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The Effect of Kuwait Climate on Automotive Brake Fluids: A Study on Brake Fluid Properties DOT 3 and DOT 4 In Kuwait

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Abstract
This study investigates the impact of Kuwait's extreme climate on the properties of automotive brake fluids, specifically DOT 3 and DOT 4. Through empirical analysis of brake fluid samples from 35 passenger vehicles of various ages and makes, the research examines changes in boiling points and moisture content. Our findings reveal significant degradation in brake fluid properties over time, with older vehicles exhibiting higher moisture content and lower boiling points, posing increased risks of brake fluid vaporization under high-temperature conditions typical of Kuwait's environment. While DOT 4 fluids initially demonstrate superior boiling points, DOT 3 fluids maintain their performance more consistently over prolonged use. This study underscores the necessity for frequent brake fluid testing and timely replacement, especially in arid climates. The results provide critical insights for optimizing vehicle maintenance practices to ensure safety and performance, contributing valuable knowledge for both local and global applications.
Keywords: Brake fluid, Boiling point of brake fluid, Water content in brake fluid.

1. Introduction

Climatic conditions can significantly impact the performance of vehicles, especially in high-temperature coastal country regions, like Kuwait. Brake fluid is a crucial component in the braking system, playing an essential role in ensuring the system's effectiveness and vehicle safety. This study focuses on the impact of Kuwait's climate on the properties of brake fluid, including boiling point and moisture content, in correlation with the age of the vehicle.

The objective is to examine how Kuwait's climate affects the boiling point and moisture content of brake fluids (DOT 3, DOT 4, and DOT 4+) in passenger cars of varying ages without prior brake fluid replacement. It seeks to compare the performance and safety implications of these fluids under Kuwait's unique environmental conditions, providing insights into their suitability and longevity in arid climates.

2. Literature Review

This literature review was conducted in a previous study [15], and since the current study extends that work, it is beneficial to reintroduce it to support the new objectives. Among the most critical safety systems found in vehicles, automotive brakes play a vital role [2]. These systems are designed to decelerate or bring a vehicle to a complete stop by utilizing the friction generated when two surfaces are pressed together, effectively converting kinetic energy into heat [3]. In vehicles, there are three primary types of brake systems: mechanical brakes, air brakes, and hydraulic brakes. However, this study will solely focus on hydraulic brakes due to their extensive usage and numerous advantages. The functionality of hydraulic brake systems is based on Pascal's law, which asserts that pressure applied to a fluid is evenly distributed in all directions [4]. When the brake pedal is pressed, it exerts force on a piston located within the master cylinder, causing an increase in brake fluid pressure. This pressure is then transmitted through the brake lines, ultimately pushing the brake shoes (in drum brakes) or brake pads (in disc brakes) against the drums or discs, resulting in the gradual or immediate reduction of wheel speed or complete cessation of movement.

When the brake pedal is pressed, the force is transmitted by the brake fluid through various components such as the brake booster, lines, and hoses, ultimately reaching the brake pads in the caliper. This process generates pressures as high as 1200 psi and causes the brake discs to heat up to temperatures surpassing 530°C [5]. The increased pressure leads to greater friction and elevated temperatures of the brake fluid, which may even reach the boiling point. Once the brake fluid boils, it transforms into vapor within the brake lines, becoming compressible and undermining the effective transfer of hydraulic braking force.

The boiling point of brake fluid is a crucial characteristic that must be high, and it is evaluated in two ways: the dry boiling point, which measures the boiling point of fresh brake fluid, and the wet boiling point, which measures the boiling point after moisture absorption. Most modern brake fluids are hygroscopic and glycol-ether-based, meaning they have the ability to absorb moisture from the atmosphere. When moisture is absorbed, it can accumulate within the brake system, causing corrosion, damage to expensive ABS components, and a decrease in the boiling point. If there is an excessive amount of moisture, the brake fluid can boil during intense braking, resulting in the formation of compressible steam. This leads to a spongy brake pedal and a decrease in braking power, potentially resulting in a complete failure of the hydraulic brake system.

The US Department of Transportation (DOT) categorizes brake fluids into different groups, namely DOT 3, DOT 4, DOT 4+, DOT 5.1, and DOT 5. Among these, DOT 3, DOT 4, and DOT 5.1 are glycol-based and have the ability to absorb water. On the other hand, DOT 5 is silicon-based and does not possess this water-absorbing characteristic [8].

The climate in Kuwait experiences significant fluctuations, ranging from an average of 43°C during the summer months to 15°C in winter, with daily lows of 23°C in summer and 5°C in

winter [10]. The annual humidity levels range from approximately 30% to 36% [1,11]. Both DOT 3, DOT 4 and DOT 4+ brake fluids possess hygroscopic properties, meaning they have a tendency to absorb moisture from the surrounding air. Over time, the moisture content in these fluids increases by around 1% to 2% per year [12]. If the water content in the brake fluid surpasses 3.7% after several years, its boiling point will significantly decrease [13]. Vehicle manufacturers recommend replacing the brake fluid every two years or after covering approximately 40,000 km [7]. According to Table 1, DOT 3, DOT 4, DOT 4+ and DOT5 -5.1, brake fluids exhibit wet boiling points of 140°C and 155°C, respectively. In demanding braking situations, the temperature of the brake fluid can exceed these boiling points, leading to the vaporization of the fluid and the formation of bubbles within the brake lines. Brake pressure fade and the subsequent loss of braking power, commonly referred to as vapor lock, pose a significant risk. In such cases, depressing the brake pedal all the way to the floor proves futile. To prevent this dangerous scenario, experts advise regularly flushing or replacing brake fluid every one to two years. Alternatively, if the brake fluid fails a boiling point and water content test, immediate action is necessary.

Table 1: Classification of brake fluid Boiling point according to DOT [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
DOT 4+	260°C	180°C	Glycol Ether
DOT 5	260°C	180°C	Silicone
DOT 5.1	260°C	180°C	Glycol Ether

3. Objective of the Study

The objective of this study is to examine the real-life impact of Kuwait's climate on the boiling point and moisture content of brake fluid in passenger cars. Specifically, the study aims to analyze how these properties vary with the age and type of brake fluid (DOT 3, DOT 4, and DOT 4+) used in vehicles that have not had their brake fluid replaced prior to testing. Additionally, the research seeks to compare the performance and safety implications of different brake fluid types under the unique environmental conditions of Kuwait. By understanding these variations, the study aims to provide comprehensive insights into the suitability and longevity of various brake fluids in arid climates.

The previous study [15] aimed to investigate the effects of Kuwait's climate on the properties of automotive brake fluids. The primary objective was to understand how the water content in brake fluid affects the rate of temperature decrease and the boiling point under real driving conditions. The specific objectives included:

1. Measuring Water Content in Brake Fluid: The study utilized a BF200 moisture analyzer to measure the water content percentage in the brake fluid of 35 different vehicles.
2. Measuring Boiling Point of Brake Fluid: The study employed a BOSCH BFT 100 boiling point tester to determine the boiling point of the brake fluid in the same vehicles.
3. Data Analysis: Analyzing the data to identify the relationship between water content, boiling point, and other factors such as vehicle age.
4. Providing Recommendations: Offering maintenance recommendations based on the results regarding optimal brake fluid practices in arid climates.

Following the results of the previous study, there emerged a need for a more comprehensive and detailed study that considers different types of brake fluids and offers a comparative analysis.

3.1 The objectives of the new current study are:

1. Evaluating the Impact of Kuwait's Climate on Brake Fluid Properties: Assessing how the boiling point and moisture content of brake fluids vary with vehicle age and type of brake fluid (DOT 3, DOT 4, and DOT 4+).
2. Analyzing Differences Between Brake Fluid Types: Comparing the performance and safety of different brake fluid types used in vehicles without prior fluid replacement.
3. Providing Comprehensive Insights: Offering a detailed understanding of the suitability and longevity of various brake fluids under Kuwait's unique environmental conditions.
4. Utilizing Advanced Measurement Tools: Using the BF200 moisture analyzer and BOSCH BFT 100 boiling point tester to ensure accurate results.

3.2 Comparison Between the Previous and Current Studies

1. Scope of Study: The previous study focused on the general impact of water content on the boiling point of brake fluids, whereas the current study includes a detailed comparison between different types of brake fluids.
2. Measurement Tools: Both studies employed the same tools for measuring water content and boiling point to maintain consistency and accuracy in results.
3. Deeper Analysis: The current study provides a more in-depth analysis by focusing on different types of brake fluids and their specific impacts.
4. Expanded Objectives: The objectives of the current study are expanded to include comparisons between different brake fluid types and to provide more comprehensive recommendations.

The results of the previous study served as a crucial starting point for understanding the impact of Kuwait's climate on brake fluids. Based on those results, it became clear that a deeper and more detailed study was necessary to consider additional factors such as the type of brake fluid, vehicle age. This step allowed for the expansion of research scope and the formulation of new, more comprehensive objectives for the current study, leading to more precise and relevant maintenance recommendations for brake fluids in arid climates.

4. Research Methodology

This research investigates the properties of brake fluid used in vehicles from 2012 to 2023 and compares them to U.S. Department of Transportation (DOT) standards and various types of new brake fluid based on the types of vehicles used.

Initially, the moisture content of new DOT 3, DOT 4, and DOT 4+ brake fluids were tested as a reference for the quality of brake fluid available in the market. Subsequently, samples of new brake fluid were taken, and their boiling points were tested and compared to U.S. standards to determine the differences and their compliance with recommended safety standards.

To begin the study, samples were taken from 35 vehicles of different models and manufacturing years. The moisture content and boiling points of these samples were tested and compared against U.S. DOT standards to evaluate the quality of the brake fluid in terms of boiling point and moisture content. The test included 23 vehicles with DOT 3 brake fluid and 12 with DOT 4 and DOT 4+ brake fluids.

Initially, the moisture content of DOT 3 brake fluid was compared with U.S. DOT standards and the results of the new fluid. The same comparison was then made for DOT 4 and DOT 4+ brake fluids. Following this, the boiling points were tested and compared to U.S. standards to determine the extent of variation based on vehicle age. Finally, the results were compared with new brake fluid to understand the degree of change between the brake fluid used in vehicles and the new brake fluid.

The study aimed to analyze the results and make recommendations, considering maintenance and manufacturers' guidelines.

4.1 Study Design

This study employs an empirical research design to assess the impact of Kuwait's climate on the properties of brake fluid in passenger cars. The study involves testing brake fluid samples from 35 vehicles with varied manufacturing years and brake fluid types (DOT 3, DOT 4, and DOT 4+).

4.2 Sample Selection

- Vehicle Selection: A total of 35 passenger cars were selected for this study. These cars varied in manufacturing years (2007 to 2023).
- Brake Fluid Types: The brake fluids tested included DOT 3, DOT 4, and DOT 4+.

4.3 Data Collection

1. Brake Fluid Sampling: Brake fluid samples were collected from each vehicle. The fluids had not been replaced prior to the testing process to ensure the study reflects real-life conditions.
2. Measurement Tools:

- BF200 Moisture Analyzer Detector: Used to measure the moisture content percentage in the brake fluid, which is a highly accurate tool designed specifically for measuring the water content in brake fluid.
- BOSCH BFT 100 Boiling Point Tester: Used to measure the boiling point of the brake fluid, which is an essential tool that provides precise measurements for determining the boiling point of brake fluids.

4.4 **Testing Procedure**

1. **Initial Testing of New Brake Fluids:**

- New samples of DOT 3, DOT 4, and DOT 4+ brake fluids were tested to establish baseline values for boiling points and moisture content.

2. **Vehicle Brake Fluid Testing:**

- Brake fluid samples were taken from each of the 35 vehicles.
- The boiling point and moisture content were measured using the specified tools.

4.5 Data Analysis

- Boiling Point Analysis: The boiling points of the brake fluids were compared against the recommended levels. The decrease in boiling point across different vehicles was analyzed to determine the impact of vehicle age.
- Moisture Content Analysis: The moisture content percentages were analyzed to identify any correlation with vehicle age.
- Comparison Between Brake Fluid Types: The performance of DOT 3, DOT 4, and DOT 4+ brake fluids were compared to evaluate their suitability and longevity under Kuwait's climatic conditions.

4.6 Limitations

• The study is limited to 35 vehicles, which may not represent the entire population of vehicles in Kuwait.
• The testing only includes vehicles that had not replaced their brake fluid prior to the study, which may introduce variability due to different maintenance practices.

4.7 Measurement of Water Content

To measure the water content in the brake fluid, the BF200 Moisture Analyzer Detector (Figure 1) was utilized. This specialized device is specifically engineered to gauge the percentage of water present in brake fluid. The process consisted of:

1. **Preparation:** Prior to beginning, it was essential to confirm that the brake fluid reservoir of the vehicle was both easily reachable and free from any dirt or debris.
2. **Measurement:** The act of submerging the BF200 probe into the reservoir containing the brake fluid.
3. **Data Recording:** Each vehicle's water content percentage was directly measured and recorded using the moisture analyzer.

Figure 1: BF200 Moisture analyzer detector (15)

Figure 2: BOSCH BFT 100 Brake Fluid Tester (15)

5. Test Was Done in the Previous Study [15]: Testing New Brake Fluids

In order to set a starting point, we utilized the BF200 Moisture Analyzer Detector and BOSCH BFT 100 Boiling Point Tester to examine a sample of five different varieties of fresh brake fluids prior to delving into real-world brake fluid conditions. This initial examination allows us to contrast the state of brake fluids in use with that of new fluids, shedding light on the influence of environmental factors and usage on brake fluid characteristics. Figure 3 displays the results of the testing conducted on the five types of brake fluid.

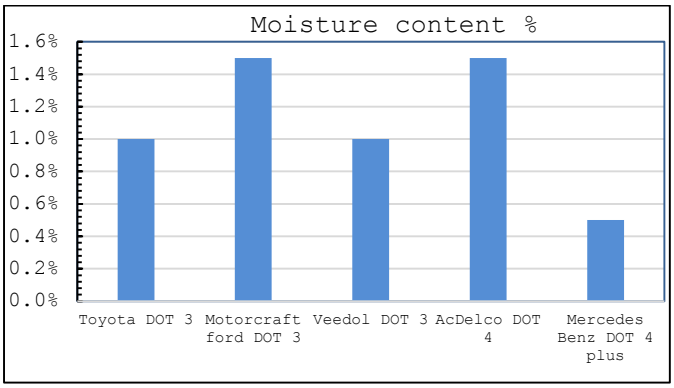

Figure 3: Five types of brake fluid had been used in this study (Moisture content %)

Upon analyzing the boiling points of various brands of new brake fluids, it was determined that all of them surpassed the required limits. The Toyota DOT 3 fluid reached a boiling point of 238°C, the Motorcraft Ford DOT 3 fluid reached 259°C, the Veedol DOT 3 fluid reached 246°C, the AcDelco DOT 4 fluid reached 269°C, and the Mercedes Benz DOT 4 Plus fluid reached an impressive 275°C. These findings validate that all new brake fluids have the initial capacity to endure the high temperatures generated during braking. However, it was noted that even though the new brake fluids were adequately sealed, they still exhibited some level of moisture content.

- **Toyota DOT 3:** 1.0%
- **Motorcraft Ford DOT 3:** 1.5%
- **Veedol DOT 3:** 1.0%
- **AcDelco DOT 4:** 1.5%
- **Mercedes Benz DOT 4 Plus:** 0.5%

The presence of moisture in brake fluids is noteworthy, as even freshly produced fluids can absorb moisture from the surrounding environment during various stages such as manufacturing, packaging, or storage. It is important to note that the moisture content in new brake fluids is comparable to that found in the brake fluid utilized in certain vehicles, which had moisture levels reaching up to 1.5%.

The moisture content percentages in the five different types of new brake fluids tested are presented in Figure 3. According to the graph, the Motorcraft Ford DOT 3 and AcDelco DOT 4 fluids exhibited the highest moisture content, measuring at 1.5%. Conversely, the Mercedes Benz DOT 4 Plus fluid demonstrated the lowest moisture content, registering at 0.5%. Both the Toyota DOT 3 and Veedol DOT 3 fluids displayed a moisture content of 1.0%. These results highlight the fact that new brake fluids can contain varying levels of moisture, which has the potential to impact their overall performance.

Regular maintenance and replacement of brake fluid is crucial, as indicated by this data. To ensure the fluid's boiling point remains at a safe level and to counteract moisture absorption, vehicle manufacturers generally advise replacing brake fluid every two years or around every 40,000 km.

6. Discussion

The results obtained from the examination of recently developed brake fluids establish a vital standard for evaluating the actual conditions in which brake fluids operate. The initial discovery of elevated boiling points in these new fluids implies that they possess the necessary capabilities to withstand the thermal strains encountered during braking. Nevertheless, the existence of moisture, even in fresh fluids, highlights the difficulty of sustaining optimal brake fluid functionality as time progresses.

The level of moisture in brake fluid plays a crucial role as it has the ability to decrease the boiling point, thereby increasing the vulnerability of the fluid to vaporize in situations of extreme heat, like during heavy braking. Surprisingly, new brake fluids can already contain 1.0% to 1.5% moisture, indicating that contamination may happen even before the fluid is utilized in a vehicle, possibly due to environmental factors during the manufacturing or storage process.

Over the course of usage, brake fluids have a tendency to absorb moisture, causing a progressive deterioration in their effectiveness. This increase in moisture content heightens the likelihood of vapor lock, a situation in which the brake fluid transforms into gas bubbles within the brake lines, compromising the overall braking capacity and potentially leading to complete brake malfunction.

Regular maintenance and replacement of brake fluid is crucial, as indicated by the data. To ensure the fluid's boiling point remains at a safe level and to prevent moisture absorption, vehicle manufacturers generally advise replacing brake fluid every two years or around every 40,000 km.

When comparing the boiling points of various brake fluids to the guidelines set by the US Department of Transportation for brake fluid DOT 3 and 4, we can observe the following.

In Figure 4, the boiling points of various brake fluid brands are juxtaposed with the classifications provided by the US

Department of Transportation. The test results for the actual boiling points of each brand are represented by the blue bars. The dry boiling points are denoted by the red bars, while the wet boiling points are illustrated by the green bars.

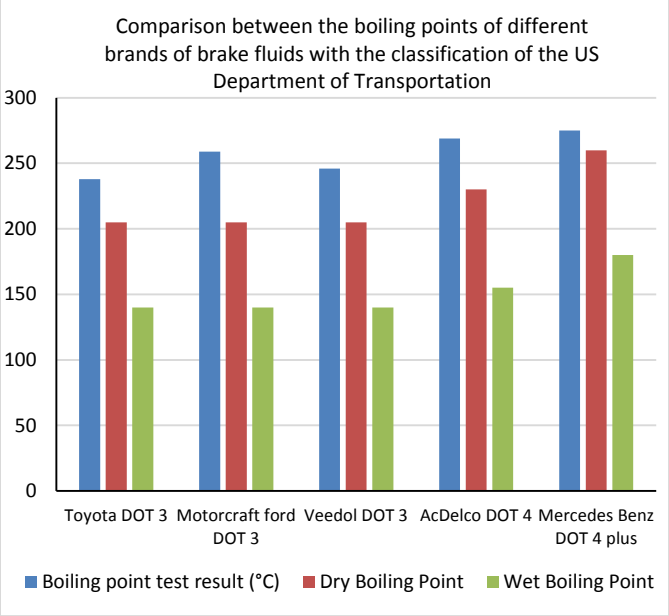

Figure (4): Comparison between the boiling point of different brake fluids

Based on the figure 4:

1- It is evident that Toyota DOT 3 surpasses both the dry boiling point and the wet boiling point with its actual boiling point of 238°C.
2- The boiling point of Motorcraft Ford DOT 3 exceeds both the dry and wet boiling points, reaching a temperature of 259°C.
3- Veedol DOT 3 exceeds both the dry and wet boiling points with its actual boiling point of 246°C.
4- The boiling point of AcDelco DOT 4 (269°C) exceeds both the dry and wet boiling points.
5- The boiling point of Mercedes Benz DOT 4 Plus exceeds both the dry and wet boiling points, reaching a temperature of 275°C.

The observed results indicate that the new brake fluids that underwent testing possess boiling points that exceed both their dry and wet boiling points as stated in their specifications. This serves as evidence of their durability and ability to withstand extreme temperatures

7. Results of the present Study:

7.1 Comparison of Water Content in DOT 3 Brake Fluid with US Department of Transportation Specifications

The water content in brake fluid (DOT 4-, DOT4+, and DOT 3) was analyzed using the BF200 Moisture Analyzer Detector. The percentage of water content in the brake fluid was determined in the first test. Figure 5 depicts the correlation between brake fluid moisture content and the manufacturing years of the vehicles that were tested. The figure 5 provides a comparison of the water content in the brake fluid of these vehicles with the specifications established by the US Department of Transportation (DOT) for DOT 3 brake fluid.

This section presents the water content test results of brake fluids collected from various vehicle models spanning different years. The analysis focuses on the percentage of moisture content and its implications on the efficiency and safety of the braking system.

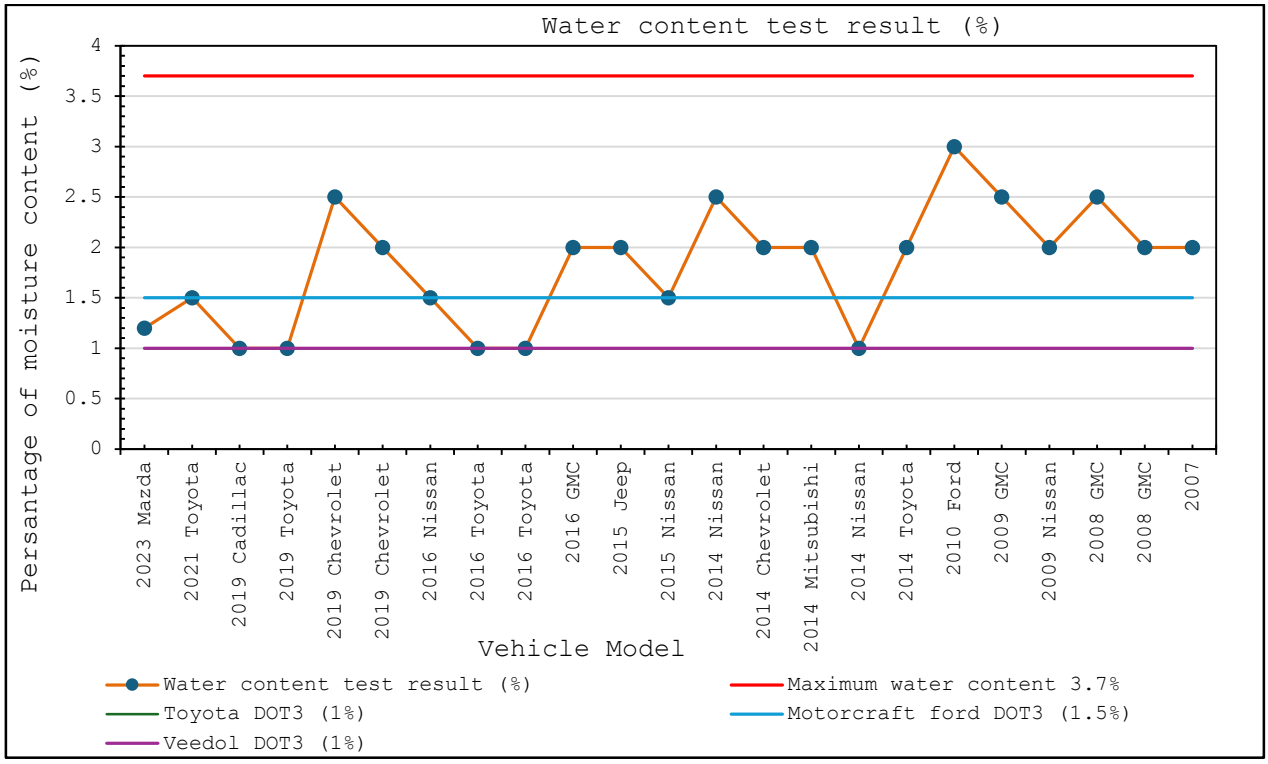

Figure 5: comparison between Water content test results of new brake fluid and vehicle brake fluid DOT 3

7.1.1 Results:

1. Overall Moisture Content Trends:
- The observed water content in the brake fluids ranged from approximately 1% to 2.8%, indicating significant variability across different vehicle models.
2. Maximum Recorded Moisture Content:
- The highest moisture content recorded was just below the maximum allowable threshold of 3.7%, highlighting potential concerns for certain vehicles.
3. Comparison with Industry Standards:
- Motorcraft Ford DOT3 (1.5%): Several vehicle models exhibited water content exceeding this standard.
- Toyota DOT3 (1%) and Veedol DOT3 (1%): The majority of the tested vehicles surpassed these thresholds, underscoring the need for rigorous maintenance protocols.
4. Notable Model-Specific Findings:
- 2019 Cadillac, 2016 Nissan, and 2014 Toyota displayed water content levels exceeding 2%, significantly above the recommended thresholds for DOT3 brake fluids.

7.2 Comparison between the water content in DOT 4 brake fluid and the standards established by the US Department of Transportation (DOT)

Now, we can see Figure 6 presents a comparison between the water content in DOT 4 brake fluid and the standards established by the US Department of Transportation (DOT). To assess the percentage of water in the brake fluid, the BF200 Moisture Analyzer Detector was employed in the initial experiment. This graph demonstrates the correlation between the moisture content in the brake fluid and the manufacturing years of the vehicles that were tested.

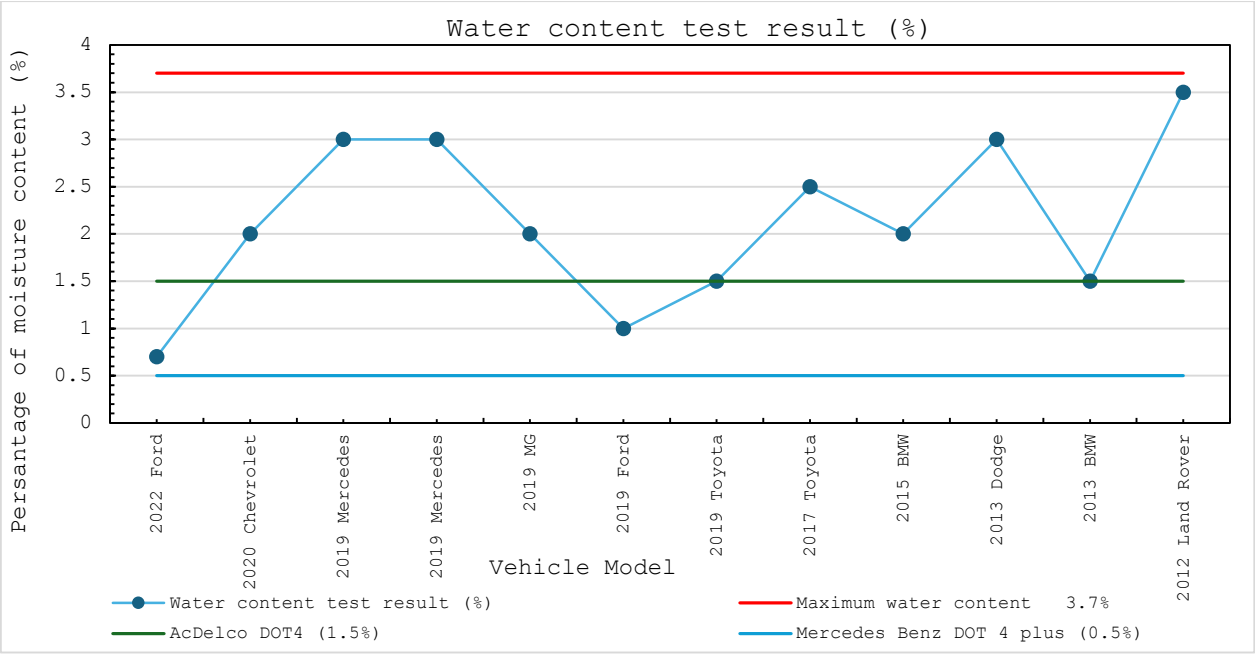

Figure 6: comparison between Water content test results of new brake fluid and 12 vehicles brake fluids DOT 4 and DOT 4+

7.2.1 Result

1. Overall Moisture Content Trends:
- The water content in DOT 4 brake fluids for various vehicle models ranged from 0.5% to 3.5%, indicating substantial variability across different manufacturing years.
2. Maximum Recorded Moisture Content:
- The highest moisture content recorded was approximately 3.5%, which is just below the maximum allowable threshold of 3.7% established by the US Department of Transportation (DOT).
3. Comparison with Industry Standards:
- AcDelco DOT 4 (1.5%): Several vehicle models exhibited water content levels exceeding this threshold.
- Mercedes Benz DOT 4 Plus (0.5%): A significant number of vehicle models had moisture content higher than this standard.
4. Notable Model-Specific Findings:
- The 2020 Chevrolet and 2019 Mercedes models displayed water content levels at the peak of around 3%, significantly higher than both AcDelco and Mercedes Benz DOT 4 Plus standards.
- Older models, such as the 2012 Land Rover, also showed high moisture content, nearing the maximum threshold.

7.3 Comparison between DOT 3 brake fluid and the specifications outlined by the US Department of Transportation

Figure 7 visually represents the boiling point comparison between DOT 3 brake fluid and the specifications outlined by the US Department of Transportation (DOT). The BOSCH BFT 100 was utilized in the second test to measure the boiling points of brake fluids in different vehicles. The graph showcases how the boiling point of the brake fluid varies depending on the year of manufacture.

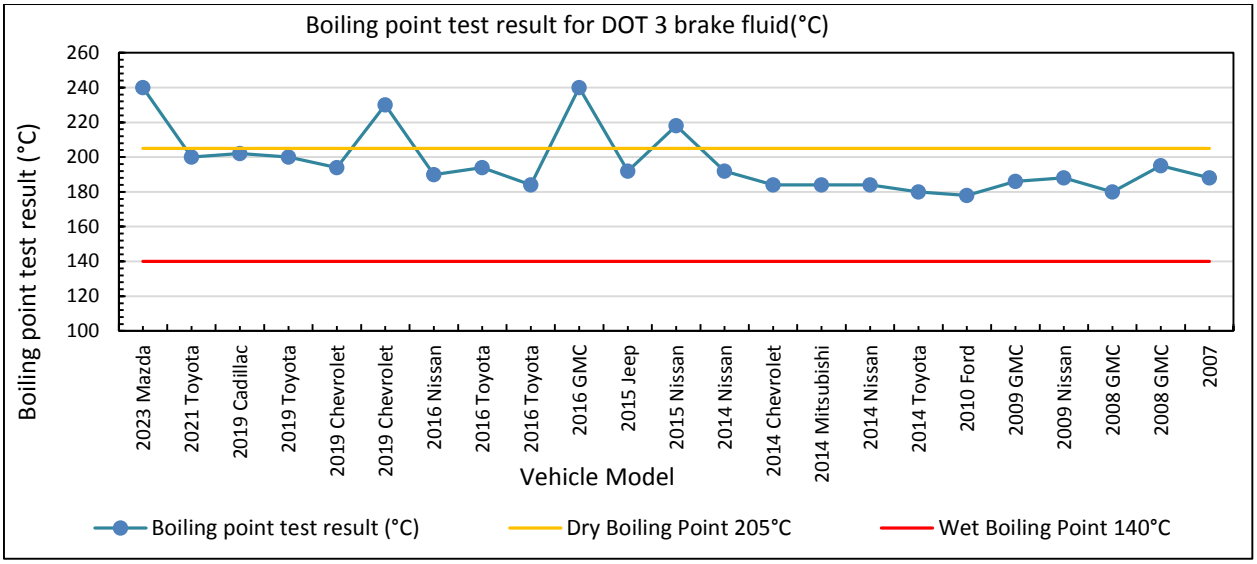

Figure 7: comparison of 23 vehicles brake fluids boiling point test results with the recommendation of US Department of Transportation (brake fluid DOT 3)

7.3.1 Results

1. Overall Boiling Point Trends:

- The boiling point of DOT 3 brake fluids across various vehicle models ranged from approximately 160°C to 240°C. This indicates significant variability in boiling point performance among different manufacturing years.

2. Comparison with Industry Standards:

- Dry Boiling Point (205°C): The yellow line on the graph represents the DOT's dry boiling point standard for DOT 3 brake fluid. Many vehicle models tested have boiling points that meet or exceed this standard.
- Wet Boiling Point (140°C): The red line denotes the wet boiling point standard for DOT 3 brake fluid. All tested vehicle models have boiling points above this threshold, ensuring minimum safety requirements are met.

3. Notable Model-Specific Findings:

- The 2023 Mazda and 2016 GMC models exhibited the highest boiling points, reaching up to 240°C.
- Older models, such as the 2007 and 2008 GMCs, showed lower boiling points but remained above the wet boiling point threshold of 140°C.

7.4 Boiling Point Test Results for DOT 4 Brake Fluids Across Different Vehicle Models

Figure 8 presents a comparison of the boiling points of brake fluids in different vehicles, based on their production year. This comparison was made using the BOSCH BFT 100, which recorded the results of the boiling point tests. The graph also includes the boiling point standards set by the US Department of Transportation (DOT) for DOT 4 brake fluid.

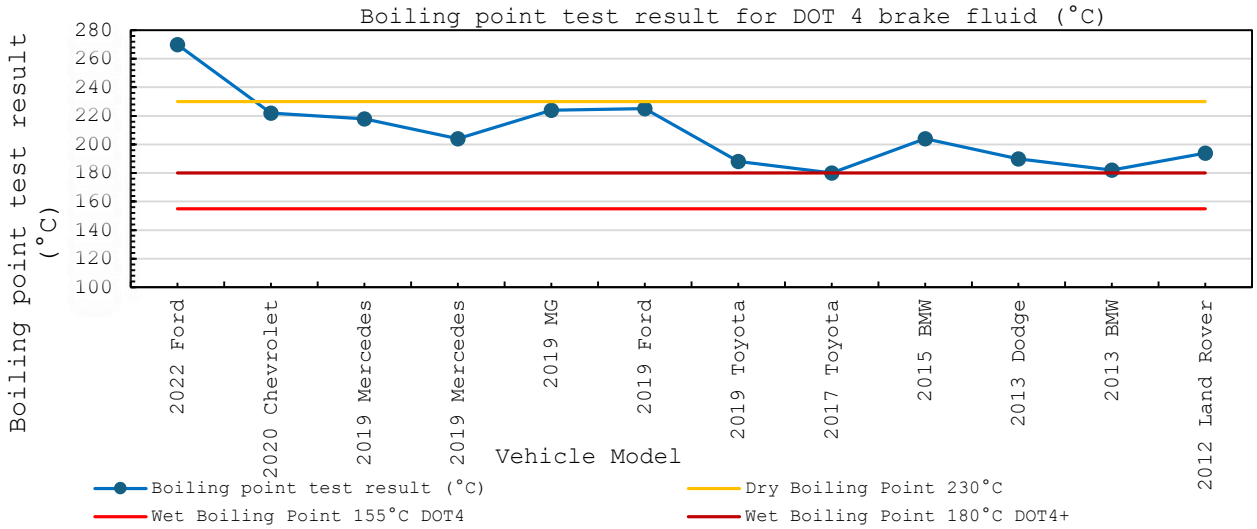

Figure 8: comparison of 12 vehicles brake fluids boiling point test result with the recommendation of US Department of Transportation (brake fluid DOT 4)

7.4.1 Results

1. Overall Boiling Point Trends:

- The boiling points of DOT 4 brake fluids across various vehicle models ranged from approximately 160°C to 260°C. This indicates significant variability in the boiling point performance among different manufacturing years.

2. Comparison with Industry Standards:

- Dry Boiling Point (230°C): Represented by the yellow line, the DOT's dry boiling point standard for DOT 4 brake fluid. Several vehicle models, such as the 2022 Ford and 2020 Chevrolet, exceed this standard.
- Wet Boiling Point (155°C): Denoted by the red line, all tested vehicle models have boiling points above this minimum safety threshold, ensuring compliance with basic safety requirements.
- Wet Boiling Point for DOT 4+ (180°C): The higher standard indicated by the orange line shows that most newer vehicles also meet or exceed this higher boiling point requirement.

3. Notable Model-Specific Findings:

- The 2022 Ford exhibited the highest boiling point at approximately 260°C, well above both the dry and wet boiling point standards.
- Older models, such as the 2012 Land Rover, displayed boiling points closer to the wet boiling point standard for DOT 4 but still above the minimum threshold.

8. Boiling Point Test Results for DOT 3 and DOT 4 Brake Fluids Across Different Vehicle Models

The boiling points of DOT 3 and DOT 4 brake fluids were compared in Figures 9 and 10, which also depict the new brake fluid specifications for different tested vehicles.

8.1 Results: Figure 9: Boiling Point Test Results for DOT 3 Brake Fluid

The boiling point test results for the brake fluids of different vehicles are depicted by the blue line. The boiling points of new brake fluids, such as Toyota DOT 3 (246°C), Veedol DOT 3 (246°C), and Motorcraft Ford DOT 3 (259°C), are represented by separate lines.

- The boiling points for various vehicle models ranged from approximately 178°C to 246°C.
- Notably, 80% of the vehicles produced between 2007 and 2017 exhibit boiling points below the 230°C mark, indicating substantial deterioration over time.
- Most models tested have boiling points exceed 140°C, DOT standards for wet boiling points (from table: 1).
- 2023 Mazda and 2016 GMC, meet or exceed Toyota DOT 3 new brake fluid boiling point 238 °C, indicating good performance in maintaining boiling points.

8.2 Results: Figure:10 Boiling Point Test Results for DOT 4, 4+ Brake Fluid

In Figure 10, the boiling point test results for various brake fluids are depicted by the orange line. The boiling points of AcDelco DOT 4 (269°C) and Mercedes Benz DOT 4 Plus (275°C) are indicated as the respective lines, representing the boiling points of these fresh brake fluids.

- Similar to DOT 3 brake fluids, the boiling points of DOT 4 brake fluids decrease as the vehicle ages, representing about 70% of the tested vehicles, boiling points below 230°C.
- The boiling points DOT 4 brake fluids across various vehicle models ranged from approximately 180°C to 275°C.
- The boiling points tend to decrease in older vehicles, indicating a decline in brake fluid performance over time.
- The 2022 Ford stands out with the highest boiling point, reaching approximately 269°C, above AcDelco DOT4, excellent performance of the brake fluid in newer models.
- Older models, such as the 2012 and 2019 Toyota, 2013 Dodge, and 2013 BMW, had boiling points closer to the wet boiling point threshold, indicating the need for more frequent brake fluid replacement in older vehicles.

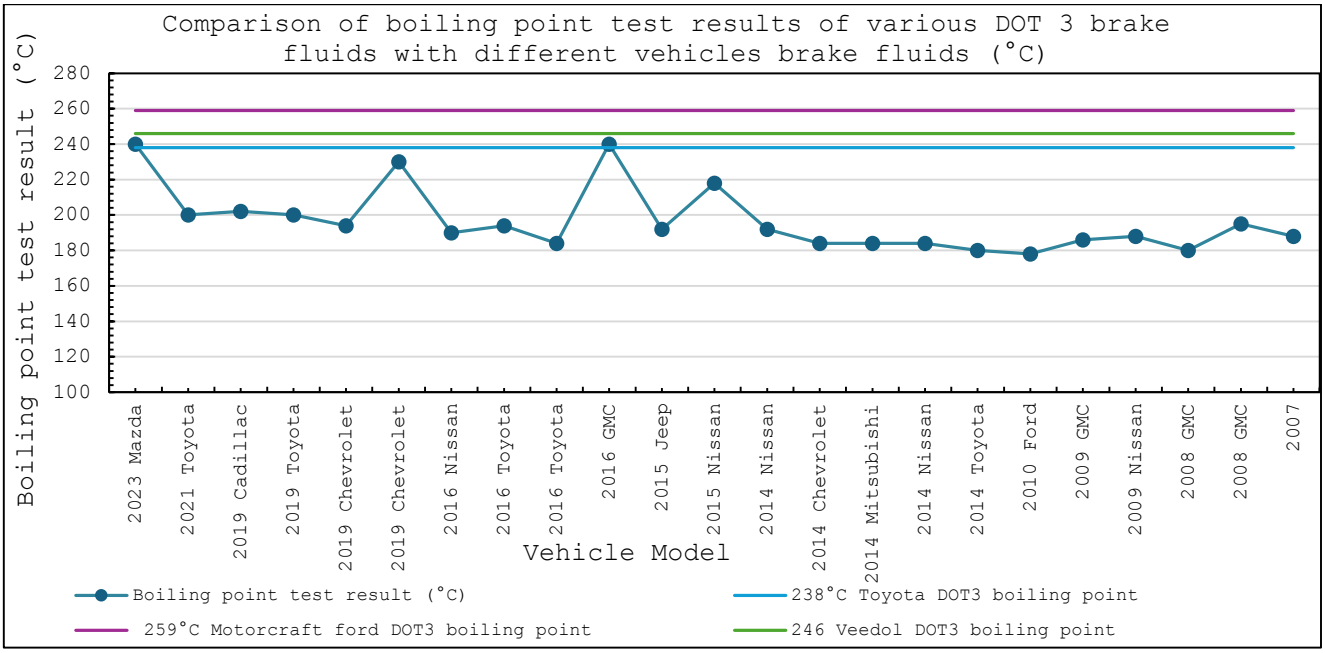

Figure 9: A comparison of 23 vehicles brake fluids Boiling point test result with new brake fluid (brake fluid DOT 3)

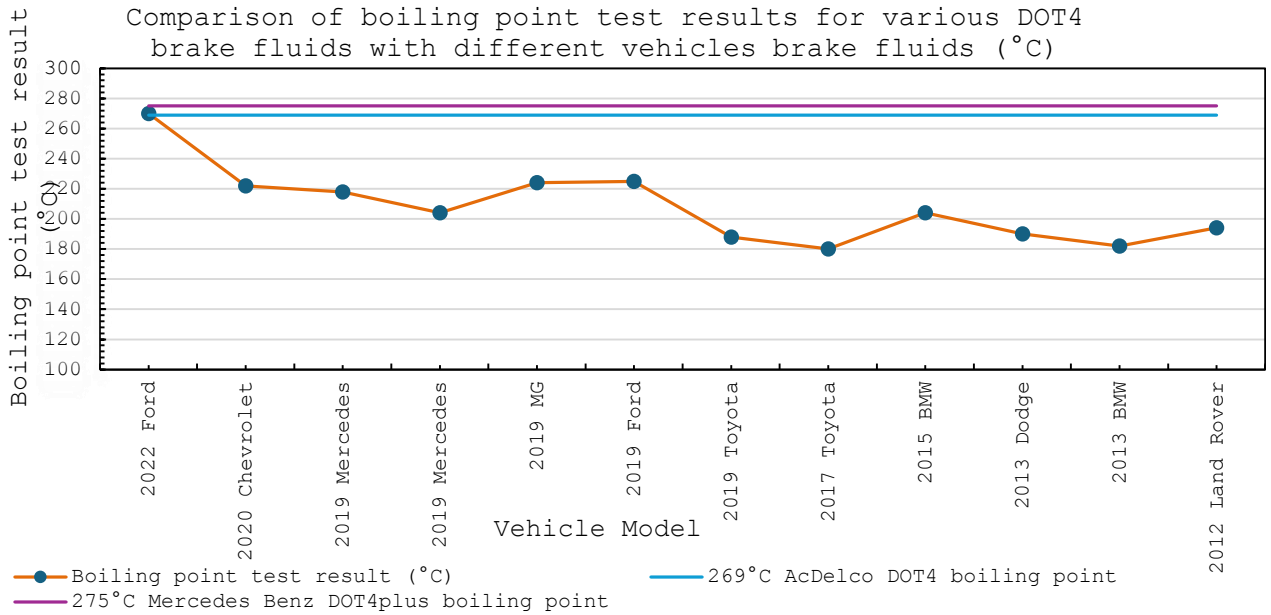

Figure 10: A comparison of 12 vehicles brake fluids Boiling point test result with new brake fluid (brake fluid DOT 4)

9. Discussion

- There is a noticeable trend where older vehicles tend to have higher moisture content in their brake fluids. This is likely due to prolonged exposure and potentially less frequent fluid replacements over the vehicle's lifespan.
- The results indicate that most vehicle models have brake fluid boiling points that comply with the dry boiling point standard of 205°C. This is a positive indicator of fluid performance in newer vehicles.
- A trend is observed where newer vehicles tend to have higher boiling points compared to older models. This could be attributed to advancements in brake fluid formulations and better maintenance practices in newer vehicles, which is expected.
- Older vehicles, although showing lower boiling points, still remain above the critical wet boiling point threshold of 140°C, indicating that while there may be some performance degradation, safety standards are still met.

Figure 5 and 6 illustrate that newer vehicles typically have lower moisture levels in their brake fluid, while older vehicles are more susceptible to having brake fluid with excessive moisture, reaching levels that are considered unsafe.

Figure 7 and 8 further highlights the relationship between the age of a vehicle and the deterioration of its brake fluid's boiling point. Newer vehicles demonstrate better preservation of high boiling points, while older vehicles experience significant declines, often approaching the wet boiling point threshold for DOT 4+ at 180°C. This underscores the importance of routine upkeep. The data strongly supports the recommendation for periodic replacement of brake fluid to ensure peak performance and safety standards are maintained. Although only one vehicle reached the allowable threshold for water content, some other vehicles came dangerously close to lower boiling point.

Figure 7 and 8, approximately 90% for both vehicles with DOT 3 and DOT 4, 4+ brake fluid, have boiling points below 238°C for DOT 3 and 238°C for DOT4, 4 + and only one vehicle between all 35 tested vehicles drop to the wet boiling point 180°C for DOT 4+, 2017 Toyota,.

The presence of water in brake fluid does not show a consistent relationship with the age of the vehicle, which could be an indicator to an appropriate sealed brake system. However, there is a gradual annual increase in water content percentage, leading to a corresponding decline in the boiling point. On average, the water content increases by approximately 0.2% each year, resulting in a decrease in the boiling point of around 5°C annually.

10. Conclusion

The study investigates the impact of Kuwait's climate on the properties of brake fluid, specifically DOT 3 and DOT 4 types. The research reveals that while new brake fluids exhibit high boiling points and minimal moisture content, these properties degrade over time due to environmental exposure and vehicle usage. Notably, even in Kuwait's arid climate, moisture absorption remains a concern, leading to a decrease in the boiling point and potential brake fluid vaporization under extreme conditions.

A comparative analysis of DOT 3 and DOT 4 fluids shows that although DOT 4 fluids initially have superior properties, DOT 3 fluids maintain their characteristics more consistently over time. This suggests that DOT 3 fluids might be more suitable for long-term use, particularly in older vehicles operating in harsh climatic conditions. Additionally, the research highlights the need for frequent inspection of brake system components, such as the master cylinder and brake caliper, to prevent potential leaks and maintain brake pressure as vehicles age.

The study recommends expanding data collection to include more vehicles of various ages and different types of brake fluids, particularly DOT 4 Plus. It also suggests conducting similar research in various climates to provide comprehensive insights into brake fluid performance under diverse environmental conditions. This broader approach will help optimize maintenance guidelines and ensure vehicle safety across different regions and driving conditions.

Overall, while degradation over time is a common occurrence for both DOT 3 and DOT 4 brake fluids, the connection between water content and boiling point is complex. It is imperative to prioritize regular maintenance and timely replacement of brake fluids to ensure optimal performance and safety.

Finally, the study makes significant contributions to the understanding of brake fluid performance in extreme climates. By following the study's recommendations, vehicle owners and maintenance professionals can enhance the reliability and safety of braking systems, particularly in older vehicles, ultimately reducing the risk of brake failure and associated accidents. This research not only informs best practices for vehicle maintenance in Kuwait but also offers valuable insights that can be applied globally in regions with similar environmental challenges.

11. Recommendations for Future works:

The study recommends expanding data collection to include a larger sample of vehicles across a broader range of ages. This will provide a more comprehensive understanding of how brake fluid properties degrade over time. Additionally, the inclusion of different types of brake fluids, particularly DOT 4 Plus, will offer insights into the performance of various brake fluids under Kuwait's harsh climatic conditions.

Further research should also be conducted in different climates to compare how environmental conditions influence brake fluid performance. This comparative approach will help develop optimized maintenance guidelines that are tailored to specific regional conditions, ensuring vehicle safety and performance across diverse environments.

To enhance the reliability and safety of braking systems, it is crucial to establish routine maintenance protocols that focus on regular inspection and timely replacement of brake fluids, particularly in older vehicles. Regular checks of brake system components, such as the master cylinder and brake caliper, are essential to prevent leaks and maintain brake pressure as vehicles age.

Overall, by following these recommendations and expanding the scope of future research, vehicle owners and maintenance professionals can significantly reduce the risk of brake failure and improve the overall safety and performance of braking systems. This research provides a solid foundation for developing best practices in brake fluid maintenance, not only for Kuwait but also for other regions facing similar environmental challenges.

Appendixes, from [15]

No	Vehicle Type	No of cylinder	Model	Odometer (Km)	Fluid type	Water content test result (%)	Boiling point test result (°C)
1	Mazda CX-9	4	2023	12000	DOT3	1.2	240
2	Ford F150	8	2022	42000	DOT4	0.7	270
3	Toyota Prado	6	2021	37000	DOT3	1.5	200
4	Chevrolet Caprice	8	2020	95000	DOT4	2	222
5	MG 6	6	2019	48000	DOT4	2	224
6	Mercedes E200	4	2019	49000	DOT4+	3	218
7	Mercedes GLC 250	4	2019	50000	DOT4+	3	204
8	Cadillac Escalade	8	2019	65000	DOT3	1	202
9	Toyota Land Cruiser	8	2019	87000	DOT3	1	200
10	Chevrolet Blazer	6	2019	104000	DOT3	2.5	194
11	Toyota Camry	6	2019	110000	DOT3&4	1.5	188
12	Chevrolet Tahoe	8	2019	207000	DOT3	2	230
13	Ford F150	8	2019	51000	DOT4	1	225
14	Toyota Camry	4	2017	141000	DOT3&4	2.5	180
15	Nissan Altima	6	2016	91000	DOT3	1.5	190
16	Toyota Land Cruiser	8	2016	200000	DOT3	1	194
17	Toyota Aurion	6	2016	216000	DOT3	1	184
18	GMC Yukon	8	2016	260000	DOT3	2	240
19	BMW X5	6	2015	107000	DOT4	2	204
20	Jeep Grand Cherokee	6	2015	122000	DOT3	2	192
21	Nissan Patrol	8	2015	161000	DOT3	1.5	218
22	Nissan Maxima	6	2014	92000	DOT3	2.5	192
23	Chevrolet Tahoe	8	2014	165000	DOT3	2	184
24	Mitsubishi Pajero	6	2014	178000	DOT3	2	184
25	Nissan Patrol	8	2014	216000	DOT3	1	184
26	Toyota FJ Cruiser	6	2014	239000	DOT3	2	180
27	Dodge Durango	8	2013	147000	DOT4	3	190
28	BMW 320i	4	2013	192000	DOT4	1.5	182
29	Land Rover	6	2012	157000	DOT4	3.5	194

30	Ford Explorer	6	2010	234000	DOT3	3	178
31	GMC Yukon	8	2009	214000	DOT3	2.5	186
32	Nissan Patrol	6	2009	337000	DOT3	2	188
33	GMC Acadia	6	2008	173000	DOT3	2.5	180
34	GMC Yukon	8	2008	264000	DOT3	2	195
35	Cadillac Escalade	8	2007	308000	DOT3	2	188

References

[1] Bhat, N. R., Lekha, V. S., Suleiman, M. K., Thomas, B., Ali, S. I., George, P., & Al-Mulla, L. (2012). Estimation of water requirements for young date palms under arid climatic conditions of Kuwait. *World Journal of Agricultural Sciences*, *8*(5), 448-452.

[2] Caban, J., Vrábel, J., Šarkan, B., Kuranc, A., & Słowik, T. (2021). Operational tests of brake fluid in passenger cars. *Periodica Polytechnica Transportation Engineering*, *49*(2), 126-131.

[3] BĄKOWSKI, H., STANIK, Z., & KUBIK, A. (2017). BADANIE PROCESÓW ZUŻYCIOWYCH PŁYNU HAMULCOWEGO W ZŁOŻONYCH WARUNKACH WYMUSZEŃ. *KWARTALNIK TRIBOLOGIA*, *273(3), 21-27*.

[4] Selvanathan, P. S., & Govindaraj, R. (2017). Enhanced Temperature Control in Disc Brakes. *Bonfring International Journal of Industrial Engineering and Management Science*, *7*(1), 05-08.

[5] Lee, K. (1999). *Numerical prediction of brake fluid temperature rise during braking and heat soaking (No. 1999-01-0483). SAE Technical Paper*.

[6] Jakóbiec, J. A. N. U. S. Z. (2006). Badania stanowiskowe płynów hamulcowych. *Archiwum Motoryzacji*, *(1), 63-78.*

[7] Caban, J., Vrábel, J., Šarkan, B., Kuranc, A., & Słowik, T. (2021). Operational tests of brake fluid in passenger cars. *Periodica Polytechnica Transportation Engineering*, *49*(2), 126-131.

[8] Wójcik, M. (2018). Rheological properties of new and used brake fluids. *Acta Mecánica Slovaca*, *22(4), 50-54.*

[9] Čorňák, Š., Balík, R., & Barták, J. (2006). THE SPECIFICS ASPECTS OF BRAKE FLUIDS EVALUATION IN OPERATION. *Perner's Contacts*, *1*(4), 1-6.

[10] Almedeij, J. (2012). Modeling pan evaporation for Kuwait by multiple linear regression. *The Scientific World Journal*, *2012*.

[11] *Climate & Weather Averages in Kuwait City, Kuwait*. (n.d.). Www.timeanddate.com. Retrieved May10, 2023, from https://www.timeanddate.com/weather/kuwait/kuwait-city/climate

[12] Halderman, J. D., & Mitchell, C. D. (2004). *Automotive brake systems*. Pearson/Prentice Hall.

[13] Federal Motor Vehicle Safety Standards 116, U.S department of transportation, National Highway Traffic Safety Administration, 1991

[14] Sanders, P. J., & Barry, J. (1985). *Conversion of Hydraulic Brake Systems from Polyglycol to Silicone Brake Fluid: Residual Polyglycol Remaining After Conversion*. MATERIALS RESEARCH LABS ASCOT VALE (AUSTRALIA).

[15] Yousef Ali Al Mulla, Jasem Alazemi & Yousef Alhouli. The effect of Kuwait climate on the Automotive brake fluids: International Journal of Applied Engineering Research Volume 18, Number 2 (2023) pp. 124-129