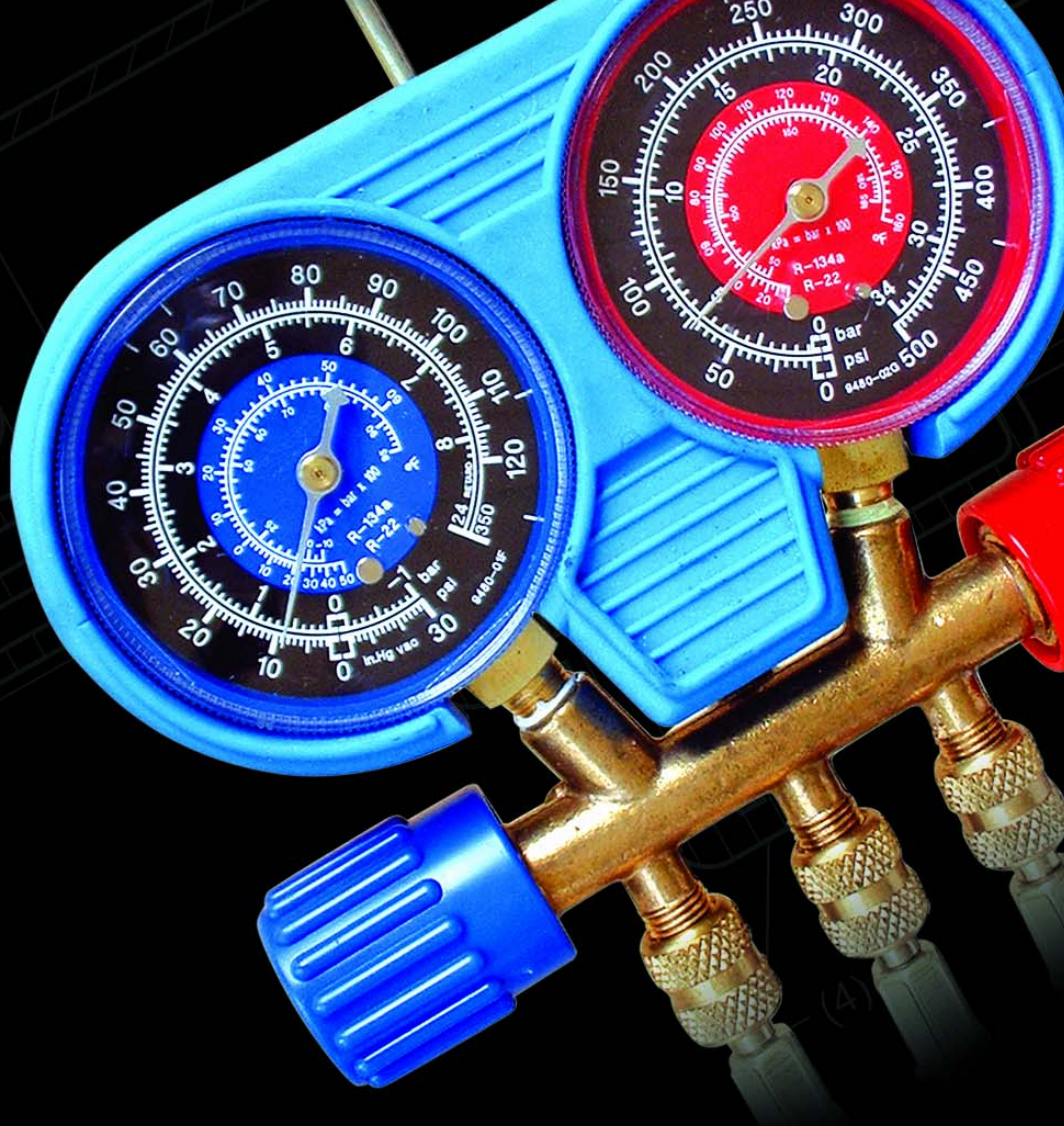
# Refrigeration Revisited

## You need to know these principles.



It's that time again — the height of the air conditioning service season. Are you truly ready? Sure, you've pulled out the recycling equipment, checked the filters, priced refrigerant, ordered PAG oil, O-rings, suction screen kits, dye, etc. But have you dusted off the basic knowledge that allows you to both troubleshoot accurately and do the job in a craftsmanlike way that avoids comebacks? No? Well, you're just sitting there reading anyway, so take a few minutes to reinforce your skills with the following look at the refrigeration principles that Subaru vehicles, and indeed all cars, rely on.

## Blend

In order for any HVAC system to work, it has to have a source of hot air and a source of cold air, a means to draw fresh air from outside and a way to recirculate cabin air (to minimize the smell of a squashed skunk or the "fresh" country aroma of a pig farm, while improving heating/cooling efficiency under extreme conditions). The hot side comes from the engine via the heater core, and the cold side from the air conditioning system via the evaporator core, both located in the plenum under the dash. Manual or ATC, we blend hot and cold to get the duct temperature required for passenger comfort.

In order to make a humid 99-degree day tolerable inside that greenhouse we call an automobile, we have to enlist the laws of physics. This is accomplished by taking advantage of the fact that as a refrigerant changes state from liquid to vapor it absorbs heat — LOTS of heat — allowing us to redirect this heat to the outside via the compressor and condenser.


*The process that produces cold air at the ducts seems almost magical until you really understand the physics.*

## Latent Heat Miracle

There are two kinds of heat, sensible and latent. Sensible heat is what you can feel and measure. Latent heat is hidden, heat that is absorbed or given off without changing the measurable temperature of the medium involved. We're all familiar with water, right? Start with a pound of water at 70 deg. F. It takes one British Thermal Unit (BTU) to raise the temperature of one pound of water one degree Fahrenheit. If we add 142 BTUs to our pound of water, we'll raise its temperature to 212 degrees. If we continue adding heat, we'll eventually boil the water away, changing its state from liquid to vapor. It takes an additional 970 BTUs to convert that one pound of water to one pound of saturated steam once the water is at 212, but the whole time the water is changing state from liquid to vapor its temperature remains at 212 degrees.

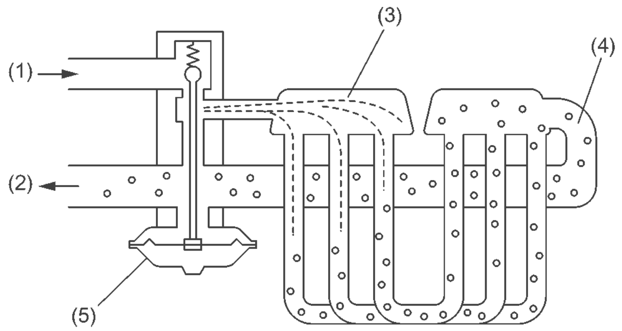
That 970 BTUs of energy is called the latent heat of vaporization, and, unlike the first 142 BTUs we added, it never raises the temperature of the water. It's the amount of heat needed to force the water molecules to jump from the surface of the boiling liquid with enough energy to escape. That's all heat is, anyway — a measure of molecular energy, of how rapidly the molecules of a substance are vibrating or moving.

All substances can exist in one of three states — solid, liquid or vapor — and all substances have latent or hidden heats of vaporization, condensation, liquefaction or solidification (sometimes called fusion). Anytime a substance changes state, hidden heat is released or absorbed in association with the change of state. The fact that steel normally exists as a solid at room temperature doesn't meant it can't exist as a liquid or vapor. It just takes a lot more heat to liquefy and subsequently vaporize steel than it does water. Water, the most abundant compound on earth, exists as liquid, solid and vapor within the normal range of temperature most of us experience in life, thus we've all seen it in its three states of ice, water and steam.

## The Medium

Everything in our surroundings is subject to these rules, including refrigerants. In order for a compound to be useful as a refrigerant it has to have certain characteristics, cold enough boiling points for example. Even though we mainly deal with R-12 and R-134a, you'd be amazed at the number of refrigerants available — we know of at least 86. Even water has a refrigerant number: R718.

We need a refrigerant that's stable, changes state at temperatures that are useful to us (different applications use different refrigerants with different boiling points) and is non-corrosive. It should also be non-flammable, non-toxic and safe to handle. For all modern automotive applications, we use R-134a. It boils at about -16 deg. F. (for comparison, R-12 boils at -21.7), and has no chlorine to damage the ozone layer.




1. From receiver drier
2. To compressor
3. Misty refrigerent
4. Vapor
5. Expansion valve

*Here's where the flash-gas miracle takes place. A huge amount of heat is absorbed considering there may be as little as 16 ounces of refrigerant in the system.*

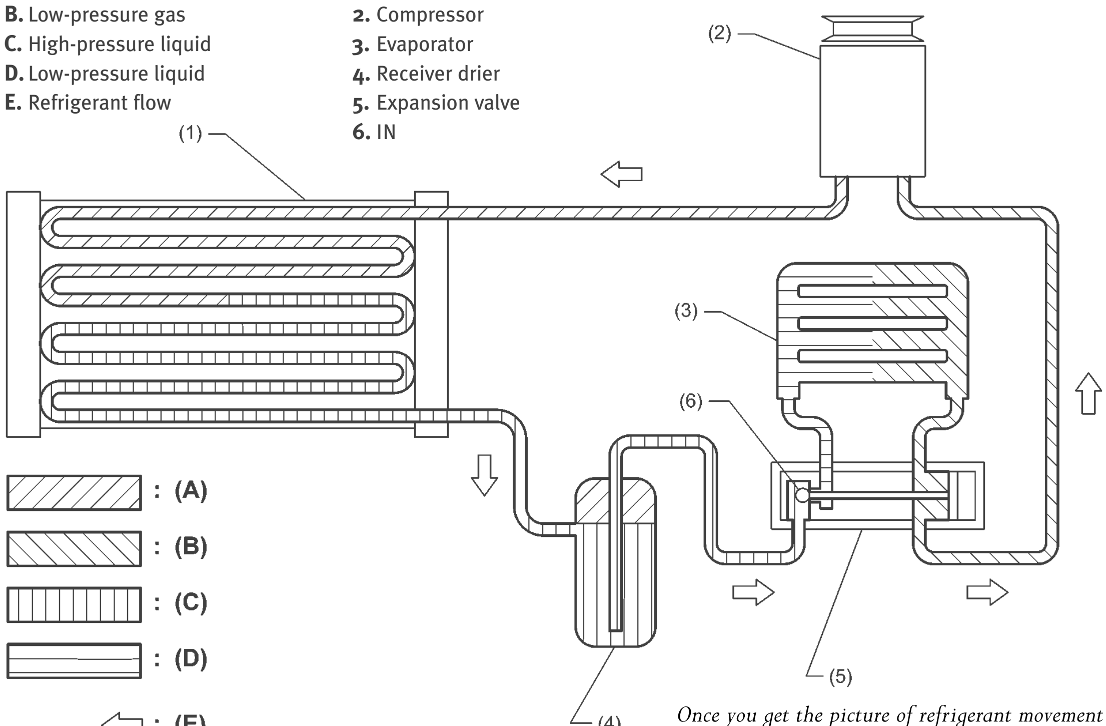
## Expansion and Flash Gas

Obviously, air conditioning systems are designed to take advantage of both physics and the characteristics of the refrigerant. Let's start the process at the expansion device (you know, an open tank of refrigerant would make a fine refrigeration system if R-134a weren't so expensive — you could just plumb a big tank to the expansion device at the evaporator inlet and dump the outlet of the evaporator into atmosphere, and you wouldn't need a compressor or evaporator). By holding the refrigerant in the system under pressure, we keep it from boiling until it's delivered to a heat exchanger located where it can cool the cabin of the car. As the refrigerant passes the expansion device, it's atomized into small droplets, and in the low-pressure area of the evaporator the outer layer of each droplet boils away, lowering the temperature of the remaining liquid to -16 deg. F. This initial boil-off is called the "flash gas." The center of the droplet remaining after the flash gas boils off, now cooled to -16 degrees, enters the tubes of the evaporator. On the opposite side of the tubes the fins are attached, increasing the surface area of the core. The blower pushes air from the cabin through the fins. In doing so, the remaining portion of the droplet boils away to a low-pressure, low-temperature vapor, absorbing 84 BTUs of heat per pound as it changes state, and the cabin air is cooled and dehumidified.

We grab this vapor and recycle it over and over by attaching the suction side of a pump to the evaporator outlet, thus maintaining a low pressure area into which our refrigerant can expand. The pump will take a large volume of low-pressure, low-temperature gas and compress it into a high-pressure, high-temperature gas. We have to do this because the gas temp at the evaporator outlet is less than ambient, and in order for us to reject heat, the vapor temperature must be higher than ambient — heat only flows from a higher to a lower temperature, the first of those immutable laws of thermodynamics. We compress and concentrate not only the volume, but also the heat. Now that the vapor is warmer than ambient, we throw it into a condenser, where (because the vapor temp is

**A.** High-pressure gas
**B.** Low-pressure gas
**C.** High-pressure liquid
**D.** Low-pressure liquid
**E.** Refrigerant flow

1. Condenser
2. Compressor
3. Evaporator
4. Receiver drier
5. Expansion valve
6. IN




*Once you get the picture of refrigerant movement and changes of state, the physics start to make sense.*

now in the 130-165 degree range) it dumps heat to the air flowing through the condenser (90 looks pretty cool compared to 130-165). As it rejects its 84 BTUs per pound, the vapor is condensed into a high-pressure, high-temperature liquid, and as is routed once again to the expansion device, where it's atomized, flash gas drops the temperature of the remaining liquid, and it changes state in the evaporator once again, absorbing another 84 BTUs per pound of heat from the cabin.

So, those few ounces of R-134a (some late model Subaru systems hold only 16 to 18 ounces) change state over and over, pumping heat from the cabin to the atmosphere. The downside? As ambient temperatures rise, the system loses capacity because liquid line temperatures also rise, and more refrigerant is expended as flash gas to cool the increasingly hotter liquid coming from the condenser. Air conditioning would stop working altogether if the ambient temperatures and humidity rise to the point where insufficient heat is dumped and liquid line temperatures get high enough so that all of the refrigerant metered by the expansion device is consumed as flash gas, and no liquid makes it into the center of the evaporator to change state and absorb heat.

## Practical Points

With that theory in mind, the following points will make more sense:

- Take a careful look at aftermarket condensers and evaporators to make sure they match the originals. A simple 3/8 in. tube-and-fin type won't work in a modern multi-flow application. Buy O.E., or only the best brand names.

- Apropos of the above, R-134a is commonly blamed for poor performance after retrofit when the real reason is often that the replacement condenser or evaporator is not up to O.E. standards for heat rejection.

- Another factor in the weak-cooling retrofit situation is air (NCGs — Non-Condensable Gases). We've seen the problem corrected by simply removing the charge and running the vacuum pump overnight. That's really what you're vacuuming, you know. You can't get much moisture out no matter how long or hard you pull the system down. That's the job of the dessicant.

- We used to have a large margin for error with compressors. Now, with speeds up to 14,000 rpm, terrifically tight internal tolerances, and lubrication issues, much more precision is needed in both remanufacturing and service.

- Compressor lubrication priorities:
  #1 Have oil in there.
  #2 Have PAG oil in there.
  #3 Have the recommended viscosity PAG oil in there.

- The switch to 42-volt systems will bring electrically-powered compressors with it, but the numbers will be small for a long, long time.

- Speaking of compressors, whenever one has worn out or broken internally how do you protect the new unit from the shrapnel that's probably been pumped into the refrigeration circuit? Forget about flushing. It's just not going to do it. While add-on filters that you splice into a line are available, there's often not enough room, and you'll introduce the possibility of a leak. That's what makes the in-line suction-side screen kit so popular. It's easy to install, and will keep any big pieces of metal from getting into the fresh compressor.

*While canister-type filters and screens are available, they're big, hard to install, and amount to a potential leak point. So, whenever you need to replace a compressor, you might want to consider adding an in-line suction screen. It'll help protect the new unit and your reputation.*

- A smelly car interior takes the fun out of motoring and can also be downright embarrassing. Broad-spectrum disinfectant sprays and foams that you inject into the evap box are commonly used to kill the bacteria, mold, mildew, and fungi that grows in moisture, and some products also coat the fins with a water-shedding acrylic. These are vastly superior to the type you spray into the outlet ducts.


*The best way to eliminate that musty odor is to deliver the disinfectant directly to the evaporator core fins.*

- The EPA's Stratospheric Ozone Information Hotline is 1-800-296-1996, and its website is www.epa.gov/ozone/609/609/html

- The automobile is down to just over one percent of man-made ozone-depleting emissions, but the Europeans are pushing for a switch to CO2 systems anyway. ■

# CO2 as a Refrigerant?

Just when we've all become nicely accustomed to R-134a, having paid heavily for that familiarity with huge upheaval, equipment expense and training time back in the '90s, the Europeans are pushing for another profound change. Hello CO2-charged A/C systems.

Whoopee. We're having enough trouble compressing and containing a few hundred psi, and now we're looking at refrigeration at 2,500 psi!

Why? For several reasons, actually. Engines are becoming so energy efficient, it'll soon get to the point that they won't reject enough heat to adequately warm the passenger compartment (think direct-injection diesel semis with their grilles buttoned up in winter). This, of course, becomes much more so with hybrid and electric cars. So, heat pump HVAC systems, which can move BTUs either out of or into the cabin, might be in our future, and CO2 lends itself to this application.

Also, carbon dioxide is about the most harmless thing in the world — you exhale it with every breath, and it makes plants grow. Even though the contribution of motor vehicle air conditioning is now down to not much more than one percent of the ozone-depleting gases our civilization produces, some people, particularly the seriously-green Europeans, say that's not good enough. For political reasons, they may ban R-134a.

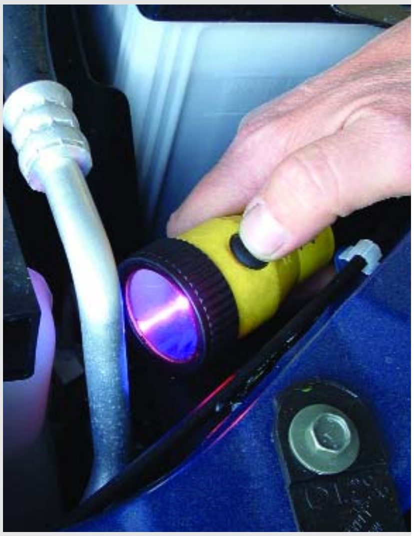
We've heard it rumored that there's another, entirely economic, reason for the push. Since the German automakers and suppliers have this technology pretty well worked out, they figure they could corner the market for systems and components. If over-zealous ecological legislation aids that effort, they won't complain.

On the other hand, Denso, the world's biggest supplier of vehicle climate control systems, acknowledges that this switch will be furiously resisted by the U.S. and others, but nevertheless intends to develop suitable components.

The experimental CO2 transcritical systems we've heard about provide levels of comfort equal to what we've got now, but the drawbacks are considerable. Besides the 2,500-psi operating pressure, there's unusual noise, ice formation in the lines, potentially-troublesome heat exchanger micro-tubes (1/300th of a mm!), and the necessity of fabulously complex controls.

To put this in perspective, suppose the political, technological, and commercial scenarios play out in such a way that CO2 systems first appear by 2010 on a couple of upscale European makes. How long will it take for the other makes to grudgingly follow? Five years wouldn't be a crazy guess. So, R-134a-charged cars will remain in the majority for probably 20 years, then gradually fall off. We think that's plenty of time to amortize your investment in that nice, new do-it-all recycling machine. ■

# Escape Routes



There's never justification for recharging until you've found and repaired any leaks that may be present. Do a careful visual inspection first using a strong light. Naturally, an accumulation of oil and dirt will tip you off to a seepage point.

Another good way to find out if a leak exists is to draw a deep vacuum and see if it holds (where it is located is another matter).

Electronic leak detectors? Well, as one technician we know says, "I have one, but it's up on the shop roof." He got so frustrated with it while working outside in the parking area that his temper took over and he just let it fly. Many other techs dislike electronic leak detectors, too — they require a lot of patience and can trick you.

That's one reason the nearly-foolproof ultraviolet light and dye method has become so popular. Pass the UV lamp (those yellow glasses intensify the effect) over all the components, hoses, connections and condensate drains, and leaks will show up in bright yellow. ■

# A/C, Subaru Style

As one independent Subaru service specialist tells ***The End Wrench***, "The systems are good. We don't have much trouble with them." That's high praise from a person in the trenches of auto repair. Still, any A/C system, no matter how well designed and manufactured, will eventually need service. The following is intended to make sure you're aware of some important specifics about that work on Subaru vehicles.

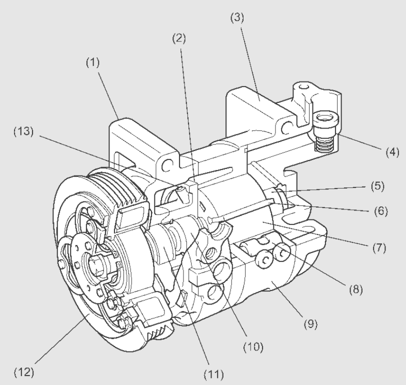
To begin with, these cars don't have a valve that stops coolant flow to the heater core. So, the first thing to think about when a customer complains that the air coming out of the ducts isn't cold enough is to make sure the blend or mix doors are working and sealing properly.

All Subaru vehicles use a cycling-type air conditioning system. That is, when the evaporator approaches freeze-up temperature the ground circuit to the compressor clutch is interrupted. This has the advantage of fast cool-down.

Three types of A/C compressors have been used since 1990:

*Fortunately, late-model Subaru vehicles have the A/C compressor at the top of the engine for easy access. Note also the convenient high-side service port.*

■ Axial piston, which is found on the SVX and the Legacy up to '93. The SVX version was of a wobble-plate design that provided variable displacement as controlled by the ECM. The ZEXEL system of the Legacy had a swash plate. Axial piston compressors will knock if the refrigerant pressure is too high.




1. Front head
2. Side block
3. Rear head
4. Check valve
5. Rear bearing
6. Vane
7. Rotor
8. Roll valve
9. Cylinder
10. Front bearing
11. Shaft seal
12. Magnet clutch
13. Trigger valve

*Most of the Subaru vehicles on the road today use a rotary vane compressor, which is highly durable and dependable.*

■ Rotary vane compressors are the most common on late models. The trigger valve, which routes system pressure to the shaft side of the vanes at low rpm to help them extend, can cause a buzz. While they won't knock, a chattering noise indicates an internal problem.

■ Scroll compressors were introduced this year and promise great performance and longevity. You probably won't be seeing one in your shop for quite a while, however.

Every SOA service compressor comes with a full system charge of the proper oil (PAG — nothing else is acceptable). To keep from over-oiling the system, which can result in poor cooling performance and even damage to the compressor, you may need to drain some oil from the new unit. So, remember to measure the amount of oil you dumped out of the old compressor.


Nothing will work right if the charge is too low, or too high. The A/C label you'll find under the hood gives you the basic amount of R-134a that the system is designed to operate on. If you're not evacuating the A/C, however, you need to hook up your gauge set and check pressures. For most Subaru models, proceed as follows:

- With the ambient temperature between 86 and 95 deg. F., park the car in the shade.
- Open the windows.
- Hold rpm at 1,500.
- Set the controls on Max and Recirc, and switch the blower to high.
- Read your gauges. Low side pressure should be between 18 and 28 psi, that of the high side 213 to 242 psi.

Remember, common causes of high head pressure are a condenser that's blocked by trash and electric fans that aren't turning on.

The automatic temperature control feature is certainly convenient, but it's a complex system. Starting in '03, a self-diagnostic mode was added. We'll refer you to the training materials on http://techinfo.subaru.com for a description of how to use it. ■