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Analysis of Operation Wear of Brake Fluid Used in a Volvo Car

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Abstract

To enable the quality and productivity of transport processes, it is becoming increasingly important to ensure the use of safe and reliable means of transport. The automobile's circuit brake system relies on the incompressibility of brake fluid based on glycol when transmitting power. Fluid operating above its boiling point contains gas which is highly compressible. This paper presents the results of the wet boiling point temperature assessment of the DOT 4 Plus brake fluid used in Volvo cars. By investigation the brake fluid of 48 cars during service inspection, we found that boiling point was within the interval 222–238° C, with a 95% probability i.e. higher than the manufacturer specified wet boiling point of 180° C. Using infrared spectrometry it was verified that the brake fluid is highly hygroscopic.
KEY WORDS: *brake fluid, boiling point, reliability, operation wear, fluids ageing, water content*

1. Introduction

The most used system for control of brake systems of cars and light commercial vehicles is the automobile dual circuit brake system. In this system, the brake fluid (BF) transfers force through pressure. This basic braking system is often equipped with additional electronic components such as Anti-lock Brake System (ABS), Anti-Slip Regulation (ASR), Electronic Data Systems (EDS), Electronic Stability Programme (ESP) etc. [1, 2].

The basic requirements for brake fluid are following: (1) to transfer the pressure acting on the main brake cylinder through the brake pedal to the brake cylinders of the vehicle's wheels; (2) lubricate and seal the entire hydraulic system; (3) protect from corrosion; (4) cool of parts with high temperature etc.

For the brake fluids production must meet industry standards. Automotive sectors across the world use several different standards. The most well-known is the US Standard FMVSS CFR 571.116, which uses the DOT (Department of Transportation) or SAE J 1703f specification, the ISO 4925 is used in Europe [3].

For the purpose of efficient transfer of force from a brake pedal to the brake pads the brake fluid must be incompressible, i.e. no free space between the molecules. The external force is thus transferred directly to the compression of chemical bonds. For this reason, the boiling point temperature must be sufficiently high; the temperature increases due to strong or repeated braking.

Because oil damages rubber seals and hose of a braking system, the brake fluids are not produced from crude oil usually. Nowadays overwhelming majority produced brake fluids are on based hygroscopic polyglycol ethers/borate esters [4, 5] (DOT 3, DOT 4, DOT 5.1). However, mineral oil-based fluids (Citroën liquide hydraulique minéral LHM) and a silicone oil (DOT 5) are also produced. The glycol, glycol ether borate esters based brake fluids represent more than 95% of the world market, while the silicone-based brake fluids represent less than 5% of the global market [4]. From the operational and safety point of view, the most important physicochemical parameters of the glycol brake fluid are viscosity [6], boiling point and pH [4]. The term for boiling point designation is the equilibrium reflux point (ERPB). An important indicator of the quality of the new brake fluid is a dry boiling point which represents the boiling point of brake fluid to the weight percent water content max. 0.2%. This value guaranteed by the brake fluid manufacturer. Wet boiling point (ERBP wet) brake fluid corresponding to a weight percentage of water content of about 3.5%. If brake fluid achieved the value of wet boiling point, must be carried out exchange of brake fluid. In operational is air humidity absorbed into brake fluid mainly through cap brake fluid reservoir [7]. The higher water content in the brake fluid gradually deteriorates the function of the braking system until it fails. Also, decreasing lubricate ability of brake fluid and cause corrosion metal parts [8, 9].

Nowadays physical (Equilibrium Reflux Boiling Point), electrical (specific conductivity, permittivity) or optical (refractometry, spectrometry) methods are used to estimate the boiling point of brake fluid. Physical method to determine ERPB is standardized and measures boiling point of brake fluid directly under controlled conditions. The method cannot be used in daily practical work due to difficulty and need a large amount of samples. This amount can be the total volume of brake fluid reservoir. Furthermore, the heated sample cannot be further to use because of chemical reactions which were done at high temperatures during the analysis. Electrical and optical methods are non-destructive methods that indicate boiling point indirectly. They use the dependence between the brake fluid water content and its other properties (electrical conductivity, permittivity, refractive index, and light absorption). Barabas et al. [10] compared conduction and capacity methods to estimate boiling point of brake fluids on based glycol. They ascertained that capacity method ensures more accurate results because conduction method is strongly affected by water conductivity. Mogami [11] described the new method for measure boiling point of the small amount of brake fluid using thermocouple; the accuracy of the method was ± 3°C.

The paper presents the results from long-term testing operational wear of brake fluid used in Volvo cars. During the technical inspection of cars were determined water content in brake fluid by the Alba Diagnostics set. The results were statistically evaluated. In the experiment, the FTIR spectrometry method was used to control the absorption of air humidity by the brake fluid over time.

2. Materials and Methods

For 48 passenger cars (different types) of the renowned Swedish Volvo factory were evaluated the current DOT 4 Plus boiling point during the regular service inspections. The physico-chemical parameters of the brake fluid have been identified from safety data sheet and are shown in Table 1. The table shows that the boiling point of the brake fluid should not be lower than 180°C. It is corresponds to the wet boiling point for this type of brake fluid, ie the boiling point of the brake fluid that absorbed 3.5% of the water.

Table 1

The physico-chemical parameters of the brake fluid

type of brake fluid	DOT 4 Plus
color	light yellow
dry boiling point	280°C
wet boiling point	180°C
mass density at 15°C	1070 $kg.m^{-3}$
viscosity at -40°C	1500 $mm^2.s^{-1}$

The boiling point was evaluated by Alba diagnostics. It is a high quality and accurate measuring instrument used to determine the boiling point of liquids based on glycol. The instrument allows measuring in a vehicle's expansion vessel or test cup that is part of the meter's accessories. Fig. 1 shows the realized measurement. For the analysis was taken approximately 20 cm^3 of the brake fluid sample into the test cup. The Alba diagnostics has been connected to an external power supply.

Fig. 1 Measure the boiling point of the brake fluid with the Alba diagnostics

The experimentally determined data were statistically processed in Statistica. Descriptive statistics were expressed. The hypotheses were tested by Student's t-test. It is a test of the mean value of one selection of one homogeneous group. The tested one-sample t-test statistics have the form (1):

$$t = \frac{\overline{x} - \mu_0}{s}\sqrt{n}\ , \qquad (1)$$

where t - one-sample t-test statistics; $\overline{x}$ - arithmetic mean; μ_0 - expected value; s - standard deviation; n - number of measurements.

Test statistics were consequently compared with the critical limits. The critical region has the form $K = \{|t| > t_{\alpha\ (n-1)}\}$. If the inequality was valid for the examined data then we rejected the zero hypothesis otherwise we do not reject it.

The ability of the brake fluid to absorb air humidity over time was assessed by the infrared spectrometry (IR spectrometry) method. The measurement was performed by FTIR-ATR (Fourier transfer infrared technic-Attenuated total reflection) technique at half-hour intervals by scanning the infrared spectra of the new DOT 4 Plus brake fluid deposited on the ZnSe crystal.

3. Results and Discussion

Verification operation wear of brake fluids expressed as a wet boiling point were evaluated at 48 samples of brake fluids taken from different types of Volvo cars. Cars were subjected to regular service checks according to the manufacturer prescribed after a certain number of kilometers or after a period of one year. Table 2 shows the results of the testing wet boiling point from different car types of company Volvo.

Table 2

Values from the measurement of boiling point

Type of vehicle	wet boiling point [°C]	Type of vehicle	wet boiling point [°C]
S40	255	V70	252
V70	228	V70	259
V50	194	V70	248
XC90	202	S60	188
XC70	246	XC90	245
S80	226	XC90	226
XC90	202	XC90	236
V70	220	C30	252
S80	250	S80	275
V70	248	XC90	248
S60	214	S60	202
XC90	148	XC70	172
XC60	248	XC90	222
S60	180	XC90	248
XC90	259	S40	180
S80	248	XC70	252
XC90	192	S40	271
V70	226	V50	244
XC70	240	S80	220
XC70	248	V70	208
XC90	263	XC90	230
XC90	246	XC90	214
XC60	252	S40	252
S80	238	S80	234

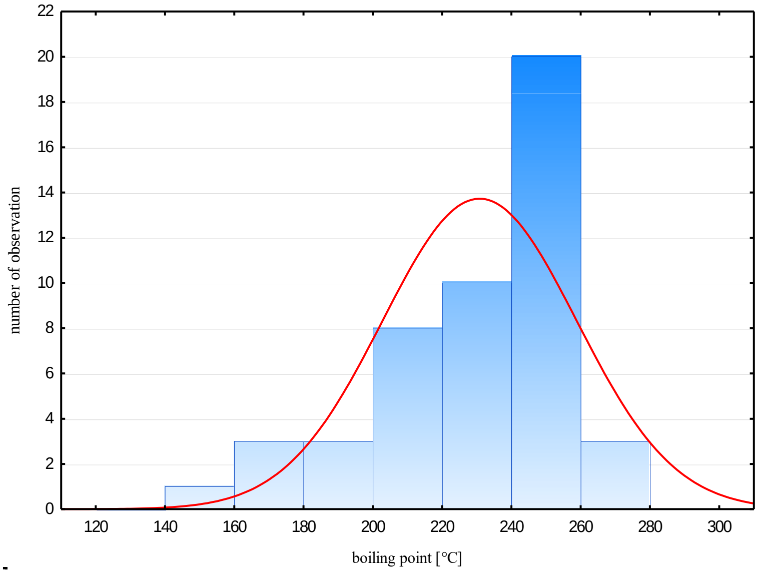


Fig. 2 Shapiro-Wilk Test of normality

The Volvo manufacturer recommends replacing the brake fluid every second year from the date of operational. Brake fluid (DOT 4 Plus) was used in the monitored cars. The boiling point (see Table 1) should not fall below 180°C, which is the wet boiling point of the brake fluid intended by the manufacturer. Based on the above, the following hypotheses were expressed and tested:

H0: The boiling point of the brake fluid reaches value of 180°C after two years of operation.

H1: The boiling point of the brake fluid is after two years of operation > 180°C

The use of statistical tests is conditional on the type of distribution. The normality of the data was verified by Shapiro-Wilk's (S-W) test [12], see Fig. 2. Shapiro-Wilk's test was S-W = 0.9229 at the significance level p = 0.0038. Fig. 2 shows that the measured values slightly deviate from the assumption of data normal distribution. When testing a larger data set ($n \geq 30$) due to the validity of the central limit clause, the failure to fulfill the assumption is not a problem. Given that in the present case the data set tested was n = 48, a one-sample Student t-test was selected for testing the hypothesis.

Descriptive statistics are shown in Table 3 from the surveyed group of the 48 samples brake fluid taken from Volvo cars.

Table 3

Descriptive statistics for the boiling point of 48 samples brake fluids

variable	$\bar{x}$	median	minimum	maximum	s	variation coefficient
	230°C	238°C	148°C	275°C	28°C	12°C

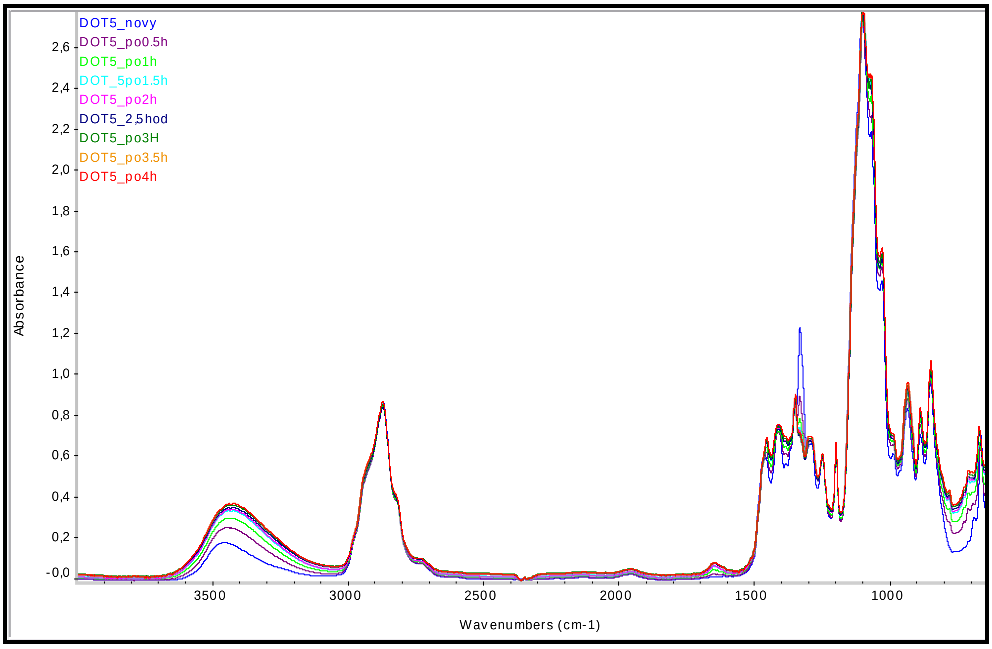
The one-sample statistical t-test was tested at a significance level of α = 0.05. The results of these statistics are shown in Table 4.

Table 4

Results of t-test

variable	confidence interval -95%	confidence interval +95%	reference value	t	degrees of freedom	p
	222°C	238°C	180°C	12,4718	47	0,0000

Table 4 shows the value of the statistics t- and p-test for the statistical significance of the hypotheses tested. the p-value is less than the chosen 5% level of significance of the test, ie the zero hypothesis is rejected at a significance level of 0.05. With a 95% probability, the actual boiling point will be between 222-238°C. It is clear that the Brake fluid (DOT 4 Plus) to comply with the requirement of the Volvo car manufacturer after two years. The boiling point is higher than the indicated boiling point (180°C) by the brake fluid manufacturer. Lee in the study [13] states that increasing vehicle speeds or kilometers have a significant effect on the water content in brake fluids. Caban et al. in their study [5] have reached a conclusion that in the case of low-kilometers vehicles without excessive load is the possibility of prolonging the brake fluid exchange interval.



Legend: the new brake fluid spectrum; BF spectrum after 0.5 hod; BF spectrum after 1 hod; BF spectrum after 1.5 hod; BF spectrum after 2 hod; BF spectrum after 2.5 hod; BF spectrum after 3 hod; BF spectrum after 3.5 hod; BF spectrum after 4 hod

Fig. 3 IR spectra of the new brake fluid during the half-hour periods

Inasmuch as the brake fluid boiling point is dependent on the amount of absorbed air humidity, therefore, the IR spectrum of the new DOT 4 Plus brake fluid was measured immediately after it was opened. The brake fluid was then left on the measuring crystal, and the infrared spectra were gradually scanned at half-hourly intervals within four hours (see Fig. 3). The primary water absorption area is located in the wavelength region 3050–3650 cm^{-1}, the secondary absorbent area corresponding to –OH bonds is in the range about 1600–1700 cm^{-1}.

Fig. 3 shows that after opening a new brake fluid package is humidity from the air absorbed immediately. The most striking increase water content in brake fluid is within two hours after opening the original brake fluid package.

4. Conclusions

Monitoring selected parameters of brake fluid and replacement at the proper time not only ensures proper function of the braking system but also contributes to the removal of brake system failure and thus increases the safety of road traffic. Based on the tests of the boiling point of the brake fluid DOT 4 Plus that used in Volvo cars was found that recommended two years exchange interval is set properly. By infrared spectrometry was verified that the brake fluid is highly hygroscopic after the opening of the original packaging. Garages technician staff should take extra care to ensure immediately closed bottle with the brake fluid after when the new brake fluid added to the car.

Acknowledgments

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