laws, new oil blends and higher combustion gasoline have forced engine design changes that have increased operating temperatures over the past decade. Consider your engine's normal operating temperatures when selecting your radiator's cooling capacity.

8. Thou shall always use a thermostat.
The thermostat controls engine coolant temperature. It stops the flow of coolant through the radiator until the coolant reaches the thermostat's preset temperature. Operating your engine within its temperature parameters reduces wear, helps control emissions and turns any moisture in the crankcase to steam where it is removed by the PCV system. Select the right thermostat for your engine's operating temperature range.

9. Thou shall protect thy cooling system with recommended coolant.
It is essential to use a premium coolant that protects the radiator, other metal parts and seals. Today's coolants are a scientific blend that normally includes water wetter and corrosion inhibitors.

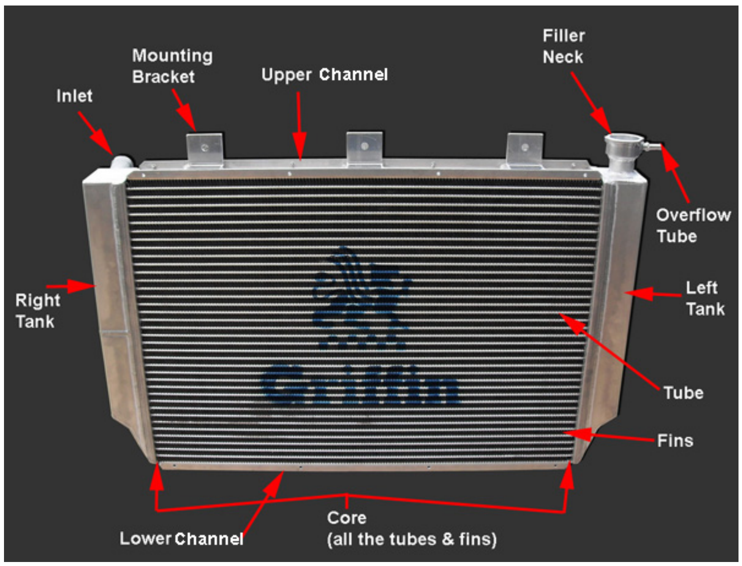
Use of a coolant that contains no silicate is recommended. Silicate is an abrasive and can cause gel formation and water pump failure. A 50/50 mix of coolant and water provides the best overall cooling efficiency. Proper maintenance (regular flushing and changing of coolant) will extend the life of your system.

10. Thou shall spend thy money wisely.
If you are having cooling problems, begin by looking at the least expensive fixes first. 1) Add an electric fan. 2) Shroud your fan. 3) Check your belts and hoses. Slipping belts or collapsed hoses mean trouble. 4) Check your radiator cap. 5) Flush and refill with premium coolant. 6) Use the proper thermostat. 7) Clean the radiator of foreign materials. 8) Overdrive the water pump 20-30%. 9) Check your water pump. Should cooling problems persist, it may be time for a new performance radiator from Griffin. Call the Griffin Customer Service Department at 1-800-722-3723 for assistance in selecting the correct radiator for your requirements.
***** WARNING: Improper wiring can cause electrolysis and destroy the radiator. Please make sure radiator is not used as a ground. *****

Now we will cover some tech details and advice on selecting the main components for any cooling system, but focusing especially on a cooling system for an offroad rig powered by a Gen III or IV GM V8

The Radiator

First - let's just go over the main parts of the radiator, because, as usual, some folks insist on using terms loosely or incorrectly which can lead to confusion.



The tanks are connected by the tubes. Coolant enters the tank with the inlet port, and flows between the tanks via the hollow tubes (which are actually very wide and thin in cross section, not round). Sandwiched between the tubes are the fins. The part that forms the actual joint between the rows of tubes and the tanks is called the header - you can't distinguish it in this pic, but you will see a pic of the header later when I show you a Griffin Rad being built. The combination of all the tubes and fins together is called the core. Thus, the two major components are the core and the tanks. The core will always have many rows of tubes between the top and bottom of the rad, but it may also have one or more rows of tubes (from front to back) for each "row" between the tanks. You can't easily tell this, because the rows of tubes would all be one behind the other. Some folks interchange the word "core" for "tubes" so that you may hear them say they have a "3-core rad". What they mean is that the core of their rad uses 3 rows of tubes, one in front of the other, for each "row" between the tanks - not that the rad has 3 complete cores!