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Brake Fluid Chemistry and FASCAR® Technology

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Disclosure of FASCAR® technology and brake fluid chemistry changes during vehicular operation

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The Science Supporting FASCAR® Brake Fluid Testing Technology

1. INTRODUCTION

Jon Petty of Phoenix Systems LLC is the inventor of FASCAR® technology, which primary use is testing the condition of vehicular brake fluid. FASCAR® was developed to form a scientific measurement and scale to quantify the changes that occur in brake fluid during vehicular use. FASCAR® can be used to accurately determine an interval for replacing brake fluid. FASCAR® is designed to address preventive maintenance issues with regard to brake system service.

The purpose of this report is to describe the technology utilized by FASCAR® and provide "third party" supportive summary documentation in addition to Phoenix Systems research using the following reports:

1. Ricker, R.E., Fink, J.L., Shapiro, L.C., and Schaefer, R.J., Preliminary Investigation Into Corrosion in Anti-Lock Braking Systems, **National Institute of Standards and Technology NIST**, NISTIR 6233, 1998

2. Jackson, G.L., Levesque, R. and Wagner, F.T., Improved Methods for Testing the Durability of Corrosion Protection in Brake Fluids, **SAE International Congress &Exposition, SAE Intl.,** SAE 971007,Corrosion Prevention SP-1265,1997.

3. Person, G.H., Boyd, R., Demeter, K., Tests on Kelsey Hayes EBC4 Antilock Brake Systems, **National Highway Traffic Safety Administration NHTSA**, Vehicle Research and Test Center, EA94-038, 2000

4. Jacobson, M.A., Corrosion of Motor Vehicles: Safety and Environmental Factors: The User's View, Corrosion of Motor Vehicles, **The Institute of Mechanical Engineers**, Conf. Publ. 16, 1974

5. Wheeler, Dean, The Use of Dissolved Copper to Indicate the Age of Brake Fluid: Ph.D. Chemical Engineering, University of California, Berkeley. March 23, 2006

6. The Motorist Assurance Program (MAP). 7101 Wisconsin Avenue • Suite 1200 • Bethesda MD 20814 Tel: (301) 634-4954 • Fax: (202) 318-0378

2. The Basics of Brake Fluid

In the past, the main concern for brake fluid was reduced boiling point due to the hygroscopic nature of brake fluid, brake system materials and typical design. Since brake fluid is hygroscopic, meaning that it will absorb moisture from the air, the boiling point of the fluid will decrease over time. The major safety concern is a rare phenomenon called vapor lock. While highly unlikely, this could occur if the temperature of the brake fluid exceeds its boiling point due to heat transfer from the brake system. Compressible gas pockets form in the brake system that result in a dramatic loss of hydraulic braking power, which is experienced by the driver as a spongy pedal that may have difficulty stopping the vehicle.

Today, reduced boiling point caused by moisture is not considered to be a problem by major US auto manufacturers and brake fluid manufacturers. Advancements is brake system and component materials design minimizes the effects of moisture absorption. In addition, new brake fluid formulations are designed with much higher boiling points. It is not common to discover a vehicle with a brake fluid boiling point below minimum DOT specifications of 285 degrees Fahrenheit. The Motorist Assurance Program (MAP) [6] study of boiling point in 469 vehicles revealed boiling failure of less than 1.5%. A test for moisture alone will not provide important data needed to determine brake fluid change intervals. For additional information regarding moisture and brake fluid see Petty, J., "Why Moisture Testing Brake Fluid is Secondary" 2008.

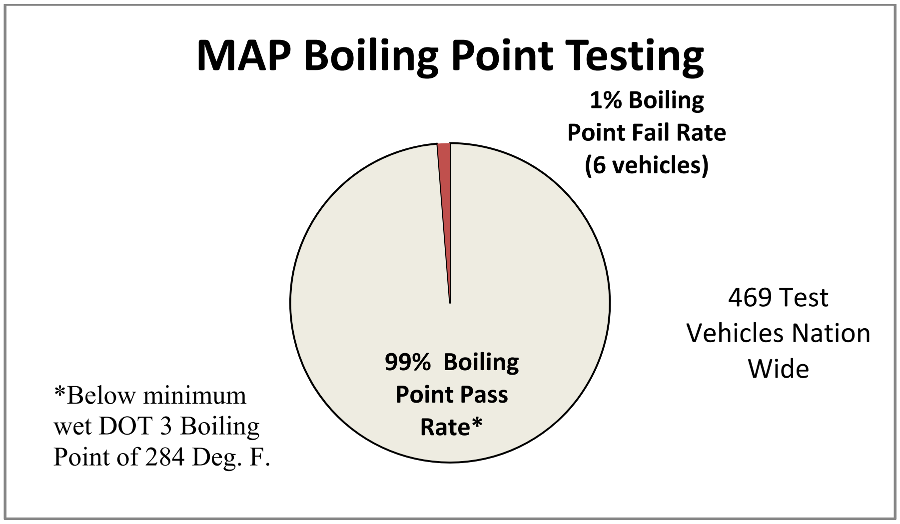

Figure 1. MAP Boiling Point Study 2006

Today, the principle brake fluid concern is corrosion and brake fluid replacement intervals. FASCAR® Technology was developed to address those concerns. FASCAR® brake fluid testing technology accurately measures the principle corrosion metal, copper. FASCAR® utilizes a simple strip with an ionic reaction zone to test the concentration of copper ions in brake fluid.

The following sections will demonstrate:

1. The primary source of copper is found in brake lines.
2. Copper is the first corrosion metal in brake fluid
3. Basic corrosion science
4. The role of corrosion inhibitors and their depletion
5. Iron corrosion begins when inhibitors are depleted
6. Copper is an "early warning" indicator of brake fluid condition.
7. Brake fluid metals attack each other and feed other break down reactions
8. Copper will plate to iron components including ABS valve seats
9. The role of copper associating with corrosion inhibitors.
10. Copper is like a brake pad wear indicator for brake fluid condition measuring "virtual age"
11. Copper is a better indication of brake fluid condition than time or vehicle mileage
12. MAP Guideline established 200 ppm copper as "required Service" for brake fluid
13. FASCAR® accurately measures copper concentrations.
14. Conclusion: Copper can serve like wear indicators on brake pads, warning when a problem is imminent rather than just warning when a problem has already developed

3. Brake Line 101

A basic understanding of the way brake lines are made will be important to establish to explain their role in brake fluid chemistry. Brake line is manufactured using a steel band with a pure (99.99%) copper coating. The steel is 0.35 mm thick and the copper coating is approx. 5 - 7 µm. See Fig. 2

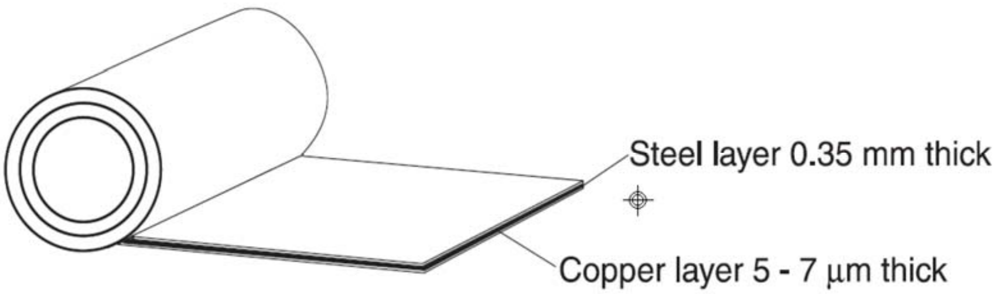

Figure 2. Brake lines have copper lining

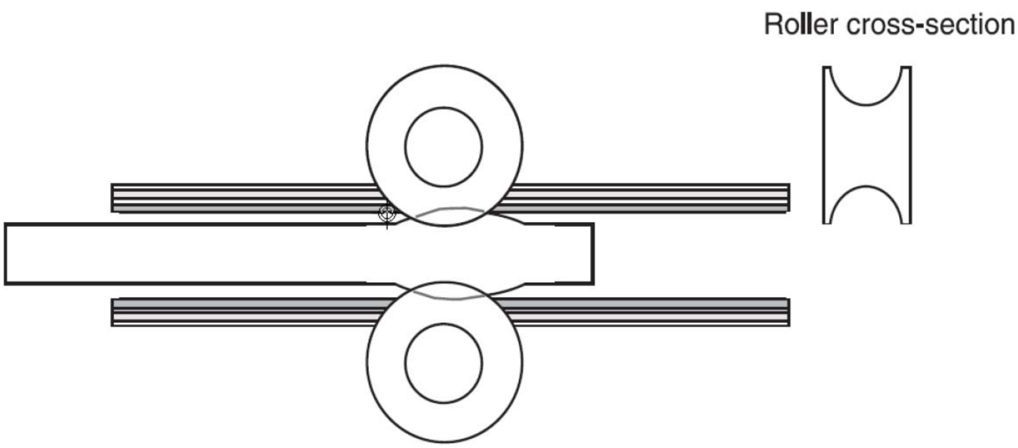

Figure 3. Metal strips are rolled to shape prior to brazing

The tube is shaped by several roll stands, Fig. 2. The wound tubes are collected together and then fed through a brazing furnace and are brazed at approx. 1090° (copper melts at 1078°). A very homogenous brazed tube results from brazing. See Fig. 4.

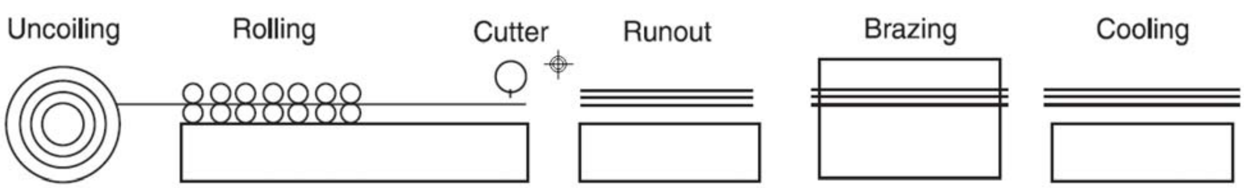

Figure 4. The brazing process for brake lines

The original anti-corrosive coatings were a hot-dip lead-tin coating to both internal and external surfaces followed by zinc-rich paint applied to the exterior. Currently coatings of aluminum-zinc and polyvinyl-fluoride have improved corrosion resistance. Some brake lines use a copper nickel alloy, but is currently used only in premium European vehicles such as Volvo.

4. Introduction to Copper in Brake Fluid

In the research of used brake fluid by Phoenix Systems, several dissolved metals in brake fluid were discovered, primarily copper, zinc and iron. Jackson et al.[2] also observed similar findings. Copper comes from the brake lines. New brake fluid has an average of less than 1 ppm (parts per million) of copper and zinc, while iron can be 2-6 ppm. Metal levels higher than these averages are the product of corrosion reactions. Experiments by both Phoenix Systems other researchers have found that dissolved copper levels in brake fluid increase nearly constantly with time of service.

The NIST report, Ricker et al [1], hypothesizes "the copper in the brake lines corrodes at a slow rate over several months or years resulting in copper ions in the brake fluid. These ions then act as oxidizers and plate out in the ABS valves when the corrosion inhibitors can no longer prevent corrosion of the ferrous components. According to this hypothesis, copper corrosion starts when the vehicle is new and proceeds at a rate that is limited by the oxidizer content of the brake fluid, mass transport of this oxidizer, and the effectiveness of the corrosion inhibitors in the brake fluid at retarding copper corrosion."

In fact, Jacobson [4] shows a micrograph of a brake line that appears to have removed most of the copper after 6 years of service. Copper is the first metal to corrode because , according to Ricker et al [3] "even though copper is in galvanic contact with more active metals, the low conductivity of the brake fluid allows copper corrosion to proceed."

Brake fluid inhibitor packages are designed to minimize iron corrosion. This was observed by Dr. Dean R. Wheeler in his report "The Use of Dissolved Copper to Indicate the Age of Brake Fluid" [5]. "A fact that is rarely appreciated is that the amines do *not* protect copper as well as they protect iron. This is backed up by the observation that dissolved-copper levels in brake fluid begin rising almost immediately upon the fluid being put into service, and the levels rise consistently throughout service. On the other hand, dissolved-iron levels do not begin to rise noticeably until the corrosion inhibitors have already been significantly depleted."

FASCAR® stands for Fluid Analysis by Stimulation of Copper Alpha Reactions.

5. Basic Corrosion Science- Water is Not the Key

Most people believe that it is the level of moisture in brake fluid that causes corrosion, otherwise, the more water, the more corrosion. This is **not** the case. The amount of absorbed water is not key in brake system corrosion. It is the loss of corrosion inhibitors that allow corrosion to take place. SAE studies show that as much as 5% moisture in brake fluid will not cause corrosion if the corrosion inhibitor package is in good condition. It was also discovered that very low amounts of moisture can accelerate corrosion if the inhibitors are depleted.

SAE J1707 (section 3.3) recognizes that hazard of corrosion contamination and states; "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" . What SAE J1707 didn't mention or realize, is that very little water contamination (less than 1%) is required to cause this corrosion when the corrosion inhibitors are depleted. Very high moisture levels (greater than 5%) will not cause corrosion if the brake fluid inhibitor package is in good condition.

For metals to corrode more than water is required. Corrosion requires a chemical reaction. According to Wheeler, “The Use of Dissolved Copper to Indicate the Age of Brake Fluid” [5],

> “A simplified corrosion reaction for a metal in liquid looks something like this:
>
> $$\text{metal} + \text{dissolved oxygen} + \text{acid} \rightarrow \text{dissolved metal.}$$
>
> Water is known to degrade the integrity of the oxide film on metals; however, water is not the only solvent that can do this. Corrosion can take place in other liquids, such as those that make up brake fluid. Furthermore, there is no practical way to keep brake fluid completely moisture free, so there will always be some water present near the metal surface. I am aware of only two scientific studies of corrosion in brake systems (both are listed in the references section). Neither showed that the amount of absorbed water in a brake fluid was a main controlling factor in how fast the metals corroded.”

To limit metal corrosion the strategy is three fold; 1) limit the available oxygen, 2) control the acid and 3) provide a protective coating.

6. The Role of Corrosion Inhibitors in Brake Fluid

Corrosion inhibitors in brake fluid have two main purposes: first, to reduce the acid level (neutralizing or buffering amines) and secondly, to form a water repelling film on the metal surfaces (filming amines). Corrosion inhibitors in good condition prevent corrosion of metal surfaces, even with high moisture levels. It takes both types of amines to protect the brake system. If one amine is compromised corrosion can occur.

The primary area of concern is contamination of the brake fluid by corrosion byproducts due to lost or impaired corrosion inhibitors. Corrosion inhibitors, pH stabilizers and antioxidants are added to brake fluid to improve the long term corrosion protection of brake systems. The corrosion inhibitors provide the general buffering of the brake system. Over time and vehicular use the corrosion inhibitors or “buffers” degrade. Jackson et al.[2]studied the changes that occur in brake fluid chemistry during vehicular service. In their extensive study they found that the buffer capacity and inhibitor concentrations dropped to as low as 9% of their initial levels after only 30 months of service.

Vehicles equipped with ABS actually experience faster degradation of corrosion inhibitors. Ricker et al. [1] found that “thermal degradation of corrosion inhibitors in a conventional system would primarily influence the rate of corrosion near the wheel cylinders where temperatures and degradation is the greatest, but in an ABS system, the increased brake fluid mixing will result in the corrosion inhibitor concentration of the entire system decreasing faster. In addition, ABS systems use close tolerance valves that must operate quickly and more concisely than conventional braking systems. That is, ABS equipped systems may be more susceptible to degradation in performance due to corrosion or deposits.” The findings of Phoenix Systems research is supported by the above reports that determine that the corrosion inhibitors are depleted over time."

Jackson et al.[2], shows a 20-fold reduction in the primary inhibitor concentration over 24 to 36 months of service.

Corrosion inhibitors are depleted over time and ABS vehicles experience accelerated depletion due to system design. ABS is standard on most vehicles today so it is important to determine what happens as corrosion inhibitors deplete.

7. Corrosion begins when Inhibitor are depleted

It is important to next establish what happens when the corrosion inhibitors have been depleted. The main result of the depletion of corrosion inhibitors is corrosion in the brake system. This is well known to the automotive trade by empirical study of brake component failures. In addition, many studies relate their findings of corrosion.

In the NHTSA report, Person et al [3], the Office of Defects Investigation (ODI) retained the services of the National Institute for Science and Technology (NIST) in Gaithersburg, MD to aid their investigation for sources of foreign particle contamination. They stated "the NIST 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."

When corrosion takes place it may take place in a specific component such as a caliper, wheel cylinder or ABS module, but that does not mean the corrosion is isolated to that part of the system. Ricker et al [1] observed that the corrosion or brake fluid degradation products can migrate to other parts of the vehicle braking system. Contamination at one point in a system can influence the performance of other parts of the system. The effects of contamination will be discussed later in greater detail.

8. Evidence of Corrosion

Once it is determined that corrosion inhibitors deplete over time and that depletion may result in corrosion, it is necessary to provide evidence that corrosion actually takes place. One familiar in the trade of automotive brake service has seen many defective brake components removed from systems that were replaced due to corrosion. The NIST report, Ricker et al [1], provides further evidence as ABS components were examined by NHTSA at their Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. The results of these examinations were reported to NIST by Jim Hague of VRTC in August of 1997. Some of their findings are summarized below:

> (1) visual evidence of corrosion damage is observed on iron alloy components approximately 1/3 of the time (typically no damage is observed to stainless steels),
>
> (2) the damage observed usually consisted of shallow pitting similar to that reported by Jackson et al.[2],

(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,

(5) the copper sponge and the copper nugget morphology were found in the shallow pits associated with and usually under the gel-like substance

Jackson et al.[2], observed corrosion damage on cast iron components removed from test vehicles and found corrosion pitting "surrounded by metallic copper". Corrosion does occur in brake systems.

Inductively Coupled Plasma Spectroscopy (ICP) testing performed by Phoenix Systems on hundreds of vehicles to determine metal levels for the service time of brake fluid. Vehicles that had high iron concentration, 50 ppm or higher, revealed evidence of visible iron corrosion of brake components. Corrosion was most commonly found in the wheel cylinders, calipers and also ABS valve and bore components in vehicles that had high iron levels. Corrosion was more apparent in areas where the fluid path experience decreased or stagnant flow.

Jackson et al.[2] observed the following "Corrosion is on occasion still observed with fluids within brake systems filled with fluids fully compliant with SAE J1703 and FVMSS 116 when fresh". *[SAE Report 971007, Improved Methods for Testing the Durability of Corrosion Protection in Brake Fluids]*

9. Copper Provides an Early Warning for Active Iron Corrosion.

Phoenix Systems research discovered a direct correlation between copper and iron levels in the brake fluid. Iron is a sign of active brake system corrosion. Inductively Coupled Plasma Spectroscopy (ICP) testing performed by Phoenix demonstrated a sharp rise in iron levels when copper levels reach approximately 150 ppm, see Fig. 5. Jackson et al.[2], found similar results in which they stated "Dissolved iron appears in the brake fluid after the initial amine corrosion inhibitors are significantly depleted and dissolved copper levels rise to around 200 ppm".

It is very important to understand the source of the iron in the brake fluid. Inspection of vehicles with brake fluid high in iron content usually displays some kind of corrosion of iron components in the system. By the time you see significant amounts of iron though, severe corrosion is active. Jackson et al.[2], stated "the appearance of this corrosion correlated with the elevated dissolved iron levels".

Jackson et al.[2], stated that "no dissolved iron at all is seen until around 30 months, after which 50-100 ppm of dissolved iron becomes typical. Cast iron components removed from some vehicles after such time show some level of pitting of the iron, with the pits typically surrounded by metallic copper."

It is important to remove the copper ions from the brake fluid and replenish the corrosion inhibitors. The direct correlation between copper levels and iron allow the use of copper levels to provide an early warning prediction for active iron corrosion. This is very strong evidence, on this basis alone, that copper testing provides an accurate indicator to the loss of brake fluids buffering capability.

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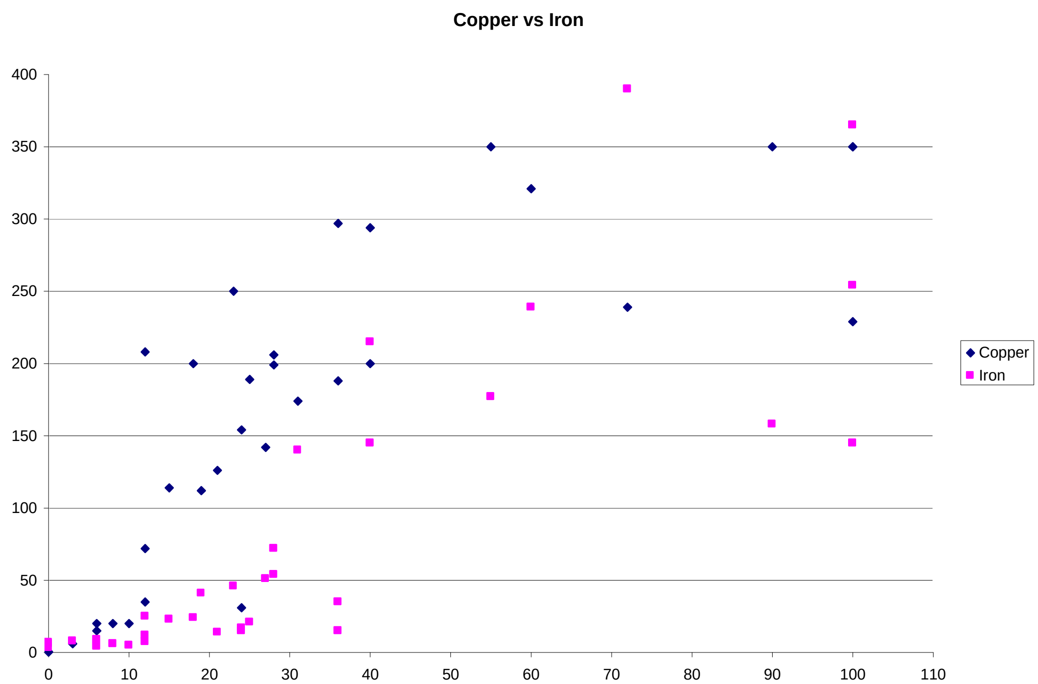

Figure 5. Copper and Iron levels vs. brake fluid age

Months

An argument could be made to directly measure the iron levels to determine brake fluid condition. At the point when iron levels rapidly increase, it is too late to prevent damage. Wheeler [5] comments, "It is true that dissolved iron could be used as an indicator of a problem, because elevated levels of dissolved iron clearly show that corrosion has occurred. However, this may not be the best practice in a routine maintenance program that is intended to keep corrosion low at all times, rather than respond to a problem after it develops. In summary, copper concentration level in the fluid is one of the clearest available indicators of time-in-service for brake fluid. It can serve like wear indicators on brake pads do, warning when a problem is imminent rather than just warning when a problem has already developed."

10. Metals attack each other when inhibitors are depleted

Wheeler [5], "The presence of high levels of dissolved copper in the brake fluid indicates that the steel surfaces in the brake system are already or will soon be under attack."

Another important consideration with regard to brake system corrosion is that metals can corrode one another. The main dissolved metals found in used brake fluid are copper, zinc and iron. New brake fluid has an average of less than 2-5 ppm (parts per million) of these metals so their presence is a result of corrosion reactions. These three metals interact with each other in ways that are important to brake fluid chemistry and brake system corrosion.

Of the three metals copper is the noblest, meaning resistant to corrosion. Basic electrochemistry teaches us that zinc will sacrifice itself to iron and iron will sacrifice itself to copper. What Phoenix Systems discovered was that copper was directly contributing to iron corrosion in the brake system. Further explanation is provided by Wheeler [5], "… 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 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."

Dissolved iron also plays a role in the formation of acidic reactions. According to Ricker et al [1] "Once iron corrosion starts producing iron ions, these ions can also react with water to form hydroxides and lower the pH, but the copper reaction is such that a lower pH will result for the same ion concentration."

Copper will attack and deposit itself on the steel surfaces once the corrosion inhibitors are sufficiently depleted. In fact, evidence supports that the copper acts as a catalyst to promote the degradation of the amine-based inhibitors. This means that copper plays a direct role in brake system corrosion.

11. PWM Valve Leaks as a Result of Copper Particulates

Phoenix Systems research determined that copper particulates can directly effect the operation of ABS valves. ABS components include PWM valves which manipulate braking pressure. The NHTSA report, Person et al [1], investigated sudden increased pedal travel due to a leak in the PWM dump valve. Their findings support Phoenix Systems research as they discovered by spectral electron microscopy, and mechanical analysis that one possible cause of PWM valve leakage was "very small particles of pure copper in various morphology present in the area of the PWM valve's dump seat and sealing surfaces." In addition, "NIST confirmed that it was possible for corrosive action to take place within the brake system of the subject vehicles so as to form particles of this type."

The copper plating to components is discussed by Wheeler [5]. "Copper, being the most noble of the three metals (copper, zinc, iron), … 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."

12. The Relationship between Copper and Corrosion Inhibitor Levels

Once the corrosion inhibitors are depleted and can no longer protect the surface of iron components, the iron components will corrode by reducing the copper ions in the brake fluid. High copper concentrations will support rapid corrosion when the inhibitors have been depleted. That is why active corroded iron components are surrounded by copper. These findings are supported by Jackson et al.[2], Person et al [3]and Ricker et al [1].

Ricker et al [1], also supports Phoenix findings stating "While this copper corrosion is in progress, the inhibitor concentration in the brake fluid is also decreasing due to thermal decomposition of the corrosion inhibiting species in the brake fluid."

Copper plays a major role as an oxidation catalyst of organic compounds (buffering agents). Oxidation of organic compounds depletes the fluids ability to protect the system. Since copper is a known catalyst for such a reaction, the copper level plays a direct role in determining the buffering capability of the brake fluid. Copper levels directly correlate to the buffering capability of the brake fluid to protect the system against the effect of acidic breakdown products in brake fluid over time. Amines are the primary corrosion inhibitor. Jackson et al.[2], shows a 20-fold reduction in the primary inhibitor concentration over 24 to 36 months of service.

Phoenix Systems testing indicated that the amine corrosive inhibitors can be significantly depleted by the time Cu levels rise to 150 ppm. It should also be noted that some of the depletion of the buffering capability of the brake fluid is that of "filming" onto various metals. High Cu levels also significantly affect the oxidation properties of brake fluid.

Copper + new brake fluid = old brake fluid

An interesting find by Phoenix Systems was that new brake fluid added to a brake system with excessive copper levels did not provide the "expected" corrosion protection of the system. This scenario is very common when brake components are replaced, such as the master cylinders, without flushing the complete brake system. For example, if a master cylinder is replaced, technicians usually add only enough new brake fluid to replace the volume of that component. Phoenix Systems found high iron levels in vehicles that experienced only partial brake fluid replacement. These vehicles also had high copper levels, in excess of 150 ppm. The high iron levels are indicators of active corrosion.

Wheeler [5] offered one possible solution for Phoenix Systems' discovery, "My analysis suggests that the presence in the brake system of copper as well as amine-based corrosion inhibitors is an unfortunate combination that in the end works to promote iron corrosion. It is known that amines associate strongly with dissolved copper. Any filming amines that associate with copper in solution cannot at the same time do their job of protecting iron. Therefore, elevated levels of dissolved copper may interfere with the effectiveness of the filming amines in preventing corrosion of the steel surfaces."

13. Copper and Virtual Age

It is also important to remember that many factors effect brake fluid chemistry: chemical and thermal stability, driving habits of the operator, frequency of maintenance, temperature and road surfaces to name a few. A simple time interval will not detect advanced degradation of brake fluid performance. Copper levels provide a clear indicator as to the condition of the brake fluid and can be used to diagnose brake fluid that is out of the norm for time and mileage.

Figure 6. Demonstrates the relationship between virtual age and copper.

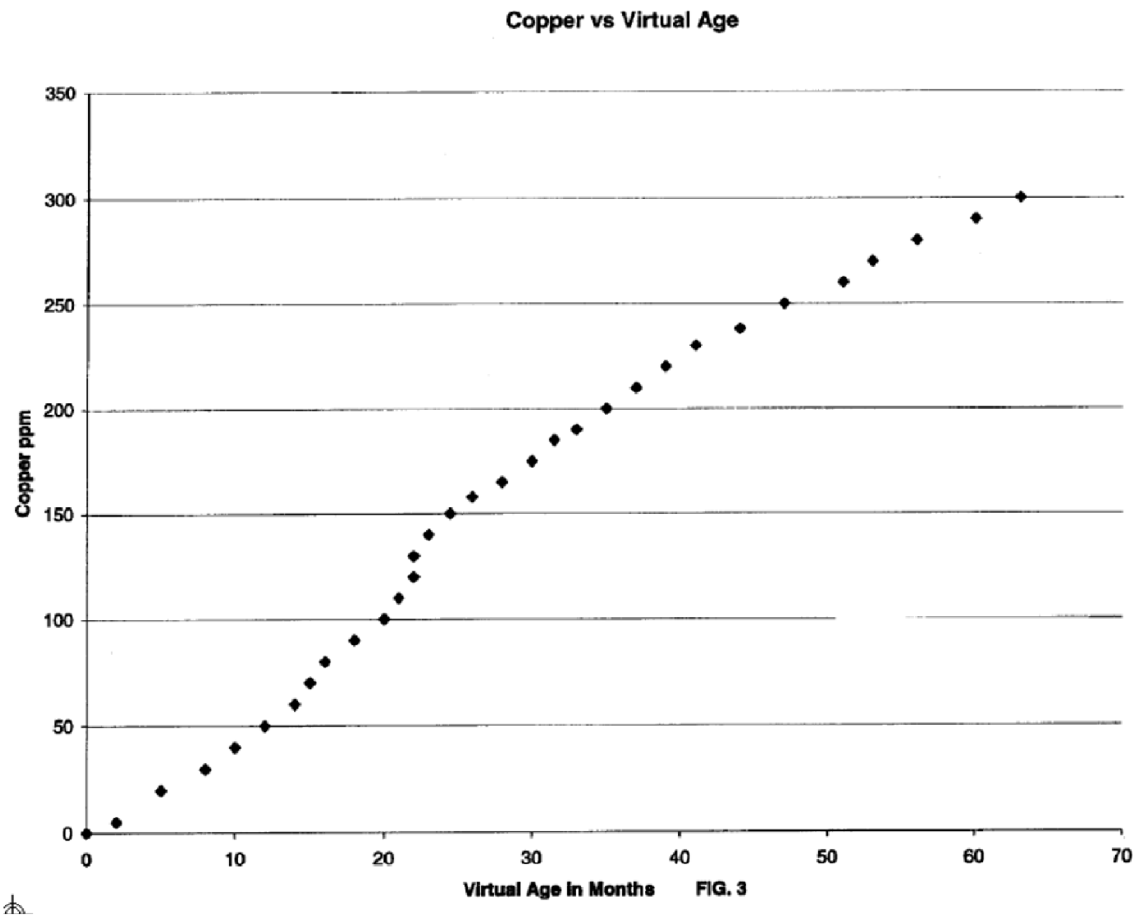

Figure 6. Copper levels and "virtual age" includes thermal reactions resulting from "hard driving" or abusive conditions.

The thermal effects on brake fluid while operating in a system are very important to the longevity of the brake fluid. When there is no thermal activity, i.e. vehicle sitting on a dealer lot for 1 year, there is little to no effect of thermal oxidation on the brake fluid. That is why brake fluid still appears as if new prior to the vehicle being driven. Copper levels have been found to directly represent the thermal effects on brake fluid condition in a vehicular braking system.

The thermal effects discussed here are the amount of heat the brake fluid is subjected to and for what period of time. The thermal effects wear the brake fluid. That is one reason why a vehicle may have only 12,000 miles, but due to the thermal effects of the brake fluid, as well as others, it may have a "virtual age" to that of brake fluid with 30,000 or more miles. This condition has been demonstrated on extreme demand vehicles that are repeatedly subjected to high amounts of heat.

Extreme conditions will cause different changes in brake chemistry even with the same vehicle and same fluid. Ricker et al [1] stated “as vehicles age, the chemistry of their brake fluids will change and will do so at different rates depending on variety of factors. That is, when a fleet of identical vehicles filled with identical brake fluids are put into service, the initial chemistry of the brake fluid environments in these vehicles will fit into a narrow spectrum or range of compositions. However, as these vehicles age and see different service conditions, the range of brake fluid chemistries in these vehicles will broaden”.

High temperatures are known to speed chemical reactions including the corrosion of copper and iron as well as speed the degradation of the inhibitor package. Phoenix Systems testing discovered a relationship between driving style and the level of dissolved metals and a reduced inhibitor level. Vehicles that experienced commercial use such as taxi, delivery or other “hard driving” conditions, had much higher levels of dissolved metals. According to Wheeler [5] “Therefore, 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. So the use of copper concentration as an indicator will naturally account for some degree of variation in user abuse of the braking system.”

Another Phoenix System discover for this “hard driving” category was a common low level of moisture absorption. It was suspected that elevated temperatures volatilized the water. This conclusion was supported by Wheeler [5], “On the other hand, elevated temperatures will tend to *reduce* the amount of water that would otherwise be in the brake fluid. This is because water, with its lower boiling point, will volatilize more strongly than other components as temperature is increased. “

14. Copper Levels Correlate to Brake Fluid Age and Time/Mileage.

Brake fluid service intervals specified by vehicle manufactures recommend brake fluid service based on time and mileage, but how accurate is using time and mileage to determine brake fluid condition?

One significant problem is knowing the service history of the vehicle. If a service facility simply looks at the mileage on the odometer and recommends a brake fluid flush, there is no way to know if the service was recently performed. The same condition exists with examining the year of the vehicle. Just because the vehicle is two years old, doesn't mean the brake fluid is good or bad and there is no way to know if the service was recently performed

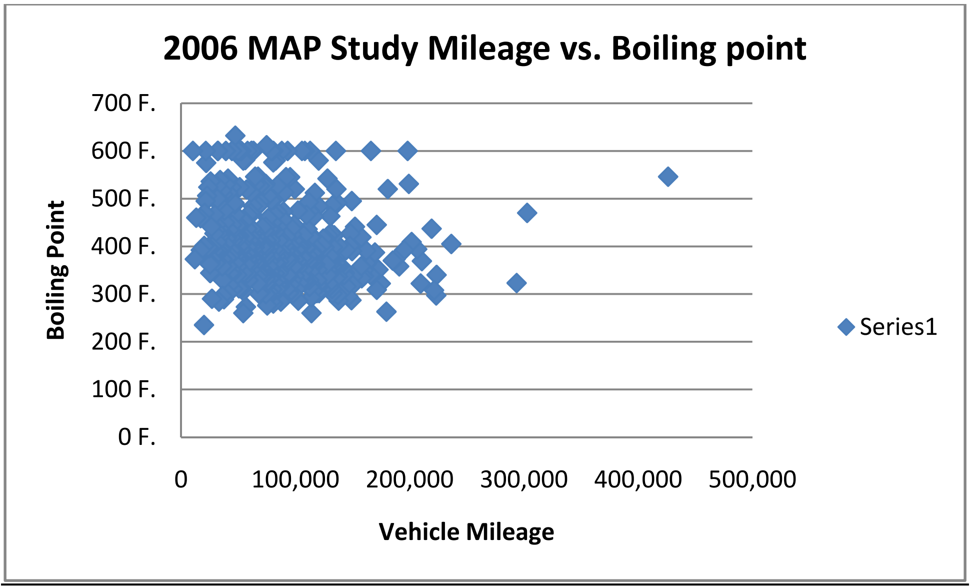

Figure 7. 2006 Mileage vs Boiling Point

Figure 7, demonstrates the map study [6] findings for vehicle mileage and boiling point. This test included 469 vehicles and as you can see from the "blob", there is virtually no linear representation correlating vehicle mileage with boiling point.

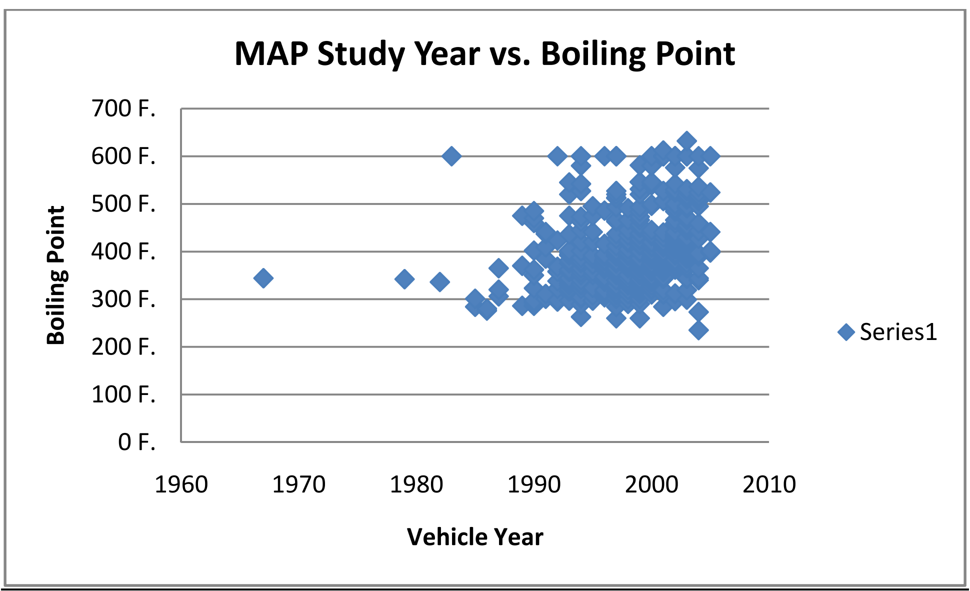

Figure 8. MAP Study 2006 Year vs Boiling Point

Figure 8 demonstrates the MAP study [6] findings for vehicle age and boiling point. This figure has a similar nonlinear data representation, providing no correlation between vehicle mileage and boiling point.

Conversely copper provides a very linear indication of age for normal driving conditions. See Fig. 9 Remember that copper will reveal the thermal effects on brake fluid condition i.e. “hard or abusive” driving. This chart is for “normal” operating conditions. In addition, copper also provided a linear representation of vehicle mileage. See Fig. 10.

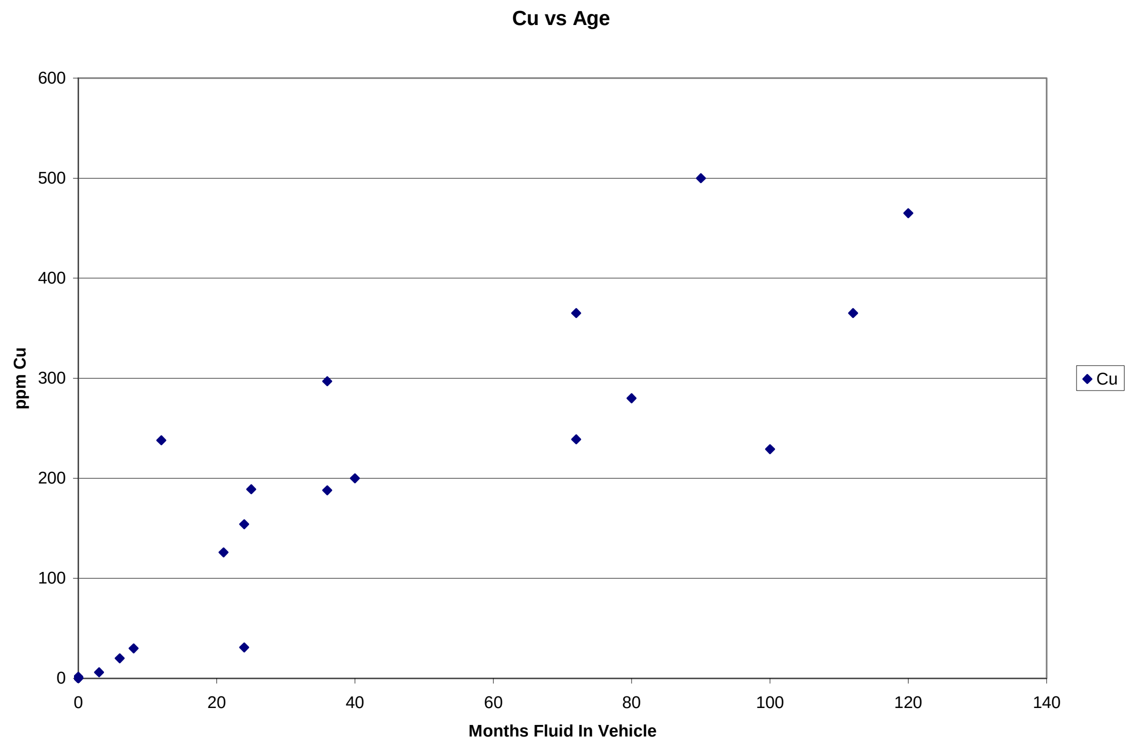

Figure 9. Copper levels versus the age of brake fluid

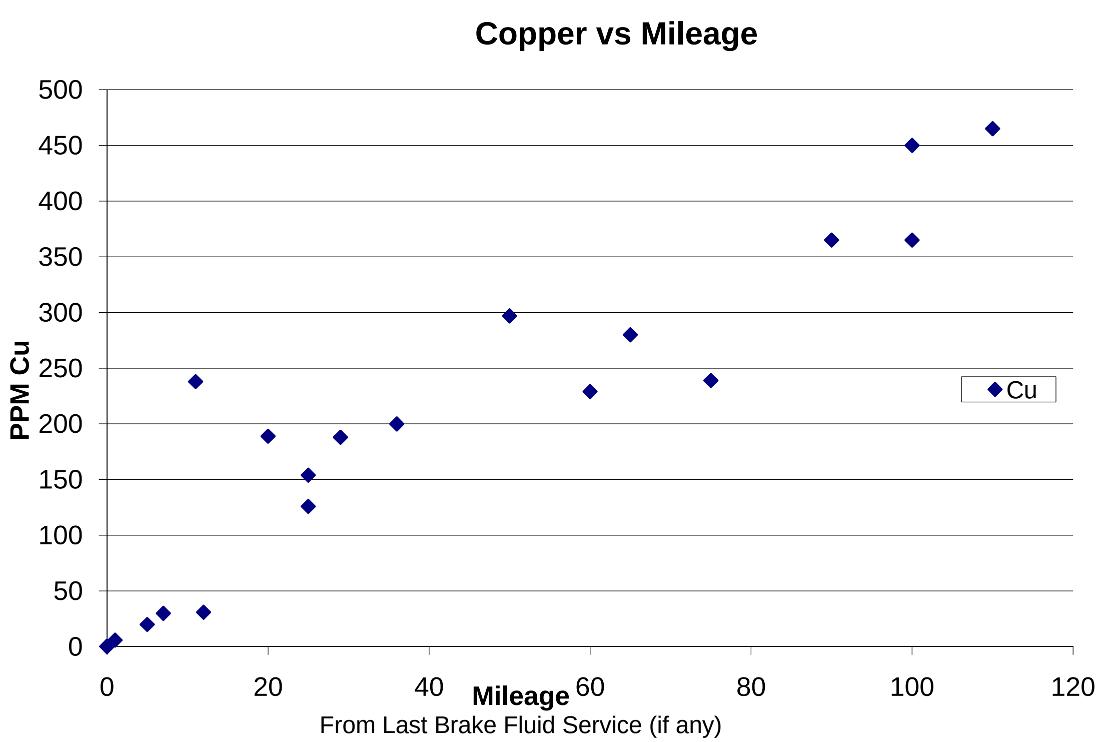

Figure 10. Copper levels and Mileage

The MAP study [6] also tested copper in brake fluid. However, the brake fluid copper testing only included a pass/fail result: meaning that the brake fluid was over 200 ppm (fail) or under 200 ppm (pass).

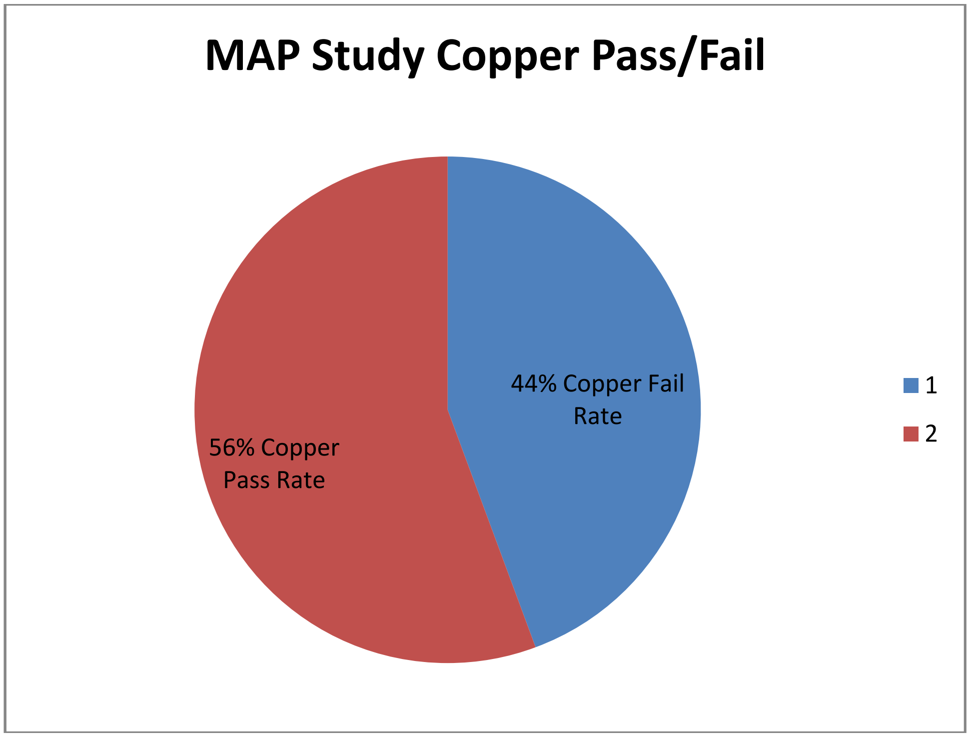

Figure 11. Copper pass and fail rates for 469 test vehicles

It has been accurately demonstrated that vehicle year and mileage (alone) give almost no conclusive evidence of brake fluid condition. Additional information is required to make an accurate determination based on vehicle age or mileage.

A brake fluid test is needed to accurately determine brake fluid condition without requiring additional data or customer interview.

15. The new MAP Guideline for Brake Fluid Service

In 2005, The Motorist Assurance Program (MAP) [6] released a new guideline for brake fluid requiring its replacement at 200 ppm.

> "Bethesda, Maryland – "The Motorist Assurance Program (MAP) has released an update to its Uniform Inspection & Communication Standards (UICS) for Brake Systems. The condition "Corrosion inhibitors depleted" and the resultant recommendation were added to the Brake Fluid Component. This update is effective immediately and comes recommended by the AMRA/MAP Technical Committee as a result of the ongoing AMRA Maintenance Service Program effort."

> Excerpt from the MAP UICS [6] for brake fluid

"Corrosion inhibitors depleted B Require fluid replacement
A copper content of 200 ppm or greater indicates a depletion of corrosion inhibitors in the brake fluid"

MAP determined that at 200 ppm copper, corresponding to a rapid increase in iron corrosion, that brake fluid was no longer able to perform the intended purpose of protecting the brake system. In conformity with the new MAP guideline, Phoenix abandoned the 0-100 scale for the actual 0-300 ppm copper measurement.

While Phoenix respects the MAP guideline of 200 ppm, we believe a more prudent level is 100 ppm copper. A level of 100 ppm provides a safe window to address preventive maintenance of the brake system. Copper at 100-200 ppm indicate brake fluid that has seen 2-3 years or 24-36K miles of normal service. All the supportive testing has determined that this is a critical period in brake fluid chemistry.

16 FASCAR® Accurately Measures Copper Concentrations

FASCAR® technology directly measures copper ions in the brake fluid and indirectly measures the age of the brake fluid. The level of copper ions can be used to predict brake fluid chemistry including: age, corrosion inhibitor levels and active corrosion. FASCAR® uses a test strip with a specialized reaction zone that is dipped in the brake fluid. The reaction zone will change colors from white to purple depending on the level of copper in the fluid. A copper rating is determined by a comparing the color on the reaction zone with the color chart. The reaction zone will maintain its color for at least one month and up to 1 year.

Phoenix Systems guarantees that the reaction zone will accurately measure copper ion for a period of three years. Independent and certified testing performed by ACT labs in Tucson Arizona utilized Inductively Coupled Plasma Spectroscopy (ICP) testing on various sample of brake fluid. The results of those tests determined the ppm value of copper in those brake fluid samples. The ppm of copper was then compared to the actual test strips dipped in the same sample of fluid. The color scale was determined accurate from 0-300 ppm as designed. The testing was certified accurate by ACT labs.

The testing scale is divided into 0, 30, 100, 200, 300 ppm copper.

17. Copper Summarized as a Brake Fluid Wear Indicator

Copper is the best overall indicator of brake fluid condition. Wheeler's [5] conclusion supports this statement, "In summary, copper concentration level in the fluid is one of the clearest available indicators of time-in-service for brake fluid. It can serve like wear indicators on brake pads do, warning when a problem is imminent rather than just warning when a problem has already developed."

It has been demonstrated that corrosion inhibitors in brake fluid deplete over time and can be severely depleted by 36 months. The depletion of corrosion inhibitors results in corrosion. Copper is not found in new brake fluid and is used as a brazing alloy in the brake lines, which represent a high surface area for brake fluid contact. Copper is the first metal to corrode in a brake system, is a principle contaminate in brake fluid and copper levels increase slowly and stably over time. The slow and steady increase in copper levels provides a means to predict the age of brake fluid under normal conditions. The age of the brake fluid can help determine when brake fluid should be serviced. Copper can also directly affect ABS components as it can plate to the valve and valve seats.

Iron levels begin to sharply increase when the copper levels reach 150-200 ppm, indicating corrosion of iron components. This also allows copper levels to be used to predict when iron levels will increase or the start of component corrosion and the depletion of corrosion inhibitors. Once corrosion begins copper acts as a catalyst to speed corrosion. The ability to predict brake fluid chemistry can establish a timeline so as to prevent the corrosion of iron components and to remove copper before it can begin to plate to various brake system components.

Copper levels can be used to determine a proper preventive maintenance schedule to prevent corrosion in a system. Copper testing provides more detailed information then time, mileage or moisture testing, as it can measure the effects of extreme or severe conditions that would necessitate the need for earlier service. In addition, brake fluid additive packages vary widely from manufacturer. A poor additive package will exhibit more rapid depletion of corrosion inhibitors, which can be detected by a copper testing, which may result in recommending fluid replacement ahead of normal schedule. The opposite is also true, a good additive package will slow depletion of corrosion inhibitors which can also be detected by a copper test.

Copper ions in brake fluid have been proven to: interfere with proper ABS valve operation, act as an oxidation catalyst, provide a precursor warning to active iron corrosion, correlate to the age and mileage of vehicular service and correlate to the buffering capability of the brake fluid.

So the use of copper concentration as an indicator will naturally account for some degree of variation in user abuse of the braking system. Copper can also associate with new brake fluid deactivating the corrosion inhibitors. The presence of high levels of dissolved copper in the brake fluid indicates that the steel surfaces in the brake system are already or will soon be under attack."

SUM of Copper Testing

1. The main source for copper corrosion is the brake lines
2. Copper is not present in new brake fluid and starts corroding immediately
3. Copper can predict the age of brake fluid
4. Copper levels can predict high levels of iron indicating active corrosion
5. Copper levels can predict depletion of corrosion inhibitors
6. Copper can deactivate new corrosion inhibitors
7. Copper plays an active role in brake system corrosion by attacking iron and acting as a catalyst for other breakdown reactions
8. Copper can plate to ABS components and interfere with proper operation of close tolerance components
9. Copper can reveal thermal influences of "hard driving" or abuse
10. Copper is more accurate than time and mileage data
11. Removal of copper is essential to brake fluid and brake system maintenance

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6. The Motorist Assurance Program (MAP). 7101 Wisconsin Avenue • Suite 1200 • Bethesda MD 20814 Tel: (301) 634-4954 • Fax: (202) 318-0378 E-mail: map@motorist.org