

## **Wrangler JK Engine Cooling**



### **Preface**

In the old days the temperature gauge was a simple and direct monitor of engine cooling. Contemporary cars with their recovery tanks, electric fans, and electronic controls provide more efficient and optimal control of engine operating temperature. But the added components also provide more failure modes. Bad things can happen before they show up on the temperature gauge or in a Diagnostic Trouble Code.

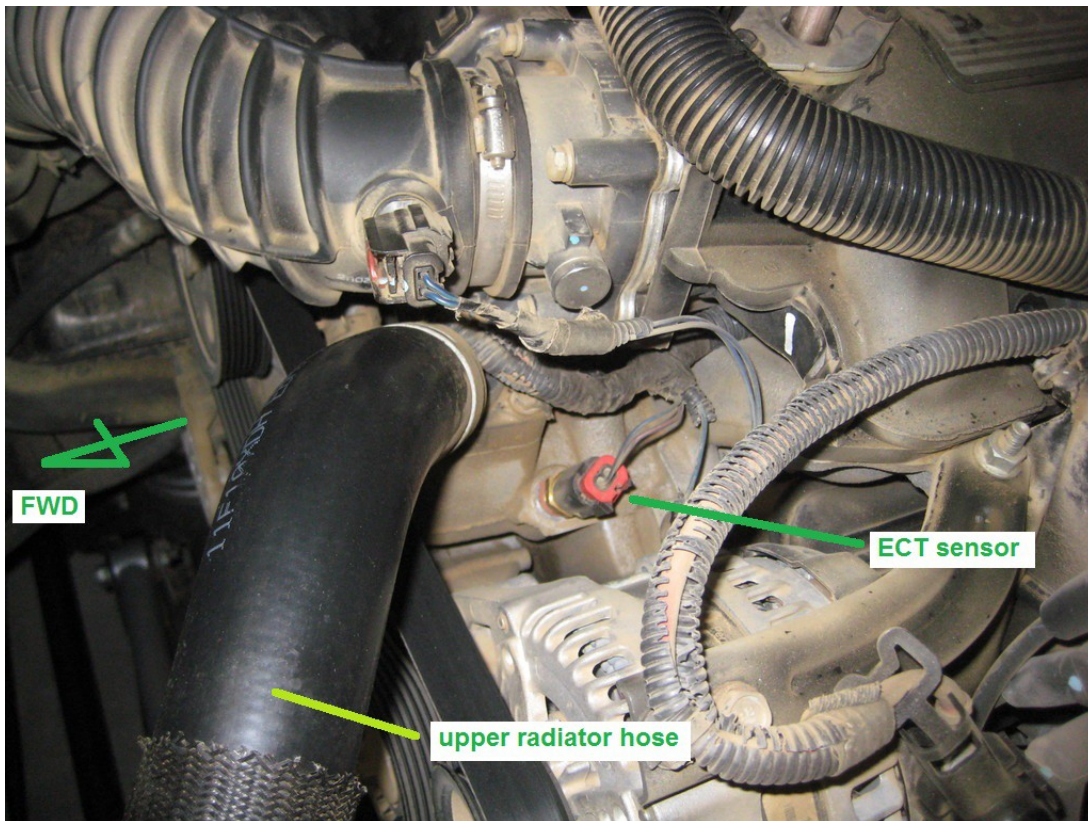
Here I describe what to expect from a normally operating system. I also describe a problem that didn't show on the gauge and didn't “throw a code”.

The particular vehicle in this case is a 2009 Jeep Wrangler JK with the 3.8l engine. The principals should also apply to most vehicles.

## **What to Expect During Normal Operation**

Here is what you should see with everything working normally. Begin with the engine cold. (Typically 70 F ambient in my case.)

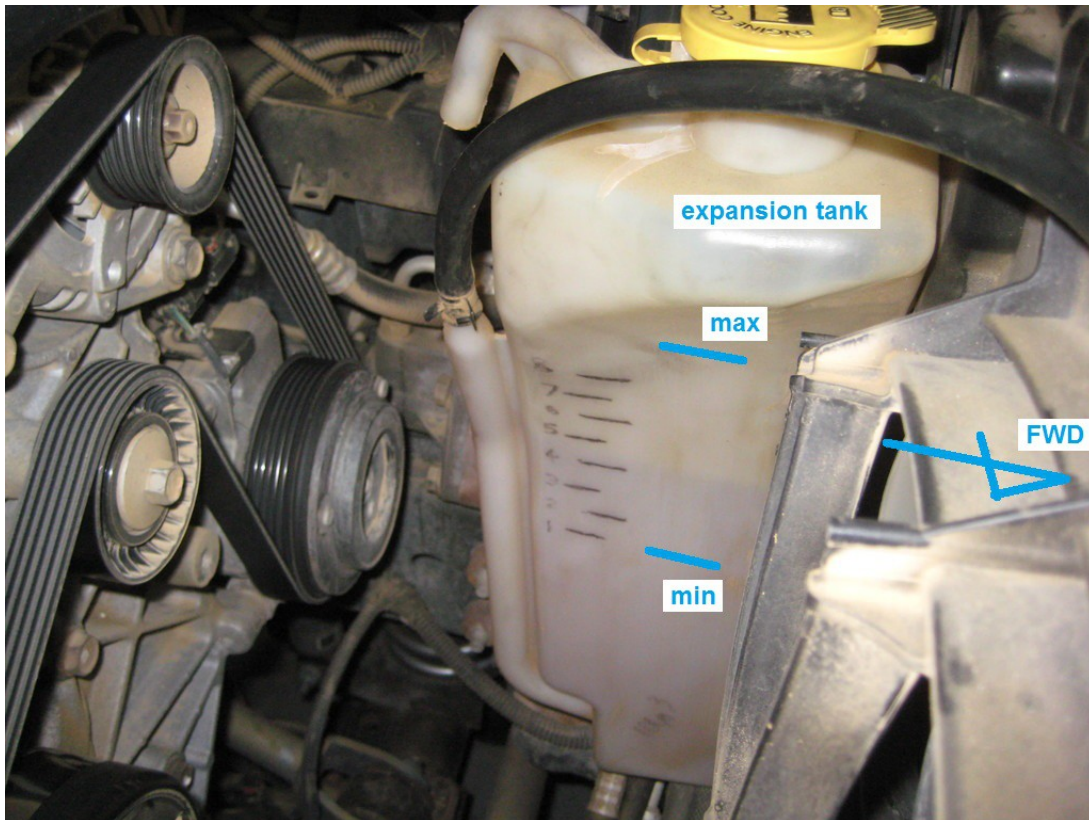
Squeeze the upper radiator hose. It shouldn't be hard to squeeze it to half its rest diameter. It should not collapse all the way. There should be no bubbling or gurgling sound. (I hear a little clicking, probably coming from a part of the thermostat.)



If the hose collapses or you hear bubbles then you have air in the system. This may be a minor problem or it could be a symptom of something more serious. (Possible causes include empty recovery tank, bad radiator cap, or even blown head gasket.)

If there is air it needs to be purged. A normally operating system can purge itself of a small amount (half a liter?) of air. If there is too much air it can't recover and bad things will happen (or have already happened). I won't cover purging here. You can find references on the internet.

Check the level in the recovery tank. It should be between the min and the max marks. Take note of your level.



I drew some extra marks on my tank so as to better see what is happening.

Start the engine.

After about 3 minutes the dash board temperature gauge should start to show something above “cold”.

After about 10 minutes the gauge needle will be about one small division below mid scale. That corresponds to a coolant temperature of about 170 F. The thermostat will still be closed and the upper radiator hose will not be hot. You should be able to get good heat from the heater.

After a couple more minutes the temperature should be about 195 F. The thermostat will open and the upper radiator hose will get hot. The gauge needle will be right at mid scale (or a hair below).

The level in the recovery tank should also have risen by between 1 and 1.5 inches. It should not rise more than a couple tenths of an inch hereafter.

After another 5 minutes the electric radiator fan should turn on at its low speed. The temperature gauge will still show at mid scale as above. The recovery tank level might be very slightly higher as just mentioned.

After about a minute the fan will turn off. Then after another 3 minutes the fan will turn on again. It will continue to cycle that way, 1 minute on, 3 minutes off. There will be practically no change in the temperature gauge indication.

When you turn the engine off and it cools off, the recovery tank level will eventually return to approximately its starting level. That will take hours.

## **The Insidious Problem**

I had a problem with my vehicle that wasn't real obvious at first.

### Symptoms

- recovery tank level at Min mark when cold and at Max mark when hot.
- Occasional bubbling, gurgling sound coming from engine when pausing after slow driving.
- Radiator fan turning on occasionally
- Temperature gauge never showed above normal (mid scale).
- No Diagnostic Trouble Codes
- Some engine knock heard while under load at low speed
- Coolant system full. No air in the system when cold.

If you are a fan of Car Talk and like to see if you can figure out the problem before Click and Clack then pause here before continuing.

## Trouble Shooting

First I calculated how much the recovery tank level should actually rise. I looked up the expansion coefficient of the coolant, coolant capacity, and thermostat setting. I calculated the level should rise a little more than an inch. So when it rose from the Min mark to the Max mark that was definitely a sign of a problem.

The first easy possible fix came to mind, radiator cap. Maybe it wasn't holding pressure and coolant was boiling at lower temperature. It would be a cheap and easy fix. \$5. Tried it. No joy.

But in testing it I noticed that if I started and immediately got rolling the recovery tank level rose the 1+ inch and stayed there. Then when I stopped and let it idle, after a few minutes the level would rise to the Max mark in a couple minutes time. Then the fan would come on. After shutting the engine off and waiting 10 minutes the level started falling quickly. In a couple minutes it was back down to the 1+ inch level. So obviously the big rise was steam expansion and the quick fall was the steam condensing again. The temperature gauge was showing at the center the whole time.

I decided to do a controlled test. Cold start, idle in the garage, and measure everything. I had an IR thermometer to measure the temperature of the manifold by the engine coolant temperature (ECT) sensor. I used an OBDII interface (BAFX interface and Torque Pro phone app) to read the ECT sensor value.

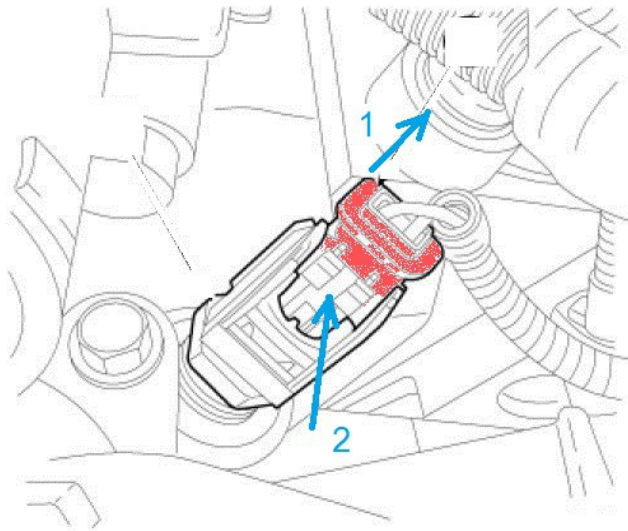
I'll spare you all of the details but there were two significant observations. When the boiling sound was heard the OBDII was showing 212 F. That temperature is significantly lower than that at which coolant should boil at in a pressurized system. And the IR thermometer was showing about 237 F on the outside by the ECT sensor. These things suggested that the ECT sensor was defective, not a hard failure but giving a low reading.

I replaced the ECT sensor. And that is what the problem was. What are the odds of that? The soft failure generally explains why it didn't throw a code. Maybe it would have eventually failed hard. In the mean time it was stressing the engine. It was running hotter, allowing steam to displace coolant, and causing engine knock.

## Repair

The ECT sensor costs about \$26 at most auto parts stores. It comes with some sealing material already on the threads.

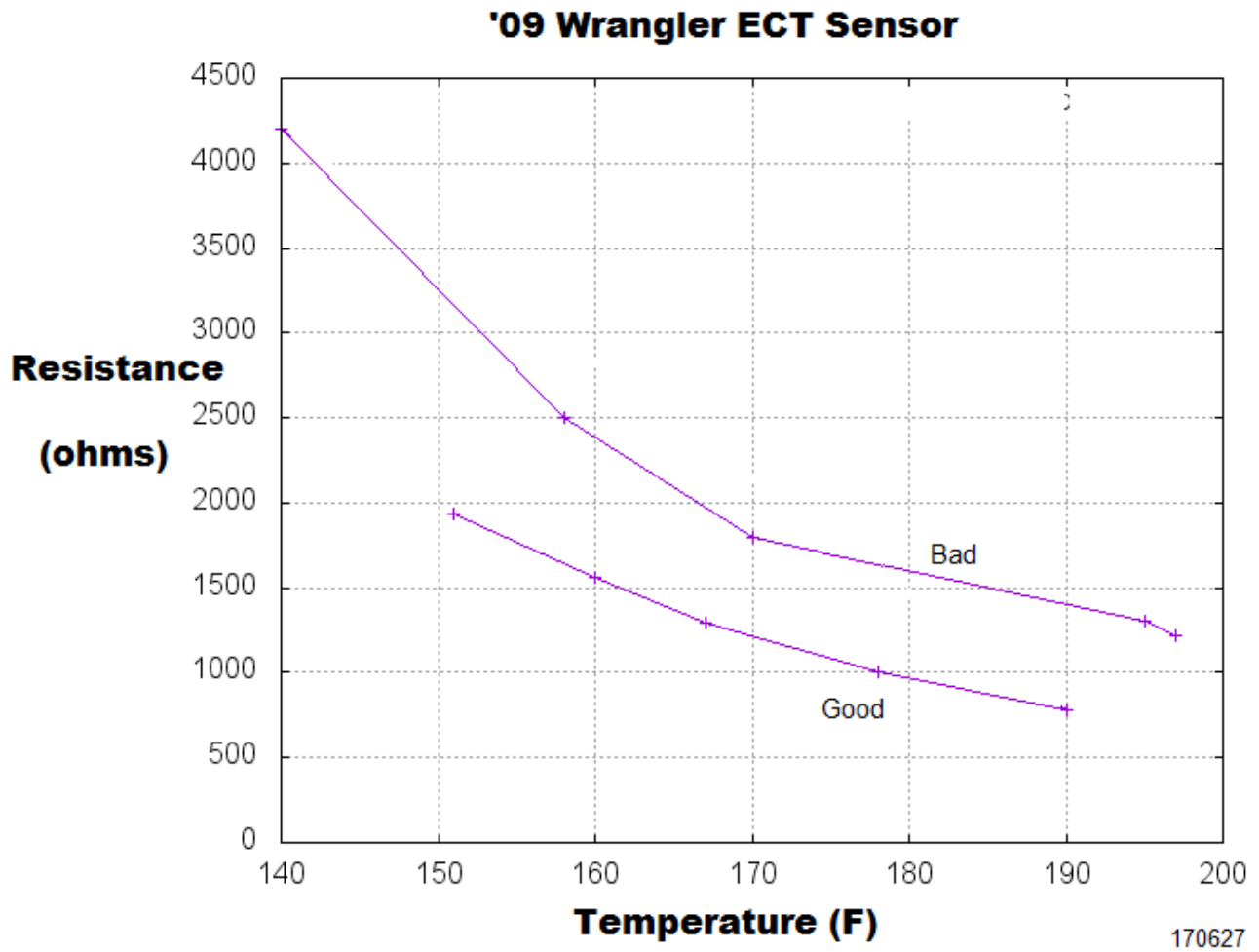
I was going to drain some coolant so it wouldn't run out when I removed the sensor. But the radiator drain is inconvenient to access. (Cheesy plastic fasteners hold the damn air dam.) So I thought I'd put rags around the sensor and do a quick swap. That wasn't necessary. The coolant sat there and didn't run out.



If you don't do this kind of thing every day then disconnecting the connector might be a minor puzzle. First you pull the red part up about a quarter inch. Then you push in on the black tab while wiggling the connector off.

### Sensor Post Mortem

I measured the performance of the new and old sensors for comparison and verification. The sensor is a negative temperature coefficient thermistor. It's resistance goes down with increasing temperature. I measured the performance with an ohmmeter, a pot of water on the stove, and a cooking thermometer. Below is a graph of the results.

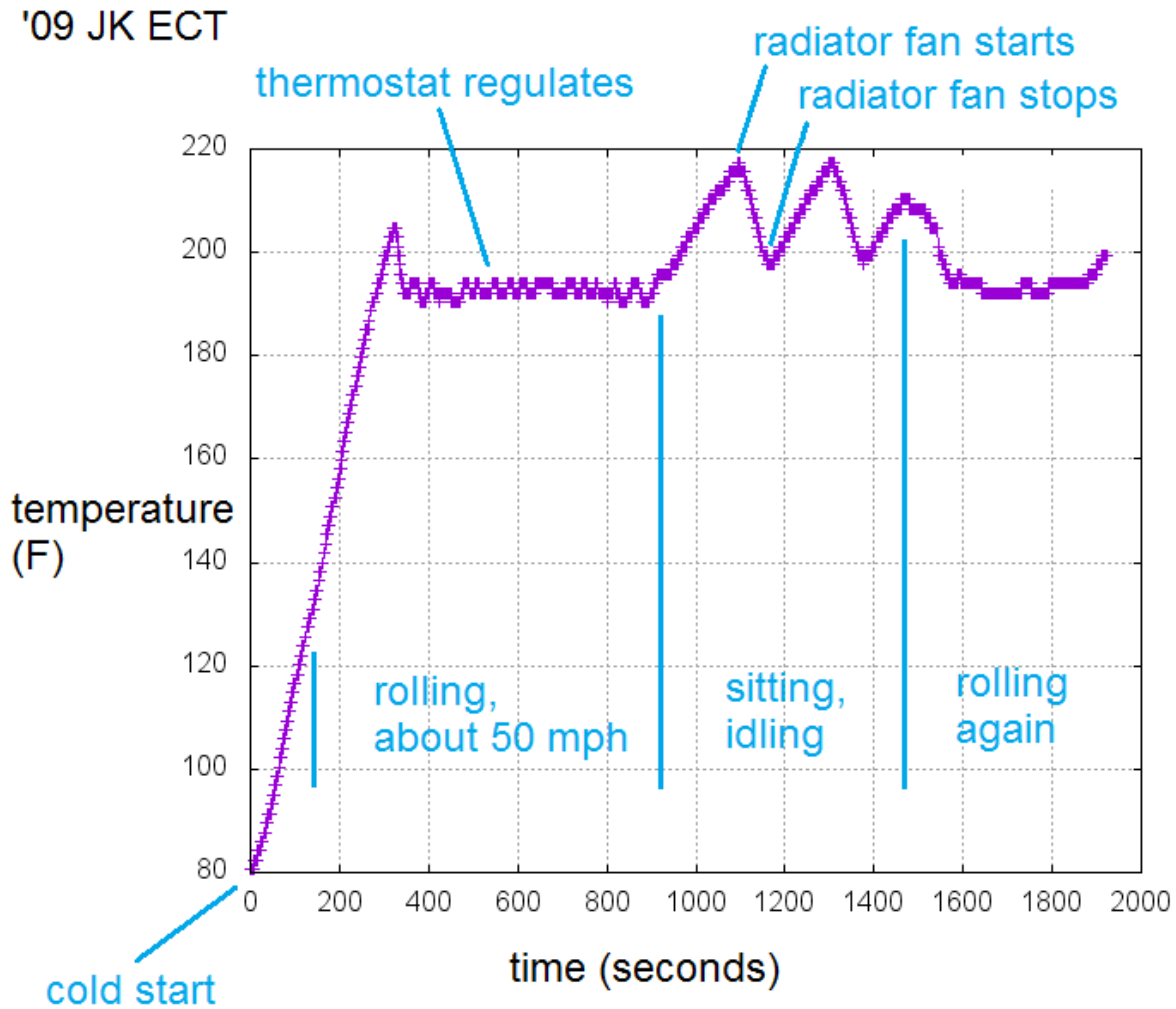


So, yeah, the bad one was bad. About 25 to 30 F off. Who would have expected such a sneaky failure mode.



## Interesting Facts

I did a test run from a cold start and recorded engine coolant temperature (with the BAFX and Torque Pro). Samples were taken once per second. The results are plotted below.



Before the engine reaches normal operating temperature (about 195 F) the thermostat is closed.

In the graph you see a spike in temperature at the 300 second point. I don't have a definite explanation for that. Maybe the thermostat sticks a bit when it first opens.

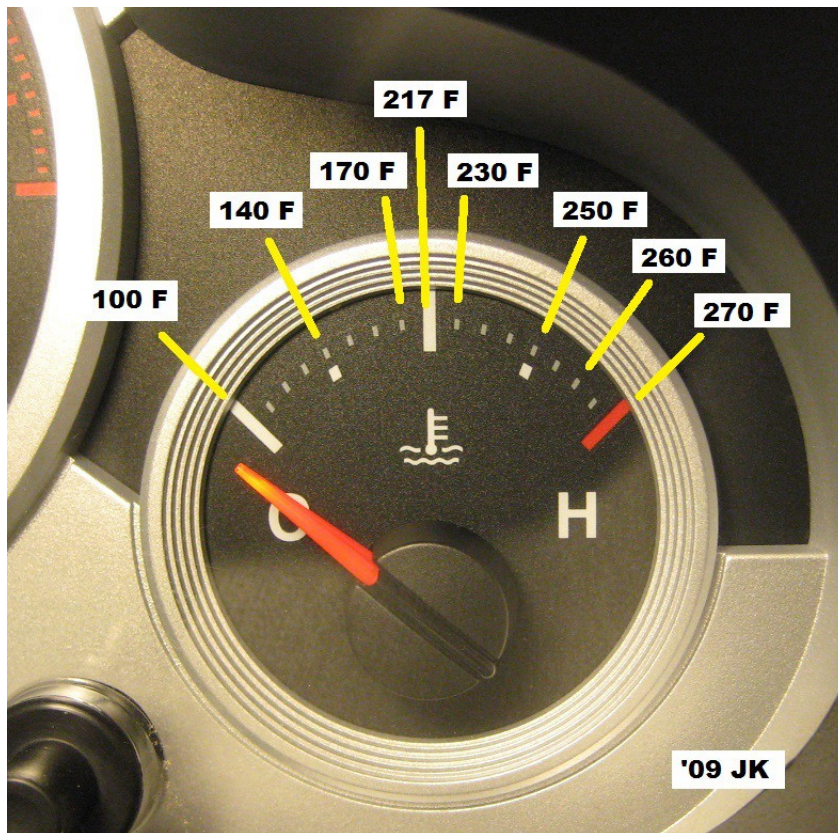
When the engine is warmed up and vehicle motion is giving good air flow over the radiator then the thermostat regulates ECT. The thermostat is set at 195 F. From other observations it seems that the vehicle has to be going about 35 mph or better (at 80 F ambient) to get enough air flow to allow the thermostat to do the regulation.

When going slow or standing still the Powertrain Control Module (PCM) basically takes over ECT regulation (using the electric fan). When the PCM sees ECT reach 213.8 F it turns the fan on (at its low speed). When the ECT gets back down to 203.8 the PCM turns the fan off. The thermostat will be fully open during this time.

.....

Note that the coolant level in the recovery tank acts like a thermometer. The level gives a general idea of the ECT. The coolant expands with temperature, just like the fluid in a thermometer. (The engine expands too but not as much.) So if the engine is cooled to an ambient of 80 F and you run it up to operating temperature, 195 F, the level will rise about an inch (with my '09 JK). If you drive it to somewhere where the ambient is 30 F overnight then the next morning you'll find the level about a half inch lower than it was at the 80 F ambient.

The temperature gauge is not linear. Below is a picture of the gauge with actual temperature values marked.

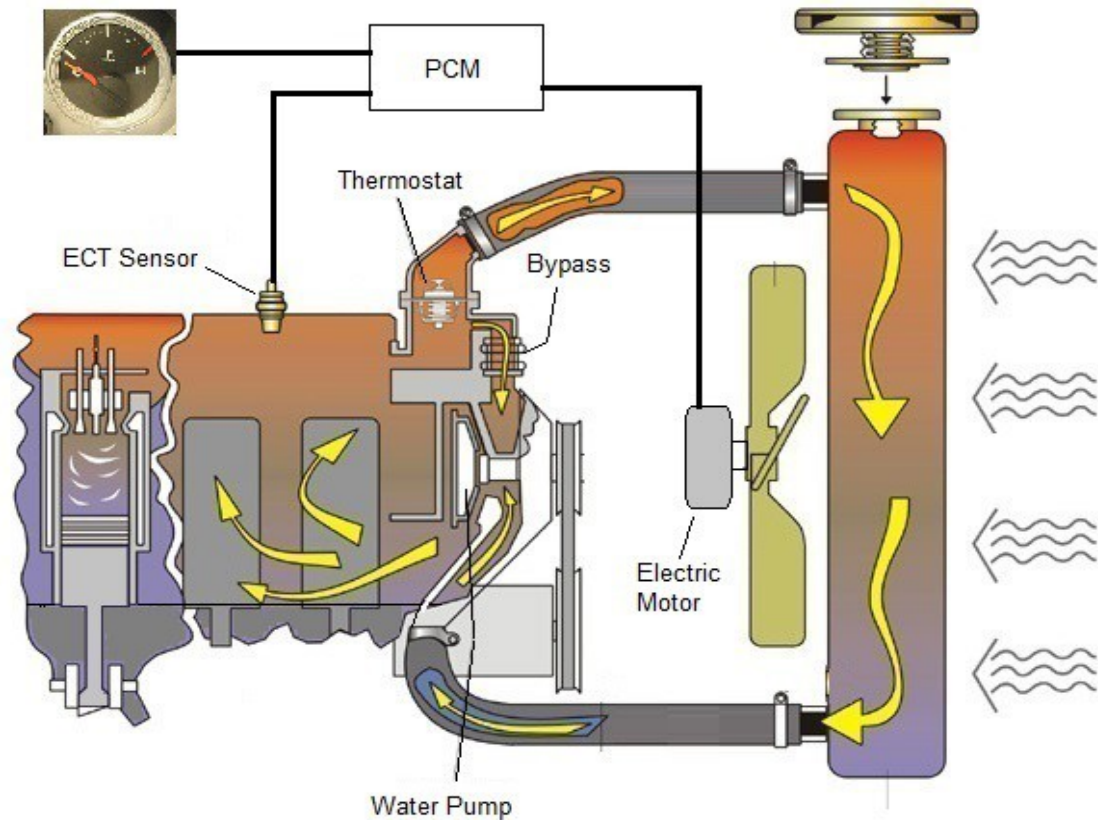


On the left side the small divisions are about 10 F each. Then there are about 50 degrees crammed into the one division on the left side of center scale. This is apparently by design. I suppose they didn't want the customer to see the 20 F swings when the fan runs.

The gauge is controlled by the PCM. The PCM reads the ECT sensor and then sends a serial digital message to the instrument cluster via a CAN bus. The message tells the gauge what angle to set the needle. Obviously it is controlled by software. The software apparently scales/compresses the gauge indication.

## System Basics

Most of you probably already know this stuff. Here is a system level overview.



Combustion is affected by cylinder and head temperature. The cooling system tries to control the temperature at a relatively fixed optimum temperature. Then the spark timing and mixture are adjusted for optimum combustion depending on load, air density, etc.

When the engine is cold the thermostat is closed. That blocks flow through the radiator. The water pump recirculates the coolant around the block and heads. The coolant bypasses the radiator by going through the bypass. (Note that in the JK the bypass is actually through the cabin heater core.) So overall, cooling is reduced to quickly get the engine up to optimal operating temperature.

When the coolant gets up to the design temperature the thermostat starts to opens. That allows coolant to flow through the radiator. The thermostat opens wider at

higher temperature. That has the effect of regulating the coolant temperature in a narrow range. That is, as long as there is good air flow through the radiator.

When the vehicle is moving slow or stopped there isn't enough air flow through the radiator. The ECT rises. The thermostat is fully open but that can't keep the temperature in range. The PCM sees the ECT rising and turns on the fan. It controls the fan to keep the temperature within limits.

The electric fan system allows the vehicle to have a smaller radiator. The radiator doesn't have to be big enough to radiate all the heat when the vehicle is stopped and the engine is idle. And it is more efficient in that no energy is put into turning the fan when traveling at highway speed and there is already sufficient air through the radiator.

Side note: ambient air is typically 100 F cooler than the target engine coolant temperature.