THE MOBILE AIR CONDITIONING SOCIETY WORLDWIDE©
MACS SERVICE REPORTS
Total Vehicle Climate and Thermal Management™

By Steve Schaeber, MACS Technical Editor

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Fluorescent Leak Detection

Things that glow have fascinated humans for thousands of years. Some happen naturally, like the bioluminescence of fireflies, or the biofluorescence of marine organisms and scorpions, and some take a little prodding to see, like fluorescent minerals and rocks that glow when exposed to UV (ultraviolet) light.

And people around the world have been using all sorts of fluorescent chemical compounds for generations for everything from leak detection (like mobile A/C) and medical imaging (for the analysis of blood circulation) to party drinks (gin and tonic) and even changing the color of a river. See Figure 1.

Wikimedia Commons

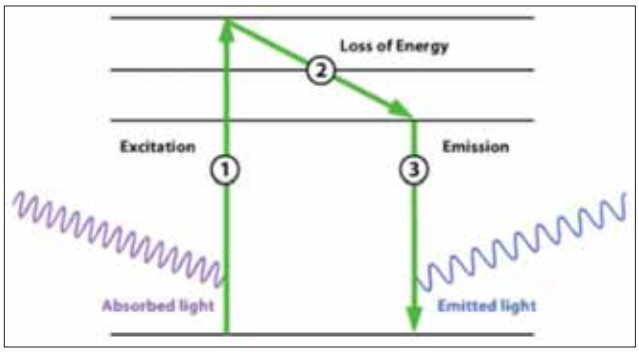
Figure 1: *The City of Chicago dyes its namesake waterway each March in celebration of St. Patrick's Day and its long rooted Irish heritage. Fluorescein had been used in the past, but now a powdered vegetable dye makes the river green.*

There's another age-old technique that people have been using to figure out how water flows, whereby a floating object is thrown into a body of water to see where it goes. Dying a liquid for the same purpose is simply an adaptation of this method, with fluorescent dyes often used in places underground or with poor lighting, such as caves and sewer systems.

The inner light

Let's begin with a quick explanation of how dye can glow.

Some molecules are able to become "excited" to a higher energy state, by absorbing energy from light. This "excited state" can't be sustained for long (only a few nanoseconds, basically, as long as they're exposed to the light), and as it wears off the molecules re-emit light energy that we can see. The whole process is called "fluorescence" which is where we get the term "fluorescent dye" from, while a "fluorophore" is the molecule that does the fluorescing. In its ground state, it's in a relatively low energy configuration, and it does not fluoresce. But when exposed to light from an external source, such as a UV flashlight, fluorophore absorbs the light energy, which puts it into a higher energy state, called an "excited state". This process is known as "excitation". See Figure 2.



Thermo Fisher Scientific

Figure 2: *This diagram shows how dye absorbs light and becomes excited. As it begins to lose energy it starts to glow, which returns the molecule to its ground state. The entire process takes just a nanosecond – or 1 x 10^{-9} second (that's just 1/billionth of a second!).*

It's just another way to dye

We're all familiar with using A/C dye to help detect current or future refrigerant leaks. It's easy to use, since

Melissa Keller

Figure 3: *Popular dye kits come with everything you need: pre-measured dosage bottles, a way to add the dye, a UV light and glasses that make it easier to find leaks.*

you just have to add the right amount (and type) of dye to the system, let it circulate so it mixes well with the oil and refrigerant, and then look around for a leak using a UV light. It may not show every kind of leak, and sometimes dye takes a while before you can see it, but once you do it's a positive indication of where the leak is at. See Figure 3.

But using dye isn't limited to A/C systems. Various dye formulations exist that make it possible to dye many other fluids, like engine coolants (Figure 4).

Dye from a different view

When engineers design systems and components, they don't generally calculate in too much for leaks. Now, that's not to say that they don't expect leaks to happen, it's just that they don't usually allow large margins for error when it comes to fluid loss. Not only does it add initial and maintenance cost to the vehicle, it adds weight, increases environmental risk and, after a point, too much of any fluid is operationally unnecessary.

So, if the engine oil spec says it needs four quarts for example, then four quarts is what it should have. If the rings are bad and its burning oil, or if there's a slow leak that drops the level down by, say, half a quart within 100 miles, then that needs to be fixed ASAP. Not only would it be environmentally irresponsible to simply continue topping off, but engine oil is relatively expensive to just keep wasting it like that.

Coolant costs a lot too, and considering how important its job is in transferring heat away from the engine, its level needs to be kept up. And there's not much wiggle room there either; most overflow or surge bottles only hold about 5% of the total coolant volume in reserve. And at upwards of $12 to $15 per gallon retail for premix, an operator who tops off every day adds significant expense to the vehicle.

And then there's the environmental issues we need to think about. Of course, we don't want to pollute the earth, and even though a particular leak might be very small (adding up to only a few drops every now and then), if we consider that leaks like those may exist on a certain percentage of vehicles across the country, they all add up to be a very large leak (when calculating the cumulative effect of all leaks from every vehicle). When each one of us individually fixes just one of those very small leaks, as a whole we are fixing one big giant leak!

Also, in some parts of the US it's a requirement that leaks be repaired. In many of the AQMDs (Air Quality Management Districts) of California for example, technicians are not allowed to recharge an A/C system if it has a known leak. It's known as the "top off law" and although it's not required federally, several other state and local ordinances have adopted California's rule.

A tool for every job

Technicians know there's a right tool for every job, and in most cases, even if you have to go out of your way to get it, using the right tool makes doing the job that much faster and easier, and the results turn out that much better. Same thing goes for dye.

When choosing an engine coolant dye, make sure the one you pick matches up with the system and coolant. For the most part, there are two different coolant dyes; one designed for "conventional green" and the other is a "universal" type that's used with the more exotic colors.

The reason is that some dyes will turn any coolant into a bright green color. That's OK if you're working with conventional green antifreeze (or if you service a specific, closed fleet of vehicles), but not so much when servicing the general public, where you get into the various "specialty coolants" like DexCool, Penta and other OE-specific products.

There have been situations where a technician added "standard" dye into a system with non-green coolant,

Figure 4: Most any circulating fluid presents a potential application for leak detection dye. As long as you can get to a spot so you can see where the leak is happening, dye can help find the exact source of:

- Refrigerant leaks
- Lubricant (oil) leaks
- Hydraulic fluid leaks
- Fuel leaks
- Heat transfer fluid (coolant) leaks

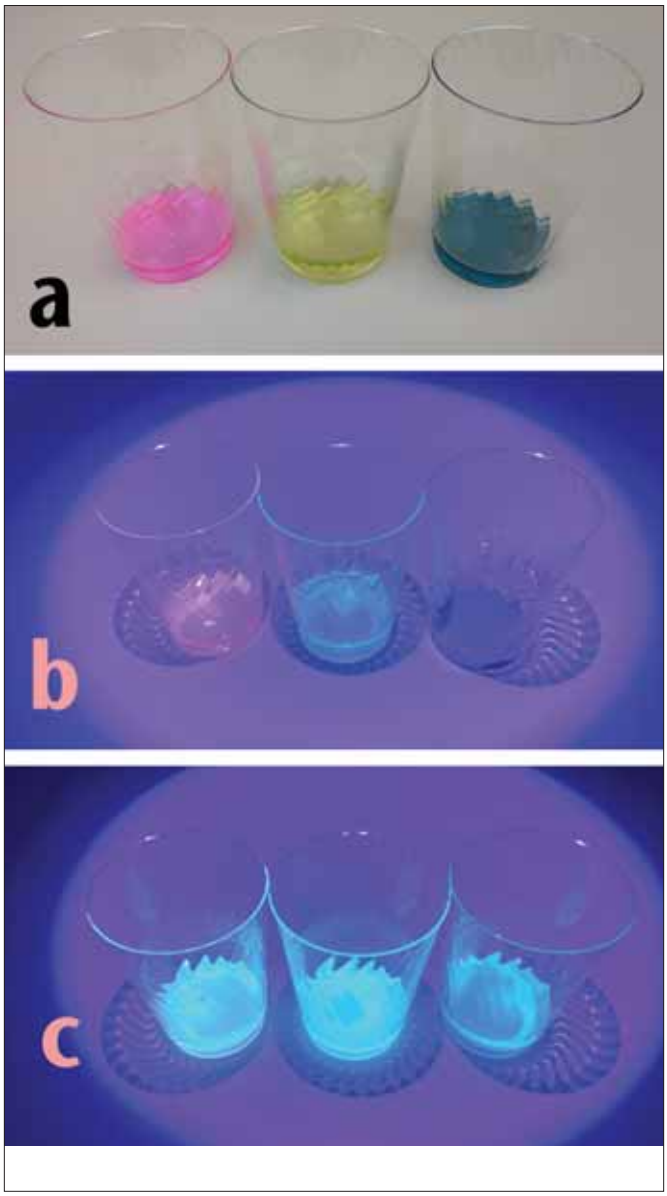


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Figure 5: *Tracer Products dye # TP3940 is safe for many coolant colors. In each from left to right is Toyota pink, conventional green and Mini blue: a) natural light; b) 400nm UV light; c) 400nm UV light with dye added. None of them changed color, but now each glows brightly.*

changing its color to look very green, even in natural light. Although it did its job and fluoresced, the base color of the coolant is changed. This might not sound like a big deal, but it has caused major problems. Consider this scenario:

A customer has yellow antifreeze that is unintentionally dyed green to check for a leak (and of course the customer doesn't have a clue). When the next technician sees the green coolant, they advise the customer that a previous shop or technician must have added the wrong coolant, which has contaminated the system, and now it all needs to be drained and flushed out, and refilled with the proper coolant.

You could imagine how the customer would react. That's a hefty bill to pick up, and in some cases the color-changing dye may not remove those long-life properties. But since the new technician doesn't know about the dye,

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Figure 6: *The entrance door and classroom window at MACS reflect sunlight through glass, which shines a rainbow on our classroom floor.*

they figure the system was topped off with the wrong fluid.

To avoid this, use the correct coolant dye. There are a few different formulas, and some are safe to add to any color of coolant. See figure 5.

The dye's always greener…

Many shop owners do what they can to bring more light into their bays and the trend today is to add those super bright, almost-blue-they're-so-white, LED shop

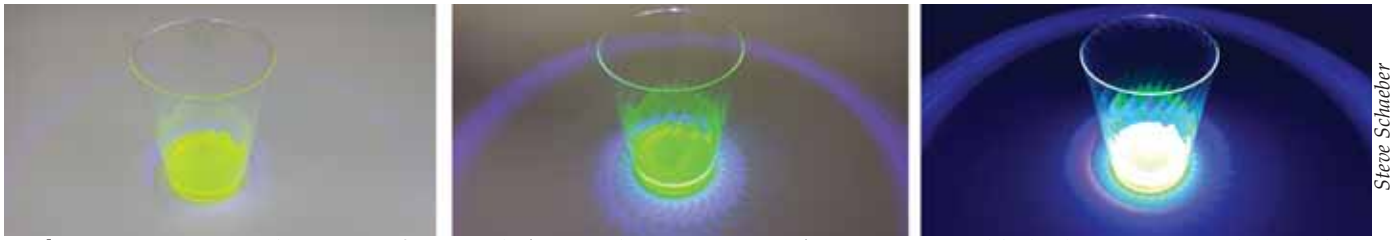

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Figure 7: *Conventional green antifreeze with dye may be easy to see under UV in natural light, but it gets even better when the lights are turned down. Otherwise much of the natural / ambient light will wash out some of the fluorescence, making it more difficult to see.*

lights. They really make for a well-lit workshop, but do just what we *don't* want when searching for dye.

There's actually quite a bit of ultraviolet light in "white light". That's part of what makes it so white. What we see as white light is actually a combination of all the different wavelengths from the visible part of the electromagnetic spectrum. You may remember science class in school where a teacher would shine sunlight through a prism or a piece of glass and then a rainbow would show up on the wall. That piece of glass was breaking apart sunlight into its component wavelengths, allowing you to see each individual color (Figure 6). If one color was missing, the light wouldn't be so "white" anymore.

That's part of the reason why you can still somewhat see dye glowing with just the natural light in the shop. But it's also why you can see it so much better when you shine a true UV light on it. All those concentrated wavelengths literally make the dye glow more, and put out more photons of light.

But that's also why it's so much easier to see glowing dye in the dark, because there's no extra color from white light to "wash out" the fluorescent color that you see with a blacklight. In fact, the darker the better! See Figure 7.

How big's the leak?

Dye isn't quantitative, meaning it can't tell you how much has leaked out, nor how big the leak is. Of course, you can use your best judgement as you would with any other leak, to determine how bad it is. But that's a judgement call, and you're just going to have to use your experience and that of those around you to determine how severe the leak is.

And in most cases, the equipment that your testing needs to work in order for the dye to work. Since it needs to be thoroughly mixed with the liquid it's detecting, the dye needs to be circulated around. So, unless it's been installed in the system for a (long-ish) period of time before the leak developed, it's not going to do much good to add dye to a system that doesn't function.

Many OEMs do install dye into their A/C systems at the factory (or they have one of their parts suppliers install it for them, most commonly, whoever handles the desiccant). But not all of them make it obvious as to which vehicles have it preinstalled, which means you'll either have to check service information, or just go out and look. A few tell you right on the underhood J639 label. See Figure 8.

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Figure 8: *This Altima label says it uses "Nissan Luminous Oil Type DH-PS", but there's another hidden clue. If you shine a UV light onto the label, it glows!*

Using the right lamp

Anyone can make a lamp, but it takes attention to detail to make one of quality. And one of the most important things to look for in a lamp is that it actually produces true ultraviolet wavelengths of light, and not just a bright blue or purple color. It's the UV that makes dye glow, so naturally finding a light that does this would be the best choice.

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Figure 9: *Not all "UV flashlights" put out the same wavelengths of light, and therefore may or may not be best suited to fluoresce the dye you're working with. That's why we recommend having several different UV flashlights of varying wavelengths. These range from 365 nm (on left, almost invisible), up to 450 nm (a very "blue" color).*

But there are some lights on the market that report to be "the brightest" and "easiest to see", which is exactly what you don't want in a UV light.

If you think about it, UV is *ultraviolet*, which means it's *beyond* the violet part of the visible light spectrum. That's a part of the spectrum that you can't see. So, if you were *really* using an *actual* UV light, you wouldn't be able to *see* any of it.

But that's not the way the vast majority of UV lights work. In fact, depending on the model that you buy, you're probably going to see quite a bit of visible light coming out (either purple or blue), and that's OK. Even

MACS Staff

Figure 10: *It's easy to focus the light beam on many modern flashlights by simply rotating or sliding the lens. Some UV flashlights can also do this, which spreads the light out evenly.*

WEAR YOUR GLASSES

You've probably heard it a hundred times, and will probably hear it a hundred more, but I'm going to say it again. Make sure you wear your safety glasses! It's an absolute MUST when performing A/C service, since we've measured the temperature of refrigerant leaking out of a system at less than -40°F. That's easily cold enough to freeze your eyes, so PLEASE don't take a chance!

But it's also important to wear those yellow glasses that come with your UV dye kit. Not only are they "safety glasses" in the traditional sense, but they also help to protect your eyes against harmful UV radiation that's being produced by your UV lamp. Plus, you get the added benefit that they "enhance" the dye, making it easier to see (Figure 11).

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Figure 11: *Like the package says, they help enhance fluorescence; but they also protect your eyes from harmful UV radiation (think back to your MACS Section 609 training classes). UV light can't shine through these yellow lenses.*

though UV is what makes dye glow, you still need to see that the light is on, it's pointing where you want it to, and shining as brightly as it should. So as long as the range of light is not too wide, meaning that it's focused on a certain band of UV, including some low frequency visible light, then you should be good.

Still, the most important thing is to make sure that the wavelength of your light matches up to the dye that you're working with, which is why we recommend having several different UV lights in your toolbox. Most dyes react well with UV light between 395 and 405 nm, but some work better (or only) with much lower wavelengths around 365 nm. Some even work best as high as 450, which is pretty much "blue" light. See Figure 9.

Let your light shine

How your light shines is about as important as the wavelength of light that it puts out. You're likely already familiar with this, as some of the most popular shop flashlights today are adjustable lens models where you can "zoom in" or "zoom out" to better illuminate the work area. This is normally done by sliding the light lens forward or backwards, or by twisting the lens to focus the beam. Many of the best UV lights will also have this feature (Figure 10).

Keep in mind too that the "intensity" of the light you see does not necessarily increase with the wattage of the lamp. Many UV lights are specialized, with some of the most intense lights produced by micro discharge lamps. But of course, with price always being a factor, here too you must balance the price you're willing to pay with the intended use and benefit you'll get from the tool.

Other features to keep in mind with UV flashlights include portability, power options and style. Rechargeable designs work best in some shops with a shared "recharging station" where cordless drills, flashlights, impact drivers and batteries are kept. Other shops prefer to just replace AA or AAA batteries, while others still like the clip-on models that connect to the vehicle's battery.

Accumulation

Tracerline

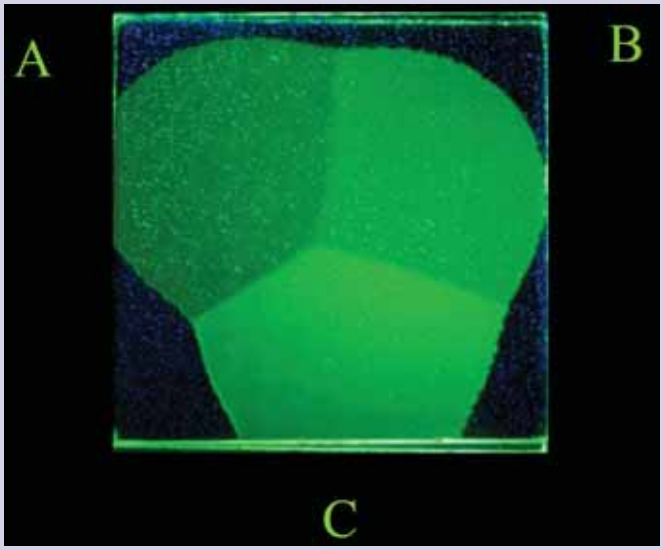
Figure 12: *Dyes can be manufactured in a variety of colors from yellows and greens to reds and blues; there's even one for engine oil that glows white!*

Ultraviolet leak detection is a cumulative process, which is the main reason it works so well. Mid-sized or larger leaks will show up quickly, but those smaller leaks will take longer to appear.

Good thing that time is on our side, because if we're able to get the dye in there early enough (or leave it in there long enough) then it should be able to show us the leak when it happens. This is why so many OEMs add dye at the factory, so that once a leak does

In order for dye to properly fluoresce to its maximum brightness, a few conditions need to be met.

- Mix dye in proper concentration with the intended fluid
- Match the wavelength of the light to the fluorescence of the dye
- A thin film of properly mixed dye (typical of what you'd see at a real-world leak site) will glow brighter than a bottle full of concentrated dye. See Figures 13, 14.



Tracerline

Figure 13: *Leaks often occur as small "seeps" of fluid or wetting of lines and components, so dye needs to be analyzed and compared under similar conditions. These three dye samples are illuminated between two pieces of glass, showing how each fluoresces by a different amount.*

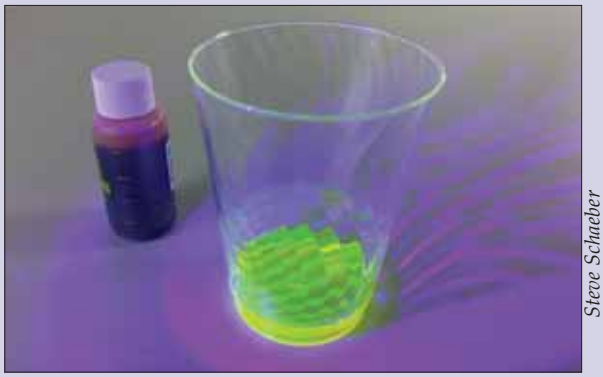


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Figure 14: *A comparison of coolant dye, both concentrated and mixed with conventional antifreeze. It looks dark brown in the bottle, but when properly mixed it's really bright yellow/green!*

occur, the dye is already there to help technicians find it.

But time's also against us, because it does take time (circulation) for dye to start working. If you add dye to a known leaky system right after the leak is discovered, chances are that it's going to take a while before you see the dye leaking out (unless you're SUPER lucky). So, it's a good thing that leaks generally tend to get worse over time, making them more obvious and easier to find.

Fluorescent Leak Detection

With all the various information and sources for the dyes and lights available on the market today, we often get asked which ones work the best. But it's tricky to give a clear answer to this question, because many of the dye formulas do work well, as long as they're paired up with the correct light source to fluoresce them.

But there are some things we do look for in a dye other than simply fluorescing. For example, its color must be easily visible (that's sort of a given) and it should also fluoresce a distinct color depending on application. That's especially important for fleet shops that like to add multiple dyes to the different liquid systems on their vehicles and equipment. Differentiating by color makes the diagnostic process much quicker and easier. See Figure 12.

Sure, most of us can tell the difference between engine oil and transmission fluid, but if both are dyed bright green, it's going to be a bit harder to quickly tell them apart. That's why fleet shops want different colors to be used for different fluids on a vehicle. That way the driver, operator or technician can quickly determine what's leaking by simply glancing under the vehicle in the parking lot or out on the street. If all the fluids were dyed the same color, they'd certainly know there's a leak, but they might have to crawl under or bring it into the shop

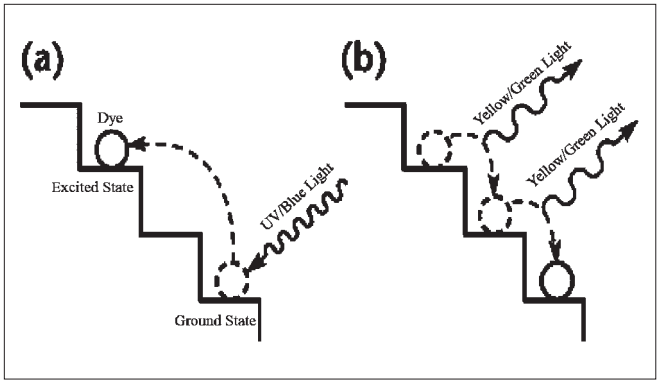

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Figure 15: *(a) When dye absorbs UV/blue light energy, it "jumps up" from a grounded to an excited state. (b) Dye then emits energy as photos that we can see, returning it to a grounded state.*

and put it up on to a lift to get a better view to be sure of where the leak is coming from.

Concentration & Chemistry

Simply put, concentration is the amount of fluorophore that's used to treat a system, and making dye easily visible has much to do with the amount of dye material that's used. It makes sense that putting in more dye can make it glow more brightly, but there does come a point when too much is too much, and you should be careful not to use too much.

For this reason, dye companies prefer to use a testing method called "thin film analysis." It allows for a fair comparison between dyes (Figure 13), and shows exactly what a user will see at a leak site, so it's more of a "real world" type of test.

How dye is matched with lights

Like we said, dye glows because one of the main ingredients is ***fluorophore***. It's normally in a "grounded state" (meaning it does not glow), but when exposed to ultraviolet (and sometimes blue) light energy, it absorbs that energy and becomes "excited", emitting energy as photons that we can see. Once the photons are released, it returns to its grounded state and the dye appears to have "turned off". See Figure 15. This is why A/C dye doesn't continue to glow after the UV light source is taken away, unlike ***phosphorescent*** materials like glow-in-the-dark paint, toys, stickers and keychains which continue to glow for minutes or even a few hours.

Knowing how this works, and how different dyes react to different wavelengths of UV light (how much they glow under certain wavelengths) is how engineers match up dyes to a particular light. They plot various graphs showing how well certain dyes perform under varying wavelengths of light (measured in nanometers), and then match them up with one of their UV light sources that will work best with that particular product (Figure 16).

Dye in the future

There's been some talk that as MAC systems continue to improve (leak less, use less refrigerant and last longer before needing to be recharged), that using leak detection dye will become somewhat unnecessary, especially as systems with extremely low oil charges become the norm. Manufacturers also continue to choose eVDCs (electronically controlled variable displacement compressors) with oil separators (which help to retain oil inside the compressor, allowing less oil to circulate), not only for the EPA credits but also as a way to improve efficiency and lower the cost of the vehicle.

But we disagree, and predict that using leak detection

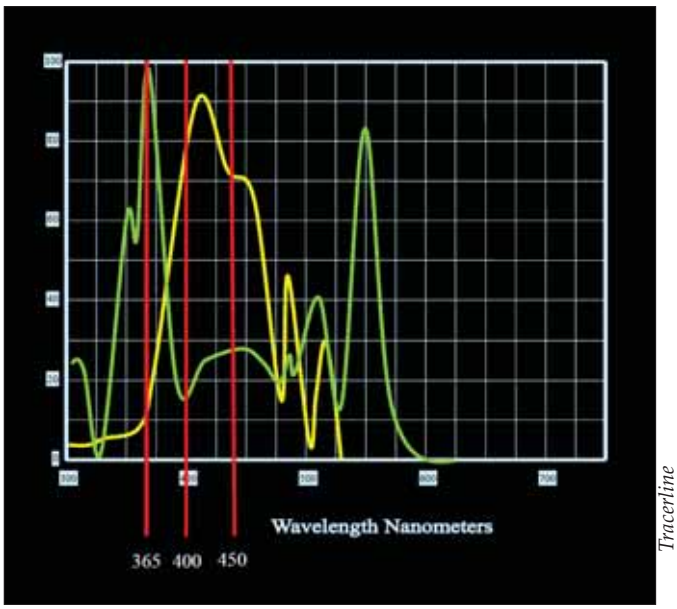

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Figure 16: *This excitation spectra shows how two different dyes match up with a particular wavelength of light. The green dye shown here will fluoresce better under a 365nm light, whereas the yellow dye will fluoresce better under a 400nm light. Either one may still fluoresce somewhat under a number of other lights, but will work best at these wavelengths.*

dye will actually become more useful in the future. Our long-term experience and multiple studies across several vehicle lines shows that adding A/C dye to a new system, or at some point along its service journey, can only help with long term leak detection and system repairs.

There's not much that's more intuitive for the technician than leak detection dye and nothing could be simpler. Just add the dye, give it time to circulate and reach the leak point, and it shows you where the leak is coming from. It's easy to see, is an absolute confirmation of the leak, and it can be shown to the customer, too.

That's not to say that dye is the be all/end all of A/C leak detection.

Unlike using an ELD (electronic leak detector), the system has to be working in order for dye to do its job. With an ELD, you need only have about 50 psi of system pres-

sure in order for the refrigerant to be able to get out of most leak sites to where the detector will be able to find it.

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Figure 17: *Applying a label like this to your customer's vehicle indicates the presence of leak detection dye.*

So, it's going to take a little planning on your part to prepare for the day when service is required.

Let's say a customer brings in their 8-year-old daily driver for an A/C performance issue (not blowing as cold as it used to), and you determine the cause to be natural leakage that's taken place over the years. In this case a simple R/R/R service would be in order. But if the particular vehicle doesn't have any dye in it from the factory, we suggest adding dye at this time. It's easiest to do when the system is evacuated, and this way the dye will already be around to help pinpoint any future leaks.

You can also sell "adding dye as a service" for vehicles that didn't come with any from the factory. Several tools are available which install A/C oil (and / or dye) into an already pressurized system, although we suggest following the tool manufacturer's instructions carefully for the proper use of their tool. Many that we've used require installing the dye through the low side service port, and in some cases, even while the system is running. It's easiest under these conditions, since the pressure is lowest on the low side, sometimes even down below 30 psi. So, it's going to be easier to "inject" the dye under these lower pressure conditions, rather than trying to "fight" against equalized pressure, which could be two or three times higher. And of course, never try to add dye through the high side service port.

Either way, be sure to apply a label to the vehicle (or mark it in some way) that alerts the owner or any future technician to the presence of leak detection dye. Many kits come with sets of labels for this very purpose. See Figure 17.

It's been said there's an ancient Chinese curse that goes, "May you live in interesting times." Some think it's a blessing, and others flip it around to mean peaceful times are boring. While today we have changing environmental regulations, automotive legislation, and technological design changes are being thrown at us at an ever-increasing rate, one could say that of our times today. Despite all this, leak detection still remains an important (if not the most important) A/C system service that we provide to our customers. Let's do it right! ■

MACS 1st Special Edition COLOR MSR!

It's always tough to cover such a colorful topic like this when writing for a greyscale publication, and we've done our best to shade these figures and images to help explain our points.
But we've also gone a step further and published this special edition PDF of MACS Service Reports in COLOR!

So if you're reading the printed (greyscale) version, and want to get the color PDF, visit our website www.macsw.org and login to the "Members Only" section. There you can access the MACS archives for ACtion Magazine, the MSR, presentations from A/Ccess (MACS' annual training event and trade show) and so much more. See you there!

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1.	A	B	C	D
2.	A	B	C	D
3.	A	B	C	D
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7.	A	B	C	D
8.	A	B	C	D
9.	A	B	C	D
10.	A	B	C	D

1. Most A/C system performance tests include measuring temperatures at:
   a. Left and right lower ducts
   b. Ambient and defroster duct
   c. Lower heater outlet and center duct
   d. Center duct and ambient (outside air)

2. A variable displacement compressor's solenoid can be easily controlled via a scan tool on a Ford. True or False?
   a. True
   b. False

3. Two technicians are discussing diagnostic approaches to an A/C performance problem on a vehicle with a variable displacement compressor. Technician A says that the solenoid should have a duty cycle of over 75% if ambient temps are over 65°F. Technician B says that a duty cycle change of the variable displacement solenoid should vary as the temperature command at the HVAC head is moved while in A/C mode. Who is correct?
   a. Technician A
   b. Technician B
   c. Both technicians A and B
   d. Neither technician A nor B

4. A vehicle with an orifice tube will see a temperature difference of _____ between the inlet and outlet of the evaporator.
   a. 0 to 5°F
   b. 20-50°F
   c. 40-80°F, depending on if R-134a or R-1234yf is used
   d. 2-12°F, depending on RPM changes or stable condition

5. Setting a variable displacement solenoid command to 90% limits the compressor's output by 90%. True or False?
   a. True
   b. False

6. Two technicians are discussing an eVDC solenoid's internal winding. Technician A says some variable displacement compressor test tools check the solenoid's internal electrical integrity. Technician B says the compressor solenoid test tool will likely set a DTC when used in the vehicle. Who is correct?
   a. Technician A
   b. Technician B
   c. Both technicians A and B
   d. Neither technician A nor B

7. The "Strategy Based Diagnostics" approach flow chart includes:
   a. Pulling DTCs prior to physically inspecting the vehicle
   b. Verifying the customer's concern prior to any other steps
   c. Checking for TSBs prior to preliminary checks / visual inspection
   d. Repairing the vehicle before spending time isolating the root cause

8. Some Toyota A/C compressors are capable of being throttled down to 0% duty cycle (no compressor operation) because they contain:
   a. A data PID for the compressor displacement solenoid displayed in voltage
   b. An internal temperature sensor within the compressor to determine duty cycle
   c. A self-equalizing pressure sensor
   d. A variable displacement solenoid with no clutch

9. Technician A says that many IHXs can drop the high side temps on each end of the IHX by more than 10°F. Technician B says that an IHX may only drop the high side line temperature by a couple of degrees. Who is correct?
   a. Technician A
   b. Technician B
   c. Both technicians A and B
   d. Neither technician A nor B

10. AirSept's EVC-2 is unique from other variable displacement compressor test tools by having:
   a. Provisions for checking the solenoid's electrical integrity
   b. An ability to raise and lower the compressor solenoid's duty cycle
   c. Provisions for measuring the low side and high side line temperatures
   d. Substitute load to prevent setting solenoid circuit DTCs when the tool is installed on the vehicle