A Little History

In the 1920's, when automobiles started switching from mechanical brakes actuated by cables and levers to hydraulic brakes, the only material available for the required flexible hoses was natural rubber. As a result, a hydraulic fluid compatible with natural rubber was required for this application and a mixture of castor oil and alcohol was found to meet this need. The use of this fluid enabled the development of hydraulic brakes in the 1920's before synthetic rubbers became available. However, it fixed this industry on the use of hydraulic fluids based on glycols, glycol ethers, alcohols, polyglycols and other related compounds that can be used with elastomeric braking system components made of natural rubber, styrene, butadiene, ethylene, propylene rubber, or polychloroprene. As a result, brake fluids are completely different from any of the other fluids used in automotive systems [42].

Today's Lockheed, Girling, and silicone brake fluids are so vastly superior to the old Girling "Green" and "Crimson", and Lockheed "Heavy Duty" fluids originally specified for most of our older British sports cars that it would make no sense to use the older types today even if they were still available. The most notable advances have been in raising boiling points, improving compatibility with other brake fluids, reducing moisture absorption, and reducing corrosion.

This article will (hopefully) present the facts and information from which we can draw some logical conclusions, leading up to the decision on what kind of brake fluid you should consider using in ***your*** vehicle.
This article will cover:

- Brake System Fundamentals
- Traditional concerns for British car owners
- Classification of Brake Fluids
- Chemistry of Brake Fluids
- Federal Motor Vehicle Safety Standard 116
- Boiling Points of Different Brake Fluids
- Water Contamination & Reduction of the Boiling Point of Glycol based fluids
  - How does the water get in?
  - Where does the water go?
  - What can be done to prevent the water from getting in?
  - How water lowers the boiling point
  - When does the lower boiling point become a problem?
  - In the real world, how many cars have contaminated brake fluid?
  - How boiling point affects selection of a brake fluid
- Water Contamination & Corrosion
  - Understanding the corrosion process; the role of copper
  - How much copper is too much?
  - Where does the copper come from?
- Dealing with Water Contamination of Glycol Based Brake Fluids
  - Flush & re-fill
  - Choosing a glycol based brake fluid based on service interval

- Testing Brake Fluid
  - Measuring boiling point
  - Refractometer
  - Electrical resistance
  - Test strips (measuring the level of copper ions)
  - Conclusions about brake fluid testing
- Silicone Brake Fluids
  - Water absorption

    - Boiling point
    - Bleeding water from systems with silicone fluid
    - Solubility of air
    - Compressibility
    - Bleeding air from systems with silicone fluid
    - What about the stories of silicone causing seals to swell all out of shape?
    - Deciding to convert from glycol to silicone brake fluid
    - Converting from glycol to silicone
- Conclusions

Brake System Fundamentals

The main function of brake fluid is to transmit the force applied to the brake pedal to the brake pads and shoes. The foundation of any hydraulic system is Pascal's Law, which is generally given as "in a fluid at rest in a closed container, a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container." [56] To do this efficiently, brake fluids must be non-compressible. In addition, they must also not boil at the highest operating temperatures encountered, thicken or freeze at cold temperatures, not corrode or chemically react with any materials in the hydraulic system, and not decompose or form sludge, gum, or varnish at any temperature. They must lubricate internal moving parts, flow easily through small passages, have a long and stable shelf life, and be compatible with other brake fluids. [5]

When brakes are applied on a moving car, the kinetic energy of the vehicle in motion is converted into heat. The faster the car is moving and the faster it is stopped, the more heat is produced. Some of this heat soaks into the brake fluid. In the late 1940s, brake fluid with a boiling point of 235°F was considered adequate. By about 1957, 302°F was the lowest S.A.E. specification for a minimum boiling point for cars with drum brakes.

Disc brakes presented new problems. In stopping faster (and often heavier) cars more quickly, they generated even more heat which had to be dissipated. Improvements in brake lining materials, brake drum and rotor design and metallurgy have also had a similar effect. To handle these higher temperatures, improvements had to be made in wheel cylinder and brake caliper seal design and materials. The extra heat created a requirement for brake fluid that would not boil at the new "normal" operating temperatures of vehicle brake systems.[5] Brake fluids must not be allowed to boil for two reasons. The first is simple: the brakes won't work because the vapor bubbles formed in the boiling fluid are compressible, and pressing on the brakes will compress the bubbles without exerting any pressure on the brake pads or shoes. The second problem is more subtle, but equally serious in the long term. When brake fluid boils, the physical and chemical properties will be changed because some of the components will be affected. The brake fluid contains chemicals that inhibit corrosion and oxidation, and these chemicals are affected by very high temperatures. Brake fluid that has boiled will boil at a lower temperature in the future.[12]

Traditional Concerns for British Car Owners

In the good old days, dire warnings of problems caused by using the wrong brake fluid in a British car were common. Anyone reading a warning like "as the cups in the master cylinder are pure [natural] rubber; it is imperative to use only the recommended fluid. Any other fluid may be dangerous" would probably take it seriously. Such strong concerns were very valid in the 1950s, but much less so now, even for 1950's vintage cars. There are several reasons why we can be less worried about our hydraulic systems "turning to goo" if the wrong fluid is used:

1) Pure natural rubber hydraulic seals are no longer made for our cars
2) More than likely, the original natural rubber seals have been replaced.
3) Brake fluids meeting current standards are compatible with the virtually every type of seal available, including natural rubber
4) Brake fluids meeting current standards are safe to mix (although mixing them is not recommended)

And this brings us to the subject of this article – brake fluid.

Classification of Brake Fluids

Brake fluids are classified by their physical properties. The standards in the US come from the Department of Transportation, which is where the "DOT" in the brake fluid classification DOT 3, DOT4, DOT 5 and DOT 5.1 comes from. The standards are set forth in the Federal Motor Vehicle Safety Standards 116 (FMVSS 116). [26] The Society of Automotive Engineers (SAE) also has standards that apply. SAE Standard J1703 (DOT 3 Brake Fluids), J1704 (DOT 4 Borate Ester Brake Fluids), and J1705 (Low Water Tolerance Brake Fluids, or DOT 5 Silicone Based Fluids) are frequently cited in publications on brake fluid, along with the International Organization for Standardization (ISO) 4925 specification for "non-petroleum based brake fluids for hydraulic systems". The DOT 3, 4, 5 and 5.1 brake fluids we will be discussing are all non-petroleum based brake fluids.

Base Chemistry

The different chemical bases currently used to make brake fluid are polyalkylene glycol ether (commonly called glycol), silicone, and mineral oil. A few vehicles, including Citroen and Rolls Royce, use a mineral or petroleum oil based central hydraulic system that also powers the brakes. To do this the brake system is fitted with special rubber components that are compatible with petroleum products. The special oil currently being used is "Liquide Hydraulique Minéral", generally called LHM. It is dyed green for identification and it is NOT compatible with conventional brake systems, nor are conventional brake fluids compatible with systems requiring LHM. Failure to use the correct fluid may result in total brake failure.[5] At the risk of offending the Citroen and Roll Royce owners, this article is going to focus on the glycol and silicone based fluids. DOT 3, 4 and 5.1 brake fluids are glycol-based. DOT 4 has borate esters which the DOT 3 does not, and DOT 5 fluids are silicone based. The association of a DOT classification number with the chemical make up of the brake fluid is an accident. There is nothing in the DOT 3 standards that prohibit borate esters, and nothing in the DOT 4 specifications requires borate esters. It just turns out that glycol based fluids with borate esters can meet the DOT 4 specification. Similarly, DOT 5 fluids do not have to be silicone based, but only silicone fluids were able to meet the DOT 5 specifications when the standard was introduced. Because the various DOT classes of brake fluid have become associated with a type of fluid, many have assumed that silicone or borate esters are somehow part of the specification. Brake fluid standards in no way specify what the fluid is made of; anything that meets the standards will be labeled DOT 3, 4, 5 or 5.1. To further confuse matters, when a low viscosity glycol based fluid meeting the DOT 5 boiling point specification was developed, they called it DOT 5.1. The "5.1" seems to imply some connection with DOT 5, and by association, silicone fluids, which is unfortunate. DOT 5.1 has a diethylene glycol-ester base, with properties similar to DOT 4, but with enhanced performance characteristics including higher boiling point and lower viscosity for use in anti-lock (ABS) brake systems. It might have been clearer to call it DOT 4.1, or DOT 6.

Federal Motor Vehicle Safety Standard 116

"The purpose of FMVSS 116 is to reduce failures in the hydraulic braking systems of motor vehicles which may occur because of the manufacture or use of improper or contaminated fluid."

[26] The FMVSS 116 details standards and the testing procedures used to measure the properties of brake fluid, which they define as “Liquid designed for use in a motor vehicle hydraulic brake system in which it will contact elastomeric components made of styrene and butadiene rubber (SBR), ethylene and propylene rubber (EPR), polychloroprene (CR) brake hose inner tube stock or natural rubber (NR).” [26] Note the inclusion of natural rubber, the material used to make the original seals and cups in British cars.

The tests are numbered 6.1 through 6.13, and are detailed below:

6.1 Equilibrium Reflux Boiling Point (ERBP)

Also know as “dry boiling point”. The term reflux simply means the fluid is kept at the boiling temperature with a water-cooled condenser to return the solvent vapors to the reaction vessel and prevent their escape. [26] This allows the boiling point to be measured with great accuracy. Brakes (especially disc brakes) can get very hot under heavy braking. The calipers heat up, and the fluid in the calipers heats up as well. If the fluid boils, the air bubbles formed will greatly reduce braking effectiveness because the force applied to the pedal will be compressing the bubbles, rather than pressing on the brake pads. If enough bubbles form, the brakes will be come totally ineffective; they will have failed.

6.2 Wet ERBP

Also know as “wet boiling point”. This test measures the boiling point of “humidified brake fluid.” Samples of the subject brake fluid are humidified by exposure to water vapor under controlled conditions with samples of SAE TEGME referee fluid. TEGME stands for **T**ri**E**iethylene **G**lycol **M**onomethyl **E**ther, brake fluid grade, referee material described in Appendix E of SAE Standard J1703. When the SAE TEGME referee brake fluid reaches 3.70±0.05 percent water by weight, the brake fluid being tested is capped and allowed to cool. The “wet” ERBP is then measured as described under (A) above. [26] Different brake fluids absorb water at different rates; brake fluid that absorbs more water during the test will have a lower boiling point than another. This test is intended to approximate the amount of water contamination that might be absorbed in a year of use in a brake system under average conditions.

6.3 Kinematic Viscosity

This consists of a series of tests that determine the flow rate of the brake fluid under controlled temperatures. This is done to ensure that the fluid does not thin out too much at high temperatures, or thicken up too much at low temperatures. [26] “Kinematic viscosity is measured in centistokes (cSt) and is a measure of a fluid’s resistance to flow or, more simply, its thickness. It must always be quoted at a stated temperature because a fluid’s viscosity will change with temperature.” [45] The procedure uses an open-ended glass tube that is “immersed vertically in a bath at the required temperature; [fluid] is introduced at the top and, as it flows down, it is brought up to the correct temperature. Its flow is then timed between two marks. The time measurement is converted to a viscosity.”[45] It is important to realize that the three attributes discussed so far—dry boiling point, wet boiling point and viscosity—are the ***only*** standards that vary from one DOT class of brake fluid to another. Every other standard applies to every brake fluid, with some noted exceptions for silicone fluids.

6.4 pH Value

The pH is a measure of the acidity of the brake fluid. The standard calls for a pH not less than 7.0 or more than 11.5, 7 being neutral, and numbers over 7 being increasingly alkaline. Acidity is a factor in corrosion. This standard does not apply to silicone based fluids. [26]

6.5 Fluid Stability

The effect of prolonged heating under reflux is tested by measuring the change in the boiling point. The sample brake fluid is also mixed with another SAE test brake fluid and the effect on the boiling point is measured. In both cases, the boiling point cannot change more than 3℃ (5.4℉) plus 0.05° for each degree that the ERBP of the fluid exceeds 225℃ (437℉). This ensures that the ERBP of brake fluid that has been boiled by heavy braking will not change significantly. It also ensures that mixing approved brake fluids will not significantly change the ERBP. [26]

6.6 Corrosion

Six specified metal corrosion test strips (steel, tinned iron, cast iron, aluminum, brass, and copper) are polished, cleaned, and weighed, then placed on a standard rubber wheel cylinder cup in a corrosion test jar. The test material is immersed in brake fluid contaminated by water, capped and placed in an oven at 100℃ (212℉) for 120 hours. After cooling, the strips, fluid, and cups are examined and tested for evidence of corrosion. The cups are checked for changes in hardness, size (not to exceed 1.4 mm), surface deterioration and blisters. [26]
"Corrosion inhibitors… used in brake fluid are typically based on a chemical group called 'amine.' The amine-based inhibitors are well known as being able to protect iron or steel from corrosion in aggressive high-temperature liquid environments." "Individual amine inhibitors work in one of two different ways: (1) by reducing the acid level (neutralizing or buffering amines) and (2) by forming a water-repelling barrier film on the metal surface (filming amines). [40]
These corrosion inhibitors are included to protect the various metal components of the brake system from the corrosion that would be caused by the water that is absorbed by the brake fluid over time.

6.7 Fluidity and Appearance

Brake fluid is chilled to expected minimum exposure temperatures (-40 and -58º F) and observed for clarity, the formation of gel, sediment, separation of components, excessive viscosity or thixotropy, which is the property of a material which enables it to stiffen or thicken on a relatively short time upon standing but upon agitation or manipulation to change to a very soft consistency or a high viscosity fluid. [26] Although it is nice to know the fluid is still functional at these extremes, it is not something most of us would be concerned about. I am sure there are not many MGs or Triumphs out on the roads at -40º F!

6.8 Water Tolerance

Sample glycol based brake fluid is diluted with water (to 3.5%). Silicone brake fluid is humidified (described in 6.2 above). The samples are stored for 120 hours at -40 º F. The fluid will fail if there is any evidence of sludging, sedimentation, crystallization, or stratification. The sample is then heated to 140º F for 24 hours and the examination repeated. No stratification is allowed, and sedimentation is allowed so long as it does not exceed 0.15 % by volume. The effect of both the cold and heat cycle on the movement of an air bubble through the test fluid is also checked; if the bubble moves too slowly through the fluid, it fails. [26]

6.9 Compatibility

This is a repeat of the Water Tolerance test, although in this case the water has been replaced by a SAE test brake fluid with known chemistry. This test ensures that fluids meeting the DOT specifications can be mixed without degrading the performance of the brake fluid. [26]

6.10 Resistance to Oxidation

Glycol based brake fluids are activated with a mixture of approximately 0.2 percent benzoyl peroxide and 5 percent water. Silicone based brake fluids are humidified in accordance with S6.2 (without measuring the ERBP), and then approximately 0.2 percent benzoyl peroxide is added. A corrosion test strip assembly consisting of cast iron and an aluminum strip separated by tinfoil squares at each end is then rested on a piece of synthetic rubber wheel cylinder cup positioned so that the test strip is half immersed in the fluid and oven aged at 70℃ (158℉) for 168 hours. At the end of this period, the metal strips are examined for pitting, etching, and loss of mass; no significant changes are allowed. [26]

6.11 Effect on Styrene-Butadiene Rubber (SBR) Wheel Cylinder Cups

This test measures the effects of a brake fluid in swelling, softening, and otherwise affecting standard wheel cylinder cups. [26] SBR rubber is a synthetic rubber commonly used to make brake system seals and wheel cylinder cups. IG Farben came up with the compound “Buna-S” in the 1930s. It became very important in this country in WW II, when SBR plants were built to produce synthetic rubber to augment our dwindling stocks of natural rubber. After the war, control of the plants transferred to commercial enterprises. About 40% of the SBR produced now winds up in tires. It is used to make automotive belts, hoses, brake components, toys, floor tiles, surgical gloves and a host of other products.[16] In this test, four standard SAE SBR wheel cylinder cups are measured and their hardnesses determined. The cups, two to a jar, are immersed in the test brake fluid. One jar is heated for 70 hours at 70℃ (158℉) and the other for 70 hours at 120℃ (248℉). Afterwards, the cups are washed, examined for disintegration, remeasured and their hardnesses redetermined. The increase in the diameter of the base of the cups shall be not less than 0.15 mm. (0.006 inch) or more than 1.40 mm. (0.055 inch); The decrease in hardness of the cups shall be not more than 10 International Rubber Hardness Degrees (IRHD) at 70℃ (158℉) or more than 15 IRHD at 120℃ (248℉), and there shall be no increase in hardness of the cups; and the cups shall show no disintegration as evidenced by stickiness, blisters, or sloughing. [26] This is a very significant test because it measures how much the SBR cups swell; the swelling is a result of agents added to the brake fluid to do just that. Note that if the fluid does ***not*** cause the diameter to change at least 0.006” it will fail. It will also fail if the diameter increases by 0.055”. Too much swelling can have adverse effects because the proper operation of the master cylinder can be impaired if ports and orifices are covered by seals or cups that have increased in size. Fluids meeting FMVSS 116 have tightly controlled effects on the SBR rubber components in the brake system. The seals in replacement brake master cylinders, wheel cylinders and calipers are SBR or EPDM rubber. The seals in the repair kits presently available are all SBR or EPDM rubber.

6.12 Stroking Properties

The lubricating properties, component compatibility, resistance to leakage, and related qualities of a brake fluid are evaluated. Brake fluid is stroked under controlled conditions at an elevated temperature in a simulated motor vehicle hydraulic braking system consisting of three slave wheel cylinders and an actuating master cylinder connected by steel tubing. Referee standard parts are used. All parts are carefully cleaned, examined, and certain measurements made immediately prior to assembly for test. During the test, which consists of a total of 85,000 strokes at 1,000 pounds per square inch, temperature, rate of pressure rise, maximum pressure, and rate of stroking are specified and controlled. The system is examined periodically during stroking to assure that excessive leakage of fluid is not occurring. Afterwards, the system is torn down. Metal parts and SBR cups are examined and remeasured. The brake fluid and any resultant sludge and debris are collected, examined, and tested. Metal parts of the test system shall show no pitting or etching that can be seen without magnification. The change in diameter of any cylinder or piston shall not exceed 0.13 mm. (0.005 inch). The average decrease in hardness of seven of the eight cups tested (six wheel cylinder and one master cylinder primary) shall not exceed 15 IRHD. Not more than one of the seven cups shall have a decrease in hardness greater than 17 IRHD. None of the eight cups shall be in an unsatisfactory operating condition as evidenced by stickiness, scuffing, blisters, cracking, chipping, or other change in shape from its original appearance. None of the eight cups shall show an increase in base diameter greater than 0.90 mm (0.035 inch). The average lip diameter set of the eight cups shall not be greater than 65 percent. During any period of 24,000 strokes, the volume loss of fluid shall not exceed 36 milliliters. The cylinder pistons shall not freeze or function improperly throughout the test. The total loss of fluid during the 100 strokes at the end of the test shall not exceed 36 milliliters. The fluid at the end of the test shall show no formation of gels. At the end of the test the amount of sediment shall not exceed 1.5 percent by volume and brake cylinders shall be free of deposits that are abrasive or that cannot be removed when rubbed moderately with a nonabrasive cloth wetted with ethanol. [26] This test is also very significant because it applies the same test to every brake fluid, regardless of the base material or the DOT class. Brake fluid that has met the FMVSS 116 standards will adequately lubricate the moving components, and the wear or degradation over time will not be significant.

6.13 Container Information

The label or printing on the bottle must, in addition to not disappearing when exposed to brake fluid, certify that the brake fluid conforms to § 571.116 (FMVSS 116). The name of the packager and the name and address of the distributor of the brake fluid must be provided. There must be a serial number identifying the packaged lot and date of packaging. The contents must be labeled as ‘‘DOT—MOTOR VEHICLE BRAKE FLUID’’ (Fill in DOT 3, DOT 4, DOT 5 SILICONE BASE, or DOT 5.1 NON-SILICONE BASE as applicable). The label also must give the minimum wet boiling point in Fahrenheit of the DOT brake fluid in the container. The following safety warnings in capital and lower case letters as indicated are also required:
(1) FOLLOW VEHICLE MANUFACTURER'S RECOMMENDATIONS WHEN ADDING BRAKE FLUID.
(2) KEEP BRAKE FLUID CLEAN AND DRY. Contamination with dirt, water, petroleum products or other materials may result in brake failure or costly repairs.
(3) STORE BRAKE FLUID ONLY IN ITS ORIGINAL CONTAINER. KEEP CONTAINER CLEAN AND TIGHTLY CLOSED TO PREVENT ABSORPTION OF MOISTURE.
(4) CAUTION: DO NOT REFILL CONTAINER, AND DO NOT USE FOR OTHER LIQUIDS. [26]
It would not be a Government regulation without specifying what went on the label. All this information is provided to make it possible for the consumer to make an informed buying decision. The safety warnings are good advice, and are there to try and prevent the common handling mistakes.

The FMVSS 116 standards have done a great deal to standardize the performance of commercial brake fluids. Any brake fluid, glycol based or silicone based, that meets these standards will perform to the levels specified and verified by the testing. The process of choosing a brake fluid is still a personal choice, and individual experience will have as much if not more to do with the eventual choice as anything else. There are a couple of areas that need further discussion before we can draw this discussion to a close.

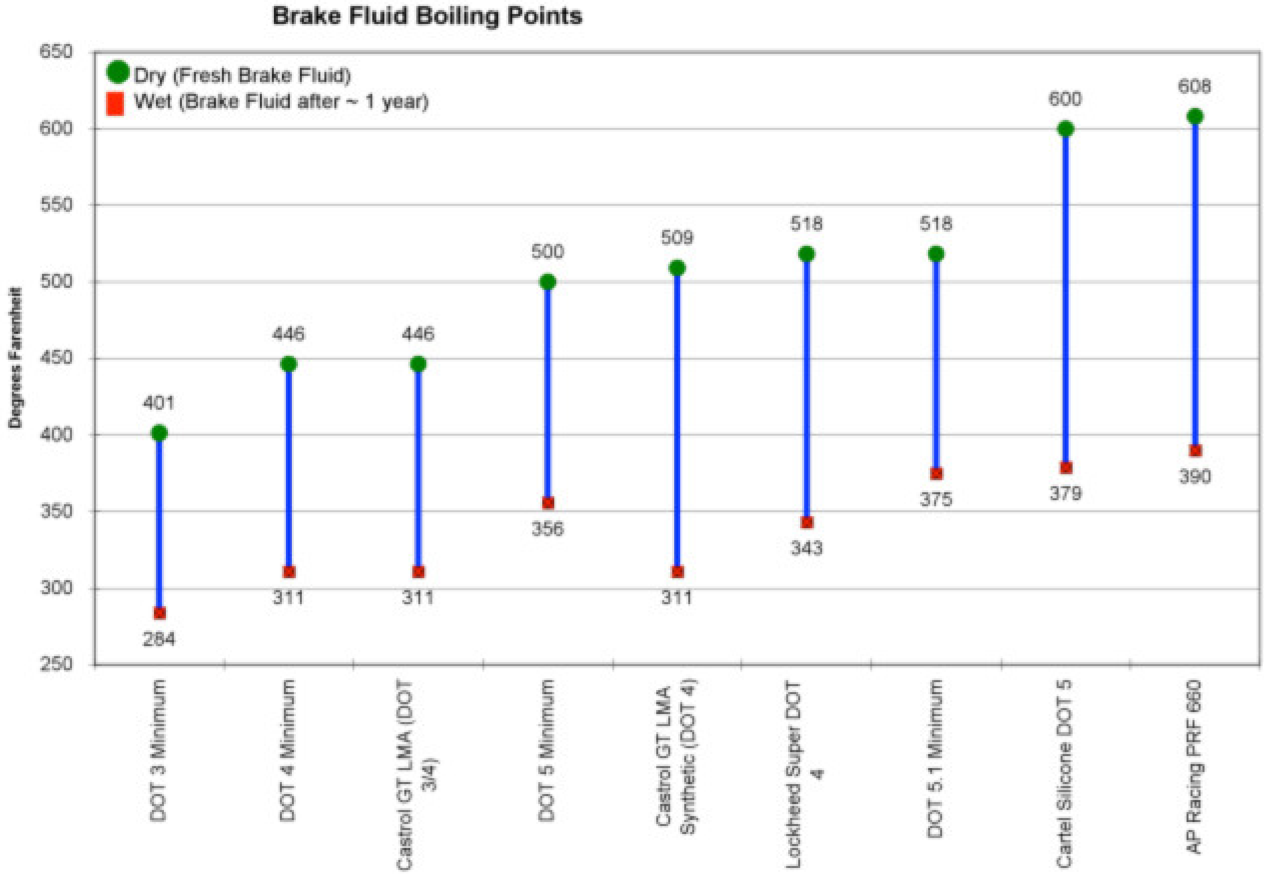
About Boiling Points

At this point we will take a closer look at the wet and dry boiling points of some specific brake fluids compared to the minimums established in the DOT specifications.

Moss #			Description	Boiling Point, ºF		Boiling Point, ºC	
				Dry	Wet	Dry	Wet
			DOT 2 Minimum	374	NA		
			DOT 3 Minimum	401	284	205	140
			DOT 4 Minimum	446	311	230	155
			Castrol GT LMA (DOT 3/4) (1)	446	311	230	155
220-455	12 oz.	360 ml	Castrol GT LMA (DOT 4)	509	311	265	155
220-505	1 gal	3785 ml	Castrol GT LMA (DOT 4)	509	311	265	155
220-400	16.9 oz.	500 ml	Lockheed Super DOT 4	518	343	270	173
			DOT 5 Minimum	500	356	260	180
220-410	1 qt	946 ml	Cartel Silicone DOT 5 (2)	600	356	316	180
			DOT 5.1 Minimum	518	375	270	191
			AP Racing PRF 660	608	390	320	199

(1) Castrol GT LMA used to have a dry boiling point of 446ºF. By changing the formulation, this has been raised to 509ºF. You will find numerous references on the internet that still give the lower (now obsolete) boiling point. When the change in formulation was made, they added the adjective “synthetic” to the label which has caused some concern. Castrol has made it clear that GT LMA has always been synthetic, the word just was not used in advertising. (2) Since DOT 5 is non-hygroscopic, you might expect the "wet" boiling point to be the same as the dry boiling point. However, this is not the case. If water is introduced into the system, it will have an effect. For example, a brake system using silicon-based fluid with liquid water actually in the caliper could show an effective boiling point equal to that of the water, or 212º F at sea level.

Graphical Comparison of Wet & Dry Boiling Points



The graph on the previous page makes it easy to see how several brake fluids compare to the DOT minimum specifications. Notice that the Castrol and AP Lockheed DOT 4 brake fluids actually ***exceed*** the dry boiling point specification for ***DOT 5*** brake fluid. Silicone brake fluid has very high wet and dry boiling points, but the AP Lockheed 660 Racing Brake Fluid has the highest of all those shown. The racing brake fluid has a dry boiling point ***90 degrees*** higher than the Lockheed DOT 4 fluid. In contrast, the wet boiling point is only ***47 degrees*** higher. The advantage of most racing brake fluids is primarily the elevated dry boiling point.

Water Contamination & Boiling Point of Glycol Based Brake Fluids

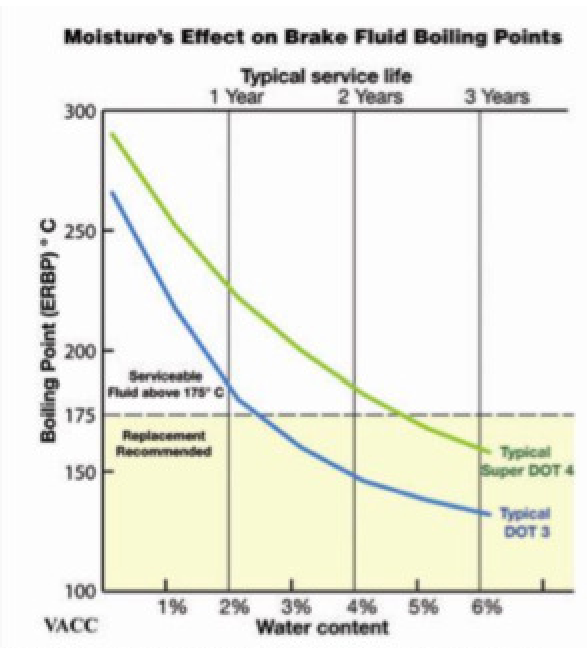
Glycol-based brake fluids are hygroscopic, meaning they absorb water from the atmosphere. “Water contamination from any source, including mechanical or accidental additions of free water, will appreciably lower the original boiling point of the brake fluid, and increase its viscosity at low ambient temperatures. Water contamination may cause corrosion of brake cylinder bores and pistons, and may seriously affect the braking efficiency and safety of the brake actuating system.”[22]

How Does the Water Get In?

Most comes from the vent in the master cylinder cap and resultant condensation in the air space above the fluid. [14] If cans of brake fluid and master cylinders are allowed to remain open to the atmosphere for too long, it will greatly increase the amount of water absorbed. Removing the reservoir cap to check the brake fluid level also increases the exposure of the brake fluid to moisture-laden air. Water molecules will also penetrate the rubber brake hose through microscopic pores that are too small for fluid to leak out, but large enough for gasses to pass through. Some modern brake hoses now have inner liners of material designed to prevent this water incursion. [46] For example, “starting in 1993, GM began using a new type of rubber brake hose with an EPM lining and outer jacketing that reduces moisture penetration by 50%.”[48] Water can also get past the seals in wheel cylinders and calipers.

Where Does the Water Go?

Once the water is inside the brake system, it is absorbed into the glycol based brake fluid and dispersed throughout the system. If you are going to have water in your brake fluid, you actually want it dispersed throughout the fluid because it minimizes the chance of corrosion caused by localized pockets of water. It also prevents a pocket of water in a caliper boiling, which would occur around 212ºF, much lower than the boiling point of the brake fluid.



GRAPH FORM THE VICTORIAN AUTOMOBILE CHAMBER OF COMMERCE (VACC), MELBOURNE, AUSTRALIA [14]

What Can be Done to Prevent the Water From Getting in?

So long as you stick with glycol based brake fluid, you can’t stop it, but you can slow it down. To combat the hygroscopic nature of glycol based brake fluids, brake fluid manufacturers add chemicals to the glycol base compounds. Castrol was very successful in this regard; the LMA in “Castrol GT LMA” stands for “low moisture absorption”. Lockheed Super DOT 4 has similar low moisture absorption properties. Note that the brake fluid formulation can slow the rate at which water is absorbed, but they cannot stop it. Things we can do start with how we check the fluid level in the reservoir. Many British cars have metal brake reservoirs fitted with metal caps, and to check the fluid the cap must be removed. The switch to transparent brake and clutch fluid reservoirs that occurred in the 1960’s was made in part to eliminate the need to open the reservoir, but there is no easy way to retrofit your British car with a clear plastic reservoir. When you check the fluid, do it quickly. Think about the gasket in the reservoir cap. Many modern reservoirs use a flexible rubber gasket that covers the entire opening. This reduces the amount of moisture that can get to the fluid through the vented cap. Note that these gaskets have accordion-like folds so that the pressure can be equalized on both sides, and there is generally a tiny slit in these gaskets, so they do not “seal” the reservoir. [See Appendix A, 582-505] Brake bleeding procedures frequently suggest that you put a piece of clear plastic wrap over the open reservoir secured with a rubber band. It will limit the exposure of the fluid to moisture while allowing you to keep tabs on the fluid level. Choose your method of bleeding the brakes to limit the amount of moisture-laden air the fluid is exposed to. Avoid using any system that puts pressurized air directly into the brake reservoir (or a remote fluid reservoir). Using a vacuum brake bleeder (See Appendix A; 056-671 Vacuum Brake Bleeder, or 386-225 Professional Air Powered Vacuum Bleeder). The important thing to remember is that although we can slow it down, we cannot stop water from getting into the brake fluid.

How Much Water Are We Talking About?

Glycol based brake fluid “typically absorbs about one percent or more moisture per year of service life. Many two-year-old vehicles have as much as two to three percent water in the brake fluid” [46]. The amount of water absorbed will continue to increase over time, and the water content can reach 7 or 8%. [14]

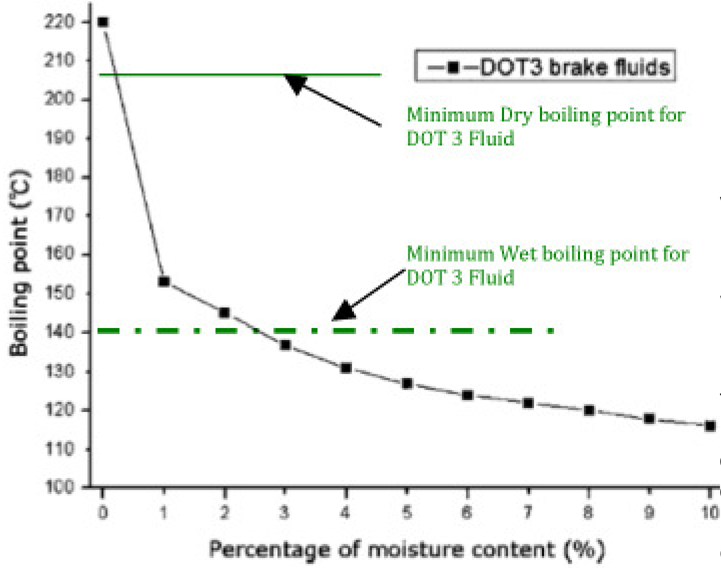


FIG. 6—*Lowering of boiling point of DOT3 brake fluids with increasing moisture content.*

Water Contamination and the Effect on Boiling Point

Water contamination will significantly reduce the boiling point of the brake fluid. “Only one percent moisture can lower the boiling point of some DOT 3 fluids down to 369° F. Two percent water can push the boiling point down to 320° F, and three percent can drag it all the way down to 293° F - which is getting dangerously close to the minimum DOT requirements.” [46] The effect of water contamination on the boiling point of DOT 3 and DOT 4 fluid is shown in the graph to the right.

The pattern shown in the graphical data from Australia is supported by numerous other sources. The study done by the National institute of Standards (NIST) related the percentage of water to the reduction in boiling point for DOT 3 brake fluid in one graph, and related the resulting drop in boiling point to years in service.

To help make sense of this, I have overlaid in green the wet and dry boiling points for DOT 3 fluid.

The implications of NIST Fig 6 are clear. When the amount of moisture reaches 3%, the boiling point of DOT 3 brake fluid will be at or below the minimum.

A look back at the graph from Australia will confirm the similarity between the two graphs.

The NIST Paper presented the same data in a second graph, (Figure 7), this time using “years in service” as the horizontal axis.

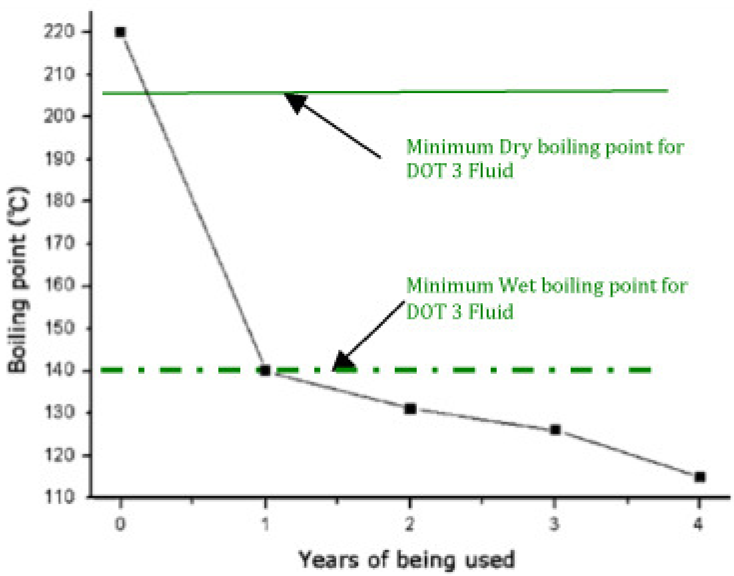


FIG. 7—*Lowering of boiling point after use of DOT3 brake fluids (75 % RH).*

It is evident that DOT 3 brake fluid can absorb enough water in 1 year to drop the boiling point of the fluid to the minimum of 140 ℃ (284℉).

It is also apparent that the reduction in boiling point is not linear over time; the initial drop over the first 12 months is the most significant. Of the total drop of 105 ℃ (221 ℉) that occurred over 4 years, 80 degrees or 76% of the drop occurred in the first 12 months.

This data is not necessarily an indication of exactly what is happening in your car. The rate of moisture absorption will depend on the actual brake fluid used, its exposure to the atmosphere through the reservoir cap, brake hoses, and caliper and/or wheel cylinder seals, and how much water vapor there is in the air where you live. If you live where the humidity level is usually quite high, your brake fluid will need to be changed much more frequently.

At What Point is The Lower Boiling Point a Problem?

It is obvious that the reduction in boiling point is not going to be a problem if the brake fluid never gets that hot. That depends on how hot your calipers or wheel cylinders get, and that will depend on how hard the brakes are applied and how fast you were going. The brakes are going to get

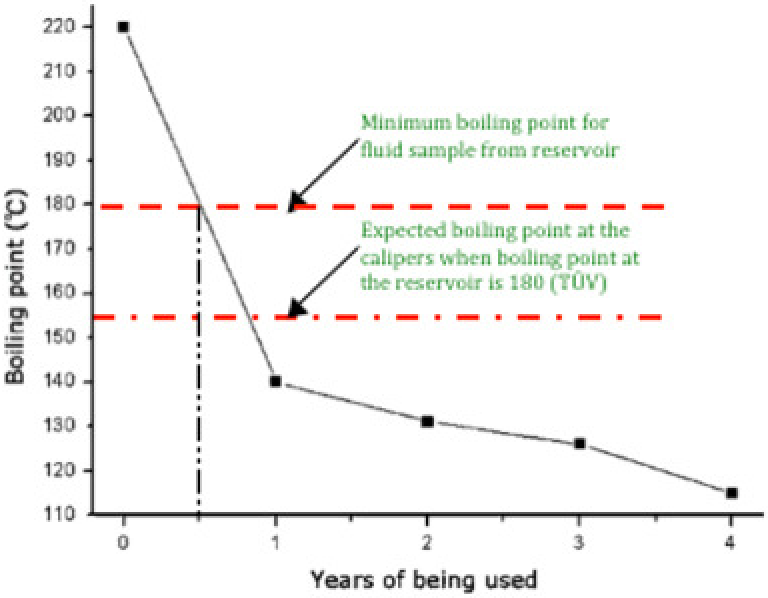


FIG. 7—*Lowering of boiling point after use of DOT3 brake fluids (75 % RH).*

much hotter coming down a long descent on a mountain road than they are motoring through town. A brief period of aggressive driving and heavy use of the brakes can also elevate brake fluid temperatures tremendously. “Brake fluid can commonly see 150–200℃ [300-392℉] at the brake calipers.” [14] The VACC suggests that 175ºC [347ºF] is the lower limit for “serviceable brake fluid”. If we accept that for the moment, it means that DOT 3 with ~2.5% water contamination and DOT 4 with 5% water contamination may boil in the calipers. The German *TÜV (**T**echnischer **Ü**berwachungs-**V**erein*, or *Technical Inspection Association), can be considered to be a Department of Transportation on steroids. They have established 180*℃ (*356*℉) *as the minimum boiling point for fluid samples taken at the reservoir. At that point, the boiling point at the calipers and wheel cylinders will be close to 155* ºC (311ºF) due to higher levels of water contamination because of the proximity of the brake hoses. [54] The absorbed water reduces the temperature at which gas bubbles begin to form in the brake fluid. When these bubbles form, they turn the virtually incompressible hydraulic fluid into a mixture of gas and liquid, which can be compressed considerably, severely reducing the efficiency of the brakes. When this happens, the brakes feel “spongy” and the brake pedal travel will increase. It may be necessary to 'pump' the pedal to get the brakes to function. If the volume of the air bubbles in the system is equal to the swept volume in the brake master-cylinder, the brakes will stop working altogether. This condition is called “vapor-lock” and it translates into brake failure, because stepping on or pumping the brakes will have no effect whatsoever. [14]

If we overlay the boiling point minimums from the TÜV, it is clear that DOT 3 fluid will last about 6 months. At that point, the boiling point of the fluid in the calipers would be about *155* ºC (311ºF).

Not surprisingly, DOT 4 brake fluid is used in new Mercedes, BMW, Volkswagen and Audi automobiles because it will have a higher wet boiling point for an extended period of time.

What About the Real World? How Many Cars Actually Have Contaminated Fluid?

All the laboratory data in all the scientific papers become purely academic if data from vehicles in daily use does not support the lab findings. As it turns out, the lab data is well supported by data collected from cars in use. One study of 83 vehicles conducted by the *TÜV* in Germany found “over 60% [50 vehicles] of the [83] vehicles tested… had brake fluid with water content above 4%. On the average 4% water reduces the boiling point by 100 degrees centigrade [212 ºF].” [54] They concluded that “even with regular fluid changes being recommended by European automobile manufacturers, high water content is a major problem in the general population of vehicles. Either the recommended service is not being followed or water is entering the system much faster than previously thought.”[54] Their conclusions could not be more clear-cut because the full service history of each vehicle could not be known with certainty. A study conducted by the National Highway Traffic and Safety Administration (NHTSA) “found that the brake fluid in 20% [344] of 1,720 vehicles sampled contained 5% or more water.”[48]

Boiling Point & Brake Fluid Selection

Looking at the data showing the boiling points for the various brake fluids, the differences are obvious. However, picking your brake fluid is not simply selecting the fluid with the highest boiling point. For the racers, the dry boiling point is critical; they must have brake fluid that can stand the tremendous heat generated by racing brakes. [6] Look at the dry boiling point for the AP Racing

PRF600 fluid in the chart above- it is 162º F above the DOT 4 specification, and nearly 100º F above the dry boiling point of the Castrol LMA. Although racing brake fluids have high dry boiling points, most are highly hygroscopic, and have relatively very low wet boiling points. In a street car, they would work extremely well if you were to change the fluid very frequently, but this rapidly becomes impractical, not to mention very expensive. For a vehicle that is not driven much, racing brake fluid makes little sense because the maintenance becomes a burden. Even if you don't drive the car, the fluid will absorb water and require frequent replacement. On the other hand, for a race car, the wet boiling point is almost irrelevant because the brake fluid is changed frequently and the fluid does not stay in the system long enough to absorb much water. However, for the average British car, the wet boiling point numbers are much more important than dry. By selecting a brake fluid with a high wet boiling point, you are picking a brake fluid that is more suitable for a car that is not going to have the fluid changed frequently. [6] A high wet boiling point minimizes the chance of the fluid boiling in the calipers under normal driving conditions. A high wet boiling point does not mean you can leave the fluid in indefinitely. It is still going to be necessary to change the brake fluid regularly, as we shall see.

Water Contamination & Corrosion

The reduction in the boiling point is clearly more of a concern than corrosion, but corrosion will eventually pose a serious problem. Given enough time, the damage will cause leaks and eventually, if left uncorrected, brake system failure. After a year in a car, most DOT 3 (glycol based) brake fluids will have 2-3% water contamination. DOT 4 (glycol and borate ester bases) fluids will have about the same amount. At this level, the corrosion inhibitors in the brake fluid will prevent any problems. If you change your fluid every year, you won't have much to worry about. However, if you let it go, there are two things that work together to make corrosion a serious problem. First, the corrosion inhibitors have a lifespan. Time and heat act to break down the chemical corrosion inhibitors. As they deteriorate over time, the protection they provide is reduced. [30] Second, the amount of water in the brake fluid will continue to increase. For years it has been common knowledge that water contamination of glycol based brake fluids will eventually lead to corrosion of brake pipes, wheel cylinders, calipers, and master cylinders, resulting in pipe leaks, "frozen" cylinder pistons, accelerated seal wear, and the formation of sludge. Many of us have owned cars that had brake systems that needed a complete overhaul because once the cars stopped being driven nobody thought to change the brake fluid.

Understanding the Corrosion Process

Water contamination has recently been shown to be a contributing factor, not the sole cause of corrosion. To understand corrosion, we need to know a little bit more about the process. The fundamental principle driving corrosion of iron or steel is simple: The natural progression is from less stable to more stable, and rust produced by the combination of oxygen and iron or steel is more stable than pure iron or steel. Copper also reacts with oxygen for the same basic reason. Most metals exposed to oxygen form "a thin layer of the metal on the surface which reacts with oxygen in the air to form a dense oxide film. This film "passivates" and protects the rest of the metal by acting as a barrier to greatly reduce further reaction with oxygen." [40] This film will be partially dissolved by water or other solvents, reducing the protection it provides. High heat and acids will accelerate the process. Not much can be done to limit the amount of oxygen dissolved in the brake fluid, and the brakes inherently generate heat. The acids can be neutralized to a certain extent by adding alkaline chemicals to the brake fluid, which is why brake fluid has a pH of 7 to 11.5. Brake fluid manufacturers also add chemicals to the fluid that stick to and coat the metal surface, providing a barrier in addition to the metal oxide film. [40] Corrosion is a complex process, and different metals behave differently. Metals that are used in combination also behave differently. Some metals are inherently more corrosion resistant than others. Consider zinc, iron, and copper. Of the three, copper is the least prone to corrosion, and zinc is the most prone to corrosion. Iron is in the middle. A galvanized nail is steel dipped in molten zinc. When exposed to water the zinc will corrode first, protecting the steel (iron alloy) underneath. If the zinc coating is

broken and dissolved oxygen comes in contact with the steel, the surrounding zinc will react and corrode before the steel does. If you put copper and iron together, the iron will corrode before the copper will. The relevance to brake systems is this: where copper metal has already been corroded and dissolved into a liquid, it will attack any iron metal (steel) it comes in contact with. This is because, like zinc does for iron, the iron will sacrifice itself for the copper. The result is that dissolved copper will come out of solution and plate onto the surrounding steel, while a proportional amount of iron will dissolve and go into solution. While the initial corrosion reaction of copper requires oxygen and acid, the second reaction where dissolved copper corrodes the iron does not have this requirement. This chemistry is important in explaining what can happen in brake systems with aged and degraded brake fluid. [40] The corrosion inhibitors that would normally protect the iron and steel to a certain extent break down over time with heat and the corrosive effects of the copper will increase. All it takes is time: another extensive study found that the buffer capacity and inhibitor concentrations "drop to less than 10% of their initial levels after only 30 months of service." [27] The NIST (National Institute of Standards and Technology) study does show that internal corrosion does take place as a result of depletion of the corrosion inhibitors in the brake fluid and the accumulation of water in the brake fluid over time.[40]
The report went on to offer the following proof of corrosion:

1. Visual evidence of corrosion damage is observed on iron alloy components approximately one-third of the time (typically no damage is observed to stainless steel);
2. The damage observed usually consisted of shallow pitting similar to that reported by Jackson's SAE paper [27];
3. In most cases, when corrosion pits were found on iron, copper deposits of varying morphology were also found;
4. The small copper particles were found both inside and outside of the shallow pits on the iron, and
5. The copper sponge and the copper nugget morphology were found in the shallow pits associated with, and usually under, the gel-like substance.

How Much Copper Is Too Much?

It is apparent that “dissolved copper levels in brake fluid increase nearly constantly with time of service. The SAE paper reports copper levels at 150 to 300 PPM (parts per million) after 30 months of service.” [40] The level of copper will vary not just with age, but also with the type us driving the vehicle has be subjected to. “An automobile that has seen "hard driving" with frequent use of brakes is likely to show greater depletion of the inhibitors and loss of corrosion protection, as well as greater copper concentration, for a given time or mileage in service.” [40] The Automotive Maintenance and Repair Association (AMRA) Maintenance Service Task Force did an extensive study of “industry data, including a review of SAE Papers, US Government reports (NHTSA and NIST) and independent laboratory studies.” [9] Their official recommendation is that “(1) Brake fluid be tested for contamination at OEM recommended brake system inspection intervals, and (2) a Brake fluid replacement service be performed, for most vehicles, when testing shows that copper content exceeds 200 PPM.” [9]

Where Does the Copper Come From?

It turns out that “in a typical vehicle the inside surface of the brake lines is the vast majority of the metallic surface area exposed to the brake fluid. A typical light duty vehicle will have approximately 14 m of brake lines and about 0.9 L of brake fluid.”[27]. In “a metallurgical cross section prepared at NIST of a brake line sample supplied by NHTSA…it can be seen that these pipes are made from a 2 layer spiral wrap of steel brazed with a copper brazing alloy. Examination of the inside diameter of a brake line at the braze joint… shows that the copper brazing alloy is exposed to the brake fluid and that a significant portion of the inside surface of the brake line is coated with the copper brazing alloy.[30] Jackson et al. [27] estimated that “the brake fluid in a typical vehicle is exposed to about 0.12 m2 of this copper alloy so that copper corrosion rates, well below that required for DOT 3 brake fluids, can result in appreciable copper ion contents in the small volume of brake fluid." [30]

Dealing with Water Contamination of Glycol Based Brake Fluids

Flush & Re-Fill

It may seem odd, but a quick look in your owner's manual will give you the answer – regular flush and refill of the brake fluid. For example, the Austin-Healey 100-6 and 3000 Workshop Manuals specify brake fluid changes every 18 months or 24,000 miles (whichever comes sooner), and examination of all fluid seals and hoses in the hydraulic system, with replacement as required, every 3 years or 40,000 miles. As old is the information is, it is still excellent advice today. Some of you with Chrysler or GM cars may be aware that they both dropped the recommendation for periodic flush and refill from the list of routine maintenance operations. According to GM, their Delco Supreme 11 DOT 3 brake fluid contains additives that many other brake fluids do not, making it essentially a lifetime fluid. There are other features of the modern brake system in the GM cars that make them comfortable with this recommendation. Among them are the sealed nature of the hydraulic system, and the special brake hoses (mentioned earlier) that resist water penetration. [48] Interestingly, Ford has come back to recommending a flush & refill of the brake system every 36,000 miles. BMW says the fluid should be changed every two years. Honda recommends a flush-and-fill every 25,000 to 30,000 miles. Subaru recommends a 30,000-mile brake fluid change. Volkswagen recommends changing the fluid every two years, and clearly states this in their owner's manuals. [48] Note that the German automakers suggesting a 24-month interval use DOT 4 fluid.

Choosing a Glycol Based Fluid Based On Service Interval

Looking at the data we have compiled, it is apparent that the drop in boiling point of DOT 3 brake fluid over time due to water contamination means you must consider changing the fluid every 12 months, regardless of how much you drive. If you live in a dry, arid climate, you can extend that somewhat. Conversely, if you live where it is wet and humid, the 12-month interval might be too long. If you use a DOT 4 fluid, be aware that it actually absorbs water faster than DOT 3 fluids, but the reduction in boiling point is less. With DOT 4, consider changing the fluid every 18 to 24 months. These are conservative recommendations, but they ***do not*** guarantee that you will eliminate the chance of a brake system vapor-lock related failure because they do not take into account the actual amount of water contamination in your brake system. To find out, you will need to physically test samples of your brake fluid.

Testing Brake Fluid

The first question you have to ask is how? We have all seen old discolored brake fluid and I used to think that was a pretty good indicator of "old" brake fluid. "A number of independent sources pointed out that the color of brake fluid cannot be used as an indicator of its condition. One brake fluid manufacturer went on to explain that some new brake fluids have additives that will cause the brake fluid to change color when exposed to the rubber seals. Another source provided data showing that brake fluid appearing almost pitch black can pass all available tests while other fluid samples appearing to be "good" could fail those same tests." [28] Digging a little deeper, it turns out that there are four recognized (and very different) methods of testing brake fluid. These devices are clearly aimed at the shops, and I doubt that any owner needs his own $350 brake fluid tester, but it will be helpful to know what's out there.

Boiling Point

Since this whole focus is boiling point reduction due to water contamination, the most obvious thing to measure is the boiling point. OTC (Owatonna Tool Corp.) offers a tester they call the 3890 Brake Fluid Safety Meter. It is powered by the vehicle battery. It will determine the minimum boiling (vaporizing point) along with minimum recommended levels for DOT 3, DOT 4, and DOT 5.1 fluids. There are no consumables. (~$350)

Alba Diagnostics, Ltd. in Scotland makes a tester called the Alba 1100. It is powered by the vehicle battery. It will determine the minimum boiling (vaporizing point) along with minimum recommended levels for DOT 3, DOT 4, and DOT 5.1 fluids. Lockheed, Snap-On, Ford, Raybestos, Ferodo, Shell, Castrol, Delphi (owns Lockheed) Lucas, Caltex, Facom, Sealey, Draper and Renault all appear to have brake fluid testers made by Alba. OTC does not say so, but Alba indicates that they make the brake fluid tester sold by OTC.

Refractometer

All liquid solutions make light bend. This bending is called refraction. If you have ever looked at a straw in a glass of water, you have seen this phenomenon. The bending of light increases at a rate proportional to the increasing solution concentration. A fluid refractometer is a precise optical instrument that measures the concentration of aqueous solutions by measuring the refractive index of a small sample. There are two kinds of refractometers. The “traditional” optical fluid refractometer is a compact hand held instrument. A drop or two of brake fluid taken from the caliper, wheel cylinder or reservoir is placed in the instrument, and the tester is held up to a light to read the results on a graduated scale. Reichert, who now owns Leica, also has traditional handheld refractometers specifically for brake fluid. (~$340). Note that Reichert sells separate instruments for DOT3 and DOT4 fluid.

The digital handheld refractometers are extremely sensitive also very accurate and conveniently show both the percent of moisture and the fluid's boiling point. A digital refractometer for DOT 3 brake fluid is available from Misco (~$420). Misco sells DOT 3 and DOT 4 handheld refractometers separately. It is unfortunate that there is not a single refractometer available that would work with DOT 3, DOT 4, and DOT 5.1 brake fluid.

Electrical Resistance

As glycol brake fluid absorb water, the electrical resistance of the fluid changes. A study published by the American Society for Testing and Materials (ASTM) found a linear “relationship between contained moisture and its corresponding boiling point as well as contained moisture and resistance for DOT3 brake fluid”. [41] This relationship between water contamination and resistance is the basis for this class of test equipment.

The Sealey VS027 checks moisture content of fluid by measuring the resistance. It must be calibrated using new brake fluid of the same exact type as in the vehicle being tested. A probe is inserted into the fluid reservoir and a button is pressed; the results display as one of four LED indicators are lit. (~£50-70) A very similar unit is available from Draper (both Sealey and Draper are in the UK).

The Sealey VS0272 is a smaller version that uses the same principle. The results are displayed as one of three LEDs light up. Green LED = moisture less than 1.5% (OK); yellow LED = moisture between 1.5% and 3.0% (Consider flushing); red LED = Moisture greater than 3.0% (Fluid should be flushed immediately) (~£55) Gunson offers a version of this tester, which Moss carries as 386-845 (~$50) .. A similar device called the “STO3S121 Electronic Brake Fluid Tester” made by Central Electronic. ($50-$60). The relatively low cost of these testers make them a reasonable addition to your toolbox.

This system is tied directly to the research into the relation of copper ions in the brake fluid to the corrosion of iron and steel brake system components. As the corrosion inhibitors in the brake fluid break down, the amount of copper in the brake fluid will rise. A chemical test strip that reacts to copper ions in the brake fluid will give you an indication of the condition of the brake fluid.

Phoenix Systems markets a kit they call “Fluid Analysis by Stimulation of Contamination Alpha Reactions”, or FASCAR. The specially treated test strips are dipped into the brake fluid for about one second. In 30 seconds, the chemicals in the test strip react to the presence of copper in the fluid. The color of the strip is compared to a chart that shows different shades of purple for numerical values of 0 to 100. A FASCAR rating of 50 corresponds to a copper concentration of 100 PPM, and indicates the corrosion inhibitors are nearly depleted. A FASCAR rating of 75-100 corresponds to a copper concentration of 200 PPM, meaning the corrosion inhibitors are depleted and the fluid should be flushed and refilled. A tube of 100 strips can be bought on the internet from a long list of suppliers. ($50-$60 per tube)

Conclusions About Brake Fluid Testing

In looking at the various test systems available, there are two distinct groups, those seeking to measure the boiling point or the amount of absorbed water in the brake fluid, and a single test that will determine the amount of dissolved copper in the brake fluid. It would seem that they are doing two different things. Those focused on the boiling point/water contamination are addressing the safety concerns raised by water contaminated brake fluid. The determination of the level of copper in the brake fluid is clearly focused on preventing corrosion of brake components, and indirectly the amount of water in the system. I would suggest that although these issues are clearly related, to declare one approach as “the best” is not justified, although the manufacturers of the various instruments will make strong arguments as to why “their approach” is the only valid way to test brake fluid.

Measuring the actual boiling point and the amount of dissolved copper in samples taken for the calipers and wheel cylinders will provide real data about the condition of the brake fluid that is likely to have the highest concentration of water and the lowest concentration of corrosion inhibitors. If you perform those two tests, you will have no trouble deciding whether it is time to replace the brake fluid or not. This is going to be most helpful when accurate records about that brake system maintenance have not been kept. Of course, the need for testing can be reasonably avoided if the vehicle is on a calendar based flush and refill maintenance program; 12 months for DOT 3, and 18-24 months for DOT 4 brake fluid.

At this point we have reviewed the history of brake systems, the classification, chemistry, properties, and regulations that apply to brake fluids. We have explored the meaning of wet and dry boiling points, and the effect of water contamination on boiling points and corrosion. We have covered methods for reducing the rate at which water gets into the system, and how to deal with water contaminated brake fluid

The implications of water absorption are clear. Just based on the reduction in the boiling point, if you use a DOT 3 brake fluid, plan on changing the fluid completely every year. With DOT 4, the fluid should be replaced every 2 years.

Through maintenance done on a regular schedule or as needed based on actually testing the brake fluid. Virtually everything we have covered to this point pertains to glycol based brake fluids. This is because the chemistries of the two types of brake fluids are so very different that it is difficult to talk about them in the same way. Now we will turn our attention to the silicone based brake fluids.

Silicone Fluids

When compared to glycol fluids, silicone has some distinct advantages. They are very stable over wide temperature ranges, and they resist physical and chemical change under severe heat, cold, sheer, oxidation, and other operational conditions that will break down other fluids. They are inert, non-corrosive, non-toxic, and have low volatility. [25] Silicone fluids also have "the lowest viscosity change with temperature of almost any hydraulic fluid." [25] The US Army began testing silicone based brake fluids in 1967.[7] The Army worked closely with manufacturers to develop a silicone brake fluid that was suitable for use in the vast range of vehicles that Army maintains, from sedans, vans, pickups and large trucks to armored personnel carriers and tanks. The Army converted to the use of silicone brake fluid in 1980, a process that took several years to complete.[2, 37] Silicone fluid has been used exclusively since then. Much of what we know about silicone fluids comes from studies done by the Army, or at the Army's request.

Water Absorption

Unlike glycol based fluids, silicone fluids are not hygroscopic. Silicone brake fluid will absorb a tiny amount of moisture (on the order of 280 parts per million, or .0028%) and then absorb no more. If we have a brake system with a total volume of 900 ml (1.9 pints), the maximum amount of water absorbed will amount to 0.0252 ml or 0.0001 pints, That is 1/100 of a teaspoon. Because water will not mix with silicone fluid, any water that gets into the system will tend to pool in the lowest parts of the system. This resistance to water absorption is a critical difference that makes silicone fluids attractive for cars that are driven seasonally, which makes the longer term issues of corrosion more important than they are with a daily driver.

Boiling Point

Silicone fluids have very high dry boiling points – generally around 600° F. The wet boiling point is a little confusing; how can a fluid that does not absorb water have a "wet" boiling point? In the graph on page 7, the wet boiling point for Cartel DOT 5 brake fluid is given as 379° F because that is the minimum required by the FMVSS 116 testing for DOT 5 fluid. The silicone brake fluid is humidified using the procedure defined in section 6.2. then checked to see if it will boil at 379 ° F, the minimum temperature. The data sheet says that the Wet ERBP is "greater than 379 ° F". In actuality, it is a little more complicated. A sample of humidified silicone brake fluid will actually have the same boiling point as the "dry" sample – in the case of the Cartel DOT 5 fluid, 600° F. Since silicone will "float on top of the water", the tiny amount of water logically will in time work is way down to the lowest points in the system. In theory, if that low spot is the caliper, the water can boil at 212° F, well below the dry or the wet boiling point.

Bleeding Water from Systems with Silicone Fluid

Because even a tiny amount of water will lead to corrosion, and water in a caliper or wheel cylinder wan boil at relatively low temperatures, it is advisable to bleed the system every s (?) to 12 months to eliminate the water.

Hazard to Paint

Unlike glycol fluids, silicone fluids do not damage paint. This is of particular importance in regard to show cars where a spill or leak of glycol fluid can have seriously ugly results. A newly rebuilt and scrupulously clean brake system filled with silicone fluid should outlast a system filled with glycol fluid by several times.

At this point, the silicone fluids have what appears to be an obvious advantage over glycol based fluids. Given all the trouble caused by water contamination of glycol based brake fluid, silicone fluid has some appeal. However there are some drawbacks, and we need to understand those before we start making choices.

Air Solubility

It has been reported that dimethyl polysiloxane fluid, which is a major component of silicon based low water tolerant type brake fluids (SAE J1705), 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 SAE J1703 type fluids. Silicone fluid will absorb more air because there is more "room" between the molecules that make up the fluid.[6] 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. [8]

Compressibility

Because of the dissolved air, silicone fluids are up to three times more compressible than glycol based fluids. This can contribute to a slightly spongy feeling brake pedal, particularly near the higher end of their temperature range but well below the dry boiling point. While this is of absolutely no consequence for normal street use, this is why silicone fluids are not used in race cars. A spongy pedal makes it difficult to modulate the brake pressure under racing conditions. [6]

Bleeding Air From Systems with Silicone Fluid

Silicone fluids have a higher viscosity, which combined with a greater tendency to absorb air leads to slow rates of fill and retention of free air entrapped during filling, which makes bleeding the system difficult. Because air bubbles do not easily dissipate in silicone brake fluid, special care must be used to prevent them from forming during pouring and bleeding operations. The best way to bleed a silicone fluid system is with a professional brake bleeder with a sealed fluid reservoir separated from an air chamber by a rubber diaphragm. The air pressure forces the fluid from the chamber into the reservoir and through the lines to the individual bleed screws. This is very effective, but few individuals will find them practical because of the large amounts of brake fluid they use. There are two vacuum bleeders that will work too. These are the "Professional Vacuum Brake Bleeder" (Moss #386-225), and the "Vacuum Brake Bleeder" kit (Moss # 056-671) will also work. (see Appendix A) If you do not have either of those, bleed the system with slow even pedal strokes. Avoid "pumping" the pedal, which will introduce air bubbles into the system. It may be necessary to bleed the system again in a day or so if there were any air bubbles that wouldn't bleed out the first time. Be aware that air in solution in silicone fluid will form bubbles if the atmospheric pressure drops, as it does when you go up quite a bit in elevation. This will result in a spongy pedal that will persist until the air is bled out of the system.

What About the Stories of Silicone Brake Fluid Causing Seals to swell?

These stories abound on the internet, but I have not actually spoken to the person it happened to, so I cannot comment on the actual incident that started the story. We do know that it is very, very unlikely that a brake fluid meeting FMVS 116 would do that. The testing is designed to make that sort of thing impossible. I can tell you that the literature is full of reference to the grotesquely swollen and gooey seals that you get if the brake system is contaminated with petroleum based oils or solvents. It does not take much of this kind of contamination to ruin all of the seals in a system. The contamination can usually be traced to the use of improper cleaners, rags contaminated with motor oil or grease, or handling the seal with hands that have petroleum based contaminants on them. We have tried to duplicate these reported problems by soaking brake cups in DOT 5 fluid, but we have never found a problem. However, these stories have a life of their own and it is doubtful that they will ever go away. It is perhaps a modern version of the traditional British natural rubber brake seal warning about using “the wrong fluid”.

Converting from Glycol to Silicone Fluid – The Decision

The decision to convert from Girling or Lockheed (or whatever you are using) brake fluid to silicone fluid is not a decision to make lightly. If you have been using a glycol based fluid and never had any issues, I suggest you stay with it. Implement a calendar based flush and fill routine to keep the brake fluid fresh and reduce the chance of a water contamination caused brake system failure. Regular fluid changes will also minimize the chance of corrosion damage. Talk to your mechanic about testing brake fluid if that appeals to you; just keep in mind that you should be testing for both copper and water in the brake fluid. If you are thinking of changing, the decision is not necessarily an easy one. With a modern car, the manufacturer specifies what you should use, and you can have confidence that the entire braking system has been designed with that specific brake fluid in mind. With our British classics, we don’t have that luxury. The specifications given when the cars were new are irrelevant. If you are considering a change, talk to members of your club. Find out what the people who have a car like yours are running. Spend some time on the various forums. If several people have made the switch to silicone and are happy with the results, you can seriously consider making the switch yourself. Why take these steps? All brake fluid, glycol or silicone based, *must* swell brake system seals to form tight seals and help prevent leaks. The maximum amount of swelling is also specified in the FMVS 116 testing. This defines a range of seal expansion that is “within tolerance.” This also means that different fluids can react with a given type of seal differently and still be within the specifications. Just because the fluid you are using is working fine does not mean another brand of brake fluid, even one that meets the same specification, will work just as well because it may not affect the seals in exactly the same way. In some master cylinders, for example, seals can swell so much that the relief port is blocked, which results in brakes that don’t release because the fluid cannot be pushed back into the master cylinders as the wheel cylinders retract. While brake fluid manufacturers will certify that their fluid meets BMW, Ford or GM specifications, they cannot be expected to say their fluid will work in an MG TD master cylinder.

Converting from Glycol to Silicone Fluid

If you do decide to convert to silicone fluid, it should be done as part of a total brake system overhaul, with freshly rebuilt or new calipers, wheel cylinders and master cylinder. Silicone fluid should not be added to a system that contains even small amounts of glycol fluid or contaminants. Merely bleeding the system is not enough, as there will be pockets of old fluid and sludge that will not bleed out. Silicone fluid tends to concentrate any residual glycol fluid, moisture and sludge into slugs instead of allowing their dispersal throughout the fluid, as does glycol fluid. This can lead to relatively severe but localized problems, rather than the more general system deterioration experienced with old moisture-laden glycol fluids. This may be a factor in reports of leakage when silicone fluid is used in non-rebuilt systems that had been operated with glycol fluid. A "new" system full of silicone fluid will require very little maintenance for years.

Conclusions

Old moisture-laden glycol brake fluid is hazardous. It can't be relied upon to stop your car reliably. Glycol based brake fluids must be changed regularly, much as engine oil must be changed. Changing the brake fluid gets rid of the water, and renews the anti-corrosion protection that you can only get with fresh brake fluid. If you use DOT 3 fluid, flush and refill every 12 months. If you use DOT 4, flush and refill every 18 to 24 months. If you would prefer to change the fluid based on actual levels of contamination, you can test boiling point directly or indirectly. You can also measure the amount of copper in the system. If you are happy with the fluid you use, don’t change. If you are contemplating a change from DOT 3 to DOT 4, or glycol based fluid to silicone, check to see what the experience of others has been. Plan on making the change as part of a total brake system overhaul. If you use silicone fluid, bleed the brakes every 6 months or so to get rid of any trapped water.

And finally, recognize that the performance of your braking system depends far more on the condition of the components than your choice of fluid. Perform the recommended service spelled out in your workshop manual to keep the brake system in top condition.

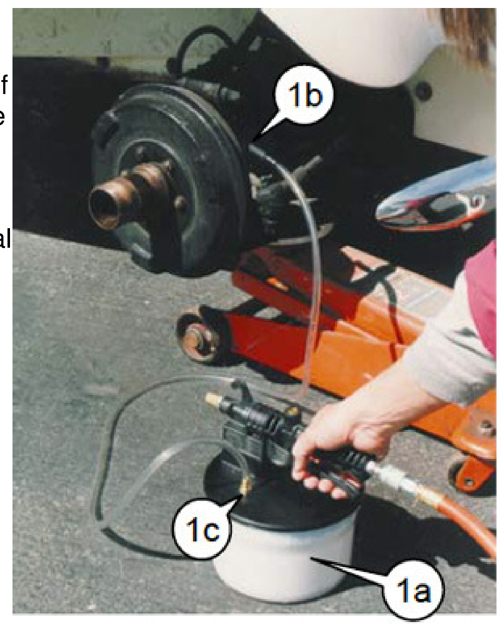
Appendix A

056-671 Vacuum Brake Bleeder

This is actually a combination of two tools, a vacuum pump, and a brake bleed kit. They can be used separately or together. A quality product made in the USA.
Warranty: 1 year.

Hand Operated Vacuum Pump
Pump has a rugged steel handle and frame with cushioned hand grips. The vacuum cylinder, cylinder head and piston are solid brass. Brass cylinder comes with a tapered barbed hose fitting. A 24-inch long black hose with hose adaptor is included. When used with the Brake Bleed Kit, one person can bleed the brakes. You can also use it to check vacuum operated components like the distributor advance mechanism.

Brake Bleed Kit
This kit makes it easy to bleed the brakes without making a mess. Adapters are included for all vehicle brake systems. The brake bleed kit can be used by itself to bleed the brakes in the conventional manner with one person to pump the brakes, and one to operate the bleed screws. If you don’t have a helper, use the brake bleed kit with the hand operated vacuum pump and you can do the job yourself. Includes special lubricant to seal the hose connections.



386-225 Professional Air Powered Vacuum Bleeder
The air flow from a compressor is used to create a pressure differential between the normal atmospheric pressure (14.7 lbs/sq in at seal level) pressing on the brake fluid in the reservoir and a lower pressure in the large tank (1a) attached to the bleeder. A section of clear tubing is attached to the brake bleed fitting at the wheel cylinder (1b) or caliper. The other end of the tubing is connected to the vacuum tank (1c). When the bleed screw is opened and the handle on the brake bleeder is squeezed, the brake fluid will be drawn into the catch tank. A copy of the manufacturer’s instructions are available on our website:
http://www.mossmotors.com/graphics/products/PDF/386-225.pdf

386-845 Brake Fluid Tester
Measures the electrical resistance of the brake fluid to determine the level of water contamination.

Green LED= moisture less than 1.5% (OK)
Yellow LED= moisture between 1.5% and 3.0% (Consider flush & refill with fresh brake fluid)
Red LED= Moisture greater than 3.0% (Fluid should be flushed and replaced immediately)

[582-505 Gasket, for 1.75” Cap](#)
This modern gasket will fit inside any 1.75” reservoir cap, as used on Austin Healeys and many other British cars. It will effectively reduce the amount of moisture that the brake fluid is exposed to.

Bibliography

[1] Silicone Brake Fluid Data, from Cartel
[2] A New Engineering Approach for Converting Vehicle Brake System to Silicone Brake Fluid, SAE 860633
[3] A Study on the Service Interval Performance of Borated and Non-Borated Glycol Ether Brake Fluids, SAE 2001-01-0947
[4] ALBA Brake Fluid Tester
[5] AN EXPLANATION OF BRAKE AND CLUTCH FLUIDS by Hugh Lundin of NORIA UK LTD
[6] Brake Fluid 1A, by Carroll Smith & James Walker (STOPTECH)
[7] Brake Fluid Comparison, swedishbricks.net
[8] Brake Fluid Explained, +GS610
[9] Brake Fluid Replacement Appropriate for All Vehicles, AMRA
http://www.4amra.com/msp/NR_fluid.htm
[10] Brake Fluid Testing, Mil Spec MIL-PRF-46176B[1]
[11] Brake Fluid, Basic Types & Components of Glycol and Silicone Based Fluids
[12] Brake Fluid Brake Fluid Myths Carroll Smith
[13] Brake Fluid comparison of name brand brake fluids
[14] Brake Fluid Effect of moisture on Boiling Point DOT3 and DOT4 Fluid
[15] Brake Fluid Seal Material Natural Rubber
[16] Brake Fluid Seal Material SBR Rubber
[17] Army Experience With Silicone Brake Fluids SAE 780660
[18] Brake Fluid Summary Cautionary Note about DOT5 Silicone Fluid
[19] Brake Fluids by Doug Jackson
[20] Castrol GT LMA Brake Fluid chemical components
[21] Compatibility of Silicone-Base Brake Fluids with Automotive Vehicle Elastomers, SAE 810804
[22] DOT4 Brake Fluids Maintenance & Handling SAE J1707
[23] DOT 3, 4, and 5.1 Fluid Properties, Carless Petroleum
[24] Engineering Design Benefits of Silicone Brake Fluids SAE 740129
[25] Fluid Power Design Handbook, by Frank Yeaple 1995
[26] FMVSS 116 Testing Procedure, DOT Document
[27] Improved Methods for Testing the Durability of Corrosion Protection in Brake Fluids, SAE 971007
[28] Industry Adopts Brake Fluid Replacement Guidelines, by Bill Williams
[29] Measured and Predicted Temperatures of Automotive Brakes Under Heavy Or Continuous Braking SAE2003-01-2712
[30] NISTIR 6233 Brake Fluid & Corrosion
[31] Series 600 DOT 4 Racing Brake Fluid AMSOIL
[32] Service Maintenance of SAE J1703 and J1704 Brake Fluids in Motor Vehicle Brake Systems SAEJ1707
[33] Silicone brake fluid having reduced air solubility, US Patent 4640792
[34] Silicone Brake Fluid, Chicagoland MG Club
[35] Silicone Brake Fluid, Part 1 & 2, Bob Adler
[37] TB 43-0002-87 US Army Order to Convert to Silicone Fluid 1981
[38] The Effect of Silicone Brake Fluid on Rayon Reinforced, Neoprene Tube and Cover Brake Hoses SAE810802
[40] The Use of Dissolved Copper to Indicate the Age of Brake Fluid Dean Wheeler
[41] Using Electrical Conductivity to determine level of water contamination
[42] What the Brake Engineer Wants From Brake Fluid SAE690222

[43] EFFECT OF WATER ON HYDRAULIC BRAKE FLUID
[44] PAGs are Rising to the Top of the Synthetic Market silicone combustion produces silicone dioxide Noria UK
[46] Unbeknownst To Many Vehicle Owners Brake Fluid Does Wear Out - Larry Carley
[47] Dow Corning Silicone Brake Fluid 2-1143
[47] TRW Brake Fluid & Grease PFB - TN-04-2005-11-EE
[48] Why Change Brake Fluid, AA1 Car
[49] Brake Fluids With Low Moisture Avidity, Castrol LMS, 1968
[50] DOT 2 Brake Fluid specifications history
[52] Numerical Prediction of Brake Fluid Temperature Rise During Braking and Heat Soaking, SAE 1999-01-0483
[53] Brake Fluid Vaporization as a Contributing Factor in Motor Vehicle Collisions, SAE 980371
[54] Analysis of Water Content in Brake Fluid, by Ryan (Leica)
[55] Castrol Response Super DOT 4
[56] Pascal's Law, Encyclopedia Britannica
[57] Brake Technology Handbook, edited by Bert Breuer and Karlheinz Bill (SAE Publication)
[58] MISCO DOT3 Brake Fluid Tester
[59] REICHERT (LEICA) BRAKE FLUIDS REFRACTOMETERS, product spec sheet
[60] DOW CORNING(R) 2-1143 SILICONE BRAKE FLUID DCC USA – English
[61] Brake Technology Handbook,