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IRON POROUS SLIDE BEARINGS IMPREGNATED WITH A SELECTED IONIC LIQUID

ŻELAZNE POROWATE ŁOŻYSKA ŚLIZGOWE NASYCONE DOBRANĄ CIECZĄ JONOWĄ

Key words: porous sleeves, iron sinter, ionic liquids.

Abstract This article presents some selected results of the research on the slide porous bearings, sintered from the iron powder Höganas NC.100.24, with 2.5% of copper addition by weight, impregnated with selected ionic liquids, through comprehensive and detailed research works [**L. 1–6**]. The research was carried out within the framework of PBR/15-249/2007/WAT-OR00002904 Research Project financed by the Ministry of Science and Higher Education, during 2007–2011 [**L. 7**]. Several times higher load capacities and durabilities were obtained in comparison with standard ø25/ø35×20 mm sleeves lubricated with previously used oils, including perfluoropolyether oils. To date, there were no bearings sintered from the iron powder and impregnated with ionic liquids. The durability and load capacity of such bearings are higher, and that is why it was decided to submit a proper patent claim to the Polish Patent Office [**L. 8**].

Słowa kluczowe: tuleje porowate, spiek żelazny, ciecze jonowe.

Streszczenie W artykule przedstawiono wybrane wyniki badań porowatych łożysk ślizgowych spiekanych z proszku żelaza Höganas NC.100.24 z dodatkiem 2,5% mas. miedzi nasączonych dobranymi cieczami jonowymi na drodze kompleksowych i szczegółowych badań [**L. 1–6**]. Badania te zrealizowano w ramach projektu rozwojowego PBR/15-249/2007/WAT-OR00002904 finansowanego przez MNiSzW w latach 2007–2011 [**L. 7**]. Uzyskano wielokrotnie wyższą nośność i trwałość w porównaniu ze standardowymi tulejami ø25/ø35×20 mm smarowanymi dotychczas stosowanymi olejami, w tym także perfluoropolieterowymi. Dotychczas nie są znane łożyska spiekane z proszku żelaza i nasączone cieczami jonowymi, dzięki czemu ich trwałość i nośność są znacznie większe, dlatego postanowiono zgłosić do Urzędu Patentowego Rzeczypospolitej Polskiej odpowiednie zastrzeżenie patentowe [**L. 8**].

INTRODUCTION

Scientific literature and catalogues of the companies producing porous bearings and lubricants show that a very wide range of products is being used for porous slide bearings impregnation. Most frequently, these are mineral or synthetic oils of various types. Sometimes, there are attempts to apply some greases or even solid lubricants suspended in oil (e.g., graphite). There are also known cases of applying substances with magnetic properties (e.g., Mikrozella, product of Klüber). The only lubricants used for porous bearings produced in Poland are mineral oils. Porous sleeves made at the Wire and Wire Goods Factory, Glwice, Poland, are being impregnated, most often, with Antykol TS-120 maintenance oil (absolute visocity η = 105 mPa·s at the temperature of 50°C). The products of POLMO Łomianki S.A. are also impregnated with Antykol TS-120 oil or, on demand, with Selektol or Hipol oils. Products made at the Trzebinia Metallurgical Factory are also impregnated with Antykol TS-120 oil and, on demand, with Hydrol or Shell Tellus oils. In Poland, there is no data about synthetic oils, greases, and other substances used for the lubrication of the porous

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slide bearings made in this country. In catalogues of Klüber Lubrication and Solvay Solexis Companies, there is a suggestion for using perfluoropolyether oils for impregnating porous slide bearings. The research works carried out by the authors of this article show that the proposal mentioned above is ungrounded. Perfluoropolyether oils used for lubricating bearings made of the iron sinter with an addition of 2.5% Cu did not turn out to be good lubricants at all [**L. 7**]. They were much worse than the series of hydrocarbon oils, including Hipol 15F 85W/90 mineral oil and Mobilube 1 SHC 75W/90 synthetic oil, which had been the best during those tests, and because of this fact, they were used as the reference oils for ionic liquids during the tribological research. Suggestions for using PFPE oils for impregnating porous slide bearings (Klüber; Solvay) are a little surprising, when you take in account their well-known poor properties during boundary and mixed friction [**L. 9**], while such working conditions are typical for porous slide bearings. Whereas, to date, no known porous bearings lubricated (impregnated) with selected ionic liquids have physico-chemical properties that suggest the possibility to achieve increased bearings load capacity and durability.

In the discussed case, exemplary standard porous sleeves were tested, which were sintered from powder Fe with the addition of 2.5% Cu, produced by POLMO Łomianki S.A., impregnated with ionic liquid CJ 007 (1,2-dimethyl-3-propylimidazole bis(trifluoromethylsulfonyl)imide) or CJ 006 (3-methyl 1-propylpirydyne bis(trifluoromethylsulfonyl)imide) which were selected through comprehensive and detailed research [**L. 1–6**]. Moreover, a series of other ionic liquidswere tested, including CJ 004, CJ 005 and CJ 008 and the reference oils: Hipol 15F 85W/90 (0-3) and Mobilube 1 SHC 75W/90 (0-26), which, from among many tested lubricants (oils: PFPE Fomblin Y 04, Y 1500, M 60, M 15, Antykol TS 120, Klüberalfa DH3-100, PAO-8 + PAO-40 and even greases: Constant GLY 2100 and Vecolit LB-414) achieved the highest operating parameters for porous slide bearings. The tribological tests of ø25/ø35×20 mm sleeves were carried out on a PŁS-01 stand (**Figs. 1** and **2**). Exceptionally good results were obtained for the porous bearings impregnated with CJ 007 liquid, i.e. 1,2-dimethyl-3-propylimidazole bis(trifluoromethylosulfonyl)imide (C10H15F6N3O4S2) (**Fig. 3**).

One of the fundamental parameters determining durability and load capacity of the porous sleeves, which is defined, among other things, by their porosity, is "aeration" and the permeability of the sleeve, defined for real fluid used for impregnation, and the variability of this parameter against time is mainly influenced by the nature of physical and chemical reaction between the lubricating liquid and the porous structure (**Figs. 7** and **8**). Moreover, CJ 007 liquid turned out to be non-toxic and non-corrosive, which is presented in **Table 2** and **Table 3** of this article.

METHODOLOGY AND RESULTS OF THE TEST MADE WITH THE USE OF PŁS-01 MACHINE

PŁS-01 test stand is show in **Fig. 1** and **Fig. 2** [**L. 7**].

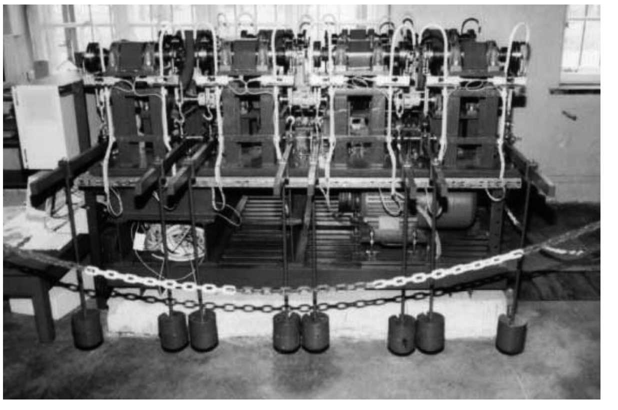

Fig. 1. Side view of PŁS-01 stand [L. 7]
Rys. 1. Widok z boku stanowiska PŁS-01 [**L. 7**]

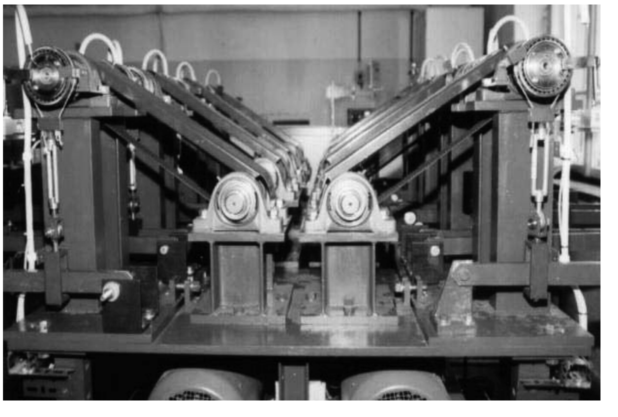

Fig. 2. Back view of PŁS-01 stand [L. 7]
Rys. 2. Widok z tyłu stanowiska PŁS [**L. 7**]

The drive assembly consist of two electric motors with a rated rotational speed of n = 1450 rpm and 4.5 kW of power. The rotational speed control system made it possible to select a required speed within the range of 0–1500 rpm for sixteen tested bearings concurrently. The PŁS-01 machine was built in the Department of Tribology, Surface Engineering, and Logistics of Service Fluids of MUT, especially for testing porous slide bearings [**L. 7**]. On the basis of previously carried out complex research works on normative tests of lubrication, surface-energetic, viscosity-temperature properties of the series of ionic liquids and lubricating oils, and their interaction with the iron and steel surface, from among over twenty lubricants, there had been chosen, for tribological comparative tests, five ionic liquids and two references lubricating oils (Hipol 15F 85W/90, marked as 0-3, and Mobilube 1 SHC 75W/90, marked as 0-26, which had shown the best properties during all previous research works on the porous slide

bearings). The ionic liquids, tested during the research, are as follows:
CJ 004 – 3-butoxymethyl-1-butylimidazole bis(trifluoro methylsulfonyl)imide,
(m_{cz} = 490.5 g·mol^{-1}, ρ_{25} = 1.33 g·ml^{-1}, t_p = –45.9°C, η_{25} = 75.53 mPa·s, VI = 170, σ_{25} = 27.569 mN·m^{-1});
CJ 005 – 1-benzyl-3-methylimidazole tetrafluoroborate, (m_{cz} = 260.1 g·mol^{-1}, ρ_{100} = 1.24 g·ml^{-1}, t_p = +77ºC, η_{100} = 18.37 mPa·s, σ_{100} = 31.415 mN·m^{-1});
CJ 006 – 3-methyl-1-propylpiridyne bis(trifluoromethyl sulfonyl)imide,
(m_{cz} = 416.4 g·mol^{-1}, ρ_{25} = 1.45 g·ml^{-1}, t_p = 0ºC, η_{25} = 51.53 mPa·s, VI = 138, σ_{25} = 32.993 mN·m^{-1});
CJ 007 – 1,2-dimethyl-3-propylimidazole bis(trifluoro methylsulfonyl)imide,
(m_{cz} = 419,4 g·mol^{-1}, ρ_{25} = 1.45 g·ml^{-1}, t_p = +15ºC, η_{25} = 86.61 mPa·s, VI = 134, σ_{25} = 33.166 mN·m^{-1});
CJ 008 – trihexyltetradecylphosphonium bis(trifluoro methylsulfonyl)imide,
(m_{cz} = 764.0 g·mol^{-1}, ρ_{25} = 1.06 g·ml^{-1}, t_p = –50ºC, η_{25} = 327.24 mPa·s, σ_{25} = 28.099 mN·m^{-1}).

The mentioned ionic liquids were also selected from among ten others, which turned out to be more toxic and corrosive, having concurrently good lubricity properties.

The load capacity tests of T-1-x porous sleeves produced at POLMO Łomianki S.A. of powder Fe with 2.5% Cu content, and then impregnated with mentioned above ionic liquids and references oils, were performed for rotational speed n = 1000 rpm v = 1.3 m·s^{-1}.

The load was gradually (step by step) increased after stabilization (and/or decrease) of resistance to motion and temperature of the bearing. The load change step was 0.4 MPa every time. It was assumed that the limit pressure (p_{gr}) was the one that preceded the pressure causing seizing (p_z). The following parameters were assumed as the seizing criterion: a rapid increase of resistance to motion, i.e. when moment of friction M_t > 2 Nm and friction factor μ > 0.3; instable bearing working, i.e. when appeared oscillations, parameter jumps (momentary seizing etc.); and, a rapid increase in bearing temperature up to T > 200–220ºC [**L. 7**].

The effect of the influence of various ionic liquids and reference oils, used for lubrication (impregnating up to about 97–98%) of T-1-x porous sliding sleeves, made of Fe (*sinter*) + 2.5% of Cu, on their load capacity, is shown in the figure below (**Fig. 3**).

These results were also related to the real conditions, when oils commonly recommended for porous slide bearings lubrication are used, for example, Klüberalfa DH3-100 (for n = 1000 rpm: p_{gr} = 0.94 MPa and p_{gr}·v = 1.22 MPa·m·s^{-1}) or Antykol TS-120 (for n = 1000 rpm: p_{gr} = 1.18 MPa, p_{gr}·v = 1,54 MPa·m·s^{-1}). These values just fall into the range of p·v = 0.9–2.1 MPa·m·s^{-1} commonly assumed as adequate for standard porous slide bearings (T-1-x). That range was marked with the dashed lines, while the marked points apply to the values of (p_{gr}) and (p_{gr}·v) achieved for Antykol TS-120 (dots) and Klüberalfa (crosses).

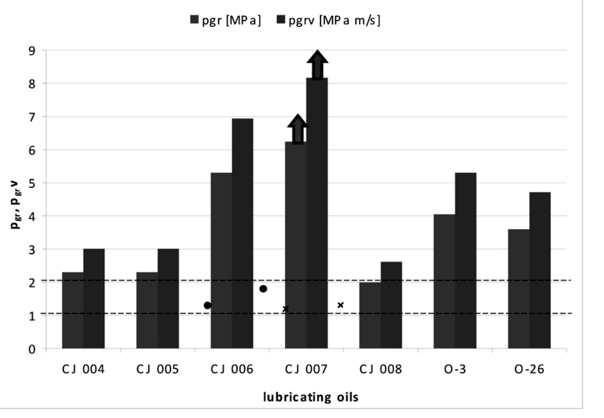

Fig. 3. Influence of the lubricant type on T-1-x load capacity, with n = 1000 rpm [L. 7]
Rys. 3. Wpływ rodzaju substancji smarującej na nośność T-1-x przy n = 1000 obr.·min^{-1} [**L. 7**]

As it can be seen in the figure above, the highest load capacity was obtained for the sleeves impregnated with CJ 007 liquid, i.e. 1,2-dimethyl-3-propylimidazole bis(trifluoromethylsulfonyl)imide. CJ 006 liquid, i.e. 3-methyl-1-propylpyridyne bis(trifluoromethylsulfonyl)-imide, also demonstrated very high load capacity. The difference between these two ionic liquids is determined by their different interaction with the porous structure, which manifests itself by their different permeability (**Table 1**) In case of CJ 006 liquid, it was probably too low. Other ionic liquids showed (p_{gr}) and (p_{gr}·v) lower than the reference oils applied. The sleeves lubricated with CJ 007 ionic liquid were not seized at all under maximum possible bearings load on PŁS-01 stand, i.e. 3200 N. CJ 007 ionic liquid (and CJ 006 also) provided porous bearings operating with a very low moment of friction and the friction factor (μ ~ 0.01), at the temperature not exceeding 80°C (*avg. val.* 60–70°C). These parameters were significantly worse for the other liquids. CJ 007 ionic liquid allowed for the stable bearings operation, and achieving a load capacity four times higher than expected for the porous slide bearings of this type, i.e. 2.1 MPa·m·s^{-1}. As it can be seen in the figure above, other ionic and reference liquids achieved or exceeded this normative value, but only in case of CJ 007 liquid lubrication, the bearings were not seized at all. The linear wear of the sleeves within the loaded area was minimum (under 2 μm), and the weight loss of ionic liquid was practically non-measurable (ionic liquids are practically non-volatile and do not oxidize) under the tests conditions on the PŁS-01 stand. It determines the very high durability of the bearings lubricated with this ionic liquid, in comparison with other oils, probably achieving even several thousand hours under high load conditions (the durability test was performed under 2000 N load, i.e. p_{gr}·v = 5,24 MPa·m·s^{-1}, and the bearings were operating for about 2000 hours without any disruptions), which could not be even carried by such oils as Antykol or Klüberalfa [**L. 7**]. Moreover, CJ 006 and CJ 007 ionic liquids are suitable for operating at very high temperatures. Both liquids are extremely thermally durable, and they do not undergo the vaporization effect at a measurable rate with the used measuring technique (TG/DTA/DSC – Labsys^{TM} SETARAM) [**L. 5**]. CJ 007 liquid can be heated up to about 400°C, and CJ 006 liquid up to about 350°C, without measurable symptoms of decomposition [**L. 10**]. Moreover, CJ 007 liquid is almost non-toxic (**Table 2**).

METHODOLOGY AND THE RESULTS OF THE POROUS SLEEVES PERMEABILITY TESTS

The oil circulation inside the porous structure and its inflow to the lubrication slot between a sleeve and a roller depends on the porous sleeves permeability. Permeability, because of its strict connection with sleeve porosity and interaction between porous structure and lubricant, also determines the porous bearing load capacity and durability. It is recommended to carry out absolute judgement of the porous structure permeability by means of the gases (PN-EN-ISO 4022: 2007) *"Permeable sintered metallic materials. Determination of fluid permeability,"* on account of the formation of the surface active substances (present in oils) on the internal walls of the nanolayer pores. The comparative assessment of the sleeve permeability with the use of real lubricating oils containing various chemically active additions allows us to determine (explain) the quality of substance functioning as the lubricant for the porous slide bearings [**L. 7**].

Sleeve air permeability ("aeration") determination was made in accordance with PN-EN-ISO 4022: 2007. The determination consisted in recognizing the volumetric air flow rate and pressure decrease during the air infiltration through ø25/ø35×20 mm sleeves porous wall with a known active surface and thickness, under laminar flow conditions on the test stand shown in the figures below (**Fig. 4** and **Fig. 5**). The determination of the sleeve oil permeability for real oils was performed according to the same standard on the appropriately prepared test stand [**L. 7**].

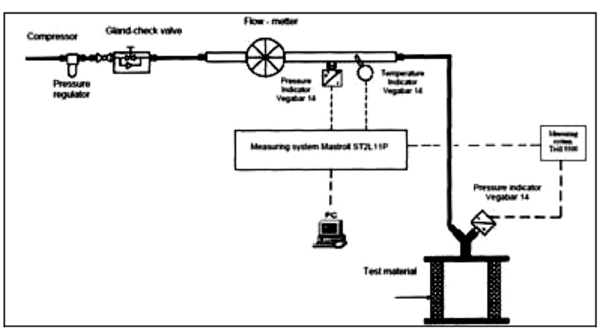

Fig. 4. Schematic diagram of the test stand for "aeration" measurement [L. 7]

Rys. 4. Schemat ideowy stanowiska do pomiaru „przewiewności" [**L. 7**]

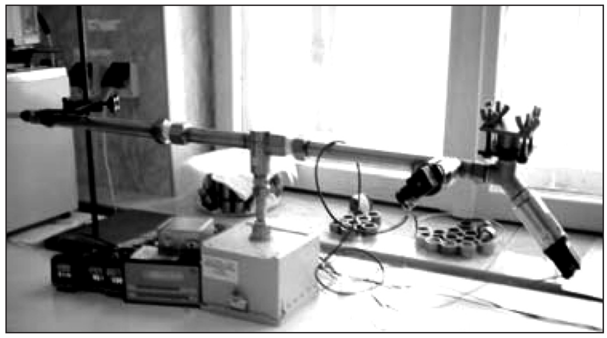

Fig. 5. General view of the test stand for "aeration" measurement

Rys. 5. Widok stanowiska do pomiaru „przewiewności" [**L. 7**]

The following figures show cumulative diagrams of permeability of T-1-x porous sleeves for air, CJ 006 and CJ 007 ionic liquids and two gear oils: 0-3 (Hipol 15F 85W/90) and 0-26 (Mobilube 1 SHC 75W/90) (**Fig. 6–8**). From among T-1-x sleeves T-1-533 sleeve was selected for the liquid tests, as the one with the higher and the most regular (linearly variable) "aeration".

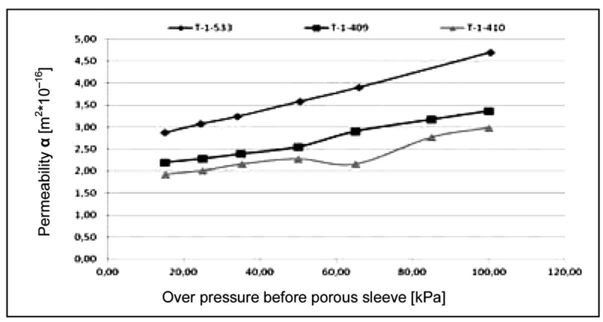

Fig. 6. Diagram of air permeability of T-1-x standard sleeves [L. 7]

Rys. 6. Wykres przepuszczalności powietrzem standardowych tulei T-1-x [**L. 7**]

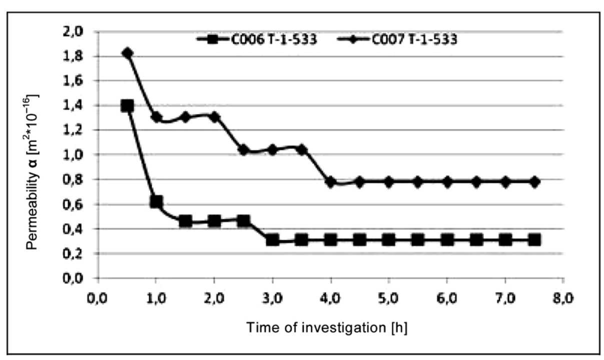

Fig. 7. Diagram of CJ 006 and CJ 007 ionic liquids permeability of T-1-533 standard sleeves [L. 7]

Rys. 7. Wykres przepuszczalności tulei T-1-533 cieczami jonowymi CJ 006 i CJ 007 **[L. 7]**

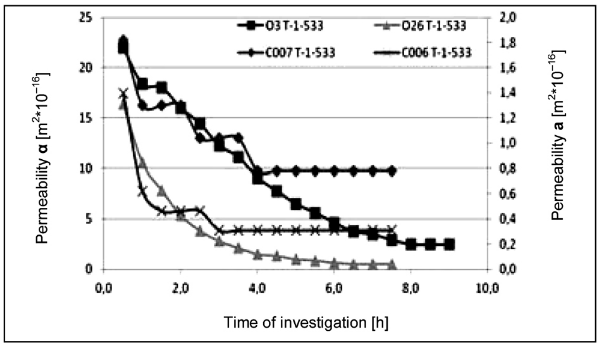

Fig. 8. Diagram of permeability of T-1-533 sleeves for CJ 006 and CJ 007 ionic liquids and 0-3 (Hipol) and 0-26 (Mobilube oils) [L. 7]

Rys. 8. Wykres przepuszczalności tulei T-1-533 cieczami jonowymi CJ 006 i CJ 007 oraz olejami 0-3 (Hipol) i 0-26 (Mobilube) [**L. 7**]

Table 1. Comparison of final stable permeability values of T-1-x

Tabela 1. Zestawienie końcowych ustabilizowanych wartości przepuszczalności T-1-x [**L. 7**]

Lubricating oil	Final stable permeability of T-1-x sleeves
CJ 006	$3.10 \cdot 10^{-17}$ m^2
CJ 007	$7.81 \cdot 10^{-17}$ m^2
0-3 (Hipol)	$2.44 \cdot 10^{-15}$ m^2
0-26 (Mobilube)	$5.14 \cdot 10^{-16}$ m^2

The presented characteristics of permeability against time indicate that high dynamics of changes at the initial period and very quick stabilization of the permeability values were achieved, which was the result of decreasing the flow rate value by the porous structure. It was observed that stabilization for CJ 006 ionic liquid was quicker than for CJ 007, and at a very low level. The value of final, stable permeability of CJ 007 was 2.5 times higher than the permeability of CJ 006 liquid (**Table 1**). Concurrently, the values of permeability for low-viscous ionic liquids were two orders of magnitude lower than the values obtained for Hipol 15F oil, and an order of magnitude lower than the values achieved for Mobilube 1 SHC oil.

Time of stabilization of the flow rate (and following permeability) for the gear oils were 6–8 hours for Hipol 15F oil, and 4–6 hours for Mobilube oil.

The stabilization of the permeability values for ionic liquids was proceeding in some stages, and it was beginning already after the first hour of the measurement. In case of CJ 006 liquid, the second stage of stabilization was occurring after about 3 hours, and then the flow rate was stable at a very low level to the end of the test. In case of CJ 007 ionic liquid, stabilizations of the liquid flow rate had two stages: the first one after about 1hour, when – after some decrease of the permeability value – for about one hour the flow rate was stable; the next stabilization stage took place between third and fourth hour, and finally, after another decrease, achieved – after 4 hours – a stable value till the end of the permeability measurement [**L. 7**].

As a result of the tribological research, it can be stated that the best parameters of T-1-x standard bearings operation, including the load capacity and durability, were achieved when the bearings were impregnated with CJ 007 ionic liquid. The operating parameters of the bearings impregnated with CJ006 liquid were worse than the ones for CJ 007, but much better than the ones for 0-3 (Hipol 15F 85W/90) and 0-26 (Mobilube 1 SHC 75W/90) oils. The weight loss of 0-3 oil was lower than the one for 0-26 oil; hence, the durability of the bearings impregnated with 0-3 oil was a little higher. In case of the ionic liquids, the weight losses were practically non-measurable. That is why there is the possibility to reach very high durability (if there are no negative obstacles) with maximum load capacity for the bearings impregnated with CJ 007 ionic liquid, which could not be seized at all on the PŁS-01 machine. It appears that the permeability of T-1-x standard bearing obtained for CJ 007 liquid is the optimum one.

METHODOLOGY AND RESULTS OF THE TESTS OF ECOTOXCITY AND CORROSIVITY OF THE IONIC AND REFERENCES LIQUIDS

Ecotoxicity tests of selected ionic liquids and reference oils were performed in comparison with *Daphnia magna*, freshwater crustaceans, in accordance with "*Daphnia sp., Acute Immobilisation Test and Reproduction Test"* – Part I (1984) OECD 202 standard, with criteria included in GHS Guidelines (Globally Harmonized Risk System of Classification and Labelling of Chemicals, Copyright @ United Nations – 2011), commonly used in the European Union (EU). According to the guidelines, a substance is extremely toxic if it has an effective concentration EC_{50} [mg·dm^{-3}], causing immobilization of 50 % *Daphna magna* test organisms after the time of 48 hours, is lower than 0.1 mg·dm^{-3}. If the value is $0.1 \leq EC_{50} \leq 1.0$ mg·dm^{-3}, the substance is defined as highly toxic; if $1.0 < EC_{50} \leq 10$ mg·dm^{-3}, the substance is regarded as moderately toxic; if $10 < EC_{50} \leq 100$ mg·dm^{-3}, the substance is regarded as slightly toxic; and, if $EC_{50} > 100$, the substance is non-toxic.

Table 2 presents the results of the evaluation of the ecotoxicity of the ionic liquids used for impregnating the porous slide bearings, and of two selected reference oils, which were the best in the comparative tests, among the lubrication oils available in the market, recommended for usage in porous slide bearings, e.g., Antykol TS-120 or Klüberalfa DH3-100 [**L. 10**].

Table 2. Results of ecotoxical ionic liquids and references [L. 10]
Tabela 2. Wyniki oceny ekotoksyczności cieczy jonowych i referencyjnych [**L. 10**]

Type of liquids	EC_{50} – 24 h (95% conf. interval) [mg/dm^3]	EC_{50} – 48 h (95% conf. interval) [mg/dm^3]	Evaluation of liquid toxicity
CJ 004	4.80 (3.18–6.12)	1.97 (1.26–2.86)	Moderately toxic
CJ 008	77.15 (70.36–85.66)	3.89 (2.39–5.41)	Moderately toxic
CJ 005	23.93 (20.23–27.54)	11.40 (8.11–14.83)	Slightly toxic
CJ 006	76.71 (72.41–80.11)	70.54 (67.88–76.25)	Slightly toxic
CJ 007	114.12 (105.24–126.59)	96.51 (85.50–107.62)	Slightly toxic (almost non-toxic)
1 SHC 75W/90	485.63 (474.23–496.33)	375.68 (363.48–386.88)	Non-toxic
PAO-6	> 1000	805.27 (795.37–816.87)	Non-toxic

As it can be seen in the **Table 2**, CJ 006 and CJ 007 ionic liquids are slightly toxic, and CJ 007 liquid, at the 24 hours test, achieved a value EC_{50} higher than 100, which means it is non-toxic, as are the reference hydrocarbon oils. CJ 006 has very low toxicity. During the corrosivity test, it was stated that these liquids are resistant to corrosion within the wide range, in relation to all metals used in tests, i.e. 100Cr6 (AISI 52100) steel, M1E copper, OMO48Z4 brass and ER5356 aluminium. The results of electrochemical measurements for previously mentioned ionic liquids can be found in Table 3 [**L. 10**].

Table 3. A comparison of the results of the tests of electrochemical corrosion for the ionic liquids [L. 10]
Tabela 3. Zestawienie wyników badań korozji elektrochemicznej w cieczach jonowych [**L. 10**]

Ionic liquids	100 Cr6 Steel		M1E copper	
	Corrosion potential E_{KOR} [V]	Potential resistance range ΔE_{ZO} [v]	Corrosion potential E_{KOR} [V]	Potential resistance range ΔE_{ZO} [v]
CJ 004	–0.03	3.20	–0.16	1.79
CJ 006	0.03	2.69	0.48	1.10
CJ 007	–0.07	2.62	0.08	1.89
CJ 008	–0.29	1.74	–0.22	2.50

Ionic liquids	OMO58Z4 brass		ER5356 aluminum	
	Corrosion potential E_{KOR} [V]	Potential resistance range ΔE_{ZO} [v]	Corrosion potential E_{KOR} [V]	Potential resistance range ΔE_{ZO} [v]
CJ 004	–0.14	1.02	–0.31	3.13
CJ 006	–0.03	0.68	–0.21	2.79
CJ 007	–0.04	1.92	–0.33	2.58
CJ 008	–0.26	1.83	–0.46	1.34

Practically all ionic liquids mentioned above demonstrate a properly wide range of electrochemical corrosion resistance. CJ 004 ionic liquid demonstrated the best properties during the tests, but in the previous tests of ecological toxicity, it was several times more harmful for the natural environment than CJ 008 liquid. The results for both mentioned liquids were far worse than the reference oils during the tests on the PŁS-01 stand, but they exceeded the value required for standard bearings: $p_{gr} \cdot v$ = 2.1 MPa·m·s^{-1}. The CJ 007 liquid (and, to a lesser degree, CJ 006 liquid) meets all of the following requirements: It does not act corrosively on the basic materials of tribological nodes; It is practically environmentally friendly and makes it possible to achieve far higher load capacity and durability of the iron porous slide bearings than the same bearings impregnated with the best, so far, gear oils (Hipol 15F 85W/90; Mobilube 1 SHC 75W/90), and several times higher values than, commonly recommended for impregnating the porous slide bearings, Antykol TS-120 and Klüberalfa DH3-100 oils.

CONCLUSIONS

Despite the ionic liquid type, it is possible to depend on the significant increase of porous slide bearings durability (working time), which is connected with their very low vapour pressure determining their almost negligible volatility and their resistance to oxidizing. In case of a properly selected ionic liquid with an optimal set of surface-energetic, viscosity-temperature, and lubricating properties, and compatible with the lubricated surface, while being non-corrosive and environmentally friendly, very high durability is provided with porous slide bearings using the recommended oils presented above. The bearings working in these lubrication conditions can have load capacities several times higher than standard bearings lubricated with the oils recommended previously (e.g., Antykol TS-120), including perfluoropolyether oils (e.g., Klüberalfa DH3-100). In the discussed case, this liquid was primarily 1,2-dimethyl-3-propylimidazole bis(trifluoromethylsulfonyl)imide. The porous slides sintered from powder Fe with the addition of 2.5% Cu achieved a load capacity 8 times higher than the bearings impregnated with, e.g., Klüberalfa DH3-100 oil, and twice the load capacity of the same sleeves lubricated with comparatively tested Hipol 15F and Mobilube 1 SHC gear oils, with a significantly lower friction factor ($\mu \approx 0.01$), which directly determines resistance to motion, i.e. minimum energy loss. Such bearings can operate at a very high ambient temperature, with a very low friction factor, which means large energy savings. That is why it was decided to submit a patent claim to the Polish Patent Office [**L. 8**].

The subjects of this application are the iron porous slide bearings (sleeves), lubricated (impregnated) with the selected ionic liquid, which allows for their operation at very high ambient temperatures, even up to do 350–400°C. According to the selected ionic liquid, the temperature operating range of the bearings can be various, from extremely negative temperatures (–50°C), to extremely high temperatures (+400°C), with medium rotational speed and under increased load. The basic problem is to select the proper ionic liquid that compatible with the porous sinter material. It will be different liquid, e.g., for bronze bearings, and different for bearings made of iron sinter. The selection process requires the series of complex and detailed research works of physicochemical properties, e.g., lubricity, surface-energetic, viscosity-temperature, toxicity, and interaction with the lubricated surface, including corrosivity, tests. Very reactive lubricants could be too intensively absorbed on the catalysing surfaces of the porous structure, rapidly decrease liquid inflow, block pores, and, as a result, lead to faster bearing seizing, despite the significant presence of the liquid inside the pores. On the other hand, inert, non-polar, and poor absorbance on lubricated surfaces provides easy and fast will flow out from the porous structure, but they will not create an appropriately durable lubricating film on the sliding surface of the bearing.

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