Brake Fluid's 101 ...

(www.synforce.com.au/tech-note downloads/)

Few items in modern motorsports have been marketed to professional racers and enthusiasts as "creatively" as brake fluid. While seemingly simple, brake fluid is saddled with just enough chemistry and material science terms to quickly outpace even most race engineers. Some terms have been tossed around with so little clarity that their true meanings are often misinterpreted, if not misrepresented altogether. Add in a few bench-racing tales and no wonder people throw up their hands and say – "Forget it! Just give me what the fast guys are using!"

"Wet" versus "dry" boiling point? Compressibility? Hygroscopic? DOT 3, DOT 4, DOT 5, DOT 5.1…

What's all this gibberish mean anyway? If you want to know what is most important about brake fluid (and how picking the right one will give you more time to work on going faster), reading these ABC's will help put you at the top of the class in Brake Fluid Science 101. Even if you skip the final exam, you will at least know WHY the pros carefully choose what they use!

Brake Fluid Specifications:

Starting at the place most of us heard about when looking at brake fluid for the first time, the U.S. Department of Transportation (DOT) has laid out some specific criteria for brake fluid labelling. The physical characteristics were sorted out by the Society of Automotive Engineers, or SAE. Yes, that is the same group of gear heads who mapped out motor oil viscosities decades ago. That was back when oil was actually sold in real metal cans that had to be stabbed with an evil- looking metal spout containing a pointy metal spike, for the benefit of our younger readers. No, really! Think about those grubby Vikings on that credit card commercial and you won't be too far off.

It is important to understand that the U.S. DOT does not test nor approve brake fluids. Anyone stating they offer a DOT-approved fluid is demonstrating they know a lot more about selling than about their own product! The DOT does publish standards that various manufacturers (and manu-pack-turers – more on that later!) claim to meet on the label. Each must do independent lab testing to rightfully claim their product has been validated to "meet or exceed" the associated DOT specification. This is done to assist a technician who needs to reach for the appropriate fluid when servicing any type of vehicle, regardless of the brand. If the reservoir cap says DOT 4, he is only responsible for putting in more DOT 4. Simple, right? Well, not exactly…

All brake fluids sold into the market must comply with Federal Motor Vehicle Safety Standard #116 (FMVSS 116). Under this standard are four DOT minimum specifications for brake fluids. They are DOT 3, DOT 4, and DOT 5.1 for fluids typically based with Polyalkylene Glycol Ether and DOT 5 for silicone-based fluids. Just by themselves, these four specs are confusing enough to keep straight, so let's to go over some of the more basic terminology

NOTE: This cannot be stated enough times -- DOT 5 is not compatible with any of the others and must never be mixed with any of them!! The DOT naming convention turned out a bit unfortunate in the end, so please read the following info for explanations in (nearly) understandable terms

Understanding Brake Fluid Terms:

Dry Boiling Point

For all DOT-compliant fluids, this is the temperature at which the fluid begins to boil when tested in the manner specifically described by the DOT. For our more techie readers, the correct term is the Equilibrium Reflux Boiling Point (ERBP). This basically means the fluid is tested brand-new, right out of a freshly opened bottle, before being contaminated by moisture, other fluids or the paint it secretly desires to eat off of your inner fender.

Wet Boiling Point

This is a similar test to the Dry Boiling Point, but this time performed on the fluid after it has had time to absorb moisture from its surroundings. Specifically called the Wet Equilibrium Reflux Boiling Point (Wet ERBP), this is the temperature the fluid begins to boil when tested in accordance with the DOT procedure. An interesting fact is that the fluid being tested is not checked for moisture content, but a reference fluid sitting close to it is. When the reference fluid reaches 3.70%±0.05% water content by weight, the fluid being tested is then put through the same procedure as for Dry ERBP to get the Wet ERBP. What this means is that the test fluid may or may not have had the same moisture content as the reference fluid (3.7%). The actual moisture content of the fluid being tested depends entirely on its chemical properties and manufacturing methods. In reference to the DOT (or SAE) test, a typical DOT 3 fluid might contain 3.0 - 3.5% moisture, while a DOT 4 fluid will typically contain a 4.0 - 4.5% moisture content by volume. Translation: a regular DOT 4 fluid will absorb moisture faster than a regular DOT 3. Fun fact: Since a brake fluid's wet boiling point is always lower than its dry boiling point, best practices for track preparation will include flushing the fluid just before the event.

-- IMPORTANT NOTE -- (extra credit opportunity!): It is possible, although certainly more expensive, to formulate a Super DOT 4 fluid, like Torque RT700™, where the tested moisture content is closer to that of DOT 3 (lower), yet still has a much greater tolerance for additional moisture. So even when the fluid has become contaminated with a greater percentage of water content, say 4.5 – 6.0% by weight, it will continue to maintain its Wet ERBP performance and not degrade further. This is precisely where the label on the bottle (and the DOT rating) falls well short of describing how the product will perform when overstressed with heat and over-laden with moisture.

High Temperature Stability

This is a measure of how stable the dry ERBP temperature is as fluid temperature increases, applying universally to all grades of brake fluids. The specification per FMVSS 166 reads, "…. The ERBP shall not change by more than 5.4°F (3°C) plus 0.05 for each degree the ERBP of the fluid exceeds 437°F (225°C)." For a fluids with high dry boiling point, this calculates to a ERBP could vary in either direction by as much as 14.05°F (9.97°C). The High Temperature Stability of Torque RT700™ is just 2°F (1°C).

Viscosity

This is where the DOT 3 spec could be interpreted as actually being better for the miniature passages of an ABS system than the DOT 4 spec. Thinking about motor oil, the higher the viscosity number, the slower the flow of the (thicker) oil. The same basic principle applies to brake fluid, although the measurement technique is different. The DOT 3 specification for viscosity at -40°F is 1500 mm2/s, where DOT 4 is 1800 mm2/s. So, the DOT 3 fluid flows better at the cold testing temperature than the DOT 4. To confuse the issue even further, DOT 5.1 fluids were developed specifically to better meet the lower viscosity requirements of the more complex

ABS and DSC systems, while also meeting the higher boiling point specifications of DOT 5 silicone-based fluids. It should also be noted the viscosity specification at 212°F / 100°C for all DOT variants is 1.5

mm2/s. While it may be better for those who race snow machines above the Arctic Circle to choose a brake fluid with a lower viscosity, fluids with a higher viscosity number at the lower test temperatures usually provide a better and more consistent braking feel, as Torque has found through extensive track-testing with professional racing drivers

Compressibility

This is not a specific DOT call-out, yet it is critically important to racers and enthusiasts. It is listed in SAE J1705, Appendix A, A.2.2.8, under the heading, "Air Solubility." Here it states, “Air Solubility – It has been reported that dimethyl polysiloxane fluid, which is a major part of silicone- based, low water-tolerant type brake fluids can typically contain dissolved air at a level of 16% ±3% by volume at standard temperature and pressure. This compares with a typical level of 5% ±2% by volume of dissolved air for glycol ether based type fluids. An increase in brake pedal travel may be experienced under severe operating conditions, especially at higher altitudes and high temperature conditions."

"The term “dissolved air” (air absorbed from the atmosphere) should not be confused with the term “entrapped” or “free air” since their effects on brake system performance can be entirely different. Air that has been absorbed from the atmosphere does not result in an increase in fluid or system volume, whereas entrapped air or free air does occupy system volume and can be easily compressed when force is applied to the system.“

The SAE standard continues, “A.2.2.8 – Compressibility – Silicone based brake fluids are more compressible than conventional brake fluids and the difference is magnified at higher temperatures.” Silicon-based brake fluids are described by DOT 5 (not to be confused with DOT 5.1), which should never be used in a racing vehicle due primarily to its compressibility.

Compressibility is largely ignored by those selling nearly all the brake fluids on the market -- and with good reason! It is better you aren’t told that their fluid could contain as much as 7% dissolved air!! Once they are tested specifically for compressibility, it is no surprise that certain "high end” racing fluids are known in the paddock for their poor pedal feel.

A research report published by Union Carbide demonstrates a relationship between the compressibility of a brake fluid and its density (or specific gravity). The greater the density of a brake fluid the less compressible it is. As there is no DOT specification, within the scope of the Polyalkylene Glycol Ether-based fluids there can be a density difference range of over 200% between fluids! Since brake feel is so important to driver confidence and, ultimately, lap times, Torque RT700™ has been successfully formulated to be the highest density brake fluid on the market today

PH

This is an indicator the fluid's corrosion resistance and high temperature stability. A higher pH will prevent corrosion for a longer time. Yet, higher pH values also reduce the fluid’s high temperature stability. The range of pH to meet FMVSS 116 is 7 -11.5. If the pH is below 7, the system is on the acidic side and may produce corrosion within the system over time. Below 6, certainly problems will occur. Steel does not corrode as long as the pH is above 9.5, but aluminum will be attacked if the pH goes above 11.5. A pH lower in the range will provide all the corrosion protection you need while maintaining maximum high temperature stability

Reserve Alkalinity

This strange term describes how a brake fluid keeps expensive brake system components protected from corrosion over time. Fluids with a higher reserve alkalinity can stay in service longer, while those with lower numbers need to be changed more frequently or risk potential corrosion of master cylinders, calipers, ABS valve bodies, steel brake tubing and other components as the fluid becomes progressively more acidic. Typical DOT 3 and DOT 4 fluids drop to 20% of their original value in 18 to 20 months of street use. Yet this drop in pH can occur much sooner when exposed to thermal oxidation and volatization – otherwise known as racing, track days, spirited canyon bombing, etc. This is another reason why even today's better brake fluids must be changed after seeing elevated temperatures. If you have ever been told to also flush your brake fluid after a track day, this is why. GREAT NEWS!! Torque RT700™ has the highest reserve alkalinity available – and by a large margin. It can be used longer, saving both money and time flushing brake fluid

Basic Brake Fluid Descriptions:

DOT 3:

The very common DOT3 specification brake fluid will be made from a glycol base and will contain glycol ethers and additives to inhibit corrosion (to prolong braking component life) and promote lubricity (to extend seal life). DOT 3 fluids have a minimum dry boiling point of 401°F (205°C) minimum and a minimum wet boiling point of 284°F (140°C). It will be clear to amber in color and be hygroscopic (absorbs moisture). It will absorb 1% to 2% of moisture content per year, depending on climate and operating conditions. This moisture absorption will reduce its boiling point, eventually lowering down to the wet boiling point or even below. It does not require a system flush before using and can be mixed with DOT 4 and DOT 5.1 without damage to the system. As with all glycol-based fluids, it can damage the paint on a vehicle.

DOT 4:

Also containing glycol, the SAE J1704 specification considers DOT 4 to be a borate ester base fluid and is also clear to amber in color. While somewhat less hygroscopic than DOT 3, it still absorbs moisture, with a minimum dry boiling point of 446°F (230°C) and minimum wet boiling point of 311°F (155°C). DOT 4 is used in many European vehicles, as well as for high altitude, towing, or high-speed braking situations. It is often favoured for the newer ABS systems. DOT 4 usually contains anti-corrosion and lubricity increasing additives and can be mixed with DOT 3 with no system damage. It will also damage the paint on a vehicle if not flushed with water immediately. Many of the high performance or racing DOT 4 fluids will contain other additives to increase fluid performance well beyond the minimum specifications.

DOT 5:

WARNING: DOT 5 has a silicone base and is purple in color. It is NOT hygroscopic, so it will not absorb moisture. It has a minimum dry boiling point of 500°F (260°C) and a minimum wet boiling point of 356° (180°C). It is compatible with the same rubber seal formulations as DOT 3/4/5.1 fluids. Also, it will not damage paint. While this initially sounds like a winning combination, it is unsuitable for racing or any type of hard use for three primary reasons:

1) When hot, air bubbles easily form, which are nearly impossible to remove and cause poor pedal feel.

2) Since it does not absorb moisture, water in the fluid settles out, causing severe localized corrosion, freezing or vapour lock.

3) It DOES NOT MIX with DOT 3, DOT 4, or DOT 5.1, so cross-contamination may occur if crew members are not aware DOT 5 is in the system. This often results in the fluid turning to gelatine in some areas and possibly causing pistons to stick.

It is best in very cold (think arctic) climates or in brake systems in weekend, antique, and collector cars that sit for long periods and are never driven far, although it is not suitable for ABS systems. Originally developed in the late 1960's by General Electric specifically for racing, it is unsuitable for racing for the above reasons

DOT 5.1:

Similar to DOT 4, yet comprised primarily of borate ester (often 70 - 80%), as well as other additives. Like DOT 3 & 4, 5.1 is also clear to amber in color and hygroscopic. This specification calls for a minimum dry boiling point of 500°F (260°C) and a minimum wet boiling point of 356°F (180°C). It is commonly used in the higher performance vehicles in Europe as it is excellent for severe duty and racing applications. It can be mixed with DOT 3 or DOT 4 without damage to the system, although is also higher in cost and has limited availability in the USA. Like DOT 3/4, it needs to be cleaned promptly if spilled on painted surfaces.

Fluid Compatibility

Brake fluid must be compatible with braking system components such as master cylinder, calipers, brake lines, ABS manifolds, bias adjusters, seals, etc. Compatibility is determined by chemistry, so no amount of advertising, wishful thinking or rationalizing can change the science of chemical compatibility. DOT 3, 4, and 5.1 fluids must, to meet the specification of Federal Motor Vehicle Safety Standard 116 (FMVSS 116) be compatible with all specified brake system materials -- except in the case of DOT 5 (silicone). Some rubber external components, such as caliper piston boots, may be attacked and compromised by silicon fluids and greases.

Water Absorption and Corrosion

While seeming counterintuitive at first, some limited degree of water absorption is desirable. DOT 3/4/5.1 glycol-based fluids will readily absorb water. The helpful part of this is that every brake system will contain some moisture, which cannot be avoided. Absorbing this moisture, while reducing the fluid’s boiling point and increasing its compressibility, allows the corrosion inhibitors in the better brake fluids to do their job and keep system components fresh. And, just like with antifreeze, these inhibitors are gradually depleted in use, which is the primary reason brake fluid needs to be changed periodically.

The one exception to this is the silicone-based DOT 5 specification fluid, which is not water miscible. This fluid keeps water molecules together, sinking to the lowest point in the system as water is heavier. It is at these water concentration sites where corrosion is first to attack

How fast does brake fluid absorb moisture?

It depends on both the fluid and the environment. A typical high performance DOT 4 fluid in a high-humidity environment will absorb as much as 4.5-5.0% moisture in as short a period as 2 weeks if not kept in a tightly sealed container. This is why the better brake fluids are packaged in a moisture-free, pure nitrogen environment, where the low-dollar department store varieties are packaged in regular air – moisture and all

How does brake fluid become contaminated?

Moisture can (and does) enter a brake system in several ways. The most common are:

1) Using old or pre-opened fluid. Keep moisture out by only using fluid from tightly sealed bottles and not storing them for long periods of time.
2) When changing or bleeding brake fluid, always replace master cylinder caps as soon as possible to prevent moisture from entering into the reservoir.

3) Condensation (small moisture droplets) can form in lines and calipers. As caliper and line temperatures heat up and then cool repeatedly, condensation occurs, leaving behind moisture/water. When water reaches 212ºF at ambient pressure, it turns to steam. The build-up of steam will create pressure in the system, sometimes to the point that caliper pistons are pushed into the brake pad. The resulting brake drag creates even more heat in the system. Many times air in the brake system is a result of water that has turned to steam and cooled back down, leaving the infamous mushy pedal.
4) Diffusion through rubber brake hoses over time. Using hoses made from EPDM (Ethlene Propylene Diene Monomer) will reduce the amount of diffusion. To essentially eliminate diffusion through the lines altogether, switch to stainless steel braided Teflon® brake lines.

What happens if I try to switch from a glycol-based fluid to a silicone-based fluid?

When introduced into an older brake system, silicone will latch onto the sludge generated by gradual component deterioration and create a gelatine-like goop. This will attract more crud and eventually plug up metering orifices or cause pistons to stick. If a system has already been changed to DOT 5, don't compound the initial mistake and change it back. Silicone is very tenacious stuff and it will never be removed completely once put in a brake system, so just change the fluid regularly. For those who race using silicone fluid, the best practice is to crack the bleed screws before each racing session to insure that there is no water in the calipers.

What causes a mushy pedal?

Both mechanical and chemical factors can contribute to a mushy pedal. On these pages, only causes related to the fluid will be discussed.

1) Air bubbles. As any race mechanic knows, even one small air bubble will irritate a driver who expects a lot from the brakes and is sensitive to how they feel when setting up a pass.
2) Dissolved air. All brake fluid contains some amount of dissolved air (even Torque RT700™). The critical question is -- How much? For the best brake pedal feel, it is important to choose a fluid with the least dissolved air to start with. This is explained in greater detail above