An Overview of Hydraulic Brake Fluid Contamination

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ABSTRACT

Brake fluid is an important fluid that transmits the braking force from the brake pedal to the road wheels. When the hydraulic fluid is contaminated, it causes low transmission of hydraulic brake pressure to wheels which can lead to road accident. The brake fluid contaminations deteriorate the quality of the hydraulic brake fluid, hurdle its operation, reduce the service life of the fluid and damage some components of the braking system. Most of these contaminations are developed during brake operation and during unhygienic repairs and maintenance. Contaminated brake fluid can reach a very high temperature of about 450°C -500°C; this leads to a chemical reaction that makes the fluid highly acidic. This breaks down the steel lines and rubber hoses and cause early failure of the cast iron and aluminum components in the braking system. After brake fluid has been severely deteriorated, corrosion of the internal components begins. Corrosion can pit the metal bores of the master cylinder, wheel cylinders and other components. This means that pistons cannot move freely, seals can be damaged and cylinders would also develop internal or external leaks. This paper came up to review the concept of the hydraulic brake fluid contamination in order to combat this phenomenon and to ensure good road and passengers' safety.

Keywords: Causes and Control of Hydraulic Brake Fluid Contamination.

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1. INTRODUCTION

Brake fluid is one of the most important, but least considerable fluid in the vehicle. Its main function is to transmit the hydraulic pressure developed in the master cylinder to actuate the brake pads and shoes in order to decelerate the motion of a moving vehicle or to absorb its kinetic energy. It also provides lubrication for some internal components of the hydraulic braking system. When the lubricating property of the brake fluid is lowered as a result of brake fluid contamination, it causes excess wear of the some components of the system thereby further contaminating the brake fluid. These contamination causes brake failure; as the result of the reduction in stopping capacity of the brake that can occurs after repeated application brake; especially at high load or high speed condition. This has led to lost of many lives and properties on the roads. Below (figure 1,0) is a simple layout of the hydraulic braking system

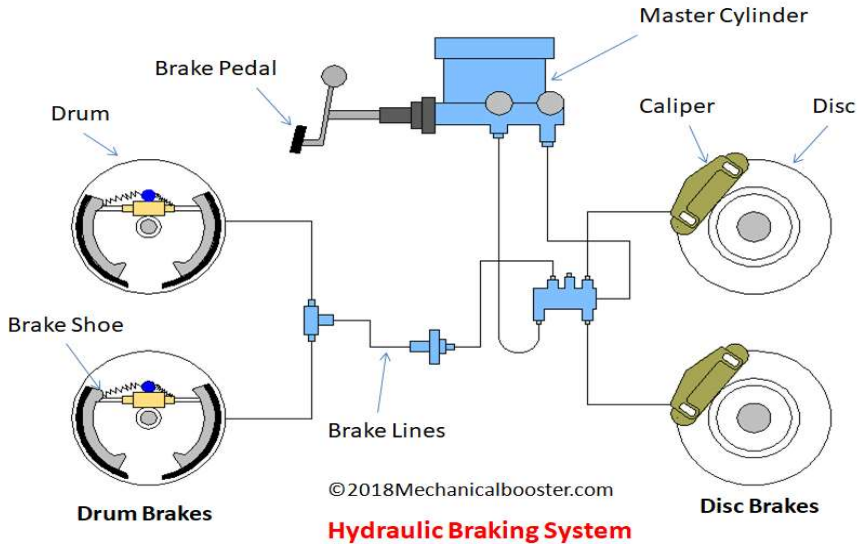

Figure 1. Layout of Hydraulic Braking System (Panka, 2018)

1.1 Statement of the Problem

Brake fluid deteriorates with time as it absorbs moisture from the atmosphere. This reduces the fluid boiling point and the lubricating property of the fluid thereby causing corrosion and wearing of the internal components of the hydraulic braking system, hence contaminating the brake fluid. Also heat generated from the braking system as a result of friction can cause the brake fluid to boil and evaporates which can causes sudden and unexpected brake failure. Brake failure is disastrous. These contaminants can lead to blockage of hydraulic fluid lines and corrosion of various components of the hydraulic braking system; thereby leading to brake failure and road accidents.

1.2 Objective

The concept of this paper came up a measure to describe the formation and effects of hydraulic brake fluid contamination in the hydraulic braking system. This is in order to subdue this phenomenon and to control brake failure in hydraulic braking system.

2. METHODOLOGY

The method used in this paper involves literature review and questioning of automobile technicians on this subject matter. This was done by consulting literatures and visiting automobile workshops. This was done in order to know the possible causes and control of hydraulic brake fluid contamination.

3. HYDRAULIC BRAKE FLUID

Hydraulic brake fluid is an important liquid substance for transmitting pressure from the brake pedal to the vehicles' wheels. Contamination in hydraulic brake fluid is very common and can cause numerous problems. Water, air, dirt, fuel, and other hydraulic oil or lubricants can all act inform of contamination.

3.1 Factor Affecting the Condition of Brake Fluid:

Hydraulic brake fluid can be affected by one of the following; (Brake Fluid Testing Technology, 2012).

i. Fluid contamination
ii. Age of brake fluid in system
iii. Thermal oxidation
iv. Presence of metal oxidation catalysts
v. Level of amines or reserve alkalinity

3.2 Brake Fluid Requirements

Brake fluid is one of the vital components that enable hydraulic braking systems to operate effectively. Its function is to transmit the input forces developed from the master cylinder to the road wheels. According to Giri, (2012), the brake fluid should have the following requirements;

i. Brake should function through hot, cold and at all the variation of temperatures affecting the braking system.
ii. It should also absorb water without having an affinity for doing so. Brake fluid must be pure and contain no contaminants which will have harmful effects on the components of the brake system.
iii. It also should serve as a lubricant for the moving parts of the brake system.
iv. It should be able to withstand time and service, in other words, the boiling point and chemical properties must remain stable.
v. The fluid should be very inert, unaffected by high or low temperature and should not affect the metallic surface and the rubber in the system, as well as to provide lubrication for the master cylinder and the wheel cylinder.

3.3 Types of Brake Fluid

DOT brake fluids and mineral oil are the two types of hydraulic brake fluid available. The Department of Transportation (DOT) rates brake fluid to temperature resistance. DOT brake fluid is the most commonly used brake fluid. All DOT brake fluids (with the exception of DOT 5) are made up of a poly-glycol base. Glycol-based fluids consist of a mixture of ingredients with as many as ten separate substances making up the final product.

These substances can be broken down into four key components: (Alex 2018).

i. **A lubricant;** such as polythene or polypropylene, to keep parts moving freely - 20-40%.
ii. **A solvent diluents;** usually glycol ether, which determines the fluid's boiling point and viscosity and accounts for 50-80% of the fluid.
iii. **A modifier-coupler;** which changes the amount of swelling of exposed rubber parts.
iv. **Inhibitors;** to prevent corrosion and oxidization.

One of the main differences separating the various classes of DOT fluid is their boiling temperature (or boiling point). This refers to the temperature where the brake fluid will start to boil or vapourise inside the brake system (Alex, 2018). This is caused by the intense heat generated, high brake application and these has an adverse effect on the performance of the entire brake system.

Table 1: Dry and Wet Boiling Point of DOT Brake Fluid (Alex, 2018)

Brake Fluid	Dry Boiling Point	Wet Boiling Point
DOT 3	205 °C (401 °F)	140 °C (284 °F)
DOT 4	230 °C (446 °F)	155 °C (311 °F)
DOT 5	260 °C (500 °F)	180 °C (356 °F)
DOT 5.1	270 °C (518 °F)	190 °C (374 °F)

Unlike DOT fluid, Mineral Oil is hydrophobic and does not absorb moisture from the environment. This means that there have no wet or dry boiling temperatures, the boiling point remains constant and never drops. The mineral oils are not governed by any standards or regulatory body, therefore the technical information on the various substances that contribute to their make-up is usually hard to understand. The table 2.0 shows the boiling points of some mineral oils (Alex, 2018).

Table 2.: Boiling Point of Mineral Oil Brake Fluid (Alex, 2018)

Mineral Oil	Boiling Point	Difference
Magura Royal Blood	120 °C (248 °F)	--
Valvoline LHM+	249 °C (480 °F)	107%
Shimano	280 °C (536 °F)	12%
Juice Lubes	290 °C (554 °F)	3.5%

4. CAUSES AND EFFECTS OF HYDRAULIC BRA KE FLUID CONTAMINATION

Brake fluids are very sensitive to contamination. Sometime as simple as dipping a finger into the brake fluid reservoir can contaminate the brake fluid thereby causing brake failure The following are the causes of hydraulic brake fluid contamination;

i. Brake fluid vaporization
ii. Friction
iii. Unhygienic repairs and maintenance
iv. Sludge
v. Use of un-recompensed brake fluid

4.1 Brake Fluid Vaporization

Most automobile brakes are hydraulically operated except the heavy trucks. If the temperature during braking exceeds the boiling point of the hydraulic fluid, the brake fluid would evaporate. Therefore, a vapor system is formed in the hydraulic braking system. Since gases are more compressible than the liquid, the pedal movement would compress the gases without activating the braking system (Atthur, 2006). The brake fluid absorbs moisture. This can reduce the boiling temperature of the brake fluid (Hunter *et al*., 1998). This can also cause corrosion of components of the braking system. It is therefore generally advisable to replace the brake fluid periodically as recommended by the vehicle manufacturer. The moisture affects the braking system in following ways (Impurities in Brake Fluid, 2018).

i. It reduces the boiling point of the brake fluid.
ii. Spongy brake pedal due to presence of water vapour/contamination..
iii. Brake failure chance increases in low temperature due to formation of ice crystal in the brake line.
iv. Moisture wears the internal component and failure results due to internal rust and brake fluid deterioration.
v. Moisture indicates the oxidation of brake fluid ingredients which lead to reduce in life span of brake fluid and its contamination.

4.2 Friction

Friction opposes motion and causes the wearing of the components in relative motion. The friction between the master cylinder, and master cylinder pistons, and seals, between the wheel cylinder and the wheel cylinder pistons and cups amd between the calipers and pistons, causes the wearing of the surfaces. This is one of the major causes of brake fluid contamination. When the brake fluid is contaminated as a result of vaporation, its viscosity and lubricating property is lowered. This can causes excess wear rate on some internal components of the system thereby contaminating the brake fluid with some small particles. These can also cause brake line blockage which can lead brake failure.

4.3 Unhygienic Repairs and Maintenance

Dirt is the enemy of the brake system (Fred, 1985). Unhygienic operations carried out during repairs and maintenance of the braking system can introduce contamination to the brake fluid. Also improper storage of the brake fluid can lead to brake fluid contamination, thereby affecting the performance of the braking system.

Petroleum means mineral oil based products like lubricating, gear, transmission, steering oil and grease etc; which are used in the vehicle. These products are sometimes introduced into the brake fluid during unhygienic repairs and maintenance. These products are rapidly and selectively absorbed by brake system rubber parts, resulting in a high degree of softening, dimensional swelling, and general deterioration of the functional properties of these rubber parts. This type of brake fluid contamination will result in unsafe braking action and may be the direct cause of complete brake failure (Impurities in Brake Fluid, 2018).

4.4 Sludge

The master cylinder is the heart of the hydraulic braking system. It draws compresses and pushes (pumps) the brake fluid through the brake lines to the wheel cylinders and calipers. As the brake fluid is performing its function, there is the possibility of breakdown of its chemical compositions. The breaking down of the chemical composition of the fluid with time forms small solid particles in the hydraulic braking system. This is called sludge. This contaminates the brake fluid thereby causing brake failure and brake line blockage.

A driver uses brakes approximately 75,000 times in a year and expects them to function properly each and every time; due to much application, fine sludge particles are formed, which can causes following brake problems (Impurities in Brake Fluid, 2018).

i. May chock the brake line.
ii. Increases the viscosity of brake fluid.
iii. Extra force is required during brake application; indirectly it takes more time to apply the brake in full strength therefore increasing chance of accident.

4.5 Use of Un-Recommended Brake Fluid

The use of un-recommended brake fluid can quickly reduce the lubricating power of the fluid thereby making the fluid to deteriorate. The will cause excess wearing and corrosion of the components of the brake system thereby contaminating the brake fluid. Some vehicle manufacturers recommend the changing of fluid between 25000 km to 60000 km. Brake fluid contamination has become much concern that vehicle manufacturers have added brake fluid service to their required maintenance schedules. Automobile experts recommend changing brake fluid every 12 to 24 months as preventative maintenance, even more often in wet and extremely humid condition (Amsoil, 2007).

5. ANALYSIS

The **Dry Boiling Point** of brake fluid is the boiling temperature of a new brake fluid from an unopened container, while the **Wet Boiling Point** is defined as the temperature at which the brake fluid would begin to boil after it has absorbed 3.7% water by volume (Alex, 2018). DOT brake fluid would reach this volume of water after roughly 2 years operation. The Department of Transportation (DOT) specify the minimum wet boiling point of DOT brake fluids after absorbing only 3.7% water content (roughly 2 years service) (Alex, 2018). It is shown in figure 2.0, that the boiling points of the various brake fluids decline much further over longer periods of time. When brake fluid reaches 8% water content, the boiling point of DOT 3 brake fluid has been reduced almost to that of water 100°C.

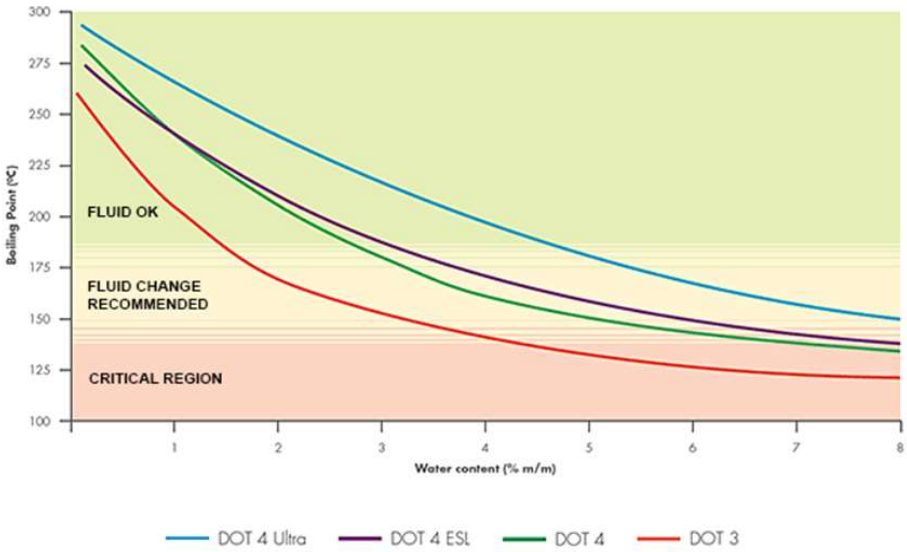

Figure 2. Impact of water contamination on Brake fluid Boiling Point (Alex, 2018)

Automobile braking systems contain steel components, such as wheels and master cylinders, valves, connected by lengths of copper-alloy-lined steel tubing. Both the steel and the copper components are unavoidably subjected to corrosion. Corrosion and wear of the metal surfaces can interfere with the proper operation of these components, leading to a diminished margin of safety of the braking system. An increased level of dissolved copper in the solution is an important indicator that the brake fluid is no longer effectively protecting metal surfaces from corrosion. The presence of high levels of dissolved copper in the brake fluid indicates that the internal steel surfaces in the brake system are already or will soon be under attack by the contaminated brake fluid (Dean, 2006). This is one of the major causes of damage of brake fluid line which has lead to brake failure.

The fluid attracts moisture through microscopic pores in rubber hoses, past seals and exposure to the air. The condition became worse in wet climate condition where the humidity is high. This can also occurs at normal driving conditions if the brake fluid is seriously contaminated. As the concentration of moisture increases, it causes a sharp drop in the fluid's boiling temperature (Changing of brake fluid, 2018). As water accumulates, congregates together, and settles in the hydraulic braking system, it corrodes the lower portion of the master cylinder, wheel cylinder, and brake lines. If the brake line are void of brake fluid over time, the the oxygen combine with the water rapidly causes corrosion and blockage in the brake fluid line. The simplified corrosion reaction for a metal in liquid can be stated as (Dean, 2006):

Metal + Dissolved Oxygen + Acid = Dissolved Metal.

Figure 3.0, also illustrate the effects of water on boiling point of hydraulic brake fluid. A new DOT 3 brake fluid must have a dry (no moisture) boiling point of at least 205°C, and a wet (moisture-saturated) boiling point of no less than 140°C. Most of the new DOT 3 fluids exceed these requirements and has a dry boiling point in the range from 220°C to 250°C. Only one percent water in the fluid can lower the boiling point of a DOT 3 to 187°C. Two percent water reduces the boiling point down to around 160°C, and three percent will take down to 145°C.

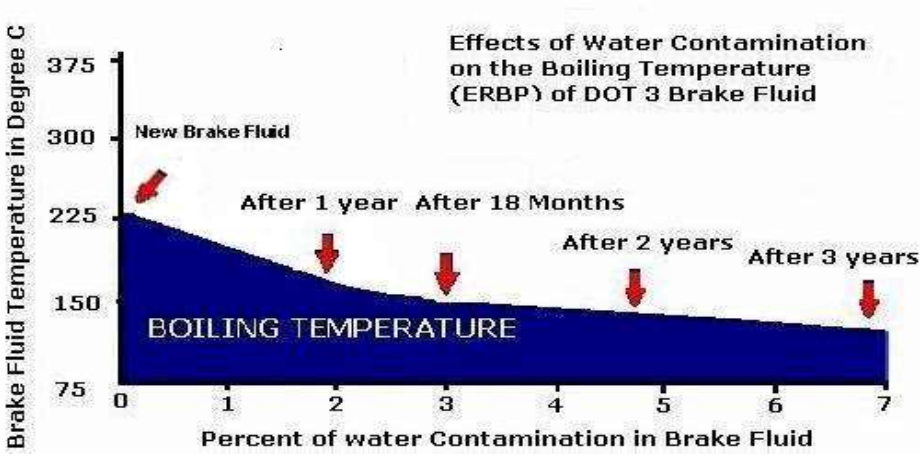

Figure 3: Effect of water on Brake Fluid Boiling Point

DOT 4 fluid, has a higher minimum boiling temperature requirement (230°C dry and 155°C wet) soaks up moisture at a slower rate but suffers an even sharper drop in boiling temperature as moisture accumulates. Three percent water will lower it's boiling point as much as 33%. Therefore it is recommended that brake fluid should change every two years. (Changing of brake fluid, 2018).

6. CONTROLLING OF HYDRAULIC BRAKE FLUID CONTAMINATION

Brake fluid is vital to ensure good road and passengers' safety, yet it is one of the most neglected fluids in the vehicles. Just as water level is check daily in the radiator before engine operation, hydraulic brake fluid level should also be checked and inspected to see if there is any contamination in the system. Brake fluid contamination can be flush from the system by a process called brake bleeding. The brake bleeding is the procedure performs on hydraulic brake system to purge out of any contamination from the brake system. This is because the contamination would cause a reduction in hydraulic pressure of the system. Bleeding are also done when old brake fluid are to be replaced with new fluid.

FASCAR, which stands for "Fluid Analysis by Stimulation of Contamination Alpha Reactions", is a simple visual test carryout to determine the condition of hydraulic brake fluid. To carry out the test, a new Strip is immersed into a vehicle brake fluid for 1 second and within 30 -120 seconds the reaction zone will change colors depending on the condition of the hydraulic brake fluid as shown in figure 4.0. The FASCAR color scale is used to compare the reaction zone color to determine the FASCAR rating (Brake Fluid Testing Technology, 2012).

Figure 4: FASCAR Rating Systems (Dean, 2006).

Brake fluids compatibility chart allows automobile brake fluid users to know which types of brake fluid that can be mix without causing harm to brake system. All glycol- based DOT fluids (3, 4 & 5.1) are fully compatible with each other and can be readily be mixed without adversely affecting the brake performance. While Silicone DOT 5, are not compatible with any of the other DOT brake fluids, nor are they able to be mixed with Mineral Oil brake fluids. The chart below (Table 3.0) shows the compatibility of the hydraulic brake fluid.

Table 3: Brake Fluid Compatibility Chart (Alex, 2018)

Brake Fluid Compatibility Chart

	DOT 3	DOT 4	DOT 5	DOT 5.1	Shimano Mineral Oil	Magura Royal Blood	LHM+ Mineral Oil
DOT 3	✓	✓	✗	✓	✗	✗	✗
DOT 4	✓	✓	✗	✓	✗	✗	✗
DOT 5	✗	✗	✓	✗	✗	✗	✗
DOT 5.1	✓	✓	✗	✓	✗	✗	✗
Shimano Mineral Oil	✗	✗	✗	✗	✓	⚠	⚠
Magura Royal Blood	✗	✗	✗	✗	⚠	✓	⚠
LHM+ Mineral Oil	✗	✗	✗	✗	⚠	⚠	✓

✓ Totally compatibile. May be mixed and used interchangeably

✗ Not compatible. Do not mix under any circumstances

⚠ Limited compatibilty - Mix at your own risk. Warranty may be voided

In order to control brake fluid contamination, the following precaution should always be taken into account;

i. The recommended vehicle brake fluid should always be used.
ii. If the brake fluids are to be mixed, the brake fluid compatibility chart should be utilized.
iii. Always change the brake fluid between 12-24 months of operation.
iv. Always inspect the condition of the hydraulic brake fluid at the reservoir daily.
v. Always bleed out old and contaminated brake fluid from the system.

7. CONCLUSION

Contaminated brake fluids are made up water metals (small particle) and dissolved metals. The behavior of water as a contaminant varies depending on the type of brake fluid. The presence of water in the system results in corrosion of the system components. Water may be introduced by maintenance, internal generation and storage. Solid contaminants are formed as the result of friction between the internal components of the system in relative motion. The metallic particles cause damage depending on their size. They cause brake line blockage and transient malfunction of the braking system.

The concentrations, types and size of these contaminants depend on the constituent elements of the internal components of the hydraulic braking system. It is hereby recommended that intensive research should be carryout on hydraulic brake fluid in order to investigate which metals or components of braking system dissolve most or have the highest concentration in the brake fluid that is mostly resulting to hydraulic brake fluid contamination. This would help in modifying the constituent elements of the brake fluid and the brake system components in order to control hydraulic brake fluid contamination and to improve the service of the brake fluid. Hydraulic brake fluid manufacturers should avoid using metallic containers, since these containers can reacts with the brake fluid during storage to cause brake fluid contamination. Therefore it is recommended that plastic or rubber containers should be used.

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