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POWRÓT

PERMEABILITY OF POROUS BEARINGS AT THE TEMPERATURE OF NORMAL BEARING OPERATION

PRZEPUSZCZALNOŚĆ ŁOŻYSK POROWATYCH W TEMPERATURZE NORMALNEJ PRACY ŁOŻYSKA

Key–words:

permeability, porosity, self–lubricating bearing

Słowa kluczowe:

przepuszczalność, porowatość, łożysko samosmarne

Summary:

In the article short review on investigations of permeability is presented. Basic properties of the porous bearings and mineral gear oil have been examined. Then permeability investigations of porous sliding bearings

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for mineral gear oil at the temperature of normal bearing operation have been performed. Achieved results of preliminary investigations show that in the chosen range of temperature (40–60°C) there is no relationship between permeability of the bearing and temperature of flowing oil.

INTRODUCTION

Porosity and permeability of the bearing decide about area of application, so there is great importance to estimate suitable values of these two parameters. Basic property of porous bearings is their ability of absorption of oil. Amount of oil absorbed by the bearing is greater when its open porosity is greater. However the value of open porosity do not contribute any information about size, shape and distribution of pores in the bearing. All above–mentioned properties could be qualified during test of permeability, which is standardised [1–4]. Permeability of porous bush decides about resistance of flow and about circulation of oil in the bearing. Amount of oil and conditions of its circulation in the bearing gap and in porous bush have a principle influence on operation of self-lubricating bearing, and therefore permeability of bush is very essential parameter, on which depend motional properties of the porous bearings [5–16].

Permeability of sleeve is constant for gases, instead when flowing fluid is liquid about large viscosity (e.g. oil) permeability of sleeve is dependent on time and on kind of liquid. Permeability of sleeve decreases as the result of creation of boundary layers on surface of capillary channels and lowering of their clearances. Permeability for oils fixes after several hours of the test.

During flow through porous body (bearing) circumstances of laminar or turbulent flow can occur. However some opinions show [1, 8, 17], that it is difficult to qualify critical value of Reynolds number, which would define kind of flow (laminar or turbulent). Wide range of porous articles, of their dimensions, of shapes and at last of porosity results in occurrence of local disturbances and of whirls of liquid at flow through porous body. It also contributes to increasing of inertial factor and to decreasing of critical Reynolds number, which is estimated to be 4…15 [17]. It must be noticed that the value of Reynolds number depends also on sizes of pores. On the whole, conditions of flow through porous body, regarding viscous and inertial resistance, describes Forchheimes' law, in the following mathematical form [1, 18–19]:

$$\frac{\Delta p}{L} = \frac{Q \cdot \eta}{F \cdot \mathbf{\acute{a}}} + \frac{Q^2 \cdot \rho}{F^2 \cdot \mathbf{\hat{a}}} \tag{1}$$

Where: Δp – change of pressure of liquid flowing through porous body, L – length of way of flow through porous body, Q – volumetric rate flow, F – active surface of flow, η – dynamic viscosity of liquid, ρ – density of liquid, α – viscous coefficient of permeability, β – inertial coefficient of permeability.

When Reynolds' number is smaller than critical value, circumstances of flow qualifies Darcy' law in the following mathematical form [1, 18–19]:

$$\frac{\Delta p}{L} = \frac{Q \cdot \eta}{F \cdot \mathbf{\acute{a}}} \tag{2}$$

Darcy' law is the most often used for permeability investigation of porous sleeve both at use of gases and of oils. Value of Reynolds number can be counted from [1, 18–19]:

$$R_e = \frac{Q \cdot \rho \cdot d_p}{F \cdot \eta \cdot \theta} \tag{3}$$

Where: θ – value expressing open porosity in percentages divided by 100; contribution of open pores in porous body examined according to Polish Standard [20], d_p – maximum size of pores (m) estimated according to Polish Standard [19].

Analysis of many opinions shows also that there is strong dependence of carrying capacity of porous bearings on their porosity and permeability [6–8, 10, 15, 16]. As far as the porosity is concerned this property is given almost by all authors, however permeability is seldom specified. Permeability is the object of theoretical analyses [7, 9, 10, 12] and of experimental researches [6–8, 15, 16]. Both theoretical as well as experimental investigations show that load carrying capacity of the bearing increases with decrease of permeability. So permeability should be considered to estimate carrying capacity. Lawrowski reminds of that dependence giving formula on constructional coefficient connected with carrying capacity:

$$\Pi = k \times \frac{\Phi}{(R - r)^3} \tag{4}$$

Where: k - coefficient dependent from dimensions of the bearing, Φ - coefficient of permeability of the bearing, R- radius of bush, r- radius of shaft [21].

Permeability of sintered materials, and among them of porous bearings, is dependent on many parameters. The most important among these parameters are kind of oil, pressure of pressing process, dimensions of powder grains, shape of grains, distribution of size of used powder. Bearings produced from powder of very diverse shape and dimensions have permeability many times lower than bearings produced from powder of regular shape and dimensions. Permeability of porous bearings is shaped on the stage of production, in process of seizing and running–in, and also during normal work of the bearing in tribological pair in dependence of kind of material and of used oil. This parameter changes also during normal work of the bearing what results from change of oil properties during oxidation process (increase of viscosity, increase of total acid number, degradation of additives, change of surface activity of oil to surface of porous channels).

Olexa [7] claims, that decrease of permeability was influenced by the following factors: material of the bearing, its structure (size and shape of pores) and kind of oil. The most significant influence had kind of oil. Olexa [7] shows also that flow of oil through porous bearing lead to obliteration as the result of creation of boundary layer on the surface of porous channels. As he proves composition of applied oils containing EP additives caused drastic lowering of permeability and almost total blockage of pores. In another paper [12] one focuses also on this effect and in next papers [21–24] authors turn attention, that use of suitable lubricity additives having plate build (e.g. boron nitride) can assure higher carrying capacity of examined bearings.

Olexa [7] and Lawrowski [5] turn attention, that main reason of the bearing seizure is stop of oil flow and its circulation as a consequence of blocking of porous channels with active additives to oils and with products of ageing process. That opinion disagrees with another one [25, 26], according to which the main reason of bearing seizure is decrease or also loss of lubricating property of oil as the result of ageing process. Generally, aged oils have good lubricating properties (i.e. anti-seizure and anti-wear properties understood in conventional meaning with reference to solid materials). On the grounds of that the most probable reason is that aged oils comprise surface-active and polar products of oxidation. Furthermore it causes decrease of permeability to value which does not assure appropriate circulation of oil. Final effect can be total blockage of pores, quick change of lubrication from regime of mixed friction to dry friction regime and seizure of the bearing. This opinion was preliminary proved in the author's investigations widely presented in [27, 28], in which it was confirmed that oils having better oxidation resistance caused smaller decrease of permeability coefficient.

There are no research results fixing critical values of permeability, which can be reached to sustain the process of self-lubrication. Superposition of permeability change of porous bush as the result of running-in and seizing process and of influence of lubricating oil, including products of oxidation process, can lead to drastic decrease of amount of lubricating oil in a bearing gap, to changes of kind of occurring friction to boundary or dry friction and in the end to seizure of a bearing.

Presented results of permeability investigations for oils are usually performed at the ambient temperature. However, a normal work temperature of porous bearing is 50–60ºC and on the grounds of that permeability of the bearing at higher temperature should be examined. It is noticeable that there are no research results of porous bearing permeability at elevated temperature of oil. Furthermore, some authors [29–32] agree that surface activity of oils and of additives comprised in oils depends on the temperature and that there is always specified area of the best activity of oil and additives. It means that permeability of oil could change depending on the temperature of the bearing operation.

The aim of presented work is to investigate influence of oil temperature on a value of permeability coefficient. There are no published results in that area. That preliminary research is the first step to wider programme of investigations of porous bearing permeability depending on the chosen properties of oil.

INVESTIGATIONS

Ten porous bearings in dimensions Ø35x25x20 were chosen. Some basic properties of the bearings were investigated according to valid Polish standards: dimensions, porosity [20], permeability for air under pressure of 3.0 kPa [1], maximum pore size [19]. Achieved results are presented in Tab.1. Technical details of used stand bed are widely presented in [27, 28].

Table 1. Research results of determined properties of porous sleeves
Tabela 1. Wyniki badań właściwości tulei porowatych

No. of the bearing	Open porosity	Coefficient of permeability for airflow under 3 kPa [m^2]	Maximum pore size [μm]
3	21,47	$1.60\cdot10^{-12}$	4.89
9	**20,05**	$\mathbf{1.60\cdot10^{-12}}$	**4.84**
11	20,43	$1.50\cdot10^{-12}$	4.70
12	**20,39**	$\mathbf{1.45\cdot10^{-12}}$	**4.59**
18	20,85	$1.46\cdot10^{-12}$	4.52
19	20,48	$1.49\cdot10^{-12}$	5.30
24	20,67	$1.43\cdot10^{-12}$	4.92
25	20,47	$1.46\cdot10^{-12}$	5.04
28	23,99	$1.44\cdot10^{-12}$	4.92
30	20,50	$1.39\cdot10^{-12}$	5.01

One oil was chosen to impregnate porous sleeves: commercial gear oil with EP additives Hipol 15F GL–5 80W/90. Only basic properties of oil were determined according to valid Polish standards: density [33] and kinematic viscosity [34] at the temperature of 20°C, 40°C, 50°C, 60°C and 100°C and viscosity index (VI) [35]. The results obtained allowed to calculate dynamic viscosity (Tab.2).

Table 2. Research results of basic properties of oil Hipol 15F
Tabela 2. Wyniki badań podstawowych właściwości oleju Hipol 15F

	Density ρ [g/cm^3]	Kinematic viscosity ν [mm^2/s]	Dynamic viscosity η [mPa·s]	Viscosity index VI
20°C	0.899	715,42	643,16	103
40°C	0.889	193.30	171.84	
50°C	0.881	113.79	100.25	
60°C	0.875	71.52	62.58	
100°C	0.853	17.94	15.30	

Then two bearings (No. 9 and No. 12) were taken to carry out investigation of permeability coefficient for oil Hipol 15F at three different temperatures: 40°C, 50°C and 60°C.

The investigation of permeability coefficient was performed at the constant overpressure of 78 kPa and at constant temperature (40, 50 and 60˚C). During the test the volumetric flow rate of oil had been measured until constant values were achieved. The calculations of global permeability were carried out according to Darcy law for laminar flow through porous material (formula No. 2). Achieved results of investigations are presented below. One also checked if Reynolds number was smaller than critical value $3 \div 4 * d_p$ (Table 3), what meant that conditions of laminar flow had been achieved.

Table 3. Calculation results of Reynolds number at specified temperature
Tabela 3. Wyniki obliczeń liczby Reynoldsa w określonej temperaturze

	Reynolds number at specified temperature		
	40ºC	50ºC	60ºC
bearing No. 9	0,00000037	0,00000115	0,00000028
bearing No. 12	0,00000047	0,00000133	0,00000037

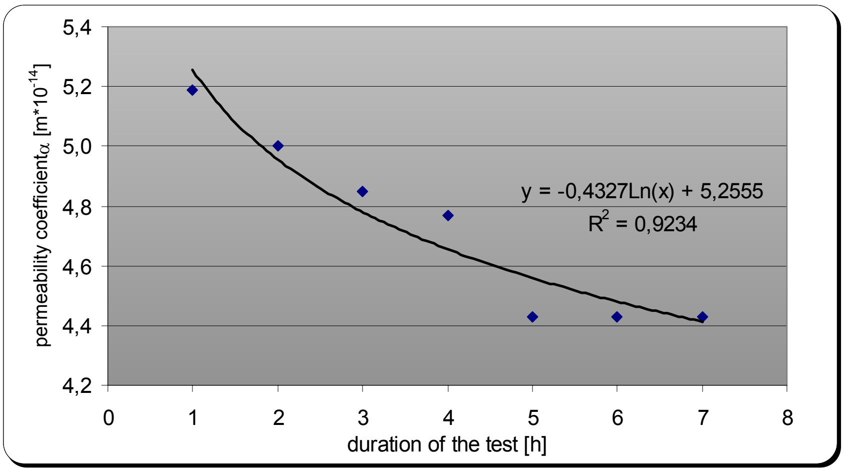

Fig. 1. Permeability coefficient α of sleeve No. 12 for oil Hipol 15F at the temperature of 40ºC
Rys. 1. Współczynnik przepuszczalności α tulei nr 12 dla oleju Hipol 15F w temperaturze 40ºC

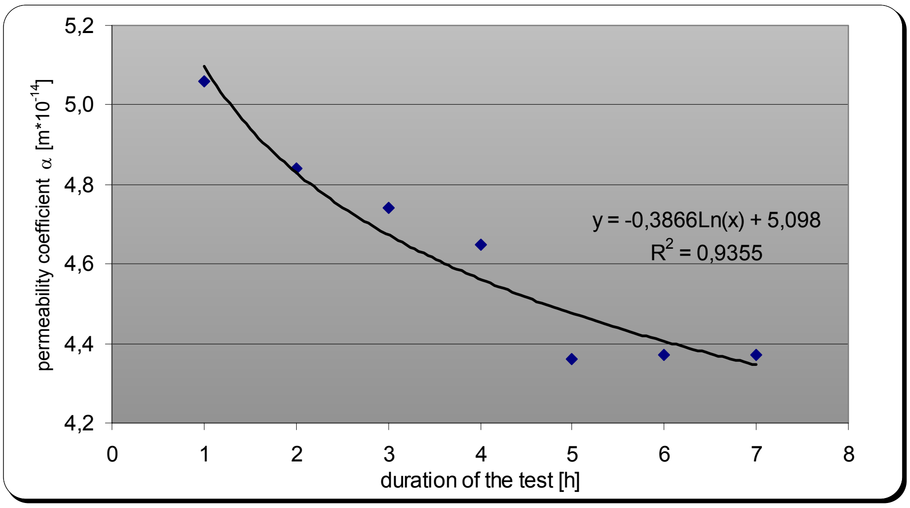

Fig. 2. Permeability coefficient α of sleeve No. 12 for oil Hipol 15F at the temperature of 50°C

Rys. 2. Współczynnik przepuszczalności α tulei nr 12 dla oleju Hipol 15F w temperaturze 50°C

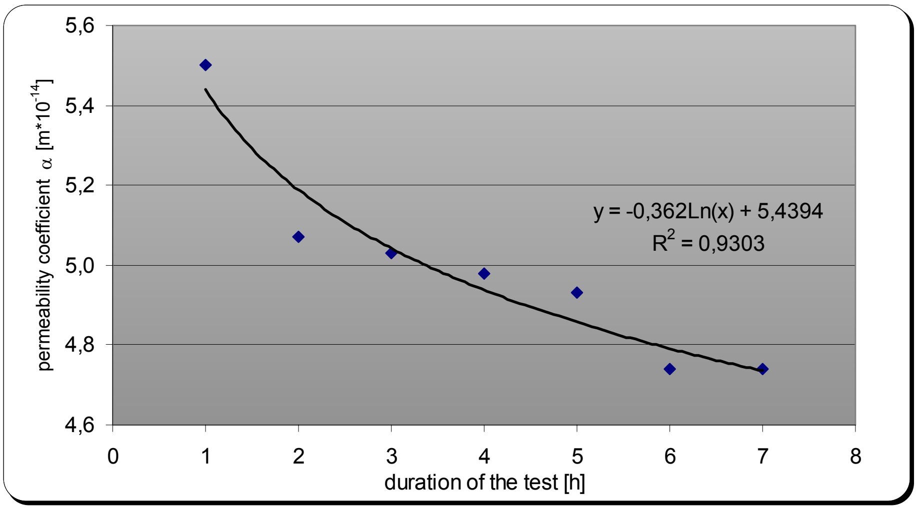

Fig. 3. Permeability coefficient α of sleeve No. 12 for oil Hipol 15F at the temperature of 60°C

Rys. 3. Współczynnik przepuszczalności α tulei nr 12 dla oleju Hipol 15F w temperaturze 60°C

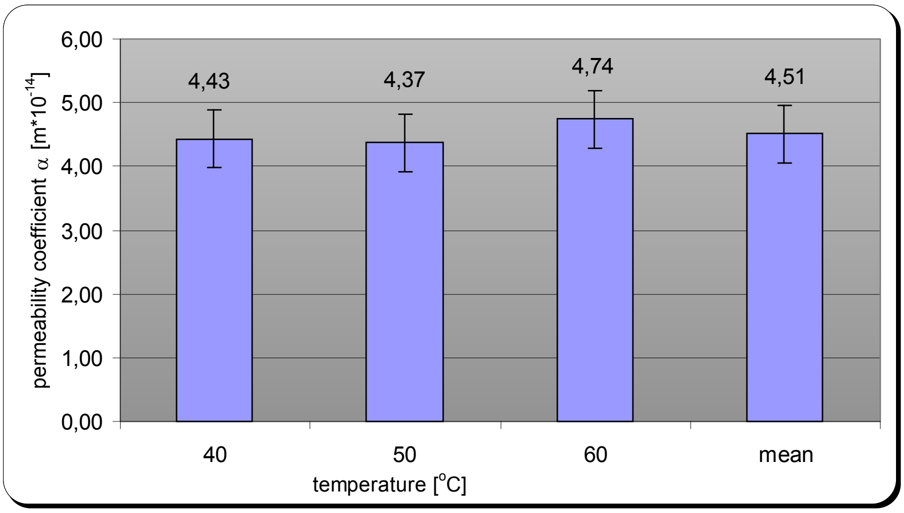

Fig. 4. Permeability coefficient α of sleeve No. 12 for oil Hipol 15F at the temperature of 40, 50 and 60ºC and with mean value of permeability coefficient

Rys. 4. Współczynnik przepuszczalności α tulei nr 12 dla oleju Hipol 15F w temperaturze 40, 50 i 60ºC oraz z wartością średnią współczynnika przepuszczalności

In the figures No. 1-3 results of permeability coefficient investigation at specified temperature are presented. In the analysis exponential functions were used to describe occurring relations, which mathematical form was estimated according to the least square method. Coefficient of correlation R^2 was also counted and value of this coefficient above 0.9 marked existence of correlation between permeability coefficient and duration of the test. For porous sleeve No.12 quite good correlation was achieved for all the temperatures (40ºC – R^2= 0.9234; 50ºC – R^2= 0.9355; 60ºC – R^2= 0.9303). During all the tests value of permeability coefficient was decreasing and after 4–5 hours was stabilised. In the Fig. 4 calculated values of permeability coefficients are presented with mean value and with acceptable measuring error (±10% of average value) according to Polish Standard [1]. It can be clearly seen that coefficient of permeability at specified temperatures is almost the same and does not exceed acceptable error. It should be also pointed out, that in the performed range of investigations for porous sleeve No. 12, coefficient of permeability does not change with change of temperature.

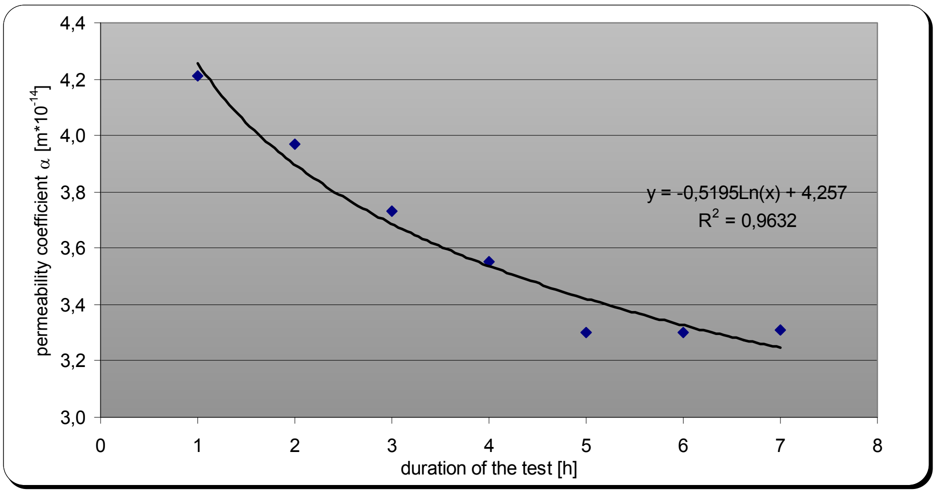

Fig. 5. Permeability coefficient α of sleeve No. 9 for oil Hipol 15F at the temperature of 40ºC

Rys. 7. Współczynnik przepuszczalności α tulei nr 9 dla oleju Hipol 15F w temperaturze 40ºC

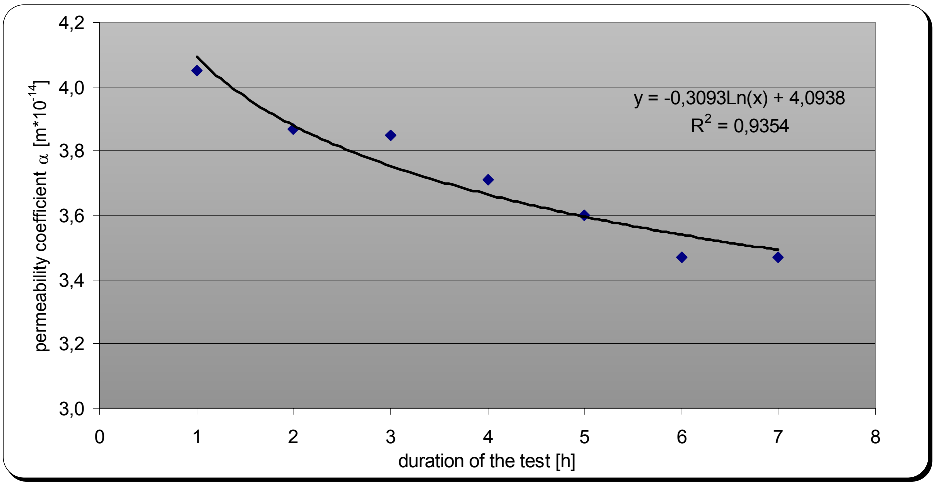

Fig. 6. Permeability coefficient α of sleeve No. 9 for oil Hipol 15F at the temperature of 50ºC

Rys. 8. Współczynnik przepuszczalności α tulei nr 9 dla oleju Hipol 15F w temperaturze 50ºC

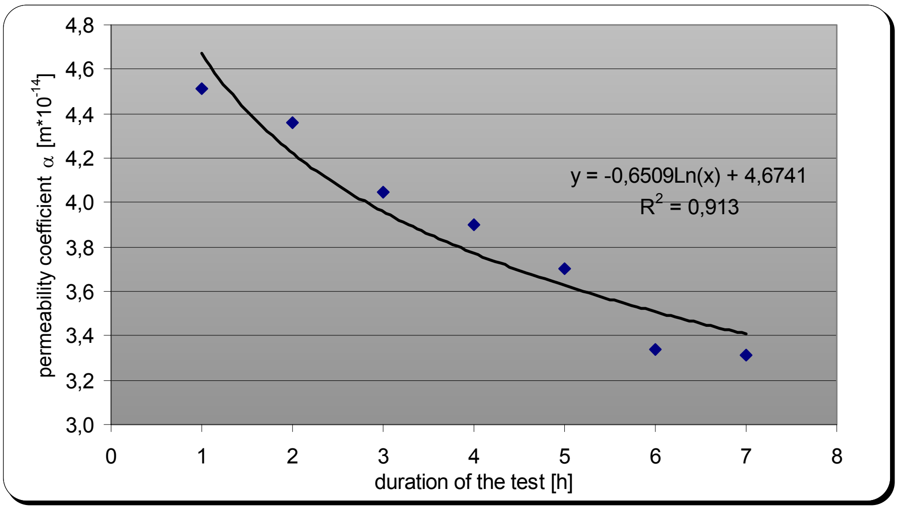

Fig. 7. Permeability coefficient α of sleeve No. 9 for oil Hipol 15F at the temperature of 60°C
Rys. 7. Współczynnik przepuszczalności α tulei nr 9 dla oleju Hipol 15F w temperaturze 60°C

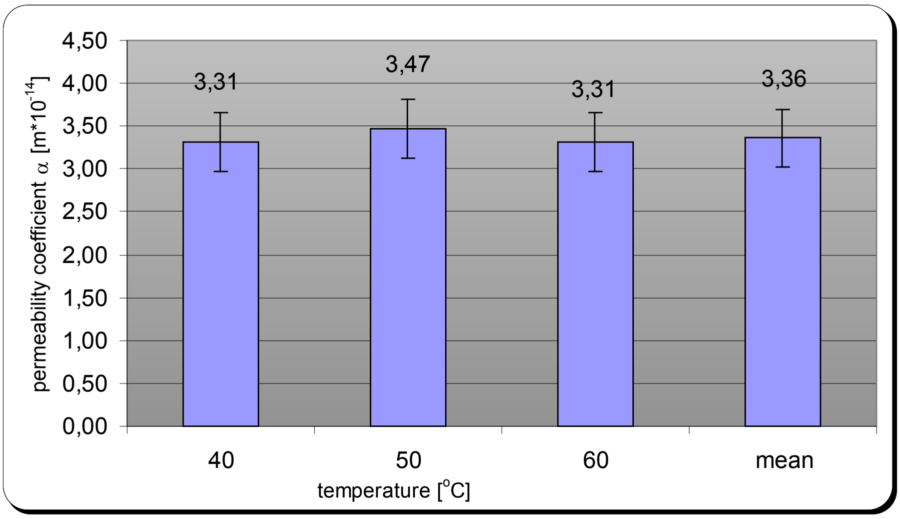

Fig. 8. Permeability coefficient α of sleeve No. 9 for oil Hipol 15F at the temperature of 40, 50 and 60°C and with mean value of permeability coefficient
Rys. 8. Współczynnik przepuszczalności α tulei nr 9 dla oleju Hipol 15F w temperaturze 40, 50 i 60°C oraz z wartością średnią współczynnika przepuszczalności

In the Fig. 5–7 results of permeability coefficient investigation of porous sleeve No.9 at the temperature of 40, 50 and 60ºC are presented.

Also quite good correlation of permeability coefficient with duration of the test was achieved (40ºC – R^2= 0.9632, 50ºC – R^2= 0.9354, 60ºC – 0.913). In the Fig. 8 calculated values of permeability coefficients are presented with mean value and with acceptable measuring error (±10% of mean value) according to Polish Standard [1]. For porous sleeve No.9 there is no dependence observed between permeability coefficient and temperature. Achieved results are quite close to mean value and do not exceed 10%.

FINAL CONCLUSIONS

The results obtained showed that coefficient of permeability does not change in dependence on temperature of oil Hipol 15F. Furthermore surface activity of oil Hipol 15F does not change significantly and does not cause change of permeability.

Results of investigations of permeability coefficient at the temperature of normal bearing operation have not been presented yet in the professional literature. This essential parameter should be examined at the temperature of the bearing operation, because oil properties change with decrease or increase of temperature. It could finally result in worsening of bearing work.

Further investigations have to be undertaken for more samples and kinds of oil to check if the coefficient of permeability depends on the temperature of other different oils. Achieved results need further testing on the stand bed to check influence of the permeability on operational characteristics of porous bearings.

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Recenzent:
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Streszczenie

W artykule przedstawiono krotki przegląd badań przepuszczalności. Zbadano podstawowe właściwości łożysk porowatych i przekładniowego oleju mineralnego. Następnie przeprowadzono badania współczynnika przepuszczalności porowatych łożysk ślizgowych dla oleju przekładniowego. Osiągnięte wyniki wstępnych badań wskazują, że w wybranym zakresie temperatury (40–60°C) współczynnik przepuszczalności łożyska porowatego nie zależy od temperatury przepływającego oleju.