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TECHNICAL WHITEPAPER:

Brake Fluid 1A

Carroll Smith's Notes on Brake Fluid

Brake fluid is possibly the single most neglected component of the automobile. Most high performance drivers check their tire pressures and change their engine oil at frequent intervals. Virtually no one (including me) ever changes the brake fluid in their street car - or even bleeds the brakes. WRONG!

The function of brake fluid is to provide an incompressible medium to transmit the driver's foot pressure on the brake pedal through the master cylinder(s) to the calipers in order to clamp the friction material against the discs. The foot pressure is multiplied by the mechanical pedal ratio and the hydraulic ratio of the master cylinders, booster (if used) and caliper piston(s).

This is a simple concept. When fresh, all brake fluids are virtually incompressible and the system works as well as its mechanical and hydraulic design allows. There are, however significant problems. Overheated brake fluid can (and will) boil in the caliper. Boiling produces gas bubbles within any boiling fluid. Gas is compressible so boiling brake fluid leads to a "soft" brake pedal with long travel. In extreme cases overheated brake fluid necessitates "pumping the brake pedal" in order to get a pedal at all.

There are four possible solutions to the boiling fluid problem:

1. Don't use the brakes so hard
2. Provide (copious) cooling air to the brakes
3. Install Titanium or Ceramic caliper pistons. Alternately install 2-piece pistons made from aluminum with a noise piece of Titanium or Ceramic. (Note that aluminum pistons are used as opposed to stainless steel to match the expansion rate of the piston to that of the caliper body to ensure the piston seal condition and preload is optimal through out the temperature range.)
4. Install Titanium pad backing plate if they are available for your caliper.
5. Change to a brake fluid with a higher boiling point.

The first is unacceptable. The second is expensive. The third is really expensive in its various forms. The fourth is relatively cheap. The fifth is easy and relatively cheap.

For most of us easing up on the brake usage is not an option and increasing cooling air to the system is filed under too difficult so we upgrade the fluid. Some of the reputable racing fluids include:

- AP 550
- AP 600
- ATE Super Blue Racing
- ATE TYP 200
- ELF HTX 115
- Motul 550
- Motul 600
- Neo 610
- Performance Friction Z rated

Finally, Castrol SRF is a racing brake fluid that is in a class by itself with patented chemistry and is, in my opinion, the best racing brake fluid on the market today.

This leads to a discussion of boiling points. Brake fluids are classified by both “dry boiling point” and “wet boiling point”. They are also classified by US Department of Transportation (DOT) rating, DOT 3, DOT 4, DOT 5, and DOT 5.1.

As we would expect the dry boiling point is just that - the temperature at which a given brake fluid boil when it is fresh out of the can. This is the rating by which most high performance drivers and all racers select their brake fluid – from the standard racing 550 degrees Fahrenheit to the 600+ degrees Fahrenheit offered by the extreme use fluids. As a point of interest, even though they may have the same DOT rating, racing fluids are less compressible than street fluids, especially after they have been overheated.

For high performance street car use, the wet boiling point is at least as important as the dry. DOT 3 DOT 4, and DOT 5.1 brake fluids are ether based and, as such they are hygroscopic in nature - i.e. they adsorb water at every opportunity. Since water boils at 212 degrees Fahrenheit (100 degrees Celsius) the adsorbed water dramatically lowers the boiling point of the brake fluid. A minute amount of water suspended in the fluid decreases the boiling point as much as 1/3. Damn!

The fluid in the system absorbs water through the breathers, through the caliper piston seals and by magic. Not only does this reduce the boiling point, the entrained water leads to

corrosion of both ferrous and Aluminum internal parts. Double Damn!! So buy your brake fluid in small containers and don't save the leftovers.

I use Ford C6AZ-19542, which was developed in the early 1960's to cure the problem caused by Lincoln Continental drivers boiling the fluid by habitually resting their left feet on the brake pedal. It is inexpensive and it works just fine.

But upgrading the fluid is not the whole answer. Unfortunately the hygroscopic nature of the ether based fluids means that they should be completely replaced at scheduled time based intervals (annually would be good) and that the system should be bled to replace the fluid in the calipers every time that it is overheated to the point of generating a soft pedal. Yes, the pedal will come back as soon as the fluid cools somewhat - but the boiling point is now reduced and the pedal will go mushy at a lower temperature the next time. Triple Damn!!!

Fortunately, changing to a 550 degree Fahrenheit fluid and replacing it annually will solve the problem for all but the most heavy footed among us.

Ah ha, you say - but what about the much touted Silicone based brake fluids? They are non hygroscopic and should take care of the reduced boiling point and corrosion problems. True! That's the good news. That is why they are specified by the U.S. Military. Unfortunately the silicone based fluids are compressible themselves so they produce a soft pedal all by themselves. For the person who doesn't care about a spongy pedal or precise modulation silicone fluids may well be the answer - but not for anyone reading this. In fact, low compressibility is a desired characteristic in a high performance brake system – lower compressibility results in more linear force output for driver input and improved driver feedback.

So, you say, "I'll just run my hot rod down to my dealership or mechanic and ask them to replace the fluid with AP 550." Two problems here. First of all they won't have it and won't know where to get it. Second and more serious (after all you could supply it yourself) all dealerships and most independent mechanics use pressure bleeders. These devices certainly speed up the process of brake bleeding, but by forcing the fluid through tiny orifices using pressurized air, any air left in the partially filled system will be forced into the fluid solution. Quadruple Damn!!!!

If you are either racing or doing lapping days, the brake fluid should be replaced both before and after each event. A cool off lap before each stop will go a long way toward preventing fluid boil due to heat soaking after the airflow stops when the car does.

James Walker's Notes on Brake Fluid

DOT Ratings

So, what exactly is the DOT rating telling us? More importantly, what is the DOT rating NOT telling us? A quick look at FMVSS116 – the US Government's Specification for brake fluids – will tell us all we need to know…

As Carroll accurately pointed out, DOT 3 fluids are usually glycol ether based, but that is not because they are required to be. In fact, FMVSS116 makes no mention whatsoever about the chemical compounding of brake fluids – it simply dictates the fluid physical properties. However, the brake fluid industry has by consensus decreed that glycol ether fluids are the most economical way to meet the requirements, so there you are.

These glycol ether fluids are typically a by-product of the process used to make certain paints and varnishes. By definition, DOT 3 fluids must have a minimum dry boiling point (measured with 0% water by volume) of 401F and a minimum wet boiling point (measured with 3.7% water by volume) of 284F. That's really about all the specification says as far as the performance enthusiast is concerned.

DOT 4 fluids are also glycol ether based, but have a measure of borate esters thrown in for improved properties including increased dry and wet boiling points. A seldom talked about characteristic though is that because of this chemistry, the DOT 4 fluid will have a more stable and higher boiling point during the early portion of its life, but ironically once the fluid does actually begin to absorb water its boiling point will typically fall off more rapidly than a typical DOT 3. By FMVSS116 standards, DOT 4 fluids must have a minimum dry boiling point of 446F and a minimum wet boiling point of 311F.

Does this make DOT 4 fluids better than DOT 3 fluids? Not always. Remember, the boiling points listed are minimums and there are DOT 3 fluids out there with higher boiling points than some DOT 4 fluids. The real differentiating factor should be that if you run a DOT 4 fluid you really should change the fluid more often than if you use a DOT 3, if for no other reason than the rapid fall off in boiling point with time.

We won't even discuss DOT 5 fluids as they are completely unacceptable to the high-performance enthusiast, but we'll include them in the following table for completeness.

PROPERTY	DOT 3	DOT 4	DOT 5
Dry BP (F)@ 0.0% H2O	401	446	509
Wet BP (F)@ 3.7% H2O	284	311	356
Chemical Composition	Glycol Ether Based	Glycol Ether /Borate Ester	Silicone Based

As a trailing note on the DOT ratings, if your car was designed for a particular type of fluid (especially prior to the development of DOT 4 fluids), you should make every attempt to stick with that fluid! For example, if your car was delivered with DOT 3 fluid, the internal components of the system (seals, brake hoses, and fittings for example) were specifically designed and tested for compatibility with DOT 3. Because DOT 4 fluids contain a different chemical composition, the system may not necessarily react in a positive fashion to the borate esters floating around in the mix.

In other cases, just the difference in viscosity of the two different fluids may cause the seals to wear at different rates. What starts as an annoying squeak might eventually become a torn seal or worse. The examples could go on and on, but the message here is this: it's fine to upgrade from DOT 3 fluid A to DOT 3 fluid B, but you should think twice (maybe even three times) before switching from DOT 3 fluid A to DOT 4 fluid of any sort.

That said, when dealing with modern hydraulic braking systems a numerically higher DOT rating is typically considered to be compatible with a lower DOT rating (except for DOT 5, of course). Unfortunately, this same generality just isn't true for most older hydraulic system materials.

Besides boiling points, what else does FMVSS116 specify?

While the performance enthusiast is most concerned about boiling points, the government holds no less than fourteen properties of brake fluid in the highest regard. Fail just one of the tests, and the product cannot be legally offered for sale in the US. In order of listing, the properties under the spotlight include:

1. Dry boiling point
2. Wet boiling point
3. Kinematic viscosity (how thick the fluid is, with lower generally considered better for flow)
4. pH value (measure of acidity, with higher generally considered better for corrosion resistance)
5. Chemical stability
6. Corrosion
7. Fluidity and appearance at low temperature
8. Evaporation
9. Water tolerance

10. Compatibility
11. Resistance to oxidation
12. Effects on rubber
13. Stroking properties (lubrication capability)
14. Fluid color

In order to detail each requirement, we would need to reproduce the entire FMVSS116 document here in its entirety. Since that would probably put 99% of all readers to sleep (the regulation is comprised of no less than twenty two pages of brake fluid minutiae), we'll just provide this handy link:

http://www.nhtsa.dot.gov

Dig around enough and you can find it. If we gave away the direct link it would take away half of the fun of navigating a federal government department website…

Why the heck do we use brake fluids that absorb water in the first place?

Believe it or not, one of a brake fluid's most vital characteristics is its ability to absorb water. Yes, you read that correctly – brake fluids absorb water by design and that is really a good thing.

What?

Whether we like it or not, water is everywhere and finds its way into everything. That's just the nature of the beast. Even our brand-new sealed brake system will eventually absorb water given enough time.

The magic of diffusion allows moisture in the air to permeate microscopic pores in the rubber brake hoses, the nylon master cylinder reservoir, and the various rubber seals in the hydraulic system. Sadly, there is nothing we can do about it and if left unchecked the water would sit in our brake system and rot it away from the inside out.

Hence the need for brake fluid to absorb this unwanted house guest. Because brake fluid absorbs water into solution, the local concentration levels are typically low enough that corrosion is slowed dramatically. As an added benefit, when exposed to low temperatures, the solution state prevents the water from pooling and freezing on its own. While water in brake fluid will certainly increase the solution viscosity at low temperatures, this is much more desirable than having little chunks of ice plugging up the system!

So, the next time you are bleeding your brakes to remove the water-contaminated fluid, don't curse at the automotive gods too loudly. After all, the fluid was only doing its job.

Hey – you didn't mention DOT 5.1 fluids!

Historically, DOT 5-level performance (specifically boiling points and viscosity) could only be achieved with silicone-based fluids. However, modern compounding has created glycol ether-based fluids which now meet DOT 5 bogeys in these key areas. Consequently, the DOT 5.1 moniker was created to differentiate between these two very different chemistries which both meet DOT 5 performance requirements.

In so many words, DOT 5.1 fluids are simply DOT 4-type fluids which meet DOT 5 performance requirements. Because of this, they typically can be mixed with DOT 3 or DOT 4 fluids without concern. In some circles, they are even referred to as 'DOT 4 Plus' or 'Super DOT 4' fluids because they are more similar to a conventional DOT 4 fluid by chemistry than they are to a conventional DOT 5 fluid. In fact, DOT 5.1 is essentially comprised of Borate Esters.

While it may not be obvious, the big advantage of the DOT 5.1 fluids is that they contain all of the nifty water-absorbing characteristics of the DOT 3 and DOT 4 fluids while simultaneously providing for very high boiling points and relatively stable viscosity over a wide range of temperatures. The best of all worlds, you could say. The table below sums it up quite nicely.

PROPERTY	**DOT 4**	**DOT 5**	**DOT 5.1**
Dry BP (F)@ 0.0% H2O	446	509	509
Wet BP (F)@ 3.7% H2O	311	356	356
Chemical Composition	Glycol Ether / Borate Ester	Silicone Based	Glycol Ether / Borate Ester

(As stated earlier, the table data above contains the minimum properties for a fluid to be called a certain type. For example there are many racing brake fluids with Dry BP performance at or above 590o F and Wet BP at or above 390o F.)

So, what is the downside of the DOT 5.1 fluids? Like most things in life, the good stuff isn't cheap. DOT 5.1 fluids typically cost three to four times as much to manufacture as a conventional DOT 4 fluids. There's always a catch…

So why is silicone-based DOT 5 fluid more compressible than other fluids?

On their own, silicone-based DOT 5 fluids are entirely different animals than DOT 3 and DOT 4 fluids. In addition to having characteristically higher dry and wet boiling points, they also tend

to have much, much lower viscosities. In other words, they flow more easily relative to temperature.

One side effect of this chemistry is that there is more “room” for air to fit in-between the individual molecules of brake fluid than in DOT 3 or DOT 4 fluids. Note that we are not talking about big bubbles of air here which are visible to the naked eye, but rather microscopic amounts of air which are finely dispersed (entrained) in the brake fluid matrix.

Now, all fluids have a certain amount of compressibility to start with, but adding even the smallest amount of air into the solution can dramatically increase the amount of elasticity in the system. In the case of silicone-based fluids, air is quite happy to take up residence between the brake fluid molecules, and as a result the fluid compressibility goes down. This is felt at your foot like stepping on a big spring. As you can imagine, more air = more spring.

Pressure bleeding do’s and don’ts

Pressure bleeding on its own is not necessarily a bad thing, but there are several steps one must take to ensure that the bleed event will result in an air-free brake system.

When we talk about pressure bleeding, we are referring to the process in which we pour our brake fluid into a pressure vessel, hook up a pressure source, and run the now pressurized fluid directly into the master cylinder reservoir. One by one the caliper bleeder screws are opened to allow the pressurized fluid to flow through the system until all of the old fluid has been purged. Simple, right?

Well yes, but beware of imitations – not all pressure bleeders are created equal. The professional units (the type you can consider using) separate the pressurized brake fluid from the pressure source (air) using a flexible rubber diaphragm. In this fashion, the pressurized air is kept from forcing its way into the fluid. As we all know, air and fluid should be kept as far apart as possible.

This brings us to the imitations. There seem to be a rash of products available lately that claim to be pressure brake bleeders at a fraction of the cost of the professional units. Like most things that sound too good to be true, well, it’s exactly that.

Like the professional units, these imitations contain a pressure vessel into which new brake fluid is poured. However, in order to pressurize the fluid, an integral pump handle is cycled to build the pressure inside the vessel without any measures taken to separate the pressurized air from the fluid. For those of you who have ever bought a $19.95 do-it-yourself potted plant and bug sprayer from Home Depot you get the idea.

Of course, having pressurized air in contact with the brake fluid will certainly force the fluid through the system just as effectively as the high-zoot professional unit, but as an added bonus we are stuffing air into the brake fluid at the same time. Talk about an unwanted surprise!

While it may not be visible to the naked eye (air can actually entrain itself in the fluid as to be visually undetectable) it's there right along with all of the nasty moisture trapped inside of it. This of course begs the question: if you are stuffing air and water contaminated fluid into your brake system, why even bother bleeding it in the first place?

Naturally there will be those who argue that the amount of air in question is not important enough to worry about, but think about this for a moment: nearly every automotive manufacturer stores their bulk brake fluid in large containers which are subjected to a constant VACUUM. Talk about an expensive process! If just storing your fluid under regular atmospheric conditions isn't good enough to keep air and water out, just imagine what shoving 30psi worth of compressed air on top of it is doing.

The professional units can cost hundreds of dollars, and for good reason; unfortunately the cost keeps them beyond the reach of most of us normal folks. Your best bet is probably to get back in the driver's seat and begin stroking the pedal with your foot again, but ultimately the choice is yours.

Picking the right fluid

No magic here. However, be forewarned that if you are taking your car to the track there are NO fluids which allow you to run indefinitely without periodic bleeding. The best that a fluid can do for you is provide stable, consistent performance while lapping, but because all fluids will absorb water over time, all fluids must be bled at some point. It's that simple.

That said, find the best DOT-compatible fluid that fits your budget and is readily available to you. If your fluid never boils on track, you're done – there's your "right" fluid. However, if fluid fade persists, you may have to bite the bullet and pay up the ladder for the next best thing. Speed costs money as the saying goes, and so does performance braking.

Brake Fluid Comparison

BRAKE FLUID	DRY BOILING POINT	WET BOILING POINT	SUGGESTED LIST PRICE
AP SUPER 600	590 ° F	410 ° F	$18.00/16.9oz.
CASTROL SRF	590 ° F	518 ° F	$69.99/33.8oz.
NEO SUPER DOT 610	610 ° F	421 ° F	$15.00/12oz.
MOTUL RACING 600	593 ° F	420 ° F	$15.00/16.9oz.
MOTUL DOT 5.1	509 ° F	365 ° F	$6.50/16.9oz.
ATE SUPER BLUE	536 ° F	392 ° F	$11.99/33.8oz
VALVOLINE SYNPOWER	503 ° F	343 ° F	$4.97/16.9oz.
ATE SL	500 ° F	329 ° F	$7.95/16.9oz.
CASTROL LMA	450 ° F	311 ° F	$3.50/16.9oz.
AP 551	528 ° F	288 ° F	$12.50/16.9oz.

by Carroll Smith, Consulting Engineer at StopTech and James Walker, Jr. of scR motorsports, exclusively for StopTech

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Through scR motorsports, he has been actively serving as an industry advisor to Kettering University in the fields of brake system design and brake control systems. He also serves as a brake control system consultant for StopTech, a manufacturer of high-performance racing brake systems. In addition, Mr. Walker contributes regularly to several automotive publications focusing on brake system analysis, design, and modification for racing and other high-performance applications. He is a recipient of the SAE Forest R. McFarland Award for distinction in professional development/education. Mr. Walker has a B.S. in mechanical engineering from

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STOPTECH

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