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ASSESSMENT OF LUBRICITY AND SORPTIVE PROPERTIES OF OILS BY INDIRECT METHOD

Key words

Tribology, lubricity, physical chemistry, chemical engineering.

Summary

This paper presents the results of experimental investigations of the lubricity and sorptive properties of selected gear oils. Four base gear oils with the same kinematic viscosity were investigated comparatively. These oils contained different quantities of a lubricity additive (Additin RC2515). The lubricity properties of the oils were tested according to ASTM D2596-69, ASTM D2270-77 and PN-76/C-04147 on the 4-Ball Test Machine. The sorptive properties of oils were evaluated by an indirect method, i.e. by means of differential scanning calorimeter DSC141. Two research aims have been realised. The first aim depended on checking the usability of differential scanning calorimetry for the indirect assessment of sorptive properties (adsorption) of oils on the true material of the tribology joint of 4-Ball Test Machine, which was used in the next test for the assessment of the lubricity properties of the oils. The second aim depended on the confirmation of interdependence: when we have better sorptive properties of an oil, than we also have a better lubricating ability.

Introduction

Gear trains often work within the range of boundary and mixed friction, particularly in the cases of temporary overloads, during the start–up and stoppage of devices. For that reason, identifying a suitable lubricity of gear oils becomes important, which is closely connected to its chemical composition and the energy state of the lubricated surface [4, 5]. The measure of lubricity is the durability of the boundary lubricating film, i.e. the durability of bonding of lubricating substance with the base. Durability may be assessed both during the formation of the boundary film (observing accompanying effects, for instance, measuring heat of sorption) or during its destruction (for instance, measuring quantity of energy that it needs supplying to break the boundary oil film). We may make conclusions concerning the durability of the boundary oil film indirectly from the course of processes that are determined by the lubricity properties of oils (for example, inclination to seizing the steel elements protected by using oil). Thus, the lubricity, which we understand as susceptibility for adsorption, may be evaluated by testing and assessing in both static conditions and dynamic conditions. Problems of the sorption of lubricating oils, in the context of their lubricating ability properties, are discussed by many authors, for example [6, 7]. However, the usefulness of differential scanning calorimetry (DSC) has not been assessed until now.

1. Investigation objects

Four gear base oils were investigated:

P1-Mobilube 1SHC 75W-90 (API MT-1/GL-5/GL-4) for high-loaded gear-boxes and driving axles;

P2-Mixture of base oils from petroleum refinery (23.32% mas. PAO-6, 76.68% mas. SN-650);

P3-Mixture P2+2% mas. of lubricity additive (Additin RC2515);

P4-Mixture P2+10% mas. of lubricity additive (Additin RC2515).

The samples of oils were placed into the cell “S” of calorimeter DSC141 [Fig. 2] for the evaluation of specific heat Cp. The mass of oil sample was about 0.0105g

The selected physical-chemical properties of oils (P1-P4) are presented in Table 1.

Table 1. Physical-chemical properties of tested oils

Oils / Parameters	P-1	P-2	P-3	P-4
Kinematic viscosity at 40ºC [mm^2/s]	101.72	99.69	98.56	100.65
Kinematic viscosity at 100ºC [mm^2/s]	15.07	10.70	10.82	11.11
Ignition temperature in closed crucible [ºC]	142.20	250.8	211.00	187.20

The elements of tribological junction of 4-Ball Test Machine were also objects of the investigation. The balls had a diameter 12.7 mm and were made from bearing steel ŁH-15. In the lubricity investigations, among others, the diameters of wear trace on the balls were measured. However, for the assessment of sorption effects during calorymetry measurements, it is necessary that the samples of steel ŁH-15 (from balls of tribological junction) are of sizes that make it possible to place these samples into microcalorimetre cells. The samples with sizes 4×4×2 mm and a mass in the range of 0.196–0.197 g were used. They were cut to size by means of an electroerosion wire machine BP-97d [Fig. 1].

Fig. 1. Individual stages of cut samples (ŁH-15 steel)

The quality and the chemical composition of the superficial layer of the balls were assessed by means of electron scanning microscope Philips XL30. The chemical composition of the superficial layer from steel ŁH-15 was as follows: C – 0.77%, Mn – 0.24%, Si – 0.4%, Cr – 1.37%, Fe – 97.22%, S – 0.01%, P – 0.02%.

2. Experimental procedures

The lubricity of selected oils (P1-P4, Table.1) were assessed by means of 4-Ball Test Machine (T-02, ITeE Radom – Poland) according to PN-76/C-04146 (ASTM D2596-69, ASTM D2783-71) [1, 2].

The parameters were determined as follows:

P(t) – seizure load for increasing continuous loading, [daN];

P(n) – last non-seizure load, [daN];

P(z) – weld point, [daN];

I(h) – load-wear index, [daN];

G(oz) – wear limiting load capacity, here for P = 150 kgf (147.15 daN) [daN/mm^2].

The indirect differential assessments of sorption effects were realised by means of calorimeter DSC141 with sapphire reference standard. The calorimeter consist of two identical calorimetric systems (Fig. 2).

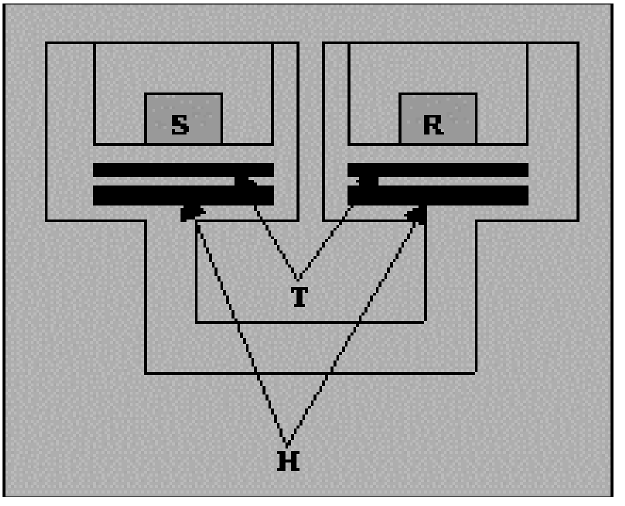

Fig. 2. Calorimetry system DSC141, R – sapphire reference, S – testing sample

Measurements of heat flow were realised when temperature increased 3deg/min, in range from 20ºC to 150ºC, for all samples from ŁH-15 and selected oils. Specific heat C_p versus temperature was measured and calculated (DSC curves) [3].

The relationship between the heat capacity and temperature for the testing sample is different from this relationship for sapphire reference. Therefore, the heat power, which is both the microcalorimetric cells, is different. In effect, the DSC curve is drawn. Using the additive rule, the average values of specific heat CpCAL for the steel – oil system were calculated from formula:

$$C_{pCAL} = \frac{m_{st} \cdot C_{pst} + m_{ol} \cdot C_{pol}}{m_{st} + m_{ol}} \tag{1}$$

where:

m_{st} – mass of steel, [g];
m_{ol} – mass of oil, [g];
C_{pst} – specific heat of steel measured in DSC141, [J/g·K];
C_{pol} – specific heat of oil measured in DSC 141, [J/g·K].

The calculated value CpCAL has been compared to the value Cpexp, which was directly assessed experimentally (Fig. 5, Fig. 6). In this experiment, the masses of the samples were as follows:

- for P1: m_{st} = 183.78 mg, m_{ol} = 10.74 mg,
- for P2: m_{st} = 184.20 mg, m_{ol} = 11.46 mg,
- for P3 m_{st} = 183.60 mg, m_{ol} = 10.29 mg,
- for P4 m_{st} = 183.18 mg, m_{ol} = 10.49 mg.

3. Results and Analysis

The results of lubricity investigations of oils are presented in Table 2.

Table. 2. Statement of lubricity parameters of oils

Oils	I_h [daN]	P_n [daN]	P_z [daN]	P_t [daN]	G_{oz} [daN/mm^2]
P1	78.89	123.61	608.22	298.73	114.6
P2	21.28	49.50	123.61	119.84	38.86
P3	37.74	78.48	245.25	183.25	60.14
P4	65.43	123.61	608.22	278.92	108.67

The lubricity tests showed that oil P1, i.e. Mobilube 1 SHC 75W-90, had the best lubricity properties. The worst of all was oil P2, according to expectation. Oil P3, containing 2% of lubricity additive Additin RC2515, had better lubricity properties than oil P2. Oil P4, containing 10% of Additin RC2515, had lubricity properties comparable to Mobilube1 SHC 75W-90. To sum up, an increase in lubricity additive caused an improvement in the lubricity properties of oils.

Selected DSC curves for oils (P1, P2, P3, P4), samples from steel ŁH-15 as well as for systems steel-oils are presented in Fig. 3–6.

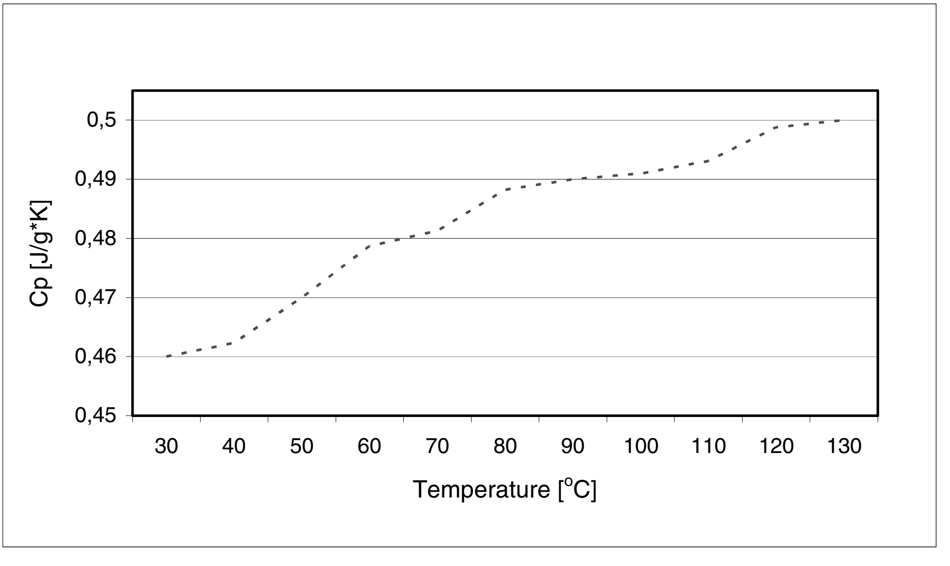

Fig. 3. DSC curves for ŁH-15 steel samples

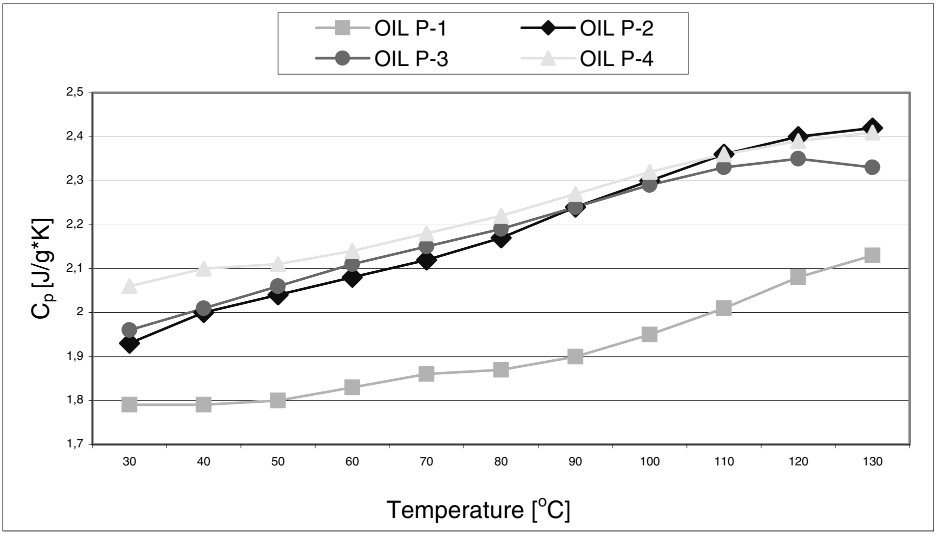

Fig. 4. DSC curves for gear oils

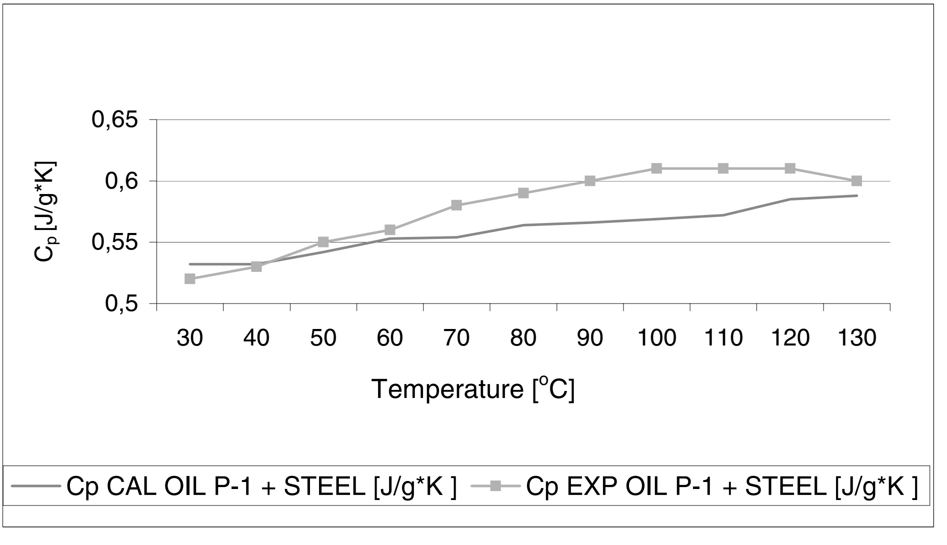

Fig. 5. DSC curves for system steel ŁH15/oil P1

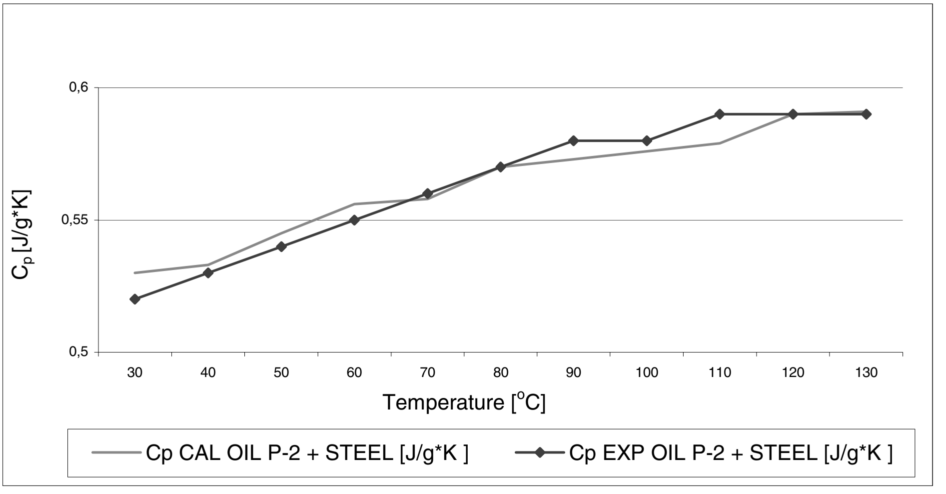

Fig. 6. DSC curves for system steel ŁH15/oil P2

It has been shown that, for systems steel-oils, there were no significant anomalies on DSC curves. However, differences were noticeable when we compared the experimental results C_{pexp} with the analytical results C_{pCAL}, according to the additive rule. For one temperature, experimental heat capacity had higher values of specific heat C_{pexp} than the mean value of the analytical specific heat C_{pCAL}, which depends on the participation of all components C_p of tested systems. This is most of all visible for oil P1 (Mobilube1 SHC 75W-90) from 40/50ºC (Fig. 5). The smallest differences were between C_{pexp} and C_{pCAL} in the ŁH–15/oil P2 system (Fig. 6). These differences increased when the percentage of lubricity additive increased. Higher values of C_{pexp} than C_{pCAL} mean that heating by 1ºC of 1g of this system needed a greater quantity of heat than would be expected from calculations. This means the manifestation of an additional interaction, which bonded the oils with ŁH-15 steel.

Conclusions

1. An increase in the content of lubricity additive Additin RC2515 caused an improvement in the lubricity properties of mixtures of base oils (PAO-6+SN650).
2. The better the lubricity properties of oils, the greater were the differences between experimental specific heat C_{pexp} and analytical specific heat C_{pCAL} which means better sorptive effects.
3. The results of the thermal investigations of oil–metal systems by means of differential scanning calorimeter SETARAM DSC141 are harmonious to the results of lubricity investigations on 4-Ball Test Machine.

References

1. ASTM D2596-69, „Standard Test Method for Measurement of Extreme-Pressure Properties of Lubricating Grease”, (4-Ball Method) (PN-76/C--04147).
2. ASTM D2783-71, VStandard Test Method for Measurement of Extreme–Pressure Properties of Lubricating Fluids”, (4-Ball Method) (PN-76/C--04147).
3. SETARAM DSC141, VInstruction for use”. Caluire-France, 1999.
4. Kałdonski T.: „Tribology and Maintenance Fluids, Part I Selected Tribological Problems”, WAT, Warszawa 1995, (in Polish).
5. Kałdonski T., Kałdonski T.J.: „Physicochemical mechanism self-lubricating sliding bearings”, Solid State Phenomena, vol. 113/2006, Zurich, 2006.
6. Hebda M., Wachal A.: „Tribology”, WNT, Warszawa, 1980 (in Polish).
7. Ozimina D.: „Antiwear layers in tribological system”. Politechnika Świętokrzyska, Kielce, 2002 (in Polish).

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Określanie smarności i właściwości sorpcyjnych olejów metodą pośrednią

Słowa kluczowe

Tribologia, smarność, chemia fizyczna, inżynieria chemiczna.

Streszczenie

W pracy przedstawiono rezultaty eksperymentalnych badań właściwości smarnościowych i sorpcyjnych wybranych olejów przekładniowych. Badano porównawczo cztery oleje bazowe o tej samej lepkości kinematycznej. Oleje te zawierały zróżnicowaną ilość dodatku smarnościowego (Additin RC2515). Właściwości smarnościowe olejów oceniono zgodnie ze znormalizowaną metodą według ASTM D2596-69, ASTM D2270-77, PN-76/C-04147 na aparacie czterokulowym. Właściwości sorpcyjne olejów oceniono metodą pośrednią, tzn. za pomocą różnicowego kalorymetru skaningowego DSC 141. Zostały zrealizowane dwa cele badawcze. Pierwszy cel polegał na sprawdzeniu przydatności różnicowej kalorymetrii skaningowej do pośredniej oceny właściwości sorpcyjnych (adsorpcji) olejów na rzeczywistym materiale węzła tribologicznego aparatu czterokulowego, który następnie był użyty do oceny właściwości smarnościowych tych olejów. Drugi cel polegał na potwierdzeniu zależności: jeśli lepsze są właściwości sorpcyjne oleju, to lepsze są jego właściwości smarnościowe.