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Rheological Properties of New and used Brake Fluids

Marta Wójcik [1,*]

[1] Rzeszow University of Technology, Department of Materials Forming and Processing, 8 Powstańców Warszawy Ave., 35-959 Rzeszów, Poland

Abstract: The operating as well as energy-efficiency criteria determine specific rheological parameters of car's fluids, including brake fluids. The aim of this paper is the determination of rheological properties of new and used DOT 3 brake fluid with the use of rotational cone-plate rheometer. The viscosity and flow curves of brake fluids were determined at ≈ 20oC and ≈ 80oC. The results of tests showed differences between new and used brake fluids. It was noted that used brake fluid was characterized by lower viscosity and higher density. The viscosity was constant in the whole range of a shear rate. Additionally, the decrease of viscosity with the increase of temperature was also observed. The linear dependence between shear rate and shear stress for both tested brake fluids was noted. The aforementioned relationship enables to classify both new and used brake fluids as Newtonian liquids.

Keywords: *brake fluids; viscosity; flow curves; rheology; Newtonian liquid.*

1. Introduction

One of the most important aspects in automobile industry is travel safety. Due to the requirements concerning the automobile safety, highly qualified mobile fluids are used in new cars. Special requirements also apply brake fluids. Brake fluids are solutions of glycol esters and polyesters with the addition of corrosion inhibitors, lubricants as well as hygroscopic substances [1]. The average brake fluid contains 70-80% of base liquid, 20-30% of lubricants and 1-5% of other additives [2]. The presence of brake fluid in a braking system ensures the low consumption of its moving parts. Additionally, the addition of corrosion inhibitors protects metal elements of braking system.

The most popular classification of brake fluids is DOT (Department of Transportation) which is written in FNMVSS No. 116 [3], ISO 4925-79 [4] and SAE J1703 [5] standards (Table 1). These classifications includes 4 types of brake fluids (DOT3, DOT4, DOT5.1 and DOT5) for which basic parameters, such as boiling point or chemical composition, are determined. The first three fluids indicate hygroscopic properties and might be mingle with water. DOT5.1 is non-hygroscopic and do not be mixed both with water as well as other brake fluids. The most popular and most commonly used are DOT3 and DOT4 [6].

The research of brake fluids includes the determination of their low- and high temperature properties, corrosion resistance, abrasion resistance, rheological characteristics and the overall stability. In this research, it was focused on the examination of basic rheological properties. Rheology is a branch of continuum mechanics which investigates the deformation of different real substances under external stresses [7]. It examines the relationship between stress and shear rate. The knowledge concerning the rheological parameters of fluids and gases is essential

*** Corresponding author:** Marta Wójcik, ***E-mail address:*** *m.wojcik@prz.edu.pl*

Tab. 1: *The degree of risk severity.*

Parameter	*Standard*					
	SAE J1703	*ISO 4925-79*	*FNMVSS No. 116*			
			DOT3	*DOT4*	*DOT5*	*DOT5.1*
boiling temperature [°C]	≥ 205	≥ 205	≥ 205	≥ 230	≥ 260	≥ 260
kinematic viscosity at 40°C [mm²/s]	≤ 1800	≤ 1500	≤ 1500	≤ 1800	≤ 900	≤ 900
kinematic viscosity at 100°C [mm²/s]	≥ 1.5					

for designing and exploitation of equipment associated with their storage and transport [8].
Most of the rheological research is related with determination of viscosity and flowability. According to Slatter [9], research of rheological properties should include three main steps: (1) measurement of viscosity, (2) selection of proper rheological model and (3) correlation between different parameters. The viscosity is defined as shear stress dived into shear rate (1) [10]. It might be defined as a resistance which occurs during the movement of fluid layers (Fig. 1). This phenomenon occurs during the laminar flow of real liquid in a wire. Viscosity is not a constant value and it depends on temperature [11]. In most cases, the viscosity decreased with the increase of temperature. Detailed information concerning the rheology of fluids, solids as well as gases is included in [12-14].

$$\eta = \frac{\tau}{\dot{\gamma}} \qquad (1)$$

where: τ is a shear stress and $\dot{\gamma}$ is a velocity of shearing.

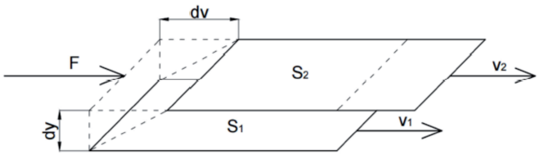

Fig. 1: *The shear in liquids.*

The real liquids might be classified as Newtonian or non-Newtonian fluids. Automobile liquids exhibit properties of Newtonian fluid [15]. For this model, the coefficient of dynamic viscosity at a given temperature and pressure does not depend on the shear rate and indicates the constant value. They meet the Newtonian equation (2) and therefore, the stresses depend on the shear rate [16]. The relationship between shear rate and shear stress might be described by means of straight line (Fig. 2). Moreover, Newtonian liquids do not indicate so called "memory effect" and thixotropic behavior [10]. More information related with rheological models is included in [17-19].

$$F = \eta \cdot \frac{dv}{dy} \cdot S \qquad (2)$$

where: η is a coefficient of dynamic viscosity, S is a cross-section of a wire, dv is a speed difference between liquid layers, dy is a distance between liquid layers.

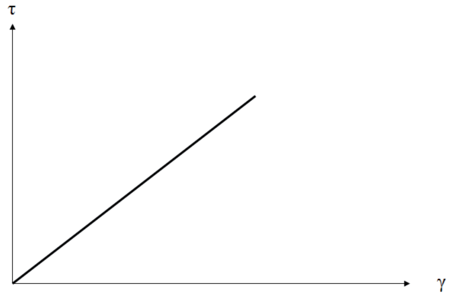

Fig. 2: *The flow curve for Newtonian fluid.*

Most papers are mainly related to rheological properties of automobile oils. Zadorozhnaya et al. [20] examined the viscosity of different modern motor oils. They observed the decrease of viscosity with the increase of shear rate. Thapliyal and Thakre [21] determined the viscosity and the flow behavior of commercial engine oils. They noted that the shear stress of oils increased with the elevation of shear rate. The viscosity was not constant and decreased as the shear rate increased. But the research concerning the rheological characteristic of brake fluids is relatively poor.

The current study aimed to characterize the rheological properties of new and used brake fluids. The density, viscosity and flow curves of liquids were examined. By means of that, the change of rheological properties of brake fluids before and after exploitation was determined and compared. The findings provide useful information concerning the change of rheological characteristics of brake fluids and might be helpful during the exploitation of vehicles.

2. Materials and Methods

In this research, samples of new and used DOT3 brake fluids produced by BORYSZEW ERG Company were applied (Figure 2). The sample of used brake fluid was derived from a braking system of car after a three year of exploitation. Physical and chemical properties of DOT3 brake liquid, as specified by the manufacturer, are presented in Table 2.

The sample of used brake liquid was derived from a braking system of car after two years of exploitation. New brake fluid was characterized by yellow colour. By contrast, the sample of used brake liquid was brown. It is a result of the absorption of chemical compounds, including heavy metals from a braking system of vehicles [22].

Fig. 3: *Samples of new and used brake fluids.*

Tab. 2: *Selected physical and chemical properties of DOT3 brake fluids (stated by the producer) [23].*

No.	Parameter	Unit	Value
1.	colour	-	yellow
2.	smell	-	weak and sweet
3.	pH	-	7.0 - 11.5
4.	freezing point	°C	< -50
5.	melting temperature	°C	-
6.	boiling point	°C	> 230
7.	flash-point	°C	> 110
8.	auto-ignition temperature	°C	> 324
9.	density	g/cm³	1.02 – 1.06
10.	solubility	-	in water and in ethanol

The density of new and used brake fluids were examined with the use of pyconmeter method. In this research, glass pycnometer with a volume of 100 cm^3 was applied. The measurement was done at room temperature (≈ 20°C). As a standard solution, water was used. The density of brake fluids (ρ_c) was calculated in line with Eq. 3.

$$\rho_c = \rho_w \frac{m_c}{m_w} \tag{3}$$

where: ρ_w is a density of water, m_c is the mass of brake fluid and m_w is the mass of water.

The flow curves and viscosity of brake fluids were determined with the use of the rotation method. In a laboratory research, a rotational rheometer (Physica MCR301, Aston Paar Company, Austria) was applied. The constant shear (C_{SR}) and the constant shear stress (C_{SS}) for the rheometer were 6.12 min/s and 30.91 Pa/mNm, respectively. In this research, the cone-shape spindle-type micrometer with a diameter of 50 mm and the angle of 1o was used.

The rheology of new and used brake fluids were investigated using cone-plate system at the measuring gap of approximately 48 μm. The viscosity and the flow curves were made with a logarithmic variable shear profile for the increasing shear rate in the range of 1 - 500 1/s in 100 seconds. The measurement was carried out at two temperatures: 20 and 80°C. By means of that, properties of brake fluids at room as well as high temperature were investigated.

3. Results and Discusion

Firstly, the density of samples was determined. The density of new and used brake fluids was 1.10 and 1.13 g/dm^3, respectively. It was noted that both samples indicated similar density. The small change of density should be a characteristic for brake fluids for which the stability of physical parameters is necessary. In comparison to data given by the manufacturer (see Table 2), it was achieved slightly higher results.

The rheology research enables to investigate the shear stress of brake fluids before and after exploitation in cars. The flow curves for samples of new and used brake fluids are shown in Figure 4. It was noted that the shear stress (τ) increased linearly as the shear rate (γ) increased. This relationship was observed for both tested samples of brake fluids. This dependence confirms that both new and used brake fluids behaved like Newtonian liquid.

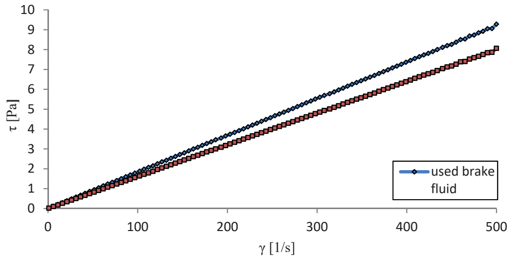

Fig. 4: *Flow curves for samples of new and used brake fluids.*

Higher values of shear stress were noted for used brake fluids in the whole range of shear rate. Depending on the shear rate, the differences between considered samples were greater or less. The samples of new and used brake fluids indicated similar shear stress for low values of shear rate (< 50 1/s). The differences were more visible for higher values of shear rate. For the highest shear rate (500 1/s), the shear stress for new and used brake fluids was 8.06 and 9.28 Pa, respectively.

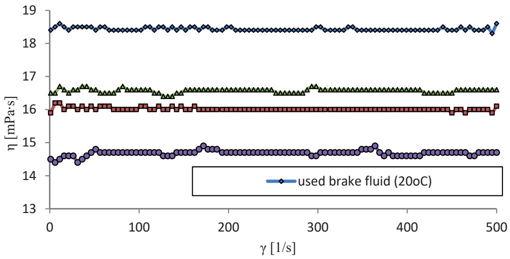

Fig. 5: *The viscosity of samples of new and used brake fluids at ≈ 20°C and ≈ 80°C.*

In order to describe better the rheological properties of DOT3 brake fluids, the viscosity (η) was examined. The obtained results are presented in Figure 5. The viscosity had a nearly constant value for a whole range of shear rate at certain temperature. It was noted for both samples. The value of the aforementioned parameter for new and used brake fluids at 20°C was approximately 16.0 and 18.4 mPa·s, respectively. The viscosity for higher tested temperature (80°C) was approximately 14.7 for new brake fluid and 16.9 mPa·s for used liquid. It was noted that the viscosity of used brake liquid was higher than for new liquid. According to Waliszewski [24], the increase of a viscosity of brake fluids after exploitation might be a result of their oxidation. The influence of temperature on the viscosity of brake fluids was also reported. The viscosity decreased as the temperature increased. It is a characteristic relationship for most liquids associated with the increase of the energy of particles movement. More particles have higher energy than activation energy as the temperature increases. For this reason, the viscosity has a lower value in higher temperatures [19].

4. Conclusions

In this paper, the density as well as the rheological characteristics of brake fluids before and after exploitation were investigated. The conclusions that are drawn as follows:

1. The exploitation of brake fluids influences their rheological characteristics.

2. The density of new DOT3 brake fluid was 1.10 g/cm³. For used brake liquid, this parameter has a value of 1.13 g/cm³. It was noted that samples of new and used DOT3 brake fluids indicated similar value of density.

3. The shear stress increased with the increase of the shear rate for both tested samples of brake fluids. It suggests that brake fluid behaves like a Newtonian liquid.

4. The exploitation of brake fluid had an impact on the viscosity. It was noted that the viscosity had
a higher value for a sample of used brake fluid.

5. The relationship between the viscosity and the shear rate was not noted. The viscosity had a constant value in the whole range of shear rate. The sample of used DOT3 brake fluid was characterized by higher viscosity.

6. The viscosity decreased with the increase of temperature.

The results of laboratory tests confirm the validity of further research concerning the rheological characteristics of brake fluids. Further tests will focus on the determination of viscosity and flow curves in a range of both low and high temperatures. In the future, the rheology of other types of brake fluids will be also investigated.

Acknowledgments

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References and Notes

[1] ***Jakóbiec, J.*** (2006). Stationary research on brake fluids. Archiwum Motoryzacji, 1, 63-78.

[2] ***Mansell, A.*** (2018). DOT Brake fluid vs. Mineral Oil- and the Win-

ner is …, from http://www.epicbleedsolutions.com/blog/dot-brake-fluid-vs-mineral-oil/, date of access: 29.11.2018.
[3] 49 CFR 571.116 - Standard No. 116 – Motor vehicle brake fluids.
[4] ISO 4925-79:2005 Road vehicles - Specification of non-petroleum-base brake fluids for hydraulic systems.
[5] J1703_201208 – SAE Standard - Motor Vehicle Brake Fluid.
[6] ***Brzeziński, M.*** (2013). Test płynów hamulcowych: sprawdzamy który jest najlepszy, from https://www.auto-swiat.pl/porady/eksploatacja/test-plynow-hamulcowych/80v9sbc, date of access: 29.11.2018.
[7] ***Ghezzehei, T.A., Or, D.*** (2001). Rheological Properties of Wet Soils and Clays under Steady and Oscillatory Stresses. Soil Science Society of America Journal, 65, 624-637.
[8] ***Bird, R.B., Steward, W.E., Lightfoot, E.N.*** (1979). Transport Phenomena. Wiley, USA.
[9] ***Slatter, P.*** (1997). The Rheological characterization of sludges. Water Science Technology, 36(11), 9-18.
[10] ***Eshtiaghi, N., Markis, F., Yap, S.D., Baudez, J.C., Slatter, P.*** (2013). Rheological Characterisation of Municipal Sludge: A Review. Water Research, 47(15), 5493-5510.
[11] ***Ryoo, R., John, M.S., Eyring, H.*** (1980). Temperature and pressure dependence of viscosity of quantum liquid 4He according to significant structure theory. Proceedings of the National Academy of Sciences of the United States of America, 77(8), 4399-4402.
[12] ***Drabent, R.*** (2003). Podstawy reologii. Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego, Olsztyn.
[13] ***Isayev, A.I., Malkin, A.I.*** (2006). Rheology: Concepts, Methods, and Applications. Chemtec Publishing, Canada.
[14] ***Tanner, R.I.*** (2000). Engineering Rheology. Oxford University Press, United States.
[15] ***Modzelewska, D., Dołhańczuk-Środka, A., Ziembik, Z.*** (2016). Studies of Kefir Rheological Properties, Proceedings of ECOpole, 10(1), 219-237.
[16] ***Fridtjov, I.*** (2014). Rheology and Non-Newtonian Fluids. Springer International Publishing Switzerland, Basel.
[17] ***Dziubiński, M., Kiljański, T., Sęk, J.*** (2009). Podstawy reologii i reometrii płynów. Wydawnictwo Politechniki Łódzkiej, Łódź.
[18] ***Hutton, J.F., Walters, K.*** (1989). An Introduction to Rheology. Elsevier, Amsterdam.
[19] ***Boger, D.V., Walters, K.*** (1993). Rheological Phenomena in Focus. Elsevier, Amsterdam.
[20] ***Zadorozhnaya, E., Levanov, I., Oskina, O.*** (2016). Study of HTHS Viscosity of Modern Motor Oils. Procedia Engineering, 150, 602-606.
[21] ***Thapliyal, P., Thakre, G.D.*** (2017). Correlation Study of Physicochemical, Rheological, and Tribological Parameters of Engine Oils. Advances in Tribology, 2017, 1-12.
[22] ***Nunney, M.J.*** (1988). Light & Heavy Vehicle Technology. Springer, Oxford.
[23] ***Boryszew ERG*** (2015). DOT3 brake fluid – safety data sheet, from https://www.boryszewerg.com.pl/upload/file/Plyn_hamulcowy_DOT_3.pdf, date of access: 29.11.2018.
[24] ***Diller, D.E., Hanley, H.J.M., Roder, H.M.*** (1970). The density and temperature dependence of the viscosity and thermal conductivity of dense simple fluids. Cryogenics, 10(4), 286-294.

Biographical notes

Marta Wójcik, PhD. Eng., *(1991). She is an assistant professor on the Department of Materials Forming and Processing at Rzeszow University of Technology. In 2015, she graduated with a Master's degree at Rzeszow University of Technology. In 2018, she received a doctoral degree in the field of environmental engineering. She is an author of several papers associated with the environmental and mechanical engineering. Her academic research is related with sewage sludge and waste management, recycling and fuzzy sets theory in engineering applications.*