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Operational Tests of Brake Fluid in Passenger Cars

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Abstract
During the operation of vehicles, the properties of liquids and consumables deteriorate, which may affect the level of safety of technical systems and road traffic safety. The results of testing brake fluid aging as a function of boiling point and percentage of water content were presented on a selected group of passenger cars. The tested vehicles were varied in terms of age and kilometer mileage. The methodology for testing the quality of brake fluid based on glycol selected passenger cars remaining in service has been presented. In this study was shown a significant decrease in the brake fluids quality during the two years of operation in vehicles. The determination of boiling point was more efficient than the determination of water content. Despite the lack of full vehicle operational information, the obtained test results allow for exciting observations.

Keywords
automotive engineering, operational, vehicle safety system

1 Introduction

The automotive industry is dominated by four main development trends: improvement of vehicle dynamics, reduction of energy consumption and emissions, and improvement of transport safety (Zöldy, 2018). In the automotive industry, chemical products are widely used both in production processes as well as in the operation of vehicles. Car chemistry is a vital assortment department that ensures the supply of operating fluids, lubricants, and cosmetics necessary for the proper functioning of vehicles (Kuranc et al., 2018). In industry and the automotive industry (e.g. in lubrication means), synthetic hydrocarbons play the most important role, in particular, poly-alpha-olefins (PAO), carboxylic esters (complexes and polyesters), polyalkylene glycols (PAG) (Beran et al., 2003), and monoalkyl ethers of glycols (Depta, 2013). From safety in the vehicle, two types of operating fluids - engine coolant and brake fluid - are the most important. The above chemical preparations must meet a number of requirements for reasons of road safety (Droździel and Wrona, 2018; Gechev et al., 2017; Hudak and Madleňák, 2017; Jurecki et al., 2017; Levulyte et al., 2016; Poliak et al., 2018; Sipos, 2017), and contamination of the natural environment and human health (Limpert, 2015; Lizbetin et al., 2019 Rimkus et al., 2018).

Currently, there are several brake fluid classes available that meet the requirements of PN-C-40005: 2002, which is equivalent to the standard issued by the DOT (Department of Transportation of the United States), commonly used in the automotive industry to determine the brake fluid class. These are classes: DOT-3, DOT-4, DOT-5, and R-3. 95 % of cars in the world use a group of products based on glycol esters (Khamidullin et al., 2006). Table 1 presents the brake fluid elemental chemical composition.

Table 1 The elemental chemical composition of the brake fluid (Poskrobko et al., 1994)

Component	Share %
alkylene glycol alkyl ethers, strongly hygroscopic substances that act as solvents	70-80
polyethylene or propylene polyglycols or borate esters of alkylene glycol alkyl ethers acting as a lubricant	20-30
inhibitors, i.e., anti-corrosion, anti-oxidation, stabilizing and anti-foaming additives	5-10

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The braking system is a crucial element of safety necessary for the safe use of the vehicle (Jegadeeshwaran and Sugumaran, 2015). In the literature, there are many works in the field of testing of friction elements of braking systems (Indira et al., 2015; Pavlov et al., 2015; Sawase and Sano, 1999; Sergienko et al., 2013; Walczak et al., 2015), and work on testing of operating fluids: fuels and engine oils (Sejkorova, 2013; Sejkorova and Senkyr, 2017; Valiś et al., 2018). However, relatively few of them relate to brake fluids, hence deserving the attention of research (Bzura, 2007; Kuranc et al. 2018; Jakóbiec, 2006; Lee, 1999; Sejkorová et al., 2018).

As it results from the Polish National Council of Road Traffic Safety Report (National Road Safety Program, 2013), up to 22.5 % of the causes of road traffic accidents among defects occurring in car safety systems are caused by a malfunction of the car braking system (National Road Safety Program, 2013). The requirements for car braking systems are set out in Regulation 13 of the United Nations Economic Commission for Europe (ECE) (UN ECE, Regulation 13, 2016). These requirements apply to braking performance, vehicle stability during braking and reliability of the braking system. The vehicle's load (its center of gravity) is also crucial for vehicle stability. The position of the center of gravity affects the weight distribution between the individual wheels during cornering. The position of this point is unstable and depends on several factors (Skrúcaný et al., 2018). Skrúcaný et al. (2018) presented the methodology of measuring the center of gravity's and the impact of its change depending on the occupancy of the car by passengers and baggage.

The exact requirements for brake fluids are presented in the PN-C-40005: 2002 standard (Polish Committee for Standardization, 2002) and the Western standards FMVSS No 116 (National Highway Traffic Safety Administration, 2011) and ISO 2005 (International Standards Office, 2005). The proper functioning of the braking system determines the properties of the brake fluid. Vehicle manufacturers recommend replacing the brake fluid every two years or after approx. 40,000 km. The fluid's purity affects the proper functioning of such systems like ABS, ASR (antiskid regulation), ESP (electronic stability program), and BA (brake assistant). Table 2 presents the required boiling point values for individual brake fluid classes.

Table 2 Required boiling point of brake fluids according to (Polish Committee for Standardization, 2002)

Brake fluid class	The boiling point of the new fluid [°C]	The boiling point of the fluid with 3.7 % water content [°C]
DOT 3	Min. 205	Min. 140
DOT 4	Min. 230	Min. 155
DOT 5.1	Min. 260	Min. 180
DOT 5	Min. 260	Min. 180

During operation of the vehicle as a result of the cooperation of individual elements of the braking system, its wear takes place. The heat released due to friction negatively influences the functioning of the car braking system, especially the friction elements and brake fluid. It has been found that during the sequence of intensive braking, the brake disc can reach a temperature of even more than 530 °C, (Lee, 1999). Excessive heat accumulation in brake linings causes the phenomenon of fading, resulting in the loss of friction properties or the occurrence of the flow phenomenon. This problem can be solved by changing the design of friction elements, e.g., by using ventilated brake discs. Another threat is the accumulation of warm energy in the brake caliper elements that causes the brake fluid temperature to increase. During the braking phase, the fluid heats up, and steam bubbles may form in it (steam cork), as a result of which the fluid transfers the lower and lower pressure force to the brake cylinder piston. This phenomenon may consequently lead to a sudden loss of braking ability.

Brake fluids based on polyglycols, glycol ethers, methylglycium borate with additions of corrosion inhibitors have highly hygroscopic properties. Water absorption changes the chemical composition and worsens the fluid's properties during operation. The increase of the water content in the liquid is associated with a decrease in the temperature of the formation of the steam cork and its boiling point. That is why it is so essential to control the quality of the brake fluid in the vehicle. The high-quality fluid helps to keep the system components in good condition and to avoid brake failure (e.g. "baking" and corrosion of the cylinders, damage to the seals of moving parts or the master cylinder). The use of new materials for the friction components of the braking system that increase the heat storage requires the use of a fluid with higher temperature parameters and more frequent control of its quality and level in the compensating tank.

The work aims to present and discuss the results of brake fluid operation tests realized on a selected group of passenger cars. The work includes testing the quality of car brake fluid based on the determination of the percentage of water content and the measurement of boiling point value in terms of the intensity of vehicle use expressed in kilometer mileage.

2 Research methodology

The brake fluid based on glycol quality tests were realized on a selected group of 32 passenger cars, at various ages and with different mileages. The research was carried out in two stages - year after year, in the same period (November-December), to obtain the total annual mileage of a given vehicle. The first stage of the research was carried out in 2017, the second in 2018. Changes in the usable properties of the fluid have been determined by the percentage of water content as well as the boiling point of the brake fluid. Subsequently, the results obtained for the measurement of the brake fluid parameters were analyzed as a function of the vehicle mileage. The tested vehicles were produced in the years 2000-2011, and the mileage values read from the odometer were in the range: 299-325 435 km.

The water content was tested using by electronic 4-diode tester (Fig. 1 (b)), and the temperature range is shown in Table 3. Boiling point measurements were made with the ATE-BFT 320 brake fluid tester (Fig. 1 (a)). In both cases, the measurement was made by immersing the measuring probe in the vehicle's compensation tank according to the instruction manual of the measuring device. The BFT 320 ATE brake fluid tester used is very precise of determining the boiling point of all types of fluids based on glycol used in vehicles.

Fig. 1 a) The brake fluid tester BFT 320 during the measurement, b) 4-diode tester

Table 3 Ranges of the boiling point of brake fluid which provide for its suitability for operation (Polish Committee for Standardization, 2002)

The color of the signaling diode	Ranges of the boiling point	Brake fluid rating
Green	Min. 205	fit
Yellow	Min. 230	fit - consider the exchange
Red	Min. 260	unfit

3 Research results

The first analysis carried out concerned about the assessment of the percentage of water content in the brake fluid. The comparison of the results of the percentage of water content in vehicles is shown in Fig. 2.

As can be seen in Fig. 2 in study 1, only for two vehicles, the result was a water content of 3 % and 4 %. In study 2, this number has doubled. It was shown that the tested vehicles in 82 % met the norm regarding the percentage of water content in the car brake fluid. After one year of operation, an approximate 10 % drop was found in vehicles with a 1 % water content in the car brake fluid. However, a slight increase in the percentage of water content in the car brake fluid of 2 % for vehicles in study 2 was obtained.

Furthermore, the vehicle population with the exact percentage of water content in the brake fluid has a downward trend in both test phases. In Study 2, the largest approx. 6 % increase in vehicles with a percentage of water content in the car brake fluid of 3 % was obtained.

Fig. 3 shows the change in the percentage of water content in the brake fluid depending on the course of the annual vehicle. Analyzing the data, it can be concluded

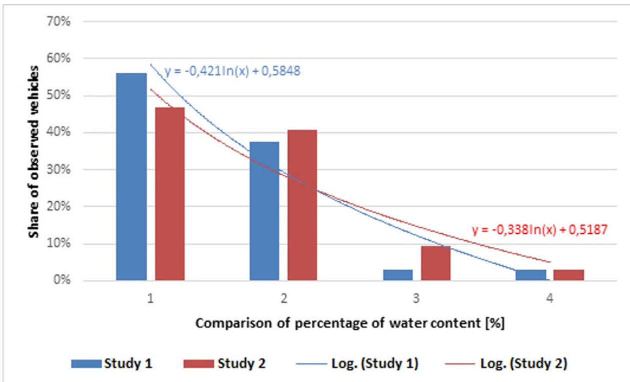

Fig. 2 Comparison of the percentage of water content in the brake fluid

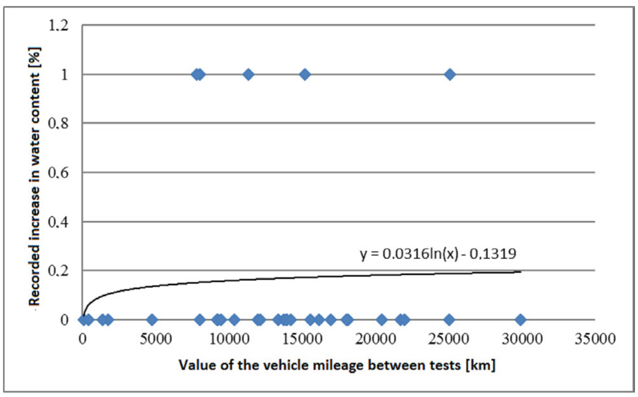

Fig. 3 An increase in the percentage of water content in the car brake fluid depending on the annual mileage

that only in 5 cases an increase in the percentage of water content in the car brake fluid was noted, i.e., its properties deteriorated by 1 %.

Fig. 4 presents the change in the boiling temperature of the brake fluid in the tested vehicles. In study 1, in the case of 2 vehicles, the boiling temperature of the car brake fluid was below 180 °C, and in these vehicles, the fluid qualifies for replacement with a new one. However, in the case of the second test, the boiling point below 180 °C was recorded for eight vehicles, and it was they who were qualified for fluid replacement. About the examination of the percentage of water content in the car brake fluid, the number of vehicles with fluid qualified for replacement after study 2, the boiling point of the fluid is twice as significant.

In Study 2, an approximate 20 % increase in the vehicle population with the boiling point of the car brake fluid in the range below 180 °C was obtained. In the next range of 180-200 °C, (the correct parameters of the fluid), also a significant increase in the vehicle population was recorded, almost 10 %. In subsequent intervals, the share of vehicles was reduced. In Study 2, no vehicle was found whose fluid boiling point would exceed 260 °C, which means that no fluid maintained high parameters in any vehicle and was aging during one year of operation.

Fig. 5 shows the change in the boiling temperature of the car brake fluid depending on the annual vehicle mileage.

Researches of the boiling temperature of the car brake fluid showed changes in the temperature value in each of the tested vehicles. Therefore, the measurement of the boiling temperature of the car brake fluid is a more precise and reliable method than the percentage determination of the water content in the car brake fluid. The analysis shows that as the mileage increases, the change in the boiling temperature of car brake fluid is also increasing, which is also evidenced by the upward trend line. The average

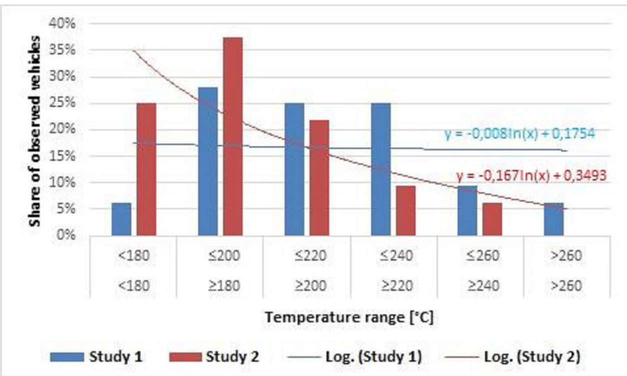

Fig. 4 Comparison of the boiling point of the car brake fluid

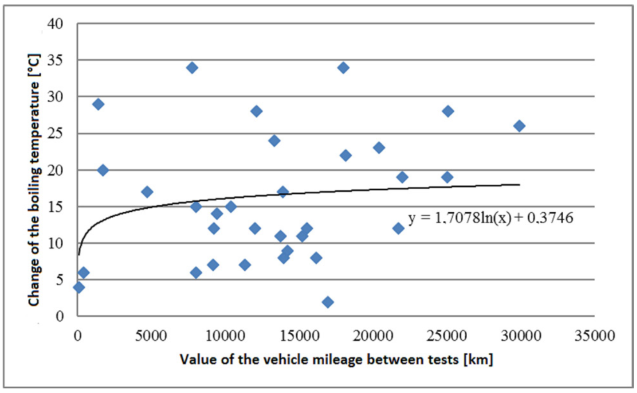

Fig. 5 Changing the value of the boiling point of the brake fluid depending on the annual vehicle mileage

change in the boiling temperature of the brake fluid in the test is 15.97 °C. It can also be noted that the high concentration of results ranges from around 10 000 km up to 15 000 km mileage of vehicles. This testifies to the more frequent use of vehicles in this mileage range.

4 Conclusion

Active safety of the car is affected by the technical condition of all structural systems that make up its structure: powertrain, chassis, steering, braking system, electric system, suspension, etc. (Droździel et al., 2014). The so-called automotive active safety systems primarily include the steering, suspension, and braking system. Monitoring selected parameters of car brake fluid and replacement at the proper time not only ensures proper function of the all braking system but also contributes to the removal of brake system defects and thus increases the safety of road traffic (Sejkorová et al., 2018). Brake fluid tests carried out have demonstrated the usefulness of the methods used to determine the changes in fluid performance. It has been shown that boiling point measurement is a more accurate method to determine the quality of the car brake fluid than the water content determining method. This is evidenced by the fact that depending on the chemical composition of the fluid (brake fluid class), the same water content causes the boiling temperature to drop to a different degree.

It was shown that in the first study, 6 % of vehicles had a liquid with weak parameters and should be replaced. In study 2, the share of vehicles with poor brake fluid quality increased to around 25 %. It should be emphasized that in the second stage of the research vehicles involved in the first test showed a fluid with wrong parameters, which indicates that drivers ignore the problem (vehicle owners). Based on the conducted studies, it can be concluded that

75 % of the tested vehicles used proper quality brake fluid. In turn, Kuranc et al. (2018) in his research, stated that only 55 % of the tested population of vehicles has fluid with the right parameters. The obtained tests are much more optimistic than the data provided by brake fluid manufacturers who claim that only in 25 % of vehicles is fluid with proper quality parameters. Brake fluid manufacturers also recommend a two-year cycle of replaced it on. The assessment of the quality of the brake fluid shows that during the two years of operation, the properties of the brake fluid deteriorate, but the replacement of the fluid may be premature.

Similarly to other investigators (Kuranc et al., 2018), it was confirmed that the higher annual mileage of the vehicle contributes to the deterioration of brake fluid parameters. In the light of the conducted tests, it is possible to recommend a higher frequency of brake fluid replacement in vehicles used in a more intensely determined by a more considerable average-year mileage. As shown in the tests, the average drop in the boiling temperature of the brake fluid was about 16 °C during the vehicle's one-year lifetime. The average boiling point in study 1 was 212.22 °C, while in study 2, it dropped to 196.25 °C.

References

Beran, E., Janik, R., Biskupski, A. (2003) "Ocena polioksyalkilenoglikoli (PAG) i modyfikacja ich struktur w aspekcie zastosowania jako bazowych olejów smarowych" (Evaluation of polyoxyalkylene glycols (PAG) and modification of their structures in terms of use as base lubricants), Przemysł Chemiczny, 82(8-9), pp. 555–558. (in Polish)

Bzura, P. (2007) "Lubricity-based estimation of the changes in the brake fluid quality", Journal of KONES Powertrain and Transport, 14(2) pp. 75–80.

Depta, M. (2013) "Estryfikacja kwasu octowego glikolem etylenowym" (Esterification of acetic acid with ethylene glycol), Przemysł Chemiczny, 92(10), pp. 1827–1829. (in Polish)

Droździel, P., Krzywonos, L., Madlenak, R., Rybicka, I. (2014) "Selected aspects of analyses of failure rates of active safety systems in buses", Communications, 16(3), pp. 114–119.

Droździel, P., Wrona, R. (2018) "Legal and utility problems of accidents on express roads and motorways", In: 2018 11th International Science and Technical Conference Automotive Safety, Casta, Slovakia, pp. 1–5.
https://doi.org/10.1109/AUTOSAFE.2018.8373315

Gechev, T., Mruzek, M., Barta, D. (2017) "Comparison of real driving cycles and consumed braking power in suburban Slovakian driving", MATEC Web of Conferences, 133, Article number: 02003.
https://doi.org/10.1051/matecconf/201713302003

Hudak, M., Madleňák, R. (2017) "The Research of Driver Distraction by Visual Smog on Selected Road Stretch in Slovakia", Procedia Engineering, 178, pp. 472–479.
https://doi.org/10.1016/j.proeng.2017.01.090

Indira, V., Vasanthakumari, R., Jegadeeshwaran, R., Sugumaran, V. (2015) "Determination of minimum sample size for fault diagnosis of automobile hydraulic brake system using power analysis", Engineering Science and Technology, an International Journal, 18(1), pp. 59–69.
https://doi.org/10.1016/j.jestch.2014.09.007

International Standards Office (2005) "ISO 4925:2005(E) Road Vehicles – Specification of Non-Petroleum-Base Brake Fluids for Hydraulic Systems", ISO, Geneva, Switzerland.

Jakóbiec, J. (2006) "Badania stanowiskowe płynów hamulcowych" (Work tests of brake fluids), The Archives of Automotive Engineering, 1, pp. 63–78. (in Polish)

Jegadeeshwaran, R., Sugumaran, V. (2015) "Fault diagnosis of automobile hydraulic brake system using statistical features and support vector machines", Mechanical Systems and Signal Processing, 52-53, pp. 436–446.
https://doi.org/10.1016/j.ymssp.2014.08.007

Jurecki, R. S., Stańczyk, T. L., Jaśkiewicz, M. J. (2017) "Driver's reaction time in a simulated, complex road incident", Transport, 32(1), pp. 44–54.
https://doi.org/10.3846/16484142.2014.913535

Khamidullin, R. F., Bashkirtseva, N. Y., Abdullin, A. I., Akhmetov, I. I. (2006) "Polyethylene glycol monomethyl ethers as the main component of brake fluid", Russian Journal of Applied Chemistry, 79(11), pp. 1853–1856.
https://doi.org/10.1134/S107042720611022X

Kuranc, A., Zając, G., Szyszlak-Bargłowicz, J., Słowik, T., Vrabel, J., Šarkan, B., Caban, J., Makarski, P. (2018) "Boiling point of the brake fluid based on alkyl ethers of alkylene glycols in vehicles being in use", Przemysł Chemiczny, 97(12), pp. 2102–2105.
https://doi.org/10.15199/62.2018.12.17

Lee, K. (1999) "Numerical Prediction of Brake Fluid Temperature Rise During Braking and Heat Soaking", SAE Technical Paper, Article number: 1999-01-0483.
https://doi.org/10.4271/1999-01-0483

Levulyte, L., Baranyai, D., Torok, A., Sokolovskij, E. (2016) "Bicycles' Role In Road Accidents A Review Of Literature", Transport and Telecommunication Journal, 17(2), pp. 122–127.
https://doi.org/10.1515/ttj-2016-0011

Limpert, R. (2015) "Brake design and safety", SAE International, Warrendale, PA, USA.

Lizbetin, J., Stopka, O., Kurenkov, P. V. (2019) "Declarations regarding the energy consumption and emissions of the greenhouse gases in the road freight transport sector", The Archives of Automotive Engineering – Archiwum Motoryzacji, 83(1), pp. 59–72.
https://doi.org/10.14669/AM.VOL83.ART4

National Highway Traffic Safety Administration (NHTSA) (2011) "49 CFR 571.116 - Standard No. 116 Motor Vehicle Brake Fluids", NHTSA, Washington, DC, USA.

National Road Safety Council (2013) "Narodowy Program Bezpieczeństwa Ruchu Drogowego 2013-2020" (National Road Safety Program 2013-2020), [pdf] Warsaw, Poland (in Polish), Available at: http://www.krbrd.gov.pl/files/file/NP-BRD-2020_przyjety_przez_KRBRD.pdf [Accessed: 06 May 2019]

Pavlov, A. V., Kudelnikova, S. P., Vicharev, A. N. (2015) "On the corrosion resistance of half-metallic composite brake pads for railroad cars", Journal of Friction and Wear, 36(2), pp. 123–126. https://doi.org/10.3103/S1068366615020130

Polish Committee for Standardization (2002) "PN-C-40005:2002 Płyny hamulcowe do pojazdów silnikowych" (Brake fluids for motor vehicles), PKN, Warsaw, Poland. (in Polish)

Poliak, M., Mrnikova, M., Simurkova, P., Medvid, P., Poliakova, A., Hernandez, S. (2018) "Social law in road transport like tool safety road transport", In: 2018 11th International Science-Technical Conference Automotive Safety, Casta, Slovakia, pp. 1–7. https://doi.org/10.1109/AUTOSAFE.2018.8373317

Poskrobko, H., Bekierz, G., Celejewski, J., Wasilewski, J. (1994) "Właściwości i możliwości zastosowania monoalkilowych eterów (C 1 ÷ C 4) glikoli etylenowych" (C-1 to C-4 Monoalkylic Ethers of Ethylene Glycols - Properties And Possible Applications), Przemysł Chemiczny, 73(4), pp. 125–127. (in Polish)

Rimkus, A., Matijošius, J., Bogdevičius, M., Bereczky, A., Török, Á. (2018) "An investigation of the efficiency of using O_2 and H_2 (hydrooxile gas-HHO) gas additives in a ci engine operating on diesel fuel and biodiesel", Energy, 152, pp. 640–651. https://doi.org/10.1016/j.energy.2018.03.087

Sawase, K., Sano, Y. (1999) "Application of active yaw control to vehicle dynamics by utilizing driving/ breaking force", JSAE Review, 20(2), pp. 289–295.

Sejkorova, M. (2013) "Determination of Total Alkalinity of Motor Oil by FTIR Spectroscopy", Chemical Letters, 107(8), pp. 643–647.

Sejkorova, M., Senkyr, J. (2017) "IR Spectrometry as Alternative Potentiometric Determination of Total Base Number Engine Oils", In: 37th International Conference on Modern Electrochemical Methods, Jetrichovice, Czech Republic, pp. 172–176.

Sejkorová, M., Verner, J., Sejkora, F., Hurtová, I., Senkýř, J. (2018) "Analysis of operation wear of brake fluid used in a Volvo car", In: Transport Means – Proceedings of the International Conference 2018, Trakai, Lithuania, pp. 592–596.

Sergienko, V. P., Tseluev, M. Y., Kolesnikov, V. I., Sychev, A. P., Savonchik, V. A., Yanuchkovskii, V. I. (2013) "Studying thermal state of friction pairs of multidisc brake", Journal of Friction and Wear, 34(6), pp. 421–428. https://doi.org/10.3103/S106836661306010X

Sipos, T. (2017) "Spatial Statistical Analysis of the Traffic Accidents", Periodica Polytechnica Transportation Engineering, 45(2), pp. 101–105. https://doi.org/10.3311/PPtr.9895

Skrúcaný, T., Synák, F., Semanová, S., Ondruš, J., Rievaj, V. (2018) "Detection of Road Vehicle's Centre of Gravity", In: 2018 11th International Science and Technical Conference Automotive Safety, Casta, Slovakia, pp. 1–7. https://doi.org/10.1109/AUTOSAFE.2018.8373334

United Nations Economic Commission for Europe (2016) Uniform Provisions Concerning the Approval of Vehicles of Categories M, N, and O about Braking. UN ECE, Regulation No 13, (2016/194).

Vališ, D., Žák, L., Pokora, O. (2018) "Perspective approach in using anti-oxidation and anti-wear particles from oil to estimate residual technical life of a system", Tribology International, 118, pp. 46–59. https://doi.org/10.1016/j.triboint.2017.09.017

Walczak, M., Pieniak, D., Zwierzchowski, M. (2015) "The tribological characteristics of SiC particle reinforced aluminium composites", Archives of Civil and Mechanical Engineering, 15(1), pp. 116–123. https://doi.org/10.1016/j.acme.2014.05.003

Zöldy, M. (2018) "Legal Barriers of Utilization of Autonomous Vehicles as Part of Green Mobility", In. International Congress of Automotive and Transport Engineering, Cluj-Napoca, Romania, pp. 243–248. https://doi.org/10.1007/978-3-319-99409-8-29