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IMPACT OF IONIC LIQUID ADMIXTURE ON ELECTORRHEOLOGICAL AND TRIBOLOGICAL PROPERTIES OF A HYDROCARBON LUBRICATING OIL

WPLYW DOMIESZKI CIECZY JONOWYCH NA WŁAŚCIWOŚCI ELEKTROREOLOGICZNE I TRIBOLOGICZNE WĘGLOWODOROWEGO OLEJU SMARUJĄCEGO

Key words: lubricating oils, ionic liquids, electrorheological effect, lubricity.

Abstract: The article describes, the relationship between the generated and fading electrorheological effect and tribological properties of hydrocarbon lubricating oils containing ionic liquid admixture. Two quasi-homogeneous mixtures were obtained as a result of miscibility tests: 1) the GP1 silicon damping oil containing ionic liquid CJ001, i.e. 1-methyl-3-octyloxymethylimidazolium tetrafluoroborate and 2) the PAO6 base polyalphaolefin oil containing ionic liquid CJ008, i.e. trihexyltetradecylphosphonium bis-(tri-fluoromethylsulfonyl)imide. The conducted ER tests revealed differences between the electrorheological properties of the two mixtures. After increasing the electric field strength to $E = 0.3 \text{ kV} \cdot \text{mm}^{-1}$ the ER effect of both mixtures disappeared. For these mixtures tribological tests were carried out on a four ball apparatus. The lubricity parameters of the tested ionic liquids are much better than base oils and the oil mixtures with ionic liquids also showed better lubricating properties than their base oils.

Słowa kluczowe: ciecze smarujące, ciecze jonowe, efekt elektroteologiczny, smarność.

Streszczenie: W artykule opisano zależność pomiędzy generowanym i zanikającym efektem elektroteologicznym (ER) i właściwościami tribologicznymi węglowodorowych olejów smarujących zawierających domieszkę cieczy jonowej. W rezultacie prób mieszania uzyskano dwie quasi-homogeniczne mieszaniny: 1) silikonowy olej tłumiący GP1 zawierający ciecz jonową CJ001, tj. 1-metylo-3-octyloksymetyloimidazoliowy tetrafluoroboran oraz 2) bazowy olej polialfaolefinowy PAO6 zawierający ciecz jonową CJ008, tj. triheksyltetradecylofosfoniowy bis-(trifluorometylosulfonylo)imid. Przeprowadzone badania ER wykazały, że obie mieszaniny wykazały różne elektroteologiczne charakterystyki. Po zwiększeniu natężenia pola elektrycznego do wartości $E = 0.3 \text{ kV} \cdot \text{mm}^{-1}$ efekt ER obu mieszanin zanikał. Tribologiczne testy dla tych mieszanin przeprowadzono na aparacie czterokulowym. Parametry smarnościowe zbadanych cieczy jonowych są dużo lepsze niż oleje bazowe, a mieszaniny z cieczami jonowymi wykazały także lepsze właściwości smarujące niż ich oleje bazowe.

INTRODUCTION

Excellent lubricating properties of ionic liquid, as separate lubricants or as additives improving lubricating properties of industrial oils, are described in tribological literature, e.g. [L. 1–8]. However, there is no information on the possible use of an ionic liquid as an electrically active

component in a mixture with hydrocarbon lubricating oil, which exhibits electrorheological (ER) properties and better tribological properties than an oil that does not contain an ionic liquid. In the search for ways to produce homogenous liquid with ER properties, such as those described in this article, such comparisons can not be omitted.

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In previously papers [L. 9–10] were presented the results of experimental studies of ER properties of hydrocarbon lubricating oils containing an admixture of ionic liquid as an electrically active ingredient. In those tests [L. 9–10] an innovative attempt was made to assess ER properties on the modernized Brookfield DV-III Ultra rotational viscosimeter, which was registered with the Patent Office of the Repub. of Poland. Moreover, thanks to the conducted tests on the basis physicochemical properties of the prepared mixtures, and tests in dielectric spectroscopy, and *in situ* microscopic tests in a direct electric field, the mechanism of ER effect formation and its disappearance was described and the impact on not only the dielectric properties of the components of the mixtures tested, but also on the differentiation their ER properties and their basic physicochemical properties (e.g. viscosity and surface tension) [L. 10]. Thus, the field of assessment and analysis of the ER properties of mixtures has been considered so far.

In this article attention is also drawn to the relationship between the generated and fading ER

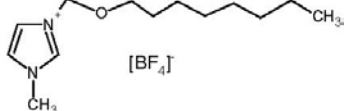
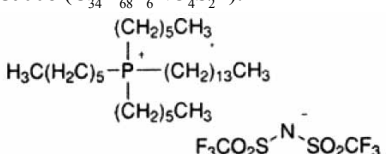
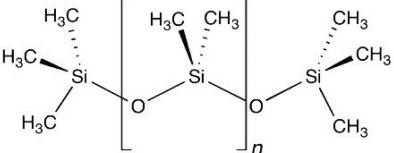
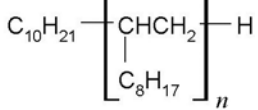
effect and tribological properties of hydrocarbon lubricating oils containing ionic liquid admixture.

MATERIALS AND METHODS

Two quasihomogeneous mixtures were obtained as a results of miscibility tests of five hydrocarbon oils and seven ionic liquids [L. 9–10]. The first mixture was the GP1 silicon damping oil containing 5% (v/v) of the CJ001 ionic liquid, i.e. *1-methyl-3-octyloxymethylimidazolium tetrafluoroborate* and the second mixture was composed of the base polyalphaolefin oil (PAO6) and 5% (v/v) of the CJ008 ionic liquid, i.e. *trihexyltetradecylphosphonium bis(trifluoromethylsulfonyl)imide*. The density (ρ), kinematic viscosity (ν), dynamic viscosity (η), viscosity index (VI), surface tension (σ), refractive index (n_D) and specific refraction (r_D) of the liquid were assessed [L. 10]. It is important to know the variability of these properties in the case of oils containing a certain amount of ionic liquid with significantly different than oil properties (**Table 1**).

Table 1. Basic properties of mixtures and their components at 25°C [L. 10]

Tabela 1. Główne właściwości mieszanin i ich składników w 25°C [L. 10]

Liquids: chemical structure	ρ [g·cm ⁻³]	ν [mm ² ·s ⁻¹]	η [mPa·s]	VI [-]	σ [mN·m ⁻¹]	n_D [-]	r_D [cm ³ ·g ⁻¹]
CJ001 (C ₁₃ H ₂₅ BF ₄ N ₂ O): 	1.116	495.00	552.42	110	26.032	1.4304	0.2317
CJ008 (C ₃₄ H ₆₈ F ₆ NO ₄ S ₂ P): 	1.061	308.43	327.24	127	28.099	1.4480	0.2523
GP1 (<i>polysiloxans</i>): e.g. PDMS 	0.823	15.33	12.61	264	19.547	1.4039	0.2971
PAO6 (<i>polyalphaolefins</i>): 	0.816	58.05	47.36	144	27.523	1.4558	0.3298
GP1 + CJ001	0.826	20.05	16.56	218	20.601	1.4061	0.2978
PAO6 + CJ008	0.820	61.08	50.08	140	27.998	1.4540	0.3302

The methods and methodologies for identifying basic physicochemical properties of mixtures and their components are discussed in detail in [L. 10]. A KSV Sigma 701 (Helsinki, Finland) tensiometer was used to measure the density (ρ) and surface tension (σ). The kinematic viscosity (ν) was measured using a Pinkievich' viscometer and an Anton Paar' micro viscometer AMVn (Graz, Austria). An Abbe' laboratory refractometer was used to determine refractive index (n_D). The absolute viscosity (η), viscosity index (VI) and specific refraction (r_D) were calculated [L. 10].

The ER test, which consisted in determining the electrorheological characteristics $\tau = f(\dot{\gamma})$, i.e. shear stress versus shear rate, in the presence of an external direct electric field was carried out on specially designed and built stand, which used a modified Brookfield DV-III Ultra viscometer [L. 10]. In order to properly interpret the results of the ER tests conducted, a reference test was carried out using a Physica MCR 101 specialised rheometer by Anton Paar GmbH, Germany.

The tests of liquid in dielectric spectroscopy were performed using an HP4192 impedance analyzer by Hewlett Packard, Palo Alto, CA, USA [L. 10]. Such tests allow the assessment of the variability of the dielectric constants (ϵ) as a function of the frequency (f) of the BIAS (DC) electric field for different values of the applied voltage (U)



Fig. 1. Test stand for measuring lubricity properties: 1 – personal computer for the test control with appropriate software installed 2 – 4-ball apparatus with a digital amplifier and a set of measuring transducers (Poland)

Rys. 1. Stanowisko do pomiaru właściwości smarowości: 1 – komputer do kontroli badań, 2 – aparat 4-kulowy ze wzmacniaczem cyfrowym i zestawem przetworników pomiarowych (Polska)

and simultaneous variability of resistance (R) and conductivity (κ) [L. 10].

In order to understand the mechanism of the ER effect, its formation and course, *in situ* microscopic examinations of the prepared mixtures were carried out - under the action of an external direct electric field. The microscopic observations were performed on a Nikon Eclipse LV100D optical microscope (Tokyo, Japan) [L. 10].

To verify the impact of the ionic liquids admixtures on the lubricity properties of lubricating oils, tests employing a four-ball apparatus and the same methodology as described by the authors in their previous studies [L. 1, 2, 5, 11]. The tribology tests were carried out on a T-02 tribotester, produced by the Institute of Sustainable Technologies in Radom, Poland (**Figure 1, Figure 2**).

Three selected tribological parameters were determined, i.e. *seizing load* $P_{(0)}$, i.e. the load achieved with a smoothly increasing, continuous and uniform, manner (linear) load with a specified speed of $408.8 \text{ N}\cdot\text{s}^{-1}$, at which under steady conditions – when the rotational speed of upper ball is 500 rpm – there will be a significant increase in the frictional resistance (frictional moment) indicating a break in the lubricating layer, characterized by a sudden increase in wear scars measured on the three lower balls of the four ball apparatus (**Figure 3 and Figure 4**).

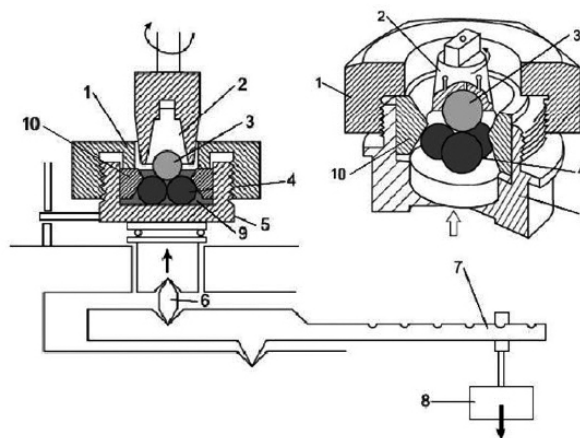


Fig. 2. Scheme of measurement unit of the 4-ball apparatus:

1 – cover fixing lower balls, 2 – upper ball grip, 3 – upper ball (rotated), 4 – lower balls (motionless), 5 – vessel with tested oil, 6 – prism, 7 – lever, 8 – load, 9 – tested oil, 10 – retaining ring

Rys. 2. Schemat jednostki pomiarowej aparatu 4-kulowego:

1 – pokrywa mocująca kulki dolne, 2 – uchwyt kulki górnej, 3 – kulka górna (obrotowa), 4 – dolne kulki (nieruchome), 5 – naczynie z badanym olejem, 6 – pryzmat, 7 – dźwignia, 8 – obciążenie, 9 – badany olej, 10 – pierścień mocujący

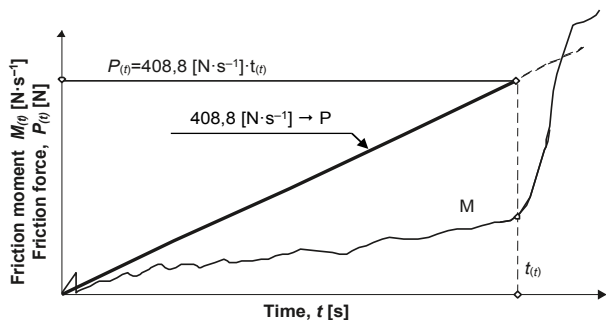


Fig. 3. Graph of the friction moment as a function of time during the determination of the $P_{(t)}$
 Rys. 3. Wykres momentu tarcia w funkcji czasu podczas wyznaczenia $P_{(t)}$

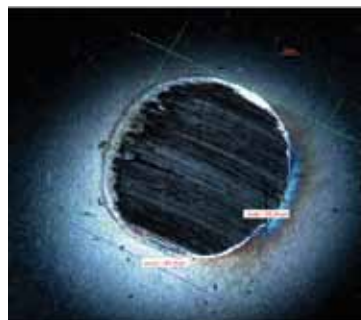


Fig. 4. Measurement of diameters of wear scars on lower balls of the 4-Ball Apparatus using a Nikon Eclipse LV 100 D microscope
 Rys. 4. Pomiar średnic śladów zużycia na dolnych kulkach aparatu 4-kulowego za pomocą mikroskopu Nikon Eclipse LV 100 D

socalled *wear limiting capacity load* $G_{(oz)}$, i.e. unit load ($N \cdot mm^{-2}$) defining the pressures in the friction junction obtained at the end of the test carried out with a constant load on the lever of four-ball apparatus ($P = 150 \text{ kgf}$, i.e. 1471 [N] – when $g = 9.8066 \text{ [m} \cdot \text{s}^{-2}]$), under steady conditions – when the rotational speed of the upper ball is 500 rpm – calculated on the average diameter of wear scars created on immobile lower balls after 60 seconds of operation of the four-ball apparatus, from the following formula:

$$G_{(oz)} = 0.52 \cdot \frac{P}{d_{av}^2}, [N \cdot mm^{-2}]$$

where:

- 0.52 – coefficient associated with force distribution in the friction node of the four-ball apparatus (*regular tetrahedron*);
- P – constant vertical load of the friction node of the four-ball apparatus [N];
- d_{av} – average diameter of scars on the lower (immobile) ball surface calculated on the basis of formula $d_{av} = \Sigma d / 6$.

Additionally, the authors determined the $p_{(oz)}$ parameter, which defining the unit pressures [$N \cdot mm^{-2}$] obtained after a full run of the smooth loading, when the four-ball apparatus automatically turn off, i.e. at the maximum allowable load $P_{max} = 800 \text{ kgf}$ (i.e. 7845.3 N when $g = 9.8066 \text{ m} \cdot \text{s}^{-2}$) – using formula $p_{(oz)} = 0.52 \times P_{max} / d_p^2$.

The first parameter $P_{(t)}$ characterizes the anti-seizing properties of the liquid and the second parameter $G_{(oz)}$ characterizes the anti-wear properties. In addition, the specified parameter $p_{(oz)}$ allows the identification of the behaviour of the lubricants

during the seizing period at constantly increasing load (after exceeding $P_{(t)}$), up to the maximum value, when the four-ball apparatus automatically switched off, as well as the determination of the appropriate wear values. The final results of the assessment of the above lubricity parameters were the arithmetic means of three measurements that did not differ from their arithmetic means by more than 10%. This method of calculation of the selected parameters is standard and commonly accepted in studies employing a four-ball apparatus.

RESULTS AND DISCUSSION

The conducted ER research showed that both produced mixtures: GP1+CJ001 and PAO6+CJ008 generated the maximum ER effect in the presence of direct electric field with the intensity up to $0.2 \text{ kV} \cdot \text{mm}^{-1}$. The tested mixtures showed different electrorheological characteristics (**Figure 5**).

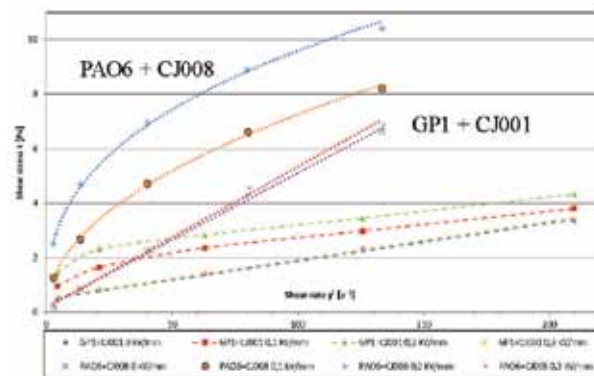


Fig. 5. $\tau = f(\dot{\gamma})$ characteristics PAO6+CJ008 and GP1 + CJ001 mixtures
 Rys. 5. Charakterystyki $\tau = f(\dot{\gamma})$ dla mieszanin PAO6+CJ008 oraz GP1+ CJ001

The GP1+CJ001 mixture in the absence of an electric field behaved like a Bingham liquid ($\tau = \eta \cdot \dot{\gamma} + \tau_0$ where $\tau_0 \approx 0.5$ Pa), and in the presence of an electrical field with the maximum value of $E = 0.2$ kV·mm⁻¹ the rheological characteristics of this mixture could be described by the Herschel-Bulkley equation ($\tau = m_1 \cdot \dot{\gamma}^{n_1} + \tau_0$ with $n_1 < 1$). The second mixture, i.e. PAO6+CJ008, behaved in the absence of an electric field like a Newton liquid ($\tau = \eta \cdot \dot{\gamma}$), and in the presence of an electric field with the maximum value of 0.2 kV·mm⁻¹, its rheological characteristics could be described by the Ostwald de Waele equation ($\tau = m_2 \cdot \dot{\gamma}^{n_2} + \tau_0$ with $n_2 < 1$). The latter mixture showed significantly better ER effect. After increasing the electric field strength to $E = 0.3$ kV·mm⁻¹ the rheological characteristics of both mixtures corresponded to those without the influence of the electric field, i.e. the mixture GP1+CJ001 to the Bingham characteristics, and the mixture PAO6+CJ008 to the Newton characteristics (**Figure 5**). The obtained ER effect was short lived and unique for the same liquid sample, which suggested irreversible changes in the internal structure of these mixtures under the influence of external high electric fields. Meanwhile, in the mechanical ER devices a large electric field is necessary for a rapid and large increase in the viscosity of the damping oils [L. 12–14]. The intelligent ER fluid shows a permanent and repeatable ER effect under the influence of an external electric field, greater at higher E kV·mm⁻¹. In the case of both tested mixtures, such an effect was not obtained. Moreover, the content of ionic liquids in the mixtures had to be reduced to 2% (v/v), because at 5% content an electrical break down (short circuit) occurred.

The reference study of the GP1+CJ001 mixture on a specialized Physica MCR101 rheometer confirmed the previous research results [L. 10] and allowed to put forward thesis on the gradual but relatively quick decomposition of the ionic liquid contained in the mixture. In **Figure 6** presents the characteristics of changes in the viscosity of this mixture as a function of time, during a step increase in the voltage supplying the system.

These studies confirmed the short term nature of the obtained ER effect and its uniqueness for the same liquid sample. This **Figure 6** shows a step increase in viscosity with an increase in the applied voltage (every 50 sec.). In the next 50 sec. period (before the voltage was increased by another 10 volts), the existing viscosity increase rapidly

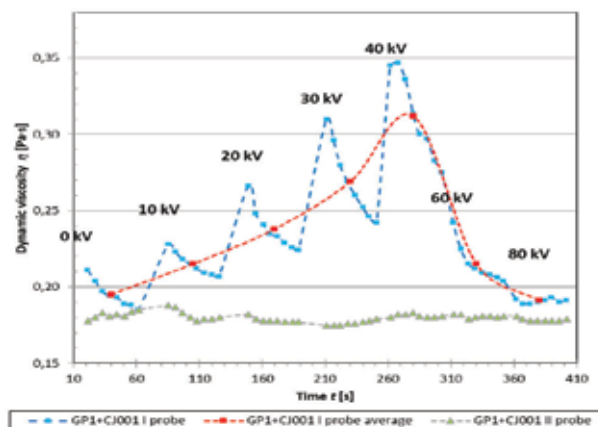


Fig. 6. Dependence between of viscosity (η) of the GP1+CJ001 mixture and time (t) during a step increase in the voltage supplying the system

Rys. 6. Zależność lepkości (η) mieszaniny GP1+CJ001 od czasu (t) podczas skokowego wzrostu napięcia zasilającego układ

decreased under the action of the electric field. Each subsequent voltage spike caused a significant increase in viscosity and then its decrease in the following seconds. The maximum value of the mixture viscosity was obtained at a voltage of $U = 40$ V, and then its rapid decrease, despite further increase in voltage, to the initial value for the mixture not subjected to the action of a direct electric field. The repeated measurement conducted for the same sample of the GP1+CJ001 mixture subjected to a direct electric field did not show any ER effect. Probably, the CJ001 ionic liquid contained in this mixture has completely decomposed. In addition, the decrease in the viscosity of the mixture was undoubtedly influenced by the process of liquid shearing in the measuring gap (0.1 mm) between the rings (electrodes) of the Physica MCR 101 viscometer, which are in a rotational – reciprocal motion.

The fading of the ER effect can be further explained by examining ionic liquids in dielectric spectroscopy, e.g. by observing changes in the $\epsilon = f(f)$ characteristics for different values (U). The variability of the dielectric constants (ϵ) as well as resistance (R) and conductivity (κ) as a function of the frequency (f) of the direct electric field BIAS (DC), for different values of the applied voltage (U), are presented in detail in [L. 10].

The studies showed, that increasing the BIAS (DC) voltage caused a decrease in the value (ϵ) of both ionic liquids (CJ001 and CJ008), much faster in the case of the CJ001 ionic liquid than in the case of the CJ008 ionic liquid. Therefore, the ER effect disappeared faster for the GP1+CJ001 mixture than for the PAO6+CJ008 mixture. However, the

end result was the same for both mixtures, i.e. total loss of ER properties caused by the decomposition of ionic liquids as a result of the action of a direct electric field of high value – enabling a significant but short term increase in the viscosity of the mixture. In order to more precisely recognize the impact of lower BIAS voltage values, on the course of the characteristics $\varepsilon=f(f)$, the ionic liquid CJ008 was additionally tested in dielectric spectroscopy. The measurements were performed in the range of the same frequency as before [L. 10], i.e. 0.1÷10,000 kHz but for lower BIAS voltage, i.e. from 0÷10V (0; 1; 2; 5; 7; 10 V). A selected example of the measurements of the electric permeability (ε) of the CJ008 ionic liquid as function of the frequency (f) of the measurement field for small BIAS (DC) voltages in the range $U= 0\div 10$ V is presented below (Figure 7a).

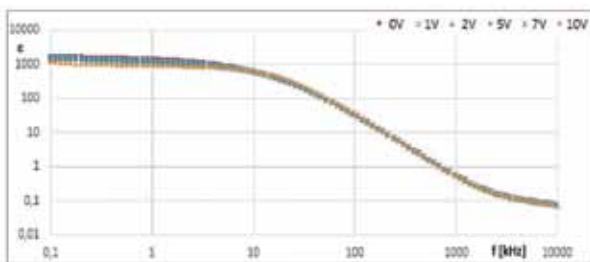


Fig. 7a. Results of the first measurement of the dependency between (ε) and the frequency (f) for the CJ008 samples in the BIAS field of low voltage (0÷10 V)

Rys. 7a. Wyniki pierwszego pomiaru zależności (ε) od częstotliwości (f) dla próbek CJ008 w polu BIAS-u niskiego napięcia (0÷10 V)

To verify whether the applied BIAS field affects the “*earlier history*” of the sample, a second (subsequent) measurement was performed for the same sample of the CJ008 ionic liquid – for the same BIAS fields (Figure 7b).

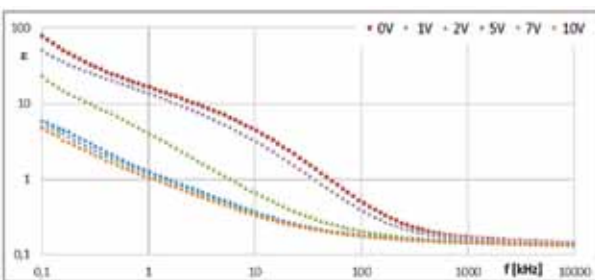


Fig. 7b. Results of the second (subsequent) measurement of the dependency between (ε) and the frequency (f) for the CJ008 sample in the BIAS field of low voltage (0÷10 V)

Rys. 7b. Wyniki drugiego (następnego) pomiaru zależności (ε) od częstotliwości (f) dla próbek CJ008 w polu BIAS-u niskiego napięcia (0÷10 V)

The measurements presented in **Figure 7** were repeated many times in different periods and under different (uncontrolled) ambient conditions (room temperature, atmospheric pressure, air humidity in the lab. room), and showed the same tendency. The treatment of the CJ008 ionic liquid with the BIAS (DC) field did not cause significant changes only for very small voltages <2V (but for 10 times smaller values of (ε) compared to the first measurement - **Figure 7a** versus **Figure 7b**), i.e. the permittivity characteristics (ε) as a function of frequency (f) were then usually similar, and sometimes the same. Thus, the relative stability of the ionic liquid can only be mentioned at very low voltages (U). This voltage range is typical for the width of the so-called electrochemical window of most ionic liquids, i.e. about 4V (± 2 V) [L. 15]. However, such small value of the potential of the direct electric field can not cause any ER effect of the mixture of hydrocarbon oil containing an admixture of ionic liquid. To cause this effect, it is necessary to interact with a very high electric field strength (E) $\text{kV}\cdot\text{mm}^{-1}$, i.e. potential greater by about two orders of magnitude (here: 0.1÷0.2 $\text{kV}\cdot\text{mm}^{-1}$), which however leads to rapid degradation (decomposition) of the ionic liquid contained in the tested mixtures (GP1+CJ001 and PAO6+CJ008).

The mechanism of ER effect generation and fading was studied under *in situ* microscopy using a Nikon Eclipse LV 100 D optical microscope. Changes in the structure of mixtures containing ionic liquids were confirmed, involving the formation of “*fibrillary chains and/or streams*” (and their subsequent destruction) and the accumulation of ionic liquid particles, at the electrodes [L. 10]. The following images (**Figure 8**) present selected characteristics sequences showing changes in the internal structure of the mixture of the base PAO6 as the matrix and 2 % (v/v) of the CJ008 ionic liquid, treated with external electric field with intensity $E=0\div 0.3$ $\text{kV}\cdot\text{mm}^{-1}$ (**Figure 8a-d**).

Table 2 presents the average values of the lubricity parameters of the tested mixtures and their components, determined on the four-ball apparatus.

The tests on the four-ball apparatus (**Table 2**) confirmed that the tribological properties of the discussed ionic liquids are exceptionally good. The lubricity parameters of these ionic liquids are much better than, not only base oils, but also than many branded engine and gear oils, which as often mentioned in the literature, e.g. [L. 1–8, 11]. Mixtures of hydrocarbon oils with an admixture of

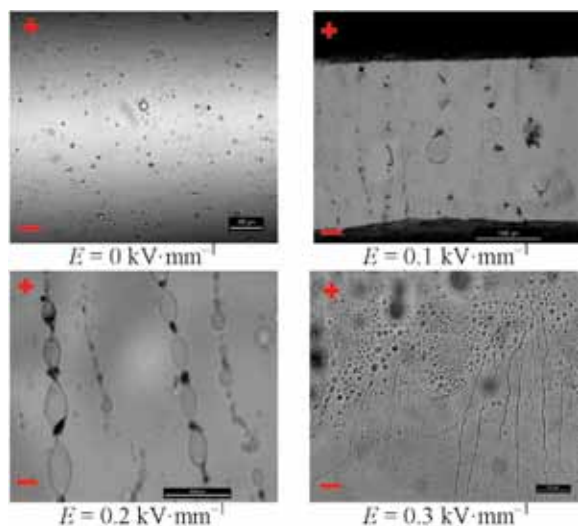


Fig. 8 (a-d). PAO6+CJ008 mixture in electric field $E = 0 \div 0.3$ observed under a Nikon Eclipse LV 100 D polarizing microscope

Rys. 8. (a-b). Mieszanina PAO6+CJ008 w polu elektrycznym $E=0 \div 0.3$ obserwowana pod mikroskopem polaryzacyjnym Nikon Eclipse LV 100 D

ionic liquids also showed better lubricity properties than their base oils. Of course, the results of tests on the four-ball apparatus, presented in **Table 2**, refer to liquids not subjected to the action of an external electric field. The construction of the tribological node of the four ball apparatus makes it impossible to conduct such direct tests. However, it seems that the observed effect of ionic liquid particles at the electrodes (**Figure 8**), and after disintegration of the ionic liquid as a result of the electric current, probably also cations and anions of this liquid, may have a positive impact on the formation of the lubricating boundary film and, consequently,

on the improvement of lubricity properties of quasihomogeneous mixtures of hydrocarbon oils with an admixture of a selected ionic liquid.

CONCLUSIONS

The conducted research and analyses show that:

1. ionic liquids are characterized by excellent lubricity parameters, better than many hydrocarbon lubricating oils; they can also significantly improve the lubricity properties of these oils by acting as a lubricity additive. This subject is widely discussed in the literature and current studies confirm such properties;
2. a small admixture of ionic liquid (here 2 %) in the hydrocarbon oil allowed the generation of ER effect in such a mixture, but it was a short term and unique effect; at higher electric field strengths, the ER effect disappeared quickly due to the fading to the ionic liquid;
3. it is impossible to prepare an intelligent quasihomogenous ER liquid from hydrocarbon oil and ionic liquid admixture;
4. cations and anions of the ionic liquid, after its disintegration under the influence of the external electric field can probably improve the lubricating properties of the base oil by influencing the formation of its boundary film on the lubricated surface.

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Table 2. Lubricity parameters of GP1+CJ001 and PAO6+CJ008 mixtures and their components

Tabela 2. Parametry smarnościowe mieszanin GP1+CJ001 oraz PAO6+CJ008 i ich składników

Type of liquid	Seizing load $P_{(t)}$ [N]	Time to get $P_{(t)}$, t [s]	Wear limiting capacity load $G_{(oz)}$ [N·mm ⁻²]	Wear scar diameter d_{av} [mm] under load $P = 1471$ [N]	Pressure $P_{(oz)}$ [N·mm ⁻²] under load $P_{(max)} = 7845.3$ [N]	Wear scar diameter $d_{(p)}$ [mm] under load $P_{(max)} = 7845.3$ [N]
CJ001	4601.3	11.25	3186.9	0.49	6200.7	0.811
CJ008	3967.3	9.70	3060.7	0.50	5635.5	0.851
PAO6 1165.7		2.85	452.8	1.30	4799.5	0.921
GP1	732.2	1.80	378.7	1.42	4262.8	0.984
PAO6+CJ008	1881.4	4.60	522.5	1.21	5099.4	0.894
GP1+CJ001	777.1	1.90	432.4	1.33	4635.9	0.936

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