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Assessment of Boiling Point and Moisture Content in Brake Fluids: Insights from Passenger Vehicles in Kuwait

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1. Abstract
This paper describes several real-world experiments to investigate the relationship between moisture content, the number of engine cylinders and the boiling point of brake fluid in the master cylinders and brake callipers of passenger vehicles. Six brands of new brake fluids (DOT3, DOT 4 and DOT 4+) and a sample group of 40 vehicles from Kuwait, characterised by a dry climate with low humidity, were selected. These vehicles were manufactured from 2007 to 2023, and their odometers ranged from 12,000 km to 337,000 km. Importantly, some of the brake fluid in these vehicles had never been replaced prior to the study, offering a diverse range of real-world conditions. Using a BOSCH BFT 100 boiling point tester and BF200 moisture analyser, the study revealed a marginal decrease in the boiling points of brake fluids and an increase in moisture content over time. Nevertheless, the boiling points remained above the minimum required temperature thresholds. Additionally, the water content in the brake fluids did not surpass the maximum permissible levels in any of the tested cars. The results show a significant drop of 38°C in boiling point in the front brake callipers compared to the master cylinder, indicating a substantial difference in brake fluid quality.
Keywords: *Kuwait, brake fluid, boiling point, moisture content, DOT 3, DOT 4*

Introduction
Brake fluid plays a vital role in vehicle safety by allowing vehicles to reduce their speed or stop. The operational principle of the brake system is to convert kinetic energy into thermal energy. As this process occurs, the friction between the disc brake pads increases [8].
Vehicle systems use hydraulic brake systems for this purpose, which depends on transferring mechanical energy in the form of pressure from the master cylinder to the brake calliper. When the mechanical energy is converted into thermal energy, the temperature of the brake disc may reach 600 degrees Celsius [2], depending on the brake pads' quality, the friction coefficient, the brake disc diameter and the force affecting the brake pads [1].
When the driver presses the brake pedal, a small piston inside the master cylinder creates a pressure of around 80 bar inside the brake system [9], which is transferred to the brake callipers through hydraulic lines [3]. These small diameter lines allow the pressurised brake fluid to flow from the master cylinder to the brake calliper and all the brake's components. At the vehicle's wheels, the brake calliper presses the brake pads, pushing them against the brake discs and transforming kinetic energy to heat energy [2].
The brake calliper contains one or more pistons that engage the brake pads to create friction against the rotating brake disc [3]. As the pistons move outward, they generate friction against the rotating brake disc, causing more heat and enabling the vehicle to slow down or stop [3]. Heavy braking could result in high friction, potentially raising the brake fluid temperatures at the calliper to the fluid's boiling point. If the brake fluid at the calliper reaches boiling point, it will vaporise inside the brake line, becoming compressible and undermining the hydraulic transfer of braking force [5].
Usually, the brake fluid's boiling point is measured only at the master cylinder and not at the brake calliper, which assumes that its boiling point is the same in all parts of the brake system [6, 7]. However, in vehicles provided with an anti-lock system (ABS), the brake lines are more complicated, which could lead to different boiling points of the brake fluid in the system, especially as it passes through a system of valves and long lines far from the master cylinder [4], as shown in Figures 1 and 2.

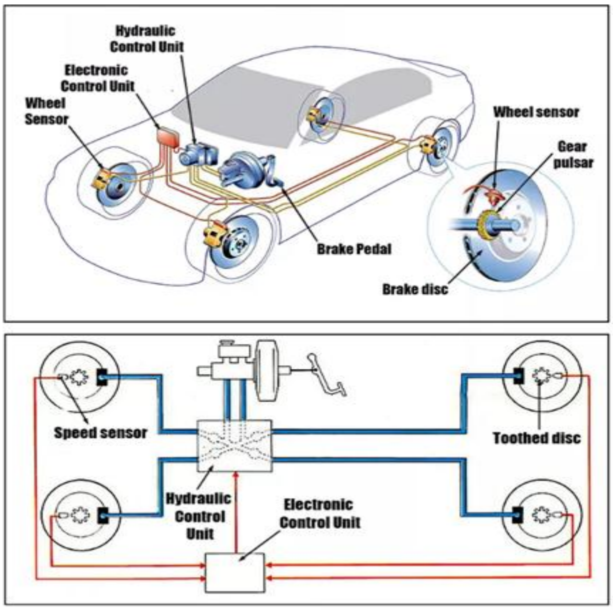


Figure 1: ABS Schematic [14].

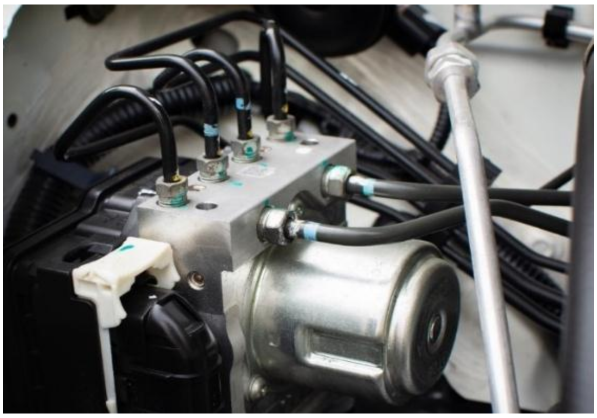


Figure 2: Photo of an ABS System [4].

Brake fluids are classified by the US Department of Transportation (DOT) based on their chemical composition, performance characteristics, and boiling points, as shown in Table 1. The table shows some of the parameters a brake fluid must meet to be classified as DOT 3, DOT 4 or DOT 4+ [5,8]. All of these are glycol-based, and DOT 3 has a lower boiling point than DOT 4 and 4+. A high boiling point makes brake fluid suitable for vehicles that place high demands on their brakes, such as performance cars [5, 8]. Most brake fluids are hygroscopic; that is, they absorb moisture from the air over time. Moisture absorption lowers a brake fluid's boiling point and can lead to reduced braking performance. Regular brake fluid checks and changes are essential to maintain optimal braking performance and safety.
The DOT's brake fluid categories help to ensure that brake fluids meet specific safety and performance standards for different types of vehicles and driving conditions [5,8].
The boiling point of brake fluid is critical because brake systems generate significant heat, especially during heavy braking. If the brake fluid boils, it creates vapour bubbles in the hydraulic system, which can compress, leading to a spongy brake pedal or even brake failure. Therefore, fluid manufacturers advise regular brake fluid maintenance and replacement every one to two years or whenever the fluid fails a boiling point test to prevent brake failure and to ensure that a vehicle's brakes operate effectively under all conditions.

Table 1: Classification of Brake Fluid Boiling Points According to the US DOT [10,11,15]

Fluid type	**Dry Boiling Point**	**Wet Boiling Point**	**Composition**
DOT 3	205 °C	140 °C	Glycol ether
DOT 4	230 °C	155 °C	Glycol ether
Q8 Brake Fluid DOT 4+ [12]	265	165	Glycol ether

This study investigates the wet boiling point and water content percentage of DOT 3, DOT 4 and DOT 4+ brake fluids in a sample of 40 vehicles from Kuwait. Kuwait's climate ranges from an average of around 43 °C in summer to less than 15 °C in winter, with daily lows of 23 °C in summer and 5 °C in winter [16]. Annual humidity varies between 30% and 36% [15, 17]. DOT 3, DOT 4 and DOT 4+ brake fluids, being hygroscopic, tend to absorb moisture from the atmosphere, with moisture content increasing by approximately 1%–2% per year [12]. If the brake fluid's water content exceeds 3.7%, its boiling point significantly drops [13]. Vehicle manufacturers recommend replacing brake fluid every two years or approximately every 40,000 km [17]. As indicated in Table 1, DOT 3, DOT 4 and DOT 4+ brake fluids have wet boiling points of 140 °C, 155 °C and 180 °C, respectively. Under extreme braking conditions, brake fluid temperatures can surpass these boiling points, leading to fluid vaporisation and bubble formation within the brake lines. This hazardous condition, known as vapour lock, can result in brake pressure loss and complete brake failure [14].

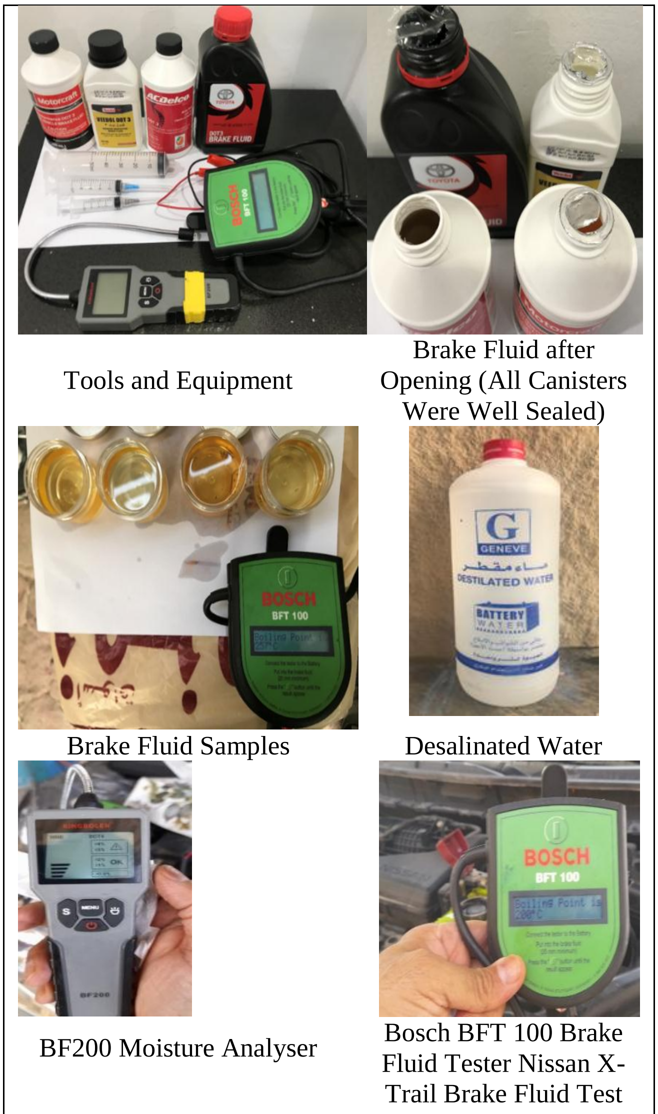
3. Research Methodology

This study aimed to study the drop in the boiling point of brake fluid after changes in its moisture content. Three experiments were conducted for this purpose. The first evaluated the drop in boiling point for four different brands of brake fluid after increasing moisture content to about 2.5%, 5% and 7.5%.
The second experiment investigated the effect of boiling point and the moisture content of brake fluid on 35 vehicles of different models, mileages and number of engine cylinders. These vehicles were manufactured from 2007 to 2023.
The last experiment investigated the drop in boiling point between the master cylinder and the front disc brake calliper in five of the vehicles.
Finally, all collected data was analysed to investigate real-world brake fluid conditions, the relationship between moisture content and boiling point and the impact of Kuwait's climate on brake fluid performance.
To establish a baseline, we tested six types of new brake fluids using the BOSCH BF200 moisture analyser and BFT 100 boiling point tester before investigating real-world brake fluid conditions. This preliminary test allowed us to compare the condition of in-use brake fluids against new ones, thereby highlighting the impact of environmental factors and usage on brake fluid properties.

4. Equipment and Experimental Procedure

The following equipment was used in the experiments and is shown in Figure 3 below:

1. Six new brake fluid canisters of different brands
2. A BF200 moisture analyser for measuring water content in brake fluid
3. A BOSCH BFT 100 boiling point tester for determining the boiling point of brake fluids
4. Empty canisters to collect and test the new brake fluids
5. Desalinated water



Tools and Equipment

Brake Fluid after Opening (All Canisters Were Well Sealed)

Brake Fluid Samples

Desalinated Water

BF200 Moisture Analyser

Bosch BFT 100 Brake Fluid Tester Nissan X-Trail Brake Fluid Test

Figure 3: Tools and Equipment Used in the Study.

Vehicles were chosen to represent a broad spectrum of 40 passenger cars commonly found in Kuwait. The selection criteria included brake fluid type, vehicles produced between 2007 and 2023, mileage, and number of engine cylinders for each vehicle.

Each vehicle underwent an inspection to verify the brake system's condition and ensure there had been no prior brake fluid replacement. Following this, each vehicle's water content and boiling point were measured sequentially to maintain consistency.

4.1. Water Content Measurement

The water content in the brake fluid was measured using the BF200 moisture analyser. This device is specifically designed to measure the percentage of water content in brake fluid. The procedure involved several steps. First, we checked that the vehicle's brake fluid reservoir was accessible and clean. Then, the probe of the BF200 was immersed into the brake fluid reservoir to take measurements. The moisture analyser provided a direct reading of the water content percentage for each vehicle.

4.2. Boiling Point Measurement

The boiling point of the brake fluid was determined using the Bosch BFT 100 boiling point tester. The BFT 100 is known for its accuracy in determining the boiling points of all types of glycol-based brake fluids. The process began by ensuring the brake fluid reservoir of each vehicle was accessible and the fluid was suitable for testing.

This methodology ensured comprehensive and reliable data collection, providing valuable insights into the effects of water content changes on brake fluid performance in Kuwait's unique climatic conditions.

5. Experimental Results

5.1. Testing New Brake Fluids

Figure 4 illustrates the moisture content of newly-opened DOT3, DOT 4 and DOT 4+ brake fluids. The first four bars are the results for the DOT 3 brake fluids, Toyota, Motorcraft, Veedol, and ACDelco. The next two bars represent ACDelco and Mercedes-Benz DOT 4 and DOT 4+ brake fluids. These findings indicate that even new brake fluids can contain varying levels of moisture, which could impact their performance.

Although brake fluid canisters are designed to keep out moisture, the moisture contents of new brake fluids varied from 1% to 2.5%, possibly due to the manufacturing processes or air exposure during bottling.

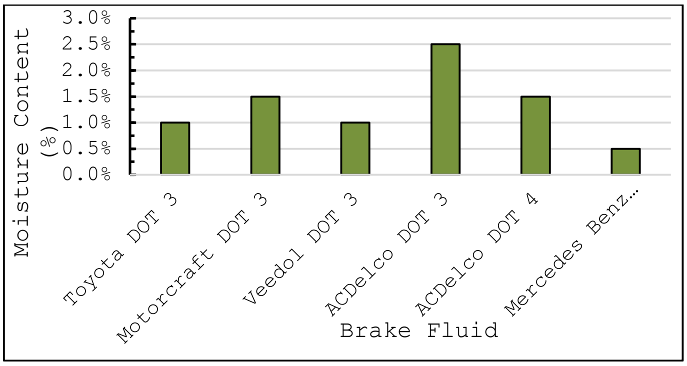


Figure 4: Initial Moisture Content of Six Brake Fluids Used in This Study.

Figures 5 and 6 compare the boiling points of different brake fluids according to the US Department of Transportation (DOT) classification, which specifies that 205 °C is the dry boiling point and 140 °C is the wet boiling point of DOT 3 fluids. Figure 5 shows that the test results of DOT 3 boiling points vary from 240 °C to 261 °C, with Motorcraft DOT 3 having the highest boiling point. Figure 6 shows that the boiling point is 269 °C for ACDelco DOT 4 and 275 °C for Mercedes-Benz DOT 4+.

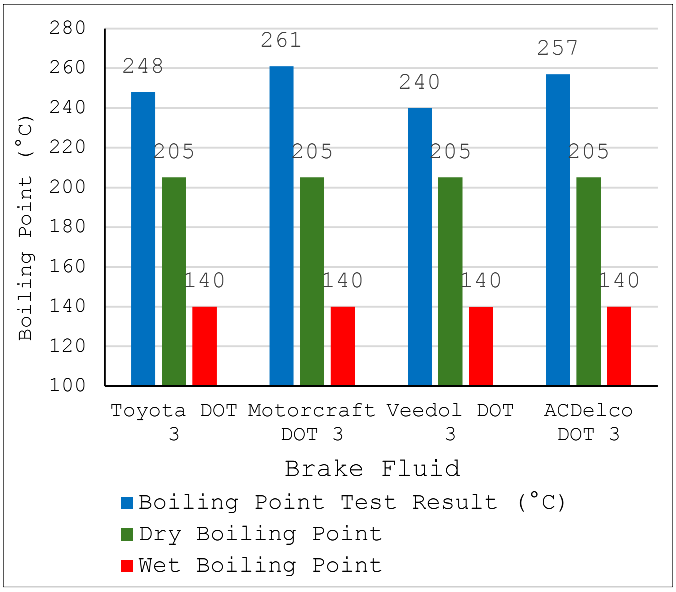


Figure 5: DOT 3 Brake Fluid Boiling Points Compared to the US Department of Transportation Classifications.

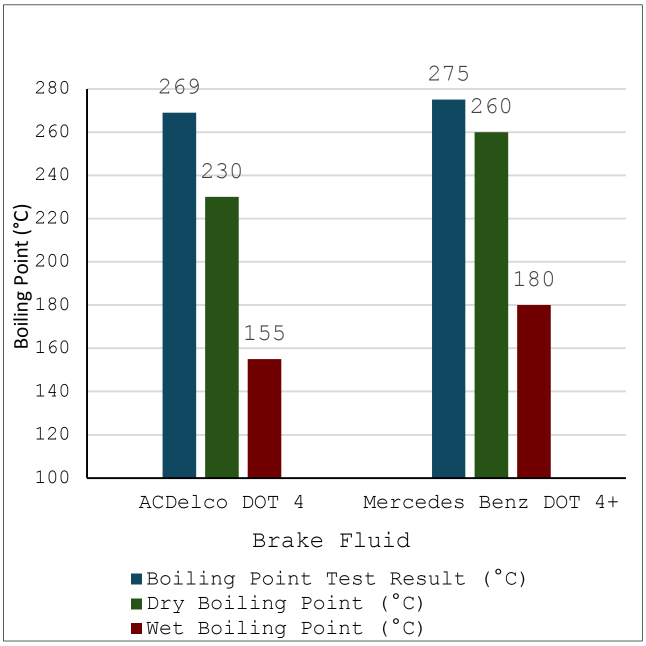


Figure 6: DOT 4 and DOT 4+ Brake Fluid Boiling Points Compared to the US Department of Transportation Classifications.

These findings confirm that all of the brake fluids studied initially exceeded the minimum specified boiling point limits, suggesting they are capable of withstanding the high temperatures generated during braking. However, despite being well-sealed, the new brake fluids exhibited some moisture content.

The presence of moisture in new fluids is significant because it shows that even new brake fluids kept in a sealed canister can absorb moisture from the environment during manufacturing, packaging, or storage. The moisture content in new brake fluids is comparable to that of in-use brake fluids found in some vehicles, which had up to 1.5% moisture content.

5.2. Changes in Boiling Point of Brake Fluids with 2.5%, 5% and 7.5% Water Content

Adding water to brake fluid in controlled amounts can help determine how moisture content affects its performance. Table 2 and Figure 7 indicate the boiling points of different brands of DOT3 brake fluid (Toyota, Veedol, Motorcraft and ACDelco) with varying amounts of water (2.5%, 5% and 7.5%) added.

The initial boiling points of the brake fluids range from 240 °C to 261 °C, which is typical for fresh, dry DOT 3 brake fluid. After water is added to a moisture content of 2.5%, the boiling points drop significantly to a range of 176 °C to 184 °C, indicating that even a small amount of moisture significantly lowers the boiling point of brake fluid.

When the moisture content is raised to 5%, the boiling points decrease further, ranging from 150 °C to 156 °C. This is a marked decline in performance, making the brake fluid much more susceptible to boiling under high-stress conditions. Finally, when the moisture content is increased to 7.5%, the boiling points fall to a critical range of 138 °C to 142 °C, meaning a much higher risk of boiling during normal braking operations, potentially leading to brake failure.

The addition of water, even in small amounts, greatly lowers the boiling point of brake fluid (by as much as 123 °C), making it unsafe for use in braking systems. This experiment clearly demonstrates the importance of maintaining brake fluid in a dry, moisture-free environment to ensure optimal performance and safety.

Table 2: Brake Fluid Boiling Point after Addition of Water.

Moisture Content in %	**Toyota DOT 3 (°C)**	**Veedol DOT 3 (°C)**	**Motorcraft DOT 3 (°C)**	**ACDelco DOT 3 (°C)**	**Average Boiling Point Drop (°C)**
New	248	240	261	257	0
2.5%	181	176	184	180	71
5%	152	154	150	156	99
7.5%	142	142	138	142	111

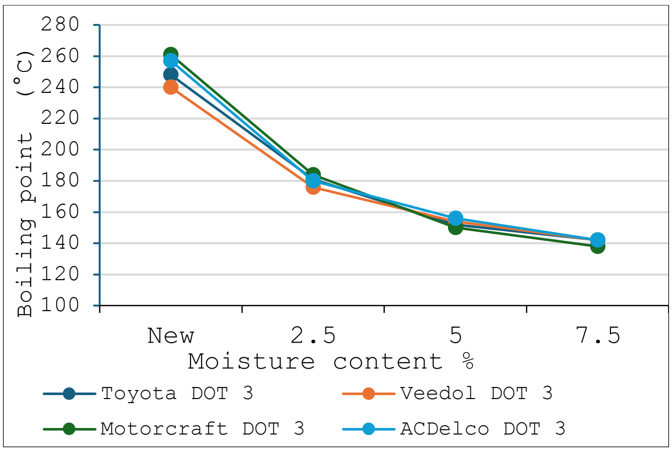


Figure 7: Decrease in Brake Fluid Boiling Point after Addition of Water.

5.3 Comparison of Water Content in DOT 3 and DOT 4 Brake Fluid with US Department of Transportation Specifications

Figures 8 and 9 compare the water contents in brake fluid at the master cylinder for 32 vehicles. Figure 8 covers DOT 3 brake fluid for 23 different vehicle models with odometer readings ranging from 1,200 km to 337,000 km. Figure 9 covers DOT 4 and DOT 4+ brake fluid for 12 vehicles with odometer readings from 4,200 km to 192,000 km. The numbers of engine cylinders for each tested vehicle, which were 4, 6 or 8, are shown on the graph line. The number of engine cylinders was expected to reflect the effect of the engine heat on the brake fluid properties. Figure 8's red line represents the maximum permissible water content for DOT 3 brake fluid, set at 3.7%. None of the tested vehicles exceed this critical threshold, but several approach it closely.

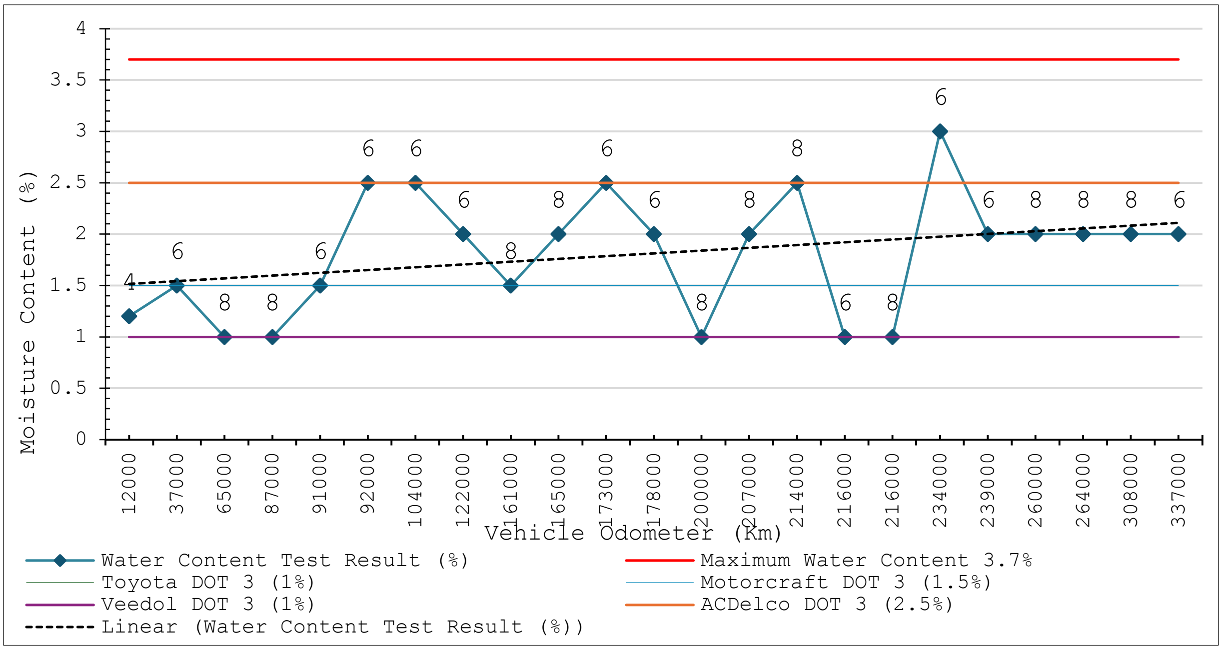


Figure 8: Water Content of New DOT 3 Brake Fluids Compared with Brake Fluid in 23 Vehicles with Different Mileages.

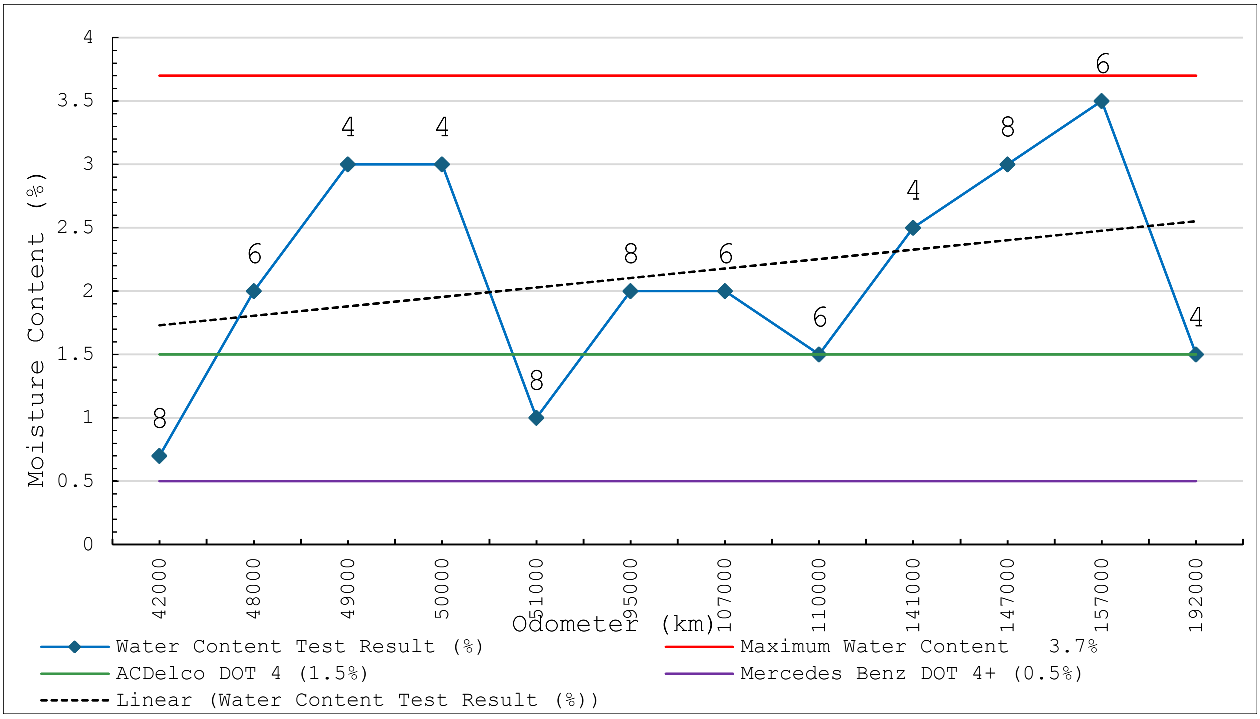


Figure 9: Water Content of New DOT 4 Brake Fluids Compared with Brake Fluid in 12 Vehicles with Different Mileages.

This comparison helps in understanding the relationship between vehicle usage, engine heat, and brake fluid water content in real life, which is fundamental for maintaining brake system safety and performance.

Figure 8 illustrates significant variations in brake fluid water content in different vehicles, with values ranging from 1% to nearly 3%. Vehicles with lower odometer readings (1,200 km to 9,100 km) generally exhibit brake fluid water content of around 1.0% to 1.5%, indicating relatively fresh fluid with less exposure to environmental moisture.

Vehicles with mileages from 9,100 km to 337,000 km had brake fluid moisture contents from 1.5% to 2.5%, with only one vehicle reaching a 3% moisture content at 157,000 km. Three vehicles, one with 200,000 km mileage and two with 216,000 km, had low brake fluid moisture content, which might be due to brake maintenance. Although some vehicles' mileage exceeded 165,000 km, the moisture content of their brake fluid remained average. The graph shows no significant correlation between moisture content and the number of engine cylinders.

Generally, the results for DOT 3 brake fluids show a trend for brake fluid moisture content to increase as the vehicle's mileage increases, regardless of the number of engine cylinders.

In Figure 9, which presents the water content percentage in DOT 4 and DOT 4+ brake fluids for 12 vehicles, the brake fluid moisture content varied from 0.7% for a vehicle with an odometer reading of 42,000 km to 3.5% for a vehicle with an odometer reading of 157,000 km. The number of engine cylinders is shown on a chart line; these could create a difference in engine temperature that affects the brake system.

The red line represents the maximum permissible water content for DOT 4 brake fluid, set at 3.7%. Although none of the tested vehicles exceeded this critical threshold, several approached it closely with moisture content readings of 3.0% and 3.5%, suggesting potential safety concerns. The brake fluid moisture content of the vehicles with 49,000 km, 50,000 km and 147,000 km travelled was 3%, while the vehicle that had travelled 157,000 km had a 3.5% brake fluid moisture content, only a 0.5% difference.

The experiment trend lines clearly depict the relationship between vehicle mileage, a vehicle's number of engine cylinders, and brake fluid quality. It shows that while newer or lower mileage vehicles generally have lower moisture content, older or higher mileage vehicles face an increased risk of moisture levels nearing unsafe thresholds.

5.4. Boiling Point vs. Vehicle Odometer and Boiling Point vs. Vehicle Model for DOT 3, DOT 4 and DOT 4+ Brake Fluids

The following sections describe the boiling point test results for various DOT 3, DOT 4 and DOT 4+ brake fluids across a range of vehicle odometers for 32 vehicles. The data is given along with the specified dry and wet boiling point standards recommended by the US Department of Transportation (DOT), which range from 140 °C to 205 °C for DOT 3 and from 155 °C to 260 °C for DOT 4 and 4+ (see Table 1); various brake fluid manufacturers independently specify other boiling points.

5.4.1. DOT 3 Brake Fluids

Figure 10 illustrates the boiling point test results for 23 DOT 3 brake fluids. Initial boiling points are significantly higher, with some vehicles showing values around 240 °C at lower odometer readings (12,000 km). The graph then shows a decline in boiling point results with increasing vehicle odometer readings (in km), indicating the degradation of the fluid over time and with usage.

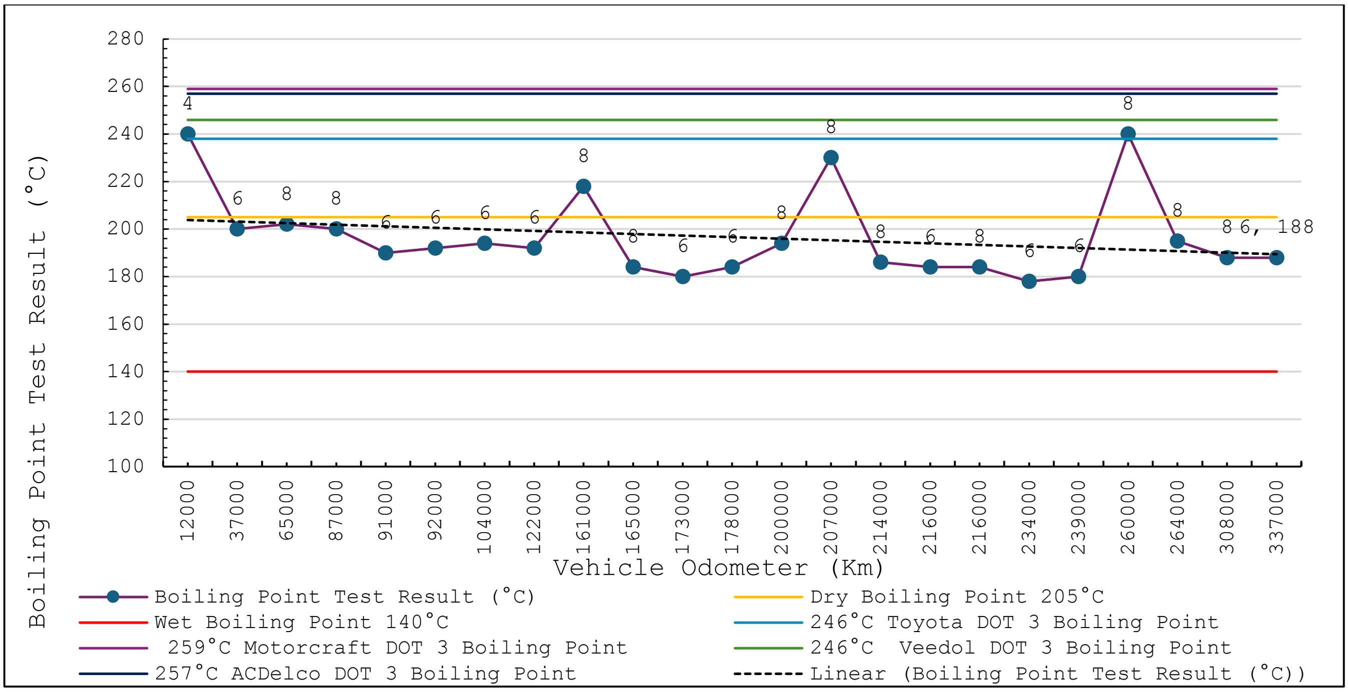


Figure 10: DOT 3 Brake Fluid Boiling Point Results vs. Odometer Readings.

The coloured lines represent the boiling points of different brake fluids. The purple line represents Motorcraft DOT 3 fluid (261 °C), the blue line is for Toyota DOT 3 (248 °C), the green line is for Veedol DOT 3 (246 °C), and the black line is ACDelco DOT 3 (257 °C).

The red line represents the wet boiling point standard of 140 °C for DOT 3 brake fluid. Specific points are marked with blue circles and annotated with numbers (4, 6, 8), indicating the number of engine cylinders for each tested vehicle.

The dotted black line represents the linear trend of the boiling point test results over time, showing a slight downward trend as the vehicle accumulates more kilometres.

Initially, the boiling point is around 200 °C at 37,000 km; from 65,000 km to about 207,000 km, it fluctuates around the dry boiling point (205 °C). After 165,000 km, it is around 184 °C, 40 °C above the wet boiling point. At 207,900 km and 260,000 km, there is a noticeable peak reaching close to 240 °C, likely due to scheduled maintenance. Overall, the boiling point tends to decrease slightly over time but remains above the wet boiling point threshold; however, regular brake fluid replacement is important.

Figure 11 shows the boiling point test results for DOT 3 brake fluid plotted against various vehicle models. Specific points are annotated with numbers (e.g., 1.2, 1.5, 2), indicating the moisture content for each tested vehicle. Similar to the odometer chart, there is a high boiling point of around 240 °C and low moisture content of 1.2% for the newest models (2023 Mazda) and a gradual decline with older models to a minimum of 178 °C (2012 Ford) and 3%. The boiling point drops significantly to around 192 °C and below for 2015 and older vehicles, and the moisture content rises from 2 to 3% in most vehicles.

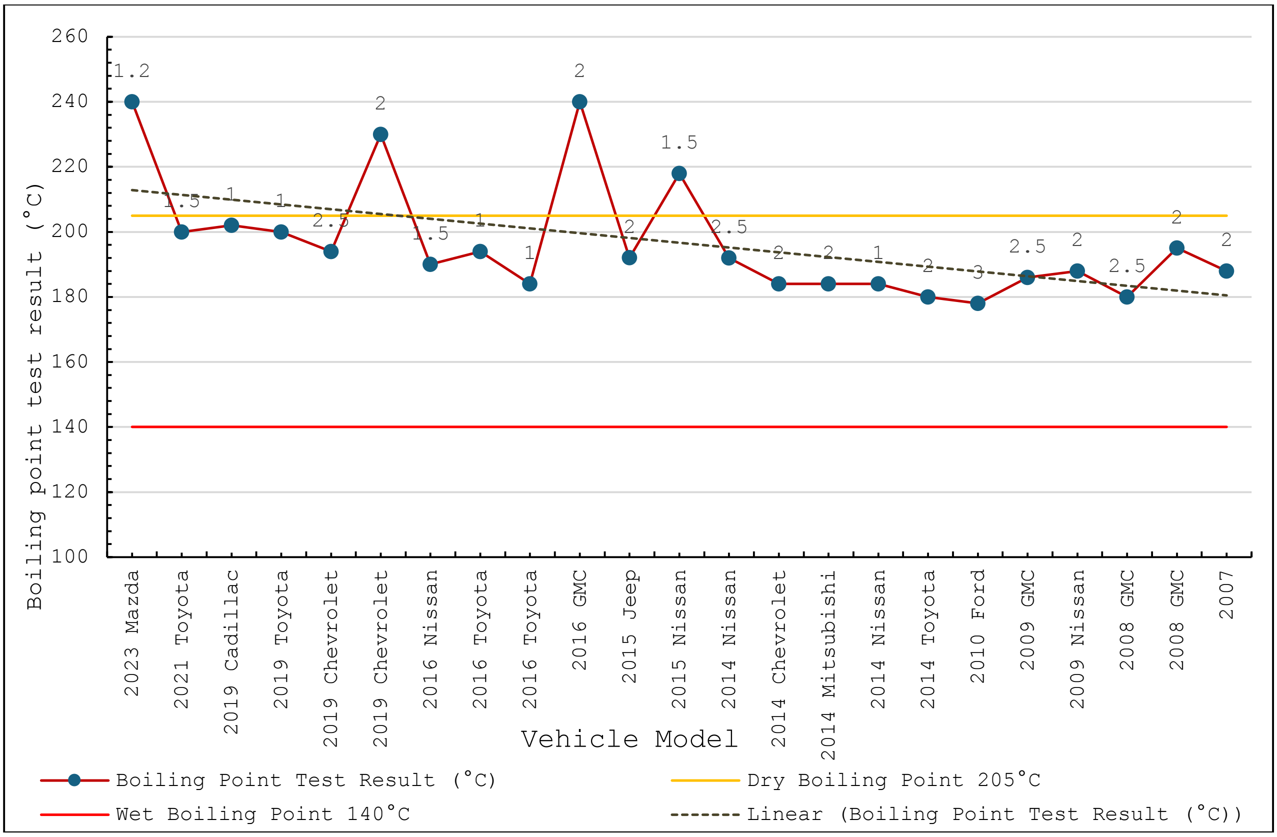


Figure 11: DOT 3 Brake Fluid Boiling Points by Vehicle Model and Year of Manufacture.

By comparing Figures 10 and 11, we can observe how both vehicle driving distance and different vehicle models (which may correlate with vehicle age and usage) impact the boiling point of DOT 3 brake fluid. This comparison can help identify patterns or trends in brake fluid performance relative to vehicle wear and tear.

5.4.2. DOT 4 Brake Fluid

Figure 12 shows the boiling point test results for DOT 4 and DOT 4+ brake fluid over 12 different odometer readings in kilometres. The chart lines represent the actual boiling point test results of the brake fluid at different odometer readings and for different brake fluids. The red line with blue points indicates actual boiling point test results, the green and brown lines are the manufacturer-specified boiling points for DOT 4 brake fluid boiling point, and the red and yellow lines are dry and wet boiling point standards recommended by the US Department of Transportation for DOT4 and 4+ fluids. The dashed line shows the trend of the boiling point test results over the odometer readings.

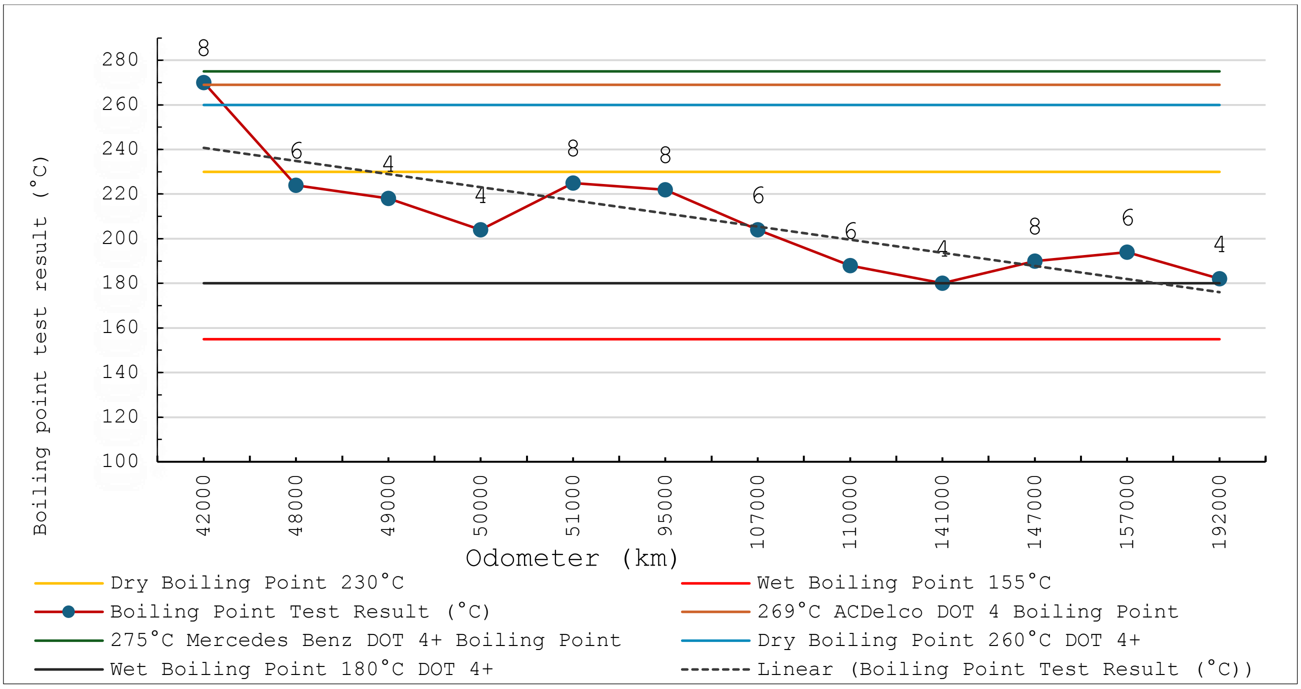


Figure 12: DOT 4 and 4+ Boiling Points by Odometer Reading.

The initial boiling point test result is around 275 °C at 42,000 km for a Ford vehicle, which is in line with the boiling point for new DOT 4+ brake fluid in Mercedes-Benz vehicles. Toyota has the lowest boiling point of 180 °C at 141,000 km, only 25 °C above the wet boiling point. BMW is the second-lowest with 182 °C at 192,000 km; both Toyota and BMW use DOT 4 brake fluid.

The number of cylinders in the tested vehicles does not show any significant relation to brake fluid quality. As the odometer reading increases, the trend line shows a decline in boiling point, which is expected due to fluid degradation over time. Although the boiling points drop with greater odometer readings, they remain above the minimum wet boiling point standards of 155 °C for DOT 4 and 180 °C for DOT 4+.

Figure 13 shows the boiling point results of DOT 4 and 4+ brake fluids across various vehicle models arranged according to year of manufacture, which helps in understanding how the brake fluid changes with use over time. Numbers above each dot indicate the moisture content percentage in the brake fluid, which is expected to affect performance. The dotted black line represents a linear trend of the boiling point test results against the year of manufacture. The line shows a declining trend for older cars. According to the US Department of Transportation (DOT), 3.7% is the highest moisture content allowable in brake fluid, which should be replaced to ensure optimal braking performance and safety before it reaches this point. The 2022 Ford's brake fluid is in excellent condition with a low moisture content of 0.7% and a boiling point of 270 °C, the highest in the test. The 2013 BMW, with an odometer reading of 192,000 km, shows a low brake fluid moisture content of 1.5%, which is expected to be due to regular maintenance. The 2012 Land Rover 2012, with a 157,000 km mileage, has the highest moisture content of the tested vehicles at 3.5% and a low boiling point test result of around 194 °C, which is close to DOT4+'s wet boiling point (180 °C).

It is noticed that the brake fluid in most vehicles manufactured in 2019 and before has a moisture content of 1.5% to 3.5% and a low boiling point compared to newer vehicles in which the brake fluid has the same or greater moisture content, which could be attributed to several factors. Like DOT 3 fluid, the boiling point of DOT 4 brake fluid decreases with increasing vehicle mileage, indicating fluid degradation.

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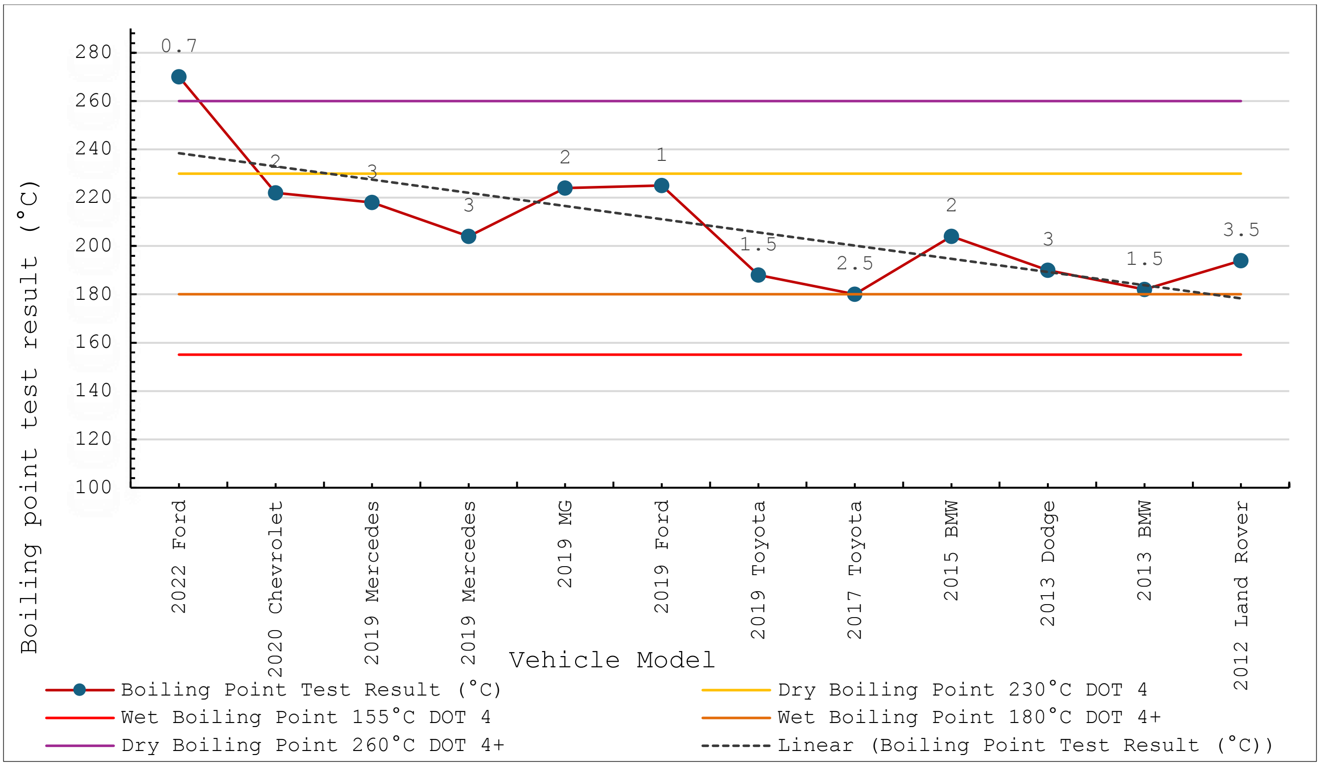

Figure 13: DOT 4 and 4+ Brake Fluid Boiling Points by Vehicle Model and Year of Manufacture.

5.5. Boiling Point: Master Cylinder vs. Front Brake Calliper

This experiment aimed to study brake fluid performance by comparing the temperature of the brake fluid in the master cylinder and the front brake callipers to determine the temperature drop between these two points. A significant drop can indicate greater fluid degradation in the callipers than in the master cylinder.

Table 3 presents the data for boiling point test results for DOT 3 brake fluid in both the master cylinder and front brake calliper of five vehicles of various models and odometer readings: 2021 Toyota Landcruiser, 125,000 km; 2018 Nissan X-trail, 108,000 km; 2008 Chevrolet Tahoe, 467,000 km; 2012 Ford Grand Marquis, unknown mileage; and 2014 Toyota Hilux, 436,000 km. Figure 14 is a graphical representation of the data.

Table 3: DOT 3 Brake Fluid Boiling Point Drop between Master Cylinder and Brake Calliper.

No	Vehicle Type	No of Cylinders	Model	Odometer (Km)	New Brake Fluid Results (For Same Vehicle Brand)	Master Cylinder		Front Brake Calliper		
					Boling point/ Moisture Content	Water Content Test Result (%)	Boiling Point Test Result (°C)	Water Content Test Result (%)	Boiling Point Test Result (°C)	Temp. Drop
1	2021 Toyota Landcruiser	8	2021	125,000	248 °C 1%	1.5	212	1.5	174	38
2	2018 Nissan X Trail	4	2022	108,000	240 °C 1%	1.5	200	1.5	176	24
3	2008 Chevrolet Tahoe	8	2008	467,000	257 °C 2.5	2.5	202	2.5	188	14
4	2021 Ford Grand Marquis	8	2012		261 °C 0.5%	2.5	194	2.5	190	4
5	2014 Toyota Hilux	4	2014	435,894	248 °C 1%	2.5	200	2.5	194	6

All test results were above the fluid's boiling point, yet there was a significant difference in temperature between the master cylinder and the brake calliper.
The Toyota Landcruiser brake fluid shows a significant drop of 38 °C, indicating the fluid in the front brake callipers is more degraded than that in the master cylinder. The 2018 Nissan X Trail shows a moderate temperature drop of 24 °C in the front callipers. The 2012 Ford and 2014 Toyota Hilux show a slight difference of 4 °C and 6 °C, respectively, suggesting minimal degradation.
Surprisingly, the maximum drop in temperature occurs in the newest vehicles, which had low mileages: 26 °C in the 2021 Toyota and 46 °C in the 2018 Nissan.

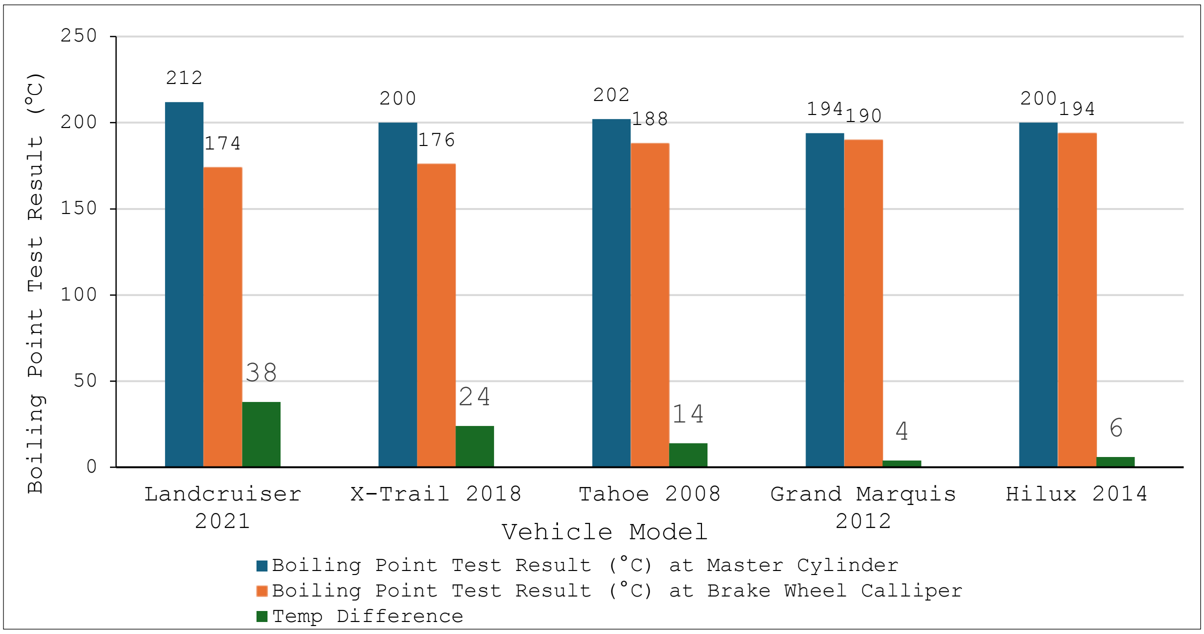

Figure 14: Differences in Boiling Point between Master Cylinder and Front Brake Calliper by Vehicle Model.

6. Conclusions and Recommendations

This paper describes several real-world experiments to investigate the boiling point and moisture content of passenger vehicle brake fluids in Kuwait.
The first experiment illustrated the relationship between boiling point and moisture content in different brand-new DOT 3, DOT 4 and DOT 4+ brake fluids. The results showed that all the tested brake fluids have actual boiling points significantly higher than their specified dry boiling points (240 °C for DOT 3, 269 °C for DOT 4 and 275 °C for DOT 4+), demonstrating their robustness and capacity to withstand high temperatures. Moreover, it showed that new brake fluids are not immune to moisture absorption in real-world conditions, and even well-sealed brake fluids can reach a moisture content of 2.5%, which could be due to environmental exposure during manufacturing, packaging, or storage.
Moisture content is a critical factor in the performance of brake fluid. When small amounts of water (to make 2.5%, 5%, and 7% moisture content) are added to a new DOT 3 brake fluid, it drastically lowers its boiling point (by 71 °C, 99 °C and 111 °C, respectively), making it unsafe for use in braking systems. These results clearly show the importance of storing brake fluid in a dry, moisture-free environment to ensure optimal performance and safety. Sealing brake fluid and protecting it from environmental exposure can help reduce moisture ingress and prolong the fluid's life.
The second experiment compared the boiling point results for DOT 3 and DOT 4 brake fluids with different moisture contents across various vehicles, odometer readings, and number of engine cylinders. The trend lines in the graphs for both DOT 3 and DOT 4 brake fluids show significant degradation in boiling points as vehicle mileage and age increase. Nonetheless, at a moisture content of 3.5%, the lowest boiling point found was 178 °C, around 38 °C above the safety threshold.
The number of engine cylinders might have a minor impact on brake fluid degradation. Engines with higher cylinder counts might show lower moisture content due to the hotter engine environment, which reduces humidity around the brake system. More experiments and comparisons should be made to analyse the correlation between the number of cylinders and the moisture content in the brake fluid.
The last experiment compared DOT 3 brake fluid's temperature drop between the master cylinder and the brake calliper for five vehicles. It concluded that there were significant drops at the front callipers of 38 °C for the 2021 vehicle and 24 °C for the 2018 vehicle, indicating fluid degradation in the front brake callipers compared to the master cylinder. Older vehicles, a 2012 Ford Grand Marquis and a 2014 Toyota Hilux, showed a slight difference of 4 °C and 6 °C, respectively, suggesting minimal degradation. More experiments and comparisons should be conducted to analyse the correlation between the boiling point at the front and rear callipers and the master cylinder.
Finally, brake fluid degradation is evident in the decreasing boiling points observed in older or higher-odometer vehicles

regardless of the number of engine cylinders or the use of DOT3, DOT 4, or DOT 4+ brake fluid. Although the presence of moisture in brake fluid is a critical factor, new brake fluids can contain 2.5% moisture content due to environmental exposure during manufacturing, packaging, or storage and high boiling point.

Regular maintenance, proper storage, and environmental considerations are essential in mitigating the adverse effects of moisture absorption. By understanding and addressing these factors, vehicle owners can ensure the longevity and reliability of their brake systems, thus maintaining optimal safety standards.

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