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MEASUREMENT OF BRAKE FLUID BOILING POINT

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The study focuses on measuring the boiling point of brake fluid. The research is based on a qualitative analysis of brake fluid samples taken from randomly selected vehicles. A total of 100 different vehicles with varying ages and mileage were included in the examination process. Using a device designed to measure the boiling point of brake fluid, indicators that directly reflect the quality of the brake fluid were evaluated, as it is one of the main factors affecting vehicle safety in road traffic. In further sections, the research focuses on how the boiling point changes depending on the vehicle's age and mileage. The results showed that the boiling point of glycol-based fluids significantly decreases with moisture absorption, with older vehicles and vehicles with higher mileage tending to have a lower brake fluid boiling point. Comparing different sampling locations also revealed that brake fluid in the reservoir often has a higher boiling point than fluid at the brake calliper, indicating a higher level of contamination at the brake calliper. In comparison, brake fluid samples from reservoirs exhibited higher boiling points than those from brake callipers, with differences of up to 20 °C in some cases. Of the 39 vehicles sampled from both locations, 59% of the samples were satisfactory at all points, 13% met the standard only in the reservoir, and 28% were unsatisfactory at any sampling point. The results emphasise the necessity of regular inspections and highlight that boiling point checks at the brake calliper could reveal risks otherwise undetectable from reservoir-only testing.

Keywords: braking; hygroscopic; temperature; safety; vehicle

Brake fluids play a crucial role in the safety and reliability of automotive braking systems. They are responsible for transmitting force from the brake pedal to the vehicle's braking mechanisms. High temperatures that can arise during intense brake use place demanding requirements on brake fluids. One of the key parameters that determine the quality and performance of brake fluid is its boiling point. The boiling point of brake fluid is a critical factor because exceeding this temperature can cause the fluid to turn into gas, leading to the formation of bubbles in the braking system. These bubbles can cause the brakes to become less effective or fail entirely, posing a serious risk to road safety. Therefore, measuring the boiling point of brake fluids is essential to ensure the proper functioning of braking systems (Straky et al., 2003).

There are two main categories of brake fluids: glycol-based fluids (such as DOT 3, DOT 4, and DOT 5.1) and silicone-based fluids (such as DOT 5). Each type of fluid has its specific properties and boiling points. Glycol-based fluids are hygroscopic, meaning they absorb moisture from the environment, which gradually lowers their boiling point (Kao et al., 2006). In contrast, silicone-based fluids are not hygroscopic and maintain a stable boiling point throughout their lifespan (Denniston, 2000; Motta et al., 2023). The boiling point of brake fluids is measured under laboratory conditions using specific equipment and procedures defined by international standards, such as the SAE J1703 standard (SAE J1703, 2018). This process involves heating the fluid under controlled conditions and recording the temperature at which vapour begins to form. The data obtained are then analysed and interpreted to determine the quality and suitability of the brake fluid for specific applications (Tseng and Chou, 2020; Caban et al., 2016).

Studies have shown that glycol-based brake fluids, such as DOT 4, can achieve boiling points up to 230 °C when dry, but this can drop below 155 °C with water absorption, significantly reducing their effectiveness (Bako et al., 2019; Sejkorová et al., 2018) Silicone-based fluids have a boiling point around 260 °C and maintain this value regardless of moisture (Jordan, 1981). These study results highlight the need for regular monitoring and replacement of brake fluids to prevent a reduction in braking performance (Sunday et al., 2019). Further studies have focused on the degradation of brake fluids during use and the impact of various factors on their properties. Research has shown that prolonged exposure to high temperatures can accelerate the degradation of brake fluid, leading to a reduced boiling point and increased risk of brake system failure (Bryant and Day, 2022; Čorňák et al., 2007). Other studies have examined the differences in brake fluid composition from different manufacturers, finding significant variations in quality and performance (Ibrahim and Petrík, 2024). Research has also shown that some brake fluids have better resistance to contamination and degradation than others (Wijayanta et al., 2020).

The aim of this research is to characterise the importance of measuring the boiling point of brake fluids, describe the methods used for this measurement, and discuss the results and their implications for vehicle safety. This study will provide a deeper understanding of the importance of proper selection and maintenance of brake fluids, which can significantly contribute to reducing the risk of brake system failure and enhancing overall road safety.

Material and Methods

The aim of the work was to analyse in detail and verify the need and objectivity of measuring the boiling point of brake fluid in road vehicles. On the basis of theoretical knowledge and previous studies, a brake fluid sample was taken from 100 different vehicles that were suitable for operation in road traffic and had successfully passed a technical inspection.

The sampling process was designed to reflect actual operating conditions as closely as possible. If the design of the vehicle did not allow direct access to the brake fluid compensating tank or it was not possible to insert the measuring probe directly into the tank, the sample was taken from the accessible part of the brake fluid compensating tank. We took 30 ml of brake fluid from each vehicle.

Overall, the approach to sampling and analysing in our study was designed to provide relevant and objective data necessary for assessing the condition of brake fluid under operational conditions and to determine whether current practices for measuring and replacing brake fluid are sufficient to ensure optimal vehicle safety.

The individual measurements were conducted using the BOSCH BFT 100 measurement device. The device operates during measurements powered by a car battery, either located directly in the vehicle's engine compartment or externally (BOSCH BFT 100 – technical specification). Throughout the data collection and evaluation process, the measurement device was maintained with valid calibration, in accordance with national metrological legislation. The calibration of the measuring device was carried out in accordance with Decree 137/2018, Appendix 1, Chapter 15.2. Distilled water was used as the calibration liquid. The measuring device determined the boiling point of the liquid (distilled water). After the test, the device recorded the boiling point of distilled water as 100 °C.

Table 1 Parameters of the BOSCH BFT 100 measuring device (BOSCH BFT 100 – technical specification)

Manufacturer	BOSCH
Model	BOSCH BFT 100
Measurable liquids	DOT 3, DOT 4, DOT 5.1
Test duration (at an ambient temperature of 0–50 °C)	30 seconds
Measurement accuracy (up to 180 °C)	±1–3%
Measurement accuracy (above 180 °C)	±3–5%

Results and Discussion

For the study, 100 vehicles of various ages and mileage were randomly selected. The condition for selecting the vehicles was that they had not had their brake fluid replaced before sampling. This means that the brake system of the vehicle contained brake fluid directly from the manufacturer. This condition ensures the objectivity and comparability of the results obtained.

According to the measurement procedure, brake fluid was sampled from each vehicle and assessed outside the reservoir. The amount of brake fluid collected was 30 ml. This approach eliminates potential measurement errors that could arise from imperfect immersion of the measuring probe into the reservoir in the vehicle's engine compartment. The brake fluid labelled DOT 4 is considered adequate if the boiling temperature determined by the device is higher than 155 °C.

Figure 1 illustrates the relationship between vehicle age (on the *x*-axis) and mileage (on the *y*-axis). The horizontal

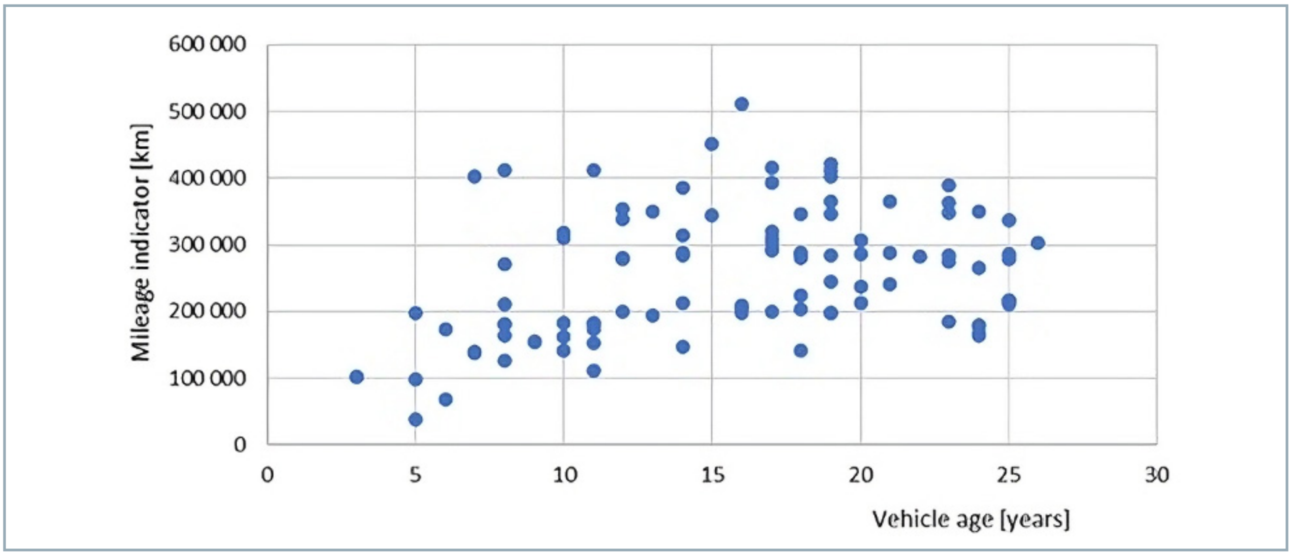

Fig. 1 Characteristics of the assessed vehicles

axis represents vehicle age in years, ranging from 0 to 30 years. The vertical axis shows mileage ranging from 0 to 600,000 kilometres.

Observing the data points on the graph, it is evident that the majority of vehicles are within the age range of 5 to 25 years. The mileage of these vehicles ranges from approximately 50,000 to 500,000 kilometres. There is no clear linear relationship between age and mileage, suggesting that older vehicles do not necessarily have more mileage than newer ones.

The maximum mileage is approximately 500,000 kilometres, typically observed in vehicles aged around 10 to 15 years. Conversely, the lowest mileage is recorded in newer vehicles, aged around 0 to 5 years, with mileage around 100,000 kilometres.

The graph highlights a broad variability in mileage depending on the vehicle's age. Most vehicles, regardless of age, have mileage between 100,000 and 400,000 kilometres. There is no significant trend indicating a straightforward increase or decrease in mileage with vehicle age, suggesting that other factors besides age might significantly influence mileage.

From the measurements carried out, it was found that 66% of the tested vehicles have brake fluid whose properties are satisfactory, while 34% of the tested vehicles use a fluid in the brake system whose condition is unsatisfactory for operation. The boiling point of the brake fluid during testing did not reach the minimum threshold set by the manufacturer for the evaluated type of brake fluid (DOT 4–155 °C). The testing results suggest that while the majority of vehicles (64%) have brake fluid in an acceptable condition, a significant portion (34%) have brake fluid that is inadequate for continued use. These results highlight the necessity for regular inspection and maintenance of brake fluid to ensure the safety and optimal performance of the braking system.

Figure 2 shows the relationship between the boiling point of brake fluid and the age of the vehicle. The horizontal axis represents the vehicle's age, ranging from 0 to 30 years. The vertical axis represents the brake fluid temperature in degrees Celsius, ranging from 0 to 300 °C.

Each blue dot on the graph represents an individual vehicle, showing its brake fluid temperature in relation to the vehicle's age. The red horizontal line denotes the threshold of 155 °C, below which the brake fluid condition is considered unsatisfactory (NOT OK). The area above this line is marked as OK, indicating that the brake fluid meets the required conditions.

The trend line, depicted by the dotted line, has the equation y = -1.3696x + 189.47 with a coefficient of determination R^2 = - 0.1064. This coefficient suggests a very weak relationship between the vehicle's age and the brake fluid's boiling point. Most data points are located near or above the 155 °C threshold, but some points fall below this limit, indicating the need for brake fluid replacement or maintenance.

The graph indicates a slight tendency for the boiling point of brake fluid to decrease with the vehicle's age. However, the majority of samples still meet the established requirements. Some older vehicles show temperatures close to or below the set threshold, highlighting the need for regular maintenance and inspection of the brake fluid to ensure safe and efficient operation.

Figure 3 illustrates the relationship between the boiling point of brake fluid and vehicle mileage. The horizontal axis shows the vehicle's mileage, ranging from 0 to 600,000 kilometres. The vertical axis represents the brake fluid temperature in degrees Celsius, ranging from 0 to 300 °C.

Each blue dot in the graph represents a single vehicle, indicating its brake fluid temperature in relation to mileage. The red horizontal line represents the threshold of 155 °C, below which the brake fluid condition is deemed unsatisfactory (NOT OK). The area above this line is marked as OK, indicating that the brake fluid meets the required conditions.

The graph shows that most vehicles have brake fluid temperatures close to or above the 155 °C threshold, although some vehicles have significantly lower boiling points, suggesting that their brake fluid should be replaced or treated. The blue dotted line represents the trend line with the equation y = -2E - 0.5x + 173.09 and a coefficient of determination R^2 = 0.0057, indicating a very weak

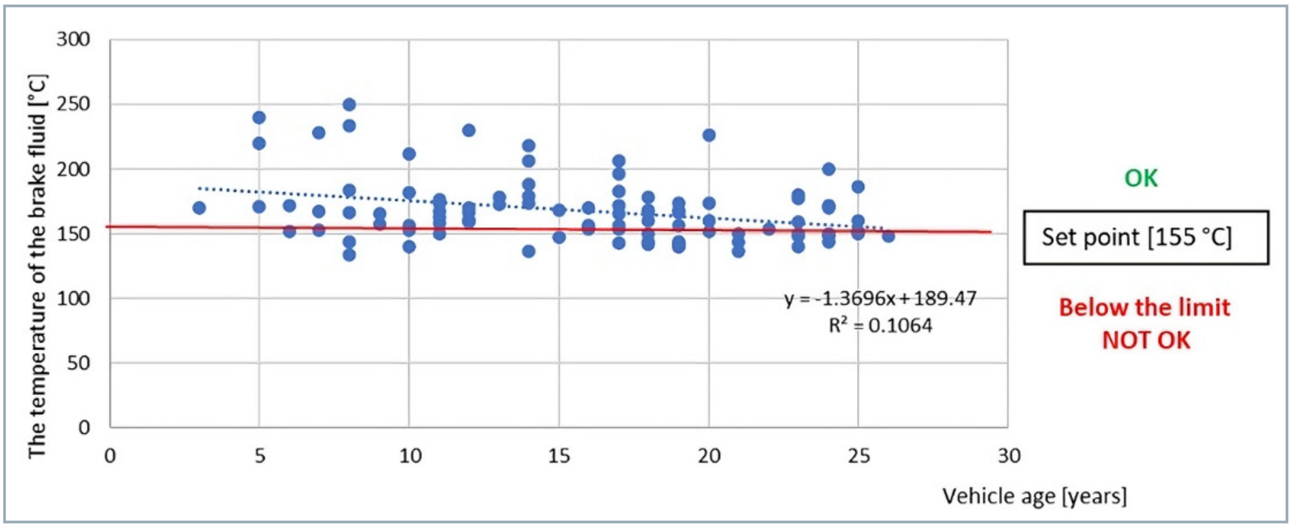

Fig. 2 Dependence between the boiling point of the brake fluid and the age of the vehicle

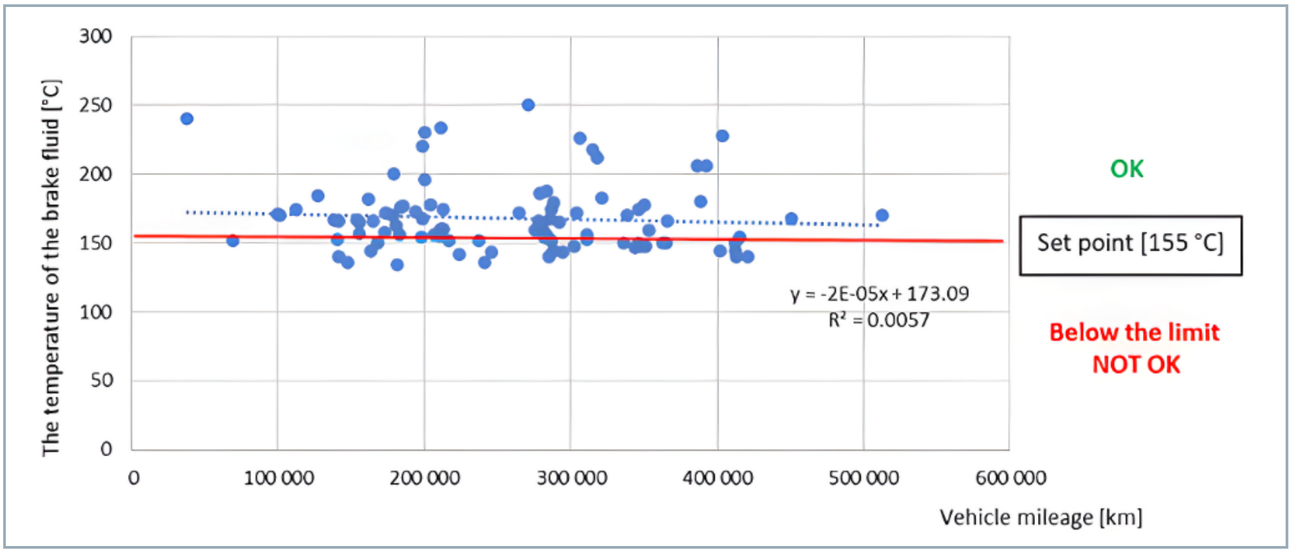

Fig. 3 Dependence between the boiling point of the brake fluid and the age milage of the vehicle

relationship between mileage and the brake fluid's boiling point.

Overall, the graph indicates that most brake fluids in the vehicles studied have boiling points within acceptable conditions, regardless of mileage. However, some exceptions that fall below the set threshold suggest the need for regular inspection and maintenance of the braking system.

One of the main reasons for comparing the boiling point of brake fluid in the reservoir versus the brake calliper is the differing exposure of the fluid to thermal and mechanical influences. In the reservoir, the brake fluid is less exposed to high temperatures and mechanical stress compared to the fluid in the brake calliper, where it heats up directly due to friction during braking. A study by Fulton reports that the boiling point of brake fluid in the brake calliper can be reduced by up to 20% compared to the reservoir due to higher thermal stress (Fulton, 2002).

Another significant aspect is the presence of contaminants and moisture absorption. Brake fluid is hygroscopic, meaning it absorbs moisture from the surrounding environment, which lowers its boiling point. This effect is more pronounced in the brake calliper, where seals and joints are more frequent sites of moisture ingress. Several studies confirm that the water concentration in brake fluid can be higher in the brake calliper, resulting in a marked decrease in the boiling point and an increased risk of vapour lock during intense braking (Barabás et al., 2017; Tseng and Chou, 2020; Podoprigora et al., 2018).

Comparing the boiling point at these two locations also allows for better diagnosis of the overall braking system's condition. If the boiling point in the reservoir is satisfactory but low in the brake calliper, it may signal local issues such as leaks or excessive wear of components. These differences can be critical for identifying potential problems before they manifest as severe failures. For the purpose of this study, a 30 ml sample was collected, just from the vehicle's reservoir. Vehicles were selected randomly, with a sample of 39 vehicles from the 100 vehicles examined in the previous section. In the Slovak Republic, during regular technical inspection, a sample is exclusively taken from the vehicle's reservoir. Given this fact, it is essential to investigate whether the brake fluid sampled from the reservoir is qualitatively identical to the fluid sampled directly from the brake calliper of the vehicle. The boiling point of the brake fluid was chosen as the quality indicator. Since the vehicles are equipped with the DOT 4 brake fluid, the controlled temperature (wet boiling point) is 155 °C.

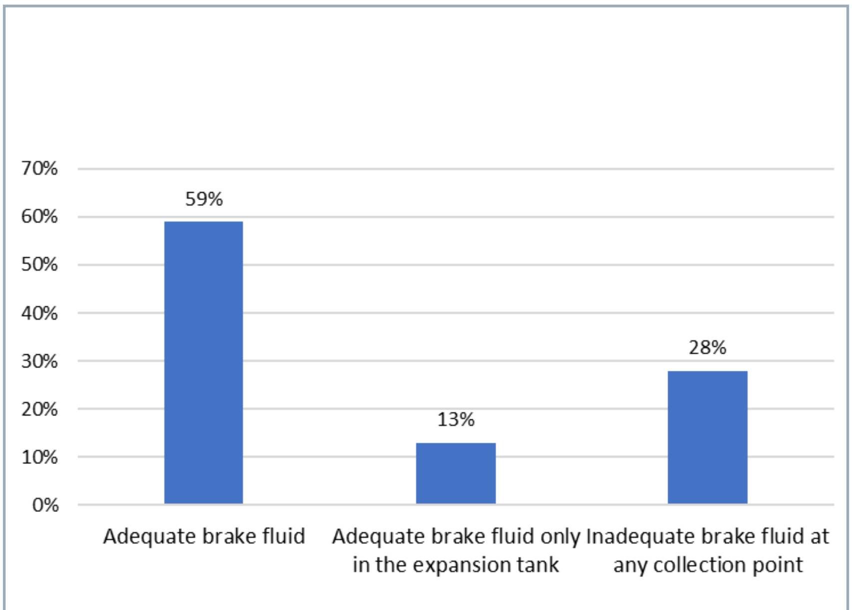

Fig. 4 Evaluation of the brake fluid based on the sampling point

Based on the measurement results, three scenarios can be observed:

- the brake fluid is satisfactory at both locations;
- the brake fluid is satisfactory only in the reservoir;
- the brake fluid is not satisfactory at either sampling location.

Figure 4 shows the assessment of brake fluid condition based on the sample collection location. The horizontal axis displays three categories of assessment: "Adequate brake fluid", "Adequate brake fluid only in the expansion tank", and "Inadequate brake fluid at any collection point". The vertical axis represents the percentage of the total number of tested vehicles falling into each category.

The first category, "Adequate brake fluid", represents samples where the brake fluid meets the requirements at all collection points. This category shows 59% of samples, indicating that the majority of tested vehicles have brake fluid in good condition throughout all the parts of the braking system.

The second category, "Adequate brake fluid only in the expansion tank", represents 13% of samples where the brake fluid meets the requirements only in the expansion tank, but not in the brake calliper. This means that in these cases, the fluid in the calliper may be contaminated or have a lower boiling point due to increased temperature or moisture presence.

The third category, "Inadequate brake fluid at any collection point", shows 28% of samples where the brake fluid does not meet the requirements at least at one collection point, which may indicate serious issues within the braking system and the need for immediate intervention.

The graph indicates that the largest portion of vehicles has brake fluid in good condition, but a significant percentage of samples (28%) have issues with inadequate brake fluid at some collection point. This underscores the importance of regular monitoring and assessment of brake fluid condition. The research highlights the need for monitoring brake fluid quality not only in the expansion tank but also in the brake calliper to ensure the maximum safety and effectiveness of the braking system.

Figure 5 shows a graphical comparison of the boiling points of brake fluid based on the sampling location. For better clarity, the results are presented in two parts (Part 1, Part 2). Both graphs illustrate the comparison of the boiling point of brake fluid based on the sampling location, comparing values taken from the brake fluid expansion tank (green bars) and from the brake calliper (orange bars). The horizontal axis lists sample numbers (vehicle numbers) from 1 to 39. The vertical axis shows the temperature of the brake fluid in degrees Celsius, ranging from 0 to 250 °C.

A red horizontal line in both graphs marks the set limit of 155 °C (wet boiling point), below which the condition of the brake fluid is considered inadequate (NOT OK). The area above this line is marked as OK, meaning the brake fluid meets the required conditions.

In Part 1 of the graph, samples 1 to 20 are displayed. Most of the green and orange bars are above the 155 °C threshold, but a few samples (e.g., 1, 2, 3, 4, 5, 7, 8, 9, 11,

Fig. 5 Comparison of the brake fluid boiling point based on sampling location

14, 17, and 18) have temperatures below this threshold, indicating that the brake fluid in these vehicles does not meet the required conditions. Significantly lower temperatures are mostly observed in the orange bars (brake calliper), suggesting a worse condition of the brake fluid in this part of the system.

In Part 2 of the graph, samples 21 to 39 are shown. Most of the bars are above the 155 °C threshold, but a few samples (e.g., 22, 23, 25, 28, 30, 32, 33, 35, 36, 38) have temperatures below this limit. As in the first graph, orange bars (brake calliper) often show lower temperatures compared to green bars (expansion tank), indicating that brake fluid in the brake calliper is more frequently in worse condition.

Both graphs together show that the boiling point of brake fluid can vary significantly depending on the sampling location. Most vehicles have a boiling point above the set limit of 155 °C, but some vehicles, especially those with brake fluid samples taken from the brake calliper, show lower values, highlighting the need for regular inspection and maintenance of the braking system.

The research segment focused on evaluating the condition of brake fluid based on the sampling location has yielded significant findings, underscoring the importance of a comprehensive approach to monitoring the brake system's condition. The analysis of the graphs suggests that brake fluid in the expansion tank often shows higher boiling points compared to fluid taken from the brake calliper. This difference may be attributed to varying operational conditions and sample collection locations.

Comparison with other research in the field shows consistency in findings. Results from various studies and professional publications highlight that regular brake fluid replacement and condition checks in all the parts of the braking system are crucial for maintaining optimal vehicle performance and safety (Caban et al., 2016; Lee, 1999).

Regarding the characteristics of assessed vehicles by age and mileage, older vehicles and those with higher mileage tend to have more kilometres, which is expected. However, variability in mileage among vehicles of the same age suggests different operating conditions and maintenance. It is not possible to definitively assess the technical condition of a vehicle based solely on these parameters. This phenomenon aligns with findings from the study by Filipczyk and Kutrzyk-Nykiel, which analysed emissions production results in the vehicles of different ages. The results of the study confirm the findings of the research. The technical condition of a vehicle may not reflect its mileage and age (Filipczyk and Kutrzyk-Nykiel, 2011). Several studies indicate that vehicle condition, maintenance, and driving style significantly impact their lifespan and emissions production (Carreón-Sierra and Salcido, 2022; Felstead et al., 2009; Harantová et al., 2022).

Results showing the dependence of the boiling point of brake fluid on vehicle age and mileage suggest that as vehicles age and accumulate mileage, the boiling point of brake fluid may decrease, likely due to contamination by moisture and other impurities. This decrease is modest, and in many cases, the boiling point remains above the set threshold of 155 °C. Research by Stanczyk et al. (2020) also demonstrated that the boiling point of brake fluid decreases with increasing vehicle age and mileage, which supports the conclusions of the results found in the research process.

Comparing the boiling point of brake fluid in different parts of the system indicates that brake fluid in the expansion tank often has a higher boiling point compared to fluid in the brake calliper. This difference may be due to varying operational conditions and sampling locations. The study by Fulton highlights similar results, where brake fluid in the brake calliper was more prone to contamination and degradation (Fulton, 2002).

Overall, research results emphasise the importance of regular and comprehensive monitoring of brake fluid condition in all the parts of the braking system. Comparison with other studies shows consistency in findings and supports the need for implementing the regular boiling point checks of brake fluid. Based on the study results, recommendations can be made to enhance road safety. The regular checks of brake fluid condition should be implemented not only in the expansion tank but also in the brake calliper to ensure the maximum safety and effectiveness of the braking system. In conclusion, research supports the need for a comprehensive monitoring of brake fluid condition, including sampling from various parts of the braking system. This approach allows for better identification of potential issues and increases vehicle operational safety. The research highlights the potential risks associated with brake fluid degradation.

Conclusion

The study shows that the boiling point of brake fluid is vital for braking system safety. The analysis of 100 vehicles revealed that glycol-based fluids lose boiling point with moisture absorption, increasing the risk of brake failure. Of the samples, 34 did not meet the required threshold. Regarding the relationship between the qualitative indicators of brake fluid condition and vehicle age, no dependency could be confirmed. The research also demonstrated that vehicle mileage does not affect brake fluid quality.

The results show a significant difference in boiling points between brake fluid in the expansion tank and the brake calliper, with calliper fluid reaching its boiling point earlier. Current methods focus on reservoir measurements, which may not reflect the true condition of the fluid. While calliper measurements would be more accurate, they cannot be conducted non-destructively under current procedures. The most accurate method is to use devices to measure the boiling point of brake fluid in vehicles; however, such a measurement cannot be performed from the calliper under current methodological procedures as it must be done non-destructively.

The regular monitoring and timely replacement of brake fluid are essential for vehicle maintenance, with intervals based on operating conditions and boiling point checks (Moravčík and Jaśkiewicz, 2018). The findings highlight the need for ongoing research and driver education to improve safety and minimise brake system failure risks.

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