TR250 & TR6 Brakes
Selecting Brake Fluid

These notes describe what I did on my car for my personal use and are provided here for entertainment; they are not meant to be instructions for others to do maintenance on their vehicles.

Brake Fluid Wars: I approached this subject with some trepidation because many folks have very strong feelings about which type of fluid is best for the TRs. The big contention is between the DOT3, DOT4 & DOT5.1 polyalkylene glycol ether based fluids (shortened to glycol-based fluids here) and the silicone based DOT5 fluid. The glycol-based fluids are very effective paint removers whereas the silicone fluid doesn't harm paint. Since I keep the TRs for many years (I've had two for over 20 years), sooner or later the brake or clutch hydraulics leak and screw up the paint. That is why I converted my '76TR6 to silicone fluid last year just before repainting it. I also plan to convert my TR250 this summer and will use silicone fluid in the '70TR6 I've been discussing in these notes.

Since investigating further, I've learned that the glycol-based fluids should be changed periodically. Some manufacturers recommend the fluid be changed as frequently as once a year. The literature suggests the life of silicone fluid is many decades. This is a second reason for me to use the silicone fluid. The silicone fluid is several times the cost of high quality glycol-based fluids, which may be a deterrent for some. The silicone fluid was difficult to obtain locally in the past, but now is available at the local auto parts stores (at least here in Ohio). I normally buy my DOT 5 from TRF who has a good price, especially during their winter parts sale. .

The wife and I both have recent model American made cars equipped by the manufacturer with DOT4 fluid. I have no interest is converting the fluid in these vehicles. I expect the manufacturers wouldn't honor the warranty if the brakes failed after I switched fluid. Also, I'll likely replace the vehicles every 6 years or so at about 60,000 miles, before I expect to have to do major brake maintenance. There is also a question about the effect small suspended air bubbles might have on the ABS --- I have no data on using silicone fluid in an ABS, just heard some questions raised that probably have no basis. So, I'm very happy with DOT4 in modern vehicles and will use the silicone fluid only in the TRs.

There is much information on the Internet about the various types of fluid. All one has to do is search on *DOT4 brake fluid* or *DOT5 brake fluid* or *mixing DOT4 and DOT5 brakes fluids,* which gets some real interesting opinions. **(Remember that the internet is free speech, not necessarily accurate speech, this note included.)** What I've done here is to try to summarize the primary characteristics of each type fluid together with some good and bad characteristics of each. A few of what I consider myths about silicone fluid are listed at the end.

Boiling Point: Boiling point is one of the most important properties of a brake fluid and is one of the major areas of improvement in the last 40 years. The Chicagoland MG club has one of the best discussions I've seen on this issue (see http://www.chicagolandmgclub.com/techtips/525.html.) Basically, over the years the performance of the brake systems has improved ----- meaning that more force is applied to the pads and shoes causing them to get hotter. If the cylinders or calipers get hot enough for the fluid to boil, the brakes cease to function because the fluid vapor locks just like with an air bubble and compresses when the pedal is pressed. In the case of the TR250 & TR6 with a separate system for the front and back, this may affect only half the system --- that part where the fluid is boiling.

I've never experienced this kind of a problem with a TR (3 cars, > 20 years and > 200K total miles). I did however experience such a problem with my wife's previous car about 5 years ago. That car was ~ 5 years old with ~ 50K miles. We were driving to a neighboring village about 20 miles away for dinner. (This kind of thing happens when you take the wife out to dinner.) Shortly after starting out, at about the edge of town, I put on the brakes and the pedal went nearly to the floor. I pumped it a couple times and the brakes returned to normal. I drove a couple hundred feet and tried again--- worked perfectly. At this point we were on a country highway. I tested the brakes again after going a couple miles --- pedal went nearly to the floor again. Operated pedal a couple times and brakes were back to normal. Since there wasn't much traffic I just operated the brakes every mile or so to keep them in shape and was very careful to slow down well ahead of congested areas. I developed a theory as to what was going on. When we reached our destination I checked the four wheels and found the right rear wheel was very hot ---all the others were normal. The theory was that the piston in one of the wheel cylinders or calipers (in this case the right rear wheel cylinder) was stuck such that the brakes were held partially on. As a result, the brakes and the cylinder got very hot. The fluid in the cylinder would heat up and boil forcing the remaining liquid fluid back toward and into the master cylinder. When the brakes were applied the fluid compressed like with an air bubble. When pumped several times, cooler (or not boiling hot) fluid was pushed into the cylinder as the vaporized fluid compressed under pedal pressure. The cooler fluid temporarily cooled the wheel cylinder, stopped the boiling and caused the fluid vapor to condense. As the car was driven further, the cylinder heated up and the cycle repeated with fluid boiling and the vapor pushing much of the remaining fluid out of the cylinder back toward the master cylinder.

The next day I pulled the right drum. Amazingly, the inside of the drum, shoes, etc were very clean, not at all like the typical TR. Of course, this car was only about 5 years old. The wheel cylinder looked new on the outside. However, when I finally got it apart, I found the inside heavily corroded and the piston very difficult to move. Water, maybe even saltwater was the likely culprit. Also, the addition of water to the fluid likely lowered the fluid boiling point drastically. The glycol fluid sucks up water like a sponge as we see below.

DOT Specifications: Lets look at those technical specifications:

DOT MINIMUM BOILING POINT SPECIFICATIONS				
Fluid Type:	**Glycol-based Fluids**			**Silicone Fluid**
	DOT3	**DOT4**	**DOT5.1**	**DOT5**
Minimum Dry Boiling Point[1]	**205 °C/401 °F**	**230°C/ 446 °F**	**~270 °C/518 °F**	**230 °C/500 °F**
Minimum Wet Boiling Point[2]	**140 °C /284 °F**	**155°C /311 °F**	**~190 °C/375 °F**	**180 °C /356 °F[3]**

[1] Dry fluid is with no water content as from a freshly opened container.
[2] Wet fluid is with 3.5% water content typical of glycol-based fluids after 24 months use.
[3] The wet boiling point for the DOT 5 fluid is the DOT specification. The silicone fluid absorbs a very small amount of water (<0.3%) so the boiling point doesn't change with use and one can expect the boiling point to remain at ~ 230 °C/500 °F for many years.

The key to the boiling point is the moisture content. Water has a lower boiling point (100°C/212°F) and as the brake fluid absorbs water, the boiling point of the mixture is lowered.

Moisture Absorption: The glycol-based fluids are very hygroscopic; which means that they readily absorb water. So what's the deal about moisture absorption, aren't the brakes sealed? The answer to that is yes and no. Yes they are sealed to keep the >1000 psi fluid for leaking out when the brakes are applied. However, water has its ways. One way water can get in is if the cap is left off the fluid container. So, be sure that any container has the top securely fastened. (Some recommend that fluid that has been open for as little as a week, even if securely sealed, not be used.) Another way is through the master cylinder. Air must enter the master cylinder to replace fluid that leaves the master cylinder to wheel cylinders and wheel calipers to adjust the piston equilibrium position as the pads and shoes wear. The air enters through a hole in the TR250/TR6 master cylinder lid and brings moisture with it. This is especially troublesome in humid climates such as summers in Ohio. Also, every time the cap is removed, fresh possibly moisture-laden air is admitted. The master cylinder caps of my late model cars contain bellows type seals with one side of the seal positioned against the fluid and the other side open to the atmosphere, essentially isolating the fluid from the atmosphere to minimize moisture absorption..

The likely primary way moisture gets into the system is through the brake hoses. Recall that there are short hoses near each wheel to allow for suspension system movement relative to the frame. Hugh Fader passed on copies of two reports to the Society of Automotive Engineers (SAE) after he learned that I was writing up something on brakes. One by G. R. Browning of General Electric Corporation presented in 1974 reported on comparison studies of glycol-based and silicone fluids. In a test of water permeation of brake hoses, one hose was filled with commercial glycol-based fluid and the other with silicone fluid, both ends were capped and the hoses submerged in water. The results are were

Brake Hose Moisture Absorption Test - Moisture Content of Fluid			
	Before Test	After 7 days Emersion	After 35 Days emersion
glycol-based Fluid	0.15%	3.03%	6.9%
silicone Fluid	0.01%	0.03%	0.03%

Note that the silicone fluid absorbed an insignificant amount of water, it also prevented water from entering the system though the brake hoses.

There was also a concern road salt might enter the brake system through the hoses with the absorbed water so a second test was run with the hoses submerged in a 5% NaCl (salt) aqueous solution. The results of that test were:

Brake Hose Cl Absorption Test - Cl Content of Fluid		
	Before Test	After 6 days Emersion
glycol-based Fluid	<1 ppm Cl	143 ppm Cl
silicone Fluid	<1 ppm Cl	<1 ppm Cl

Browning also reported on controlled tests of vehicles equipped with glycol-based fluid driven from 10K to 50K miles over 21 to 28 month periods where measured water absorption ranged from 3.2% to 6.7%. Similar tests of silicone fluid equipped vehicles driven for 4K to 28K miles over 10 to 18 month periods showed water absorption ranging from 0.03% to 0.26%. The inescapable conclusion from this is that Glycol fluid absorbs sufficient water in two years or less so that the boiling temperature is likely at or below the wet boiling temperature listed above. Therefore, if one is using glycol-based fluids, the wet boiling point should be assumed unless the fluid is changed several times a year. Clearly, if one is in a situation where the brakes are likely to overheat such as going down long hills frequently, one should change glycol fluids more frequently or use silicone fluid.

Note that this is not new data; it was published to the SAE in 1974. So, as far back as 1974 it was well known that glycol fluids absorb water as well as salt and silicone fluids don't. Probably an equally or more important finding is that silicone fluid keeps moisture and salt out of the brake system.

Compatibility of Silicone Fluid with Seals and Hoses: The rubber seals in the brake system swell in the presence of brake fluid thus improving the sealing properties. The silicone fluids Browning reported on in 1974 met established swelling requirements for SBR cups, ethylene propylene (EP) seals, natural rubber cups, and Neoprene brake hoses. A tentative specification had been published for such compatibility prior to that report. So, no problem with compatibility with the seals. Apparently some earlier seal failure attributable to silicone fluid (pre 1974?) were traced to early swelling agents. I had a recent discussion with one of the mechanics at a local military maintenance depot. He said they had some seal problems with an early yellow silicone fluid. He said the current fluid is purple and they are having no trouble. I don't know the era of the yellow silicone fluid but I'm pretty sure the silicone fluid of the late 80s was purple. Of course, the DOD might have had a special formulation.

Compatibility of Silicone Fluid with glycol-based Fluids: The two types of fluid in fact don't mix (they are not miscible). If mixed and then allowed to stand, they separate into two layers, like cream on milk (for those old enough to remember non homogenized milk). Browning reported on extensive tests of running systems with 50/50 silicone/glycol mixtures. Several other reports of tests of mixed fluid systems are available on the Internet. Every case I've found reported no failures. Being an engineer, I figured I should run a little test of mixing the fluids and see what happened. The following shows the result from my basement laboratory.

Step1: Fill the container about half full of Castrol LMA (DOT4) and then gently add about half as much silicone fluid (DOT5). The yellowish fluid on the bottom is the DOT4 and the purple fluid on the top the DOT5. The container is a Heinz baby food container from our days with babies, the youngest of which is now 32 years old. (She throws nothing out, which is OK at times like this).

Step 2: Vigorously agitate so that the two fluids are thoroughly mixed. Note that the purple is everywhere.

Step 3: Wait 30 minutes and observe results. Note that the purple is now on the bottom, not quite as dark and doubled in size. So, did the silicone swell to double size and get heavier so that the glycol fluid now floats on top, and the glycol fluid shrink to half the size? What really happened is that the glycol fluid absorbed the purple dye from silicone fluid. The first time I ran this experiment I used roughly

equal amounts of each so the result wasn't as obvious.

Step 4: Fill the container the rest of the way to the top with water and then shake vigorously. Note that everything appears to be all mixed together in the photo.

Step 5: Observe after two hours. Note that the now clear silicone fluid on the top hasn't increased much if any in volume from Step 1 while the glycol fluid has increased in volume because it absorbed the water. Why did I want two hours this time instead of 30 minutes as in Step 3? Answer: I forgot to check after 30 minutes.

Compressibility: The one real problem found with the silicone fluid is that it is more compressible than glycol fluid, especially at elevated temperature. G W Holbrook of Dow Corning Corporation reported on Alpine testing of Silicone Brake fluids at a SAE meeting in 1981 (another report Hugh Fader gave me). Alpine descents are used in Europe to study brakes. Similar tests are run in the US. The long hills provide a good test bed to apply brakes repeatedly to get the temperature high enough to make the brakes fail.

The compressibility shows up as a slightly softer pedal and additional required pedal movement. The compressibility of the fluid at 1200 psi (about the maximum pressure for the TR6) reported by Holbrook is:

Compressibility of Brake Fluid at 1200 psi		
Temperature	**Silicone Fluid**	**Glycol Fluid**
25°C/77 °F	**0.85%**	**~0.3%**
66°C/150°F	**1.00%**	**~0.3%**
93°C/200°F	**1.23%**	**~0.3%**
121°C/250°F	**1.53%**	**~0.3%**
149°C/300°F	**1.84%**	**~0.4%**
177°C/350°F	**2.11%**	**~0.4%**
204°C/400°F	**2.41%**	**~0.5%***
232°C/450°F	**2.68%**	**~0.6%***

260°C/500°F	**2.89%**	**~0.7%***
316°C/600°F	**3.60%**	
*** The likely boiling point of DOT4 glycol fluid in autos is less than 400 °F so these measurements are meaningless.**		

The compressibility is not a significant problem throughout the system because the fluid in the master cylinder and the lines will stay cooler, probably less than 150°F. The fluid in the calipers and cylinders however can get very hot and is the source of concern. Holbrook developed formulas to determine the amount of increased pedal motion based on the system parameters such as the fluid capacity of each cylinder and pedal mechanical ratio. He also measured the increased pedal motion and found close agreement with the calculations. At 400 °F wheel cylinder/caliper temperature, pedal travel increased by 13.5 mm to 18 mm (0.5 to 0.7 inches) in two sample systems. The brakes with silicone fluid continued to operate at this temperature in spite of the compressibility. The effects of compressibility started to become a problem at temperatures well above where the glycol fluid would vapor lock.

Holbrook emphasized that the dry boiling point is of no value in practical systems using glycol fluids. He cited studies of samples taken from new cars on dealers' lots; some American cars equipped with DOT 3 and some European cars equipped with DOT4. Some of the American cars equipped with DOT3 actually met the DOT3 minimum dry temperature of 401°F while none of the European cars equipped with DOT4 met the lower DOT3 minimum 401°F requirement. My guess is that it had been longer since manufacture for the European cars, in part due to the transport interval.

I have noticed no increase in pedal softness on my '76TR6 as a result of using the silicone fluid. It should be noted that the reaction disk in the servo provides a designed softness or pedal compression of about 1/4 inch to improve the feel of the brake pedal, so that shouldn't be confused with fluid compression.

Pedal Motion Calculations. I decided to calculate the pedal motion due to brake fluid compressibility for the TR250/TR6. Holbrook simplified the calculation of the pedal motion by ignoring the compressibility of the fluid in the master cylinder and lines. This introduced minimal error as confirmed by measurements. I decided to go a step further and do the calculation for the entire system for both silicone and glycol fluids.

I used the same basic technique as Holbrook of computing the volume of fluid and then multiplying that volume by the compressibility of the fluid to determine the additional fluid required to due to the compressibility. This extra volume was then used to compute extra master cylinder motion and that to compute additional pedal motion.

The compressibility of the fluids, especially silicone fluid are a function of the temperature so the results were computed for several temperatures. The master cylinder, PDWA and pipes are expected to stay cooler and likely not exceed 150 ^{o}F so the contribution of those parts are assumed to remain at 150 ^{o}F in all situations. The amount of fluid in the wheel cylinders and calipers increases as the pads and shoes wear so those computations were made for several cases.

Note that these calculations were made using the dimensions of TR250 and TR6 components. The same technique can be used for any system.

The first thing I did was to compute the added pedal motion due to compressibility of the upper part of the system that stays relatively cool.

The master cylinder diameter is 0.812 " at the front and 0.77" at the back . I decided to use an average of 0.8". The cylinder length is 6.2". The pistons are complex shapes whose volume can probably best be computed by placing them in a calibrated container of liquid and observing the increase in volume. I held the pistons beside a ruler and estimated the length of a rod the diameter of the MC that would displace the same volume. This turned out to be 1.1" for each piston. Therefore the approximate volume of the fluid in the master cylinder is the cylinder length less these two equivalent piston lengths multiplied by the cylinder cross sectional area, or

MC volume = $(6.2"-1.1"-1.1")\pi(0.8"/2)^2 = 2.0$ inches^3

The same technique was used to compute the PDWA volume where the diameter is 5/16", the length 1.7" and the length of an equivalent piston 1.2", thus

PDWA volume = $(1.7"-1.2")\pi(0.312"/2)^2 = 0.4$ inches^3

The length of each hose and pipe is tabulated in the accompanying note on pipes. The total length of all the pipes and hoses is ~305" with an inside diameter 0.118" , thus

Pipe & hose volume= $305"\pi(0.118"/2)^2 = 3.3$ inches^3

The total volume of the upper part of the system is the sum of the three parts just calculated:

Total volume of upper part = $(2.0 + 3.3 + .04)in^3 = 5.4$ inches^3

The added fluid required due to compressibility of fluid is merely this volume multiplied by the compressibility percentage of the fluid $C_{\%}(T_U)$ where T_U represents the temperature of the upper part of the system:.

Additional fluid required due to compressibility = $5.4\ C_{\%}(T_U)$ inches^3

The master cylinder motion required to replace this fluid is the volume of the fluid required divided by the master cylinder cross sectional area. In this case the diameter of the primary piston (0.812") is used.

Master cylinder motion = $5.4\ C_{\%}(T_U) / \pi(0.812''/2)^2 = 4.2\ C_{\%}(T_U)$ inches

Recall that the pedal lever has a 3.85:1 mechanical advantage over the master cylinder piston so master cylinder motion must be multiplied by 3.85 to get the pedal motion:

Pedal motion upper = $P_U = (3.85)(4.2)\ C_{\%}(T_U)$ in= $16.2\ C_{\%}(T_U)$ inches

At 150 ^oF this computes to 0.16" for silicone fluid and .05" for glycol fluid. Hardly seems worth the effort to compute.

The next step was to compute the added pedal motion due to compressibility of the wheel area of the system that can get very hot.

Front brakes:

Front Wheel Caliper Piston Diameter = D_{FC}= 2.125"

Length of fluid area between front caliper piston and rear of caliper cylinder (sum of 4) with brakes applied = L_{FC}

Master cylinder diameter for front brake part = D_M= 0.812"

Master cylinder motion for front brake due to compressibility = M_{FC}

Compressibility percentage (function of temperature) = $C_{\%}(T)$

The volume of the fluid in the front cylinders that must be replace due to compressibility is:

$\pi(D_{FC}/2)^2\ L_{FC}\ C_{\%}(T)$

The master cylinder motion to replace this fluid is:

$M_{FC} = [\pi\ (D_{FC}/2)^2\ L_{FC}\ C_{\%}(T)]\ /\ \pi\ (D_M/2)^2$

This can be simplified by plugging in the known parameters:

$M_{FC} = (D_{FC}/D_M)^2\ L_{FC}\ C_{\%}(T) = (2.125/0.812)^2\ L_{FC}\ C_{\%}(T) = 6.85\ L_{FC}\ C_{\%}(T)$

Rear brakes:

Rear Wheel Cylinder = D_{WC}= 0.70" (I'm ignoring the 0.75" cylinders on the '76TR6.)

Length of fluid area between rear wheel piston and rear of wheel cylinder (sum of 2) with brakes applied = L_{WC}

Master cylinder diameter for rear brake part = D_M= 0.812" (Note that the piston driving the front brakes is actually 0.774" diameter but the pedal pushes the primary piston of 0.812" diameter which supplies fluid to both the front and rear brakes.)

Master cylinder motion for rear wheel cylinders due to compressibility = M_{WC}

Compressibility percentage (function of temperature) = $C_{\%}(T)$

Skipping a few steps I arrived at:

$M_{WC} = (D_{WC}/D_M)^2\ L_{WC}\ C_{\%}(T) = (0.70/0.812)^2\ L_{WC}\ C_{\%}(T) = 0.74\ L_{WC}\ C_{\%}(T)$

The total master cylinder motion due to the wheel area is the sum of the motions required by the front and the rear:

Master cylinder motion for wheel part = $(6.85\ L_{FC} + 0.74\ L_{WC})\ C_{\%}(T)$

Recall that the pedal lever has a 3.85:1 mechanical advantage over the master cylinder piston so master cylinder motion must be multiplied by 3.85 to get the pedal motion:

Pedal motion for wheel part of the system = $P_W = (6.85\ L_{FC} + 0.74\ L_{WC})\ 3.85\ C_{\%}(Tw)$

Values of $C_{\%}(T_w)$ (T_w= temperature of the wheel part of the system) at a pressure of 1200 psi are listed in an earlier table. (I chose to do the calculations at 1200 psi, which is about the maximum pressure for a TR6.)

The total pedal motion due to compressibility is the sum of the motion due to compressibility of the upper part of the system and this part due to the compressibility in the wheel part or

Total pedal motion = $P_D = P_U + P_W = 16.2\ C_{\%}(T_U) + (6.85\ L_{FC} + 0.74\ L_{WC})\ 3.85\ C_{\%}(T_w)$

So, the remaing task was to figure out L_{FC} and L_{WC}

From the previous equation it is seen that the multiplier for the rear brakes is much less than for the front brakes so for simplicity I measured the depth of the rear cylinder (1.0") measured the length of the piston behind the seal (0.4") and subtracted the two (1.0"-0.4"=0.6") and then doubled it for the two wheel cylinders so that:

L_{WC} = 2 (0.6") = 1.2".

This corresponds to the pistons being pushed out of the cylinder as far as they can go without the seals leaving the cylinders --- a worse case.

The front brakes need to be treated more carefully because of the larger multiplier. The first thing I did was measure the distance between the pistons with the pistons pushed in the calipers as far as they can go (seated) and found it to be 1.88". There are little posts in the center of the bottom of the cylinders that keep the pistons from reaching the bottom of the cylinders. These posts are each about 0.075" high. To compute open distance behind the pistons of one caliper, I started with the distance between the two seated pistons, added the height of two posts and then subtracted the thickness of the rotor and subtracted the thickness of two pads. This was then doubled to get L_{FC}. The pads and rotor wear with use so I did the three cases listed below:

Computation of L_{FC}, the length of fluid area between front caliper piston and rear of caliper cylinder (sum of 4) with brakes applied.			
	Rotor and Pad Condition		
	New	**Average**	**Heavily worn**
Distance Between Seated Pistons	1.88"	1.88"	1.88"
Height of two posts in bottom of cylinders	+0.15"	+0.15"	+0.15"
Thickness of two pads & shims	-1.29"	-0.90"	-0.50"
Thickness of Rotor	-0.50"	-0.47"	-0.45"
Open distance (one caliper)	0.24"	0.66"	1.10"
L_{FC} (Fluid length for both calipers)	0.48"	1.32"	2.20"

The next variable is compressibility and how it is affected by temperature. The four temperatures listed below were selected for the next calculations.

Temperature	**Compressibility $C_{\%}(T)$**	
	Silicone	**Glycol**
150 ^{o}F	1.0%	0.3%
284 ^{o}F (min wet BP of DOT3)	1.7%	0.4%
311 ^{o}F (min wet BP of DOT4)	1.9%	0.4%
446 ^{o}F (min dry BP of	2.7%	0.6%

DOT4)			

At this point all the data was available to compute the pedal travel due to the compressibility of the fluids. The temperature of the upper part of the system (T_U) was assumed to be 150 °F for all cases. The pedal travel due to compressibility was computed for the four different wheel temperatures (T_w). The results are tabulated in the next table.

Additional brake pedal travel due to brake fluid compressibility Silicon fluid is listed first and then glycol fluid in parenthesis			
Temperature	Front Pad Condition		
	New	Average	Heavily worn
150 °F	0.3" (0.1")	0.5" (0.2")	0.8" (0.2")
284 °F (min wet BP of DOT3)	0.4" (0.1")	0.8" (0.2")	1.2" (0.3")
311 °F (min wet BP of DOT4)	0.5" (0.1")	0.9" (0.2")	1.3" (0.3")
446 °F (min dry BP of DOT4)	0.6" (0.1")	1.2" (0.2")	1.8" (0.4")

The first row for 150 °F is what I'd expect for my normal driving. The second row at 284 °F is at the minimum wet boiling point of DOT3, the expected boiling point after a year or two of fluid service and my guess is the maximum likely temperature one will encounter in a standard TR250/TR6 brake system. The third row is at 311 °F, the minimum wet boiling point of DOT4, the expected boiling point after a year or two of fluid service. The boiling points will likely be lower in humid environments. Once the fluid boils, the brakes fail. The last row is at 446 °F, the minimum dry boiling point of DOT4 --- fresh fluid. Note that these calculations give similar results to Holbrook's calculations and measurements. The calculations show that I won't have a problem in applications where DOT4 is satisfactory (third row). If I were stressing the system beyond where DOT4 is suitable, I'd keep the rear brakes adjusted and renew the pads when they're about half gone.

I measured and recorded below the brake pedal position on my '76TR6 and my '68TR250 for the following conditions:

Pedal at rest --- distance to floor.
Pedal position when initial resistance felt --- distance to floor.
Pedal position with maximum force ---- distance to floor.
Pedal position on the floor (no master cylinder resistance) --- distance to floor.

The TR6 has DOT5 and the TR250 DOT4. The rear brakes hadn't been adjusted for several thousand miles at least and I wasn't about to do it in the cold weather. The engine was running so that the servo was contributing. That should give at least 1200-psi hydraulic pressure. The wheel cylinders and calipers were at the ambient temperature of about 40 °F. The floors have carpet and pads. These are rough measurement but give some ideal of the margins available --- about 2 inches for the TR6 and 1.5 inches for the TR250. (I adjusted the brakes when it got warmer and those measurements are shown in parenthesis.)

Fluid Type	Measured Pedal Position From Floor (cool fluid)			
	At Rest	Initial Resistance	Full Force	On the floor
'68TR250 (DOT4)	7.5"	6.5"	4.0"(4.5")	2.5"
'76TR6 (DOT5)	7.5"	6.5"	4.5" (4.75")	2.5"
( ) measured value after the rear brakes were adjusted.				

Note that the maximum possible pedal motion from the table above is 5 inches. The cylinder depth of the master cylinder is 6.2". The length of the primary piston is 2.7" and the compressed length of the secondary piston is 2.3". The maximum possible motion of the primary piston is the cylinder depth less the sum of the piston lengths or 1.2". The pedal motion to move the piston is 3.85 times greater or 4.6". The total pedal motion includes some slack in the servo so this is in close agreement with the measured data above.

These measurements and the calculations above demonstrate to me that the predictions of the dire consequences of using silicone fluid due to compressibility are overblown. I'm not surprised since both the US military and the US Postal Service use silicone fluid and, while I sometimes question some of the operational processes and procedures of both those organizations, I'm sure that both have sufficient data to expose any significant problem with the silicone fluid due to compressibility or anything else.

Retention of Suspended Air: The silicone fluid is prone to retain small air bubbles generated when the fluid is agitated such as splashing the fluid when filling the master cylinder reservoir or vigorously pumping the pedal when there is air in the master cylinder such as when initially filling the system. These air bubbles are of course compressible and make for a very soft pedal if not bled from the system. Unfortunately, the bubbles, once generated, tend to remain in suspension for several days. This has not been a problem for me as I was careful when filling and bleeding the system. The bubbles at the top end of the system seem to work out through the reservoir and those in the bottom of the system work out when the wheel cylinders and calipers are bled the second time. I bled my '76TR6 a second time a few days after the initial filling and found no air and no change in the pedal characteristics. This is probably another concern that is overblown. .

Summary: So what have I learned:

- Silicone based DOT5 fluid has a higher dry boiling temperature that DOT3 & DOT 4 fluids.
- All glycol-based fluids (DOT3 DOT4 & DOT5.1) can quickly absorb moisture that lowers the boiling point to the wet minimum DOT specification or in many cases even lower.
- In one study virtually all glycol-based systems examined after 24 or more months use had the 3.5% or greater moisture content used for the wet boiling point specifications. In some cases, this much absorption occurred in as little as a few months as the vehicles sat on new car lots.
- Silicone based DOT5 fluid has a much higher real wet boiling point than any of the glycol-based fluids discussed here because it absorbs very little water and the wet boiling point is essentially the same as the dry boiling point.
- Silicone based DOT 5 fluid prevents entry of moisture and salt into the brake system through the hoses.
- Silicone based DOT 5 fluid was reported to be compatible with all types of brake seals way back in the the early 70's.
- Silicone based fluid doesn't mix with glycol-based fluid.
- Extensive testing of brake systems with 50/50 mixes of silicone and glycol-based fluids have shown that the mixtures performed properly with no failures recorded.
- Silicone based DOT5 fluid is slightly compressible but the compressibility is manageable at temperatures below which the standard Glycol fluids vapor lock (wet boiling point).
- Silicone based fluid retains small suspended air bubbles. This requires extra care when filling the reservoir and may require a subsequent bleeding a few days after first filling the system to extract any air bubbles that remained in suspension during the initial bleeding.
- Glycol-based fluids attack paint whereas the silicone fluids do not.

My Conclusions: The conclusions I draw from these data are:

- The glycol-based fluids give satisfactory performance in the light duty use I give our relatively new autos. Because the fluid absorbs moisture and becomes contaminated quickly I plan to make it a practice in the future to change the brake fluid at the same time I flush the cooling system, every three or four years.
- If I lived in a mountainous area where the brakes might be subjected to high temperatures I'd definitely change glycol fluid at least once a year or switch to DOT5 silicone fluid, keep the rear brakes in adjustment and renew the pads when worn to half new thickness.
- If I were racing I'd use a glycol based racing fluid and change out the fluid before every race.
- I will use DOT5 silicone fluid in all my TRs in the future to prevent paint damage and to protect the hydraulic systems from contamination and corrosion.

Switching fluid type: Given that I've decided to switch fluids in my TRs, how and when do I plan on doing it? I guess the first point to make is that switching fluid will not fix leaking seals or uncorrode (a word I just invented) corroded pistons or cylinders. So, if the brakes have a problem, fix the problem and that is then an excellent time to switch fluids. **(I just thought of another point -- some folks have their cylinders bored and then sleeved with brass to minimize corrosion. The use of DOT5 fluid will likely eliminate any future corrosion and is much less effort & expense than brass sleeves.)** I switched fluid in my '76TR6 last summer when I had the master cylinder off as part of the repainting project. I will do the same for my TR250 when I repaint it this summer. I guess if I had a TR with good paint and glycol fluid and knowing what I do now, I'd switch the fluid ASAP ---- in a few weeks or less. The cost and frustration involved to repair damaged paint is just too great.

Before doing the fluid switch a year ago I inquired of the Triumph and 6PACK email lists as to recommendations as how to do the job. I got many suggestions that fell into three categories described below.

Experienced Suggestions: This set of suggestions came from people that had actually done the job. Many reported changing fluid after rebuilding the entire system and some blew out the lines before filling with silicone fluid. Others merely added the DOT5 at the master cylinder and then bled the system until the purple fluid flowed from each bleed nipple. In every case these folks reported excellent results. Some had over ten years service on the vehicles with no failures reported. Several of the vehicles were the daily driver later model cars and one case involved a motor home that the fluid had been switched more than ten years previously.

Thoughtful Suggestions: This group of suggestions came from folks that had great concern that some contaminated glycol fluid might be left in the system and suggested that every effort be extended to get out all the glycol-based fluid. There may be a problem in the wheel cylinders and calipers because the silicone fluid floats on the top and next to the bleed nipple and it is possible for the DOT5 to flow freely from the bleed nipple while there is still a pocket, possibly large pocket of the glycol fluid remaining in the lower part of the cylinder/caliper. None of the folks in this group said they had experienced any trouble with switching fluid (if they actually switched the fluid) and none reported actually finding pockets of contaminated glycol fluid in the wheel cylinders/calipers either before or after switching to silicone fluid.

Randall Young contributed: *I have found what I believe were pockets of glycol fluid when disassembling brakes that were converted only by bleeding. It certainly looks (and is) a mess, (almost like tar) but it* *doesn't seem to hurt anything. Might cause problems if it accumulated in the valves of an ABS system for instance, but none of my cars have ABS.*

Off The Wall Suggestions: These folks made dire predictions if silicone fluid were used in a TR at all, or if the fluid was switched without taking drastic steps. One group said that the seals in the TRs were natural rubber and the swelling agents in the silicone fluid didn't work properly with rubber seals. No source of the data was cited nor was any actual experience and failures cited. We know from Browning's report that the silicone fluid produced as early as 1974 was compatible with all types of rubber used in brake systems. I don't know the type of seals used in TR250s/TR6s to which this is addressed but I expect all replacement hoses and seals meet or exceed DOT specifications and thus will work just fine with DOT5 fluid.

The other group of "off the wall" suggestions said to replace all rubber components (hoses & seals) and flush the system with alcohol. Again, no basis were made for this suggestion nor did any of these folks say they actually did this nor did they present any data to show something bad would happen if it wasn't done. I think the alcohol was to absorb and remove any moisture from the system, which of course is a good ideal since the moisture won't mix with the DOT5 and you don't want water lying around the system. However, if there were glycol fluid in the system previously, it would have sucked up any water. [Unfortunately, if you flush with alcohol, you're then stuck with alcohol residue that is probably worst than water.] Replacing the seals and hoses seems to suggest that the glycol fluid somehow damaged the seals and hose components such that they will quickly fail if DOT5 fluid is introduced into the system. I've seen seal deterioration from glycol-based fluids --- that's why the seals fail and the fluid leaks and ruins the paint. However, I assumed that was normal deterioration. One basis for this suggestion might be that DOT5 fluid will allow a higher performance from the brake system than the glycol-based fluids and if the seals and hoses are old, they should be replaced before the brake system is subjected to the greater stress possible with the silicone based fluid.

What I actually did: So --- what did I do with my '76TR6? As mentioned previously, I had the master cylinder and PDWA off to powder coat them to improve the appearance. I used compressed air to blow out the lines and wheel cylinders. In the case of the calipers that can store considerable fluid, I pressed the pistons all the way back into the calipers to force as much of the old fluid out as possible. I then reinstalled the master cylinder, PDWA and interconnecting lines, filled the system with silicone fluid and bled the system. I bled the system again in a week or so and detected no air exiting the bleed nipples nor observed any subsequent system improvement. The DOT5 has been in the system for a year and I'm very happy with the performance. I can see no difference between the operation of that system and my TR250 equipped with DOT4.

My '70TR6 which was the source of the parts overhauled in these notes will be reassembled with 100% rebuild parts and all new pipes and hoses except for the pipes between the master cylinder and PDWA. There should be no traces of glycol-based fluid in the system.

The next time: I'll be repainting my TR250 this summer. The master cylinder and PDWA will be out as part of that project. I'll take them apart and powder coat them to improve the appearance. I'll probably replace the seals since they're at least 15 years old. However, seal replacement is less of a concern now since any leaking DOT5 fluid won't ruin the paint. I plan to use the same approach as I did with my '76 TR6 with one exception. This time I'm going to flush the system thoroughly with new DOT4 fluid before I remove the master cylinder. The purpose of this is to get any contaminated glycol-based fluid out of the wheel cylinders and calipers. Since the fresh fluid will readily mix with any contaminated fluid, most contaminated fluid should be flushed out of the system. **[Alcohol is probably the last thing I'd flush the system with because it has a boiling point of 175 ^{o}F, much lower than the water you're trying to remove because of the low boiling point. If I had alcohol residue in the calipers, I'd probably want to flush with water to get the alcohol out.]** I will then force the pistons back into the calipers and use compressed air to blow the glycol-based fluid out of the system. Any of the DOT4 remaining in the system will be isolated in the bottom of the wheel cylinders and calipers. The hoses and top part of the system will be filled with DOT5 preventing moisture from entering the system. This will prevent moisture reaching any pockets of DOT4 in the wheel cylinders or calipers thus preventing a lowered boiling point of the glycol-based fluid. In this case any remaining DOT4 fluid will work to reduce the compressibility since it will be in the area exposed to the greatest temperature rise --- the best of both worlds. **An argument could be made that the best possible system would be to intentionally fill the wheel cylinders and calipers with fresh DOT4 and then add DOT 5 slowly so as not to flush the DOT4 out of the wheel cylinders and calipers ------ however, I won't go there.**

Myths? The following are items I picked up over the Internet in early 2002.

From http://www.kipmotor.com/Default.htm:

Why can't I use generic brake fluid in my British car?

> *British brake & clutch systems use natural rubber components which are only compatible with vegetable based brake fluid. American brake & clutch systems use synthetic rubber components which are only compatible with mineral based brake fluid. The only vegetable based brake fluid commonly available in the US is CASTROL GT LMA. Use of improper fluids or mixing of fluids can lead to complete failure of brake and clutch hydraulics. Use of any fluid other than CASTROL GT LMA violates all warranty on brake/hydraulic parts.*

This seems to be something from yesteryear but is on a current website. I don't know the date of publication but my 68TR250 and 76TR6 I think are past warranty. From the reports to the SAE cited earlier, the silicone fluids supposedly worked properly with natural rubber seals.

On this subject Randall Young Contributed: *I have experienced American (Wagner brand I believe) brake fluid eating British brake seals. I cannot explain how this happens, but my guess is that the seal swellers used (at least then, this was roughly 1974-1978) would damage the reputedly natural rubber seals used in British brake systems then. Enough people have said this no longer happens that I believe them, but I don't know if it's a change in the brake fluid, or in the seals supplied. When I moved to California in May 1978, I brought my (previous) TR3A with me. Until then, I had been using American brake fluid (whatever was cheap, after all it's all DOT approved, right ?) and replacing a seal (not always the same one) 2-3 times a year. Shortly after I got here, I bought all new seals from Moss motors, flushed the system thoroughly with fresh DOT-3 and replaced all the seals. Drove the car probably less than 5 miles as a test drive, then parked it for about a month. At the end of the month, one rear seal was weeping, and the fluid I bled from all 4 brake bleeds (before working on the seal) was discolored. I then repeated the entire exercise with Castrol brake fluid (don't recall if it was LMA, but I don't think it was), and the brakes remained leak-free for roughly a year of occasional driving. Of course, about 16 months later, one of the hard lines rotted through and I wrecked the car, but that's a different story.*

After Randall contributed this I realized that the references cited earlier stated that the silicone fluid of the 70s was compatible with rubber seals but didn't state that the glycol fluid of the era was also compatible with rubber seals. I had considerable trouble with clutch system seals during the early to mid 80s using both the cheapest available US fluid and later Castrol fluid. The fluid in the clutch master cylinder turned black in less than a year. The TRs set for nearly ten years during the 90s. I haven't had that trouble since then and the clutch seals in my both my TR250 and '76 TR6 were installed in the mid to late 80s (the seals were changed in the '76 last year when I powder coated the cylinders). I have no ideal whether I used Castrol fluid with the last rebuild in the 80s. So I don't know whether the seals or the fluid or both changed since my earlier troubles. I am pretty sure some of the early replacement seals were crap. The problem may have been cured when I started using replacement seals from TRF.

Another one ......

> *Rubber swelling additives must be mixed with silicone fluid to make the seals work properly. These additives are compatible only with EPDM rubber. When silicone is used with SBR rubber, the rubber swells too much and becomes too soft to seal against the brake line pressure. Most drum brakes still use SBR seals.*

Silicone fluids of the 1972 era were reported to be compactable with SBR seals and current sources indicate that current silicone fluids are still compatible with all rubber formulations used on brake system seals.

This one is from a Land Rover site

> *Be careful not to mix the 2 different kinds. When "upgrading" to DOT5 brake fluid you should pay attention to some important points. First off all make sure ALL rubber components you use in your brake system are DOT5 ready. Older rubber parts will be eaten away by DOT5. Secondly flush your brake system thoroughly. Better renew all parts.*

No supporting data. Previous data suggests that there may be more of a problem with DOT3 and DOT4 than DOT5, especially if the seals are very old.

Special Thanks to Randall Young for reading the draft of this note and identifying numerous errors. He correctly pointed out that I used silicon (sand) and silicone (for brake fluid and breast enhancement) interchangeably. Much of this note was written between visits to the beach when on vacation in Tenerife. I guess I got all confused which was which.