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# RESEARCH IDEA AND METHODOLOGY FOR DETERMINING TEST PARAMETERS FOR THE LUBRICITY EVALUATION OF OIL/REFRIGERANT MIXTURES

## KONCEPCJA BADAŃ I METODYKA WYZNACZANIA PARAMETRÓW BADAŃ DLA OKREŚLANIA WŁAŚCIWOŚCI SMARNYCH MIESZANIN OLEJ/CZYNNIK CHŁODNICZY

**Key words:**

oil/refrigerant mixture, lubricity

**Słowa kluczowe:**

mieszanina olej/czynnik chłodniczy, właściwości smarne

**Abstract**

The problems with lubrication in refrigeration compressors are usually caused by the presence of the oil-refrigerant mixture in friction nodes. One cannot assess lubricity properties of oil under its operating conditions based on test results that characterize oil exclusively. For this purpose, it is necessary to test the lubricity properties of the oil-refrigerant mixture.

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The article presents the concept of an assessment method for the lubricity properties of oils for refrigeration compressors in a mixture with a refrigerant. The essential elements of the proposed method are the procedure for selecting wear test duration time ($\tau_t$) and the oil-refrigerant mixture formation time ($\tau_m$).

## INTRODUCTION

The problems with lubrication in refrigeration compressors are usually caused by the presence of the oil-refrigerant mixture in friction nodes. The presence of a refrigerant in the oil impairs its lubricity properties **[L. 1–4]**. The refrigerant should form a mixture with the lubricating oil in the full range of temperatures and operating pressures. Fulfilling this criterion allows the oil to return from the system to the refrigeration compressor. At the same time, oil does not stay in heat exchangers. Most mechanical damage to reciprocating refrigeration compressors is caused by the improper lubrication of sliding nodes due to an insufficient amount of oil (it stays in the system) or the dissolution of refrigerant in oil. Therefore, the important issue is the assessment of the lubricity properties of oil under operating conditions (in the mixture with a refrigerant).

Lubricity (tribological) properties of oil-refrigerant mixtures have previously been evaluated by applying different research methods **[L. 5–23]**. Testing was implemented on various types of model friction nodes due to the use of standard samples, accelerated time, and the low costs of research compared to the real objects such as refrigeration compressors.

One of the first devices to test wear in oil-refrigerant mixtures was the Falex machine. The authors of **[L. 5]** used it to test wear in the mixtures of mineral oils with R12. In turn, in **[L. 6]**, the Falex machine was used to test different oils including mainly synthetic ones in the mixture with R134a. The mixture in these tests was produced by letting the refrigerant through oil. A significant limitation for the use of standard machines to test wear was the inaccurate modelling of typical conditions occurring in the real refrigeration compressors. In general, it led to testing mixtures at atmospheric pressures, wherein the amount of the refrigerant in the mixture is much lower than at the pressure existing in the compressor. Furthermore, there was the risk of other gases escaping from the environment to the tested mixtures.

The availability of testing wear in the oil-refrigerant mixture, where the pressure of the agent was above the atmospheric one, enabled the modernization of the Falex machine **[L. 7, 8]**. The friction node was enclosed in a properly hermetically sealed chamber, which allowed for the use of overpressure during wear tests. In order to produce the oil-refrigerant mixture, a small quantity of the refrigerant was supplied to the test chamber above the oil present there.

The tests at the higher pressures of the refrigerant were presented in **[L. 9, 10]**. A four-ball tester was used. However, the range of the applied pressures did not correspond to the values that may occur in the majority of the refrigeration compressors used at that time. The four-ball tester was also used in **[L. 11]**.

In **[L. 12]** wear tests in the oil-refrigerant mixture were carried out using a modified Almend-Wieland machine. The frictional matching used in these tests best corresponds to the actual geometry of slide bearings due to the distributed surface contact. Other authors, however, used friction nodes enabling the achievement of measurable wear during a relatively short test duration time.

In recent years, the most commonly used test benches have been of the pin-on-disc (or ball-disc) **[L. 13–18]** and block-on-ring types **[L. 19–23]**. A number of these studies addressed the mixtures of oils and HFCs (mainly R134a) **[L. 13, 15, 17, 18, 20, 22]**. On the other hand, the mixtures of oils and HCs (mainly isobutene R600) were tested less frequently **[L. 14**, **19, 23]**.

Particular researchers produced the oil-refrigerant mixtures in different ways. Most frequently, one maintained a permanent access of the refrigerant of a constant pressure **[L. 13, 14, 16, 17, 19, 21–23]**, or a portion of a refrigerant was repeatedly supplied to oil **[L. 18, 20]**. In many cases, the process of mixture formation was not performed, or its parameters, such as the refrigerant pressure and the duration of the oil-refrigerant mixture formation, were not stated.

It is worth noticing that the formation of the oil-refrigerant mixture takes place through absorption. One can differentiate between two basic types of absorption mechanisms:

1. Simultaneous natural convection and molecular diffusion, and
2. Molecular diffusion exclusively.

For instance, the first type occurs for polyester oils (POE) with hydrofluorocarbons (HFCs, i.e. R134a) **[L. 24, 25]**; whereas, the other type is for mineral oils (MO) with HCs (for instance propane R290) **[L. 26, 27]**. The natural convection mechanism is characterized by a much larger pace of the mixture formation due to the higher density of the refrigerant than oil.

This article presents the following:

– The concept of a testing method allowing the evaluation of the lubrication properties of oils for refrigeration compressors in the oil-refrigerant mixture;
– A procedure for selecting the wear test duration time ($\tau_t$) and the oil-refrigerant mixture formation time ($\tau_m$).

## THE CONCEPT OF THE ASSESSMENT METHOD OF THE LUBRICATION PROPERTIES OF THE OIL-REFRIGERANT MIXTURE

The authors of this article have proposed their own concept for assessing the lubrication properties of the oil-refrigeration mixture. In order to assess these properties, the sample wear of the model block–on–ring node was used

(**Fig. 1a**). The above matching was selected because its nature of movement corresponds to the geometry of the elements the crank mechanism of reciprocating refrigeration compressors. Furthermore, while filling half the height of the ring, there is an opportunity to map the impact of the refrigerant on the compressor nodes lubrication conditions already at the stage of transporting the lubricating medium into the friction area.

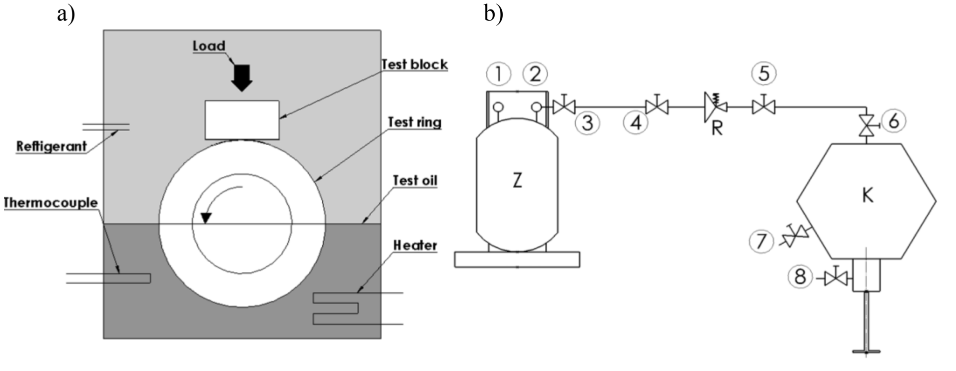


**Fig. 1. (a) Scheme of the hermetic block-on-ring type wear tester, (b) the instrumentation for supplying refrigerant: Z – refrigerant cylinder, R – pressure reducer, K – chamber, 1-8 – ball valves**

Rys. 1. (a) Schemat komory stanowiska badawczego z węzłem tarcia typu rolka – klocek, (b) idea zasilania komory badawczej czynnikiem chłodniczym: Z – zbiornik czynnika chłodniczego, R – reduktor ciśnienia, K – komora badawcza, 1–8 – zawory kulowe

In the proposed assessment method, the process of sample wear occurs under the following conditions:

– The achievement of a clear loss in material in a relatively short period of time, and
– Reflecting the actual conditions in the exploitation of refrigeration compressors.

At the test bench (**Fig. 1b**) one can map the input forces characteristic for the state of compressor start after an extensive standstill. The amount of refrigerant in the mixture with oil inside the compressor is then the largest. During the break in operation of the refrigeration unit, the oil in the crankcase of the compressor is directly affected by a large amount of refrigerant in the conditions determined by the ambient temperature. The long exposure time promotes the maximum amount of refrigerant (for the given conditions) in the mixture with oil.

## THE METHODOLOGY FOR DETERMINING TEST PARAMETERS FOR OIL-REFRIGERANT MIXTURES

The key element of the proposed method is the procedure for obtaining the oil-refrigerant mixture. In order to accomplish this task, it was necessary to construct a suitable chamber (**Fig. 1a**) equipped with the instrumentation to supply the refrigerant and to select the following test parameters:

- Refrigerant pressure in the test chamber ($p_s$),
- Wear tests duration time ($\tau_t$), and
- Oil-refrigerant mixture formation time ($\tau_m$).

The procedure for selecting the above parameters is presented visually in **Table 1**.

**Table 1. Parameters selection procedure**
Tabela 1. Procedura ustalania parametrów testu

| Lp | PARAMETER | | | MEDIUM | | | SELECTION PROCEDURE | |
|---|---|---|---|---|---|---|---|---|
| | pressure in chamber ($p_s$) | wear test duration time ($\tau_t$) | mixture formation time ($\tau_m$) | refrigerant | oil | oil-refrigerant mixture | data | criterion |
| 1 | selection | | | X | | | log p-h diagram | saturated vapor under ambient conditions |
| 2 | constant – selected in step 1 (air) | selection | | | X | | test series results – various ($\tau_T$) | clear wear (greater than 0.5 $mm^3$) |
| 3 | constant – selected in step 1 (refrigerant) | constant – selected in step 2 | selection | | | X | test series results – various ($\tau_M$) | wear stabilization |

The authors' proposed concept of testing lubrication properties of the oil-refrigerant mixture involves executing tests at the ambient temperature. This temperature determines the conditions inside the crankcase during the compressor's extensive standstill period. In the test chamber, one must therefore maintain the pressure corresponding to the saturation pressure ($p_s$) of the given refrigerant at the ambient temperature. This parameter is dependent on the tested refrigerant and should be taken from the 1g p-h diagrams for each refrigerant.

The other highlighted parameter – wear test duration time ($\tau_t$) – should be determined to achieve clear sample wear. The authors of this article assumed that the sample wear should be greater than 0.5 $mm^3$. Then the relative uncertainty of wear volume measurement calculated by means of the total differential is less than 15% (**Table 2**).

**Table 2. Wear volume and measurement uncertainty depending on the width trace of wear**

Tabela 2. Zużycie objętościowe oraz niepewność jego oszacowania w zależności od szerokości śladu zużycia

| Width trace of wear x [mm] | Wear volume V [$mm^3$] | Wear volume measurement uncertainty ΔV [$mm^3$] | Relative uncertainty ΔV /V [%] |
|---|---|---|---|
| 1.0 | 0.050 | 0.015 | 30.75% |
| **2.0** | **0.401** | **0.063** | **15.76%** |
| 3.0 | 1.359 | 0.146 | 10.78% |
| * * * | | | |
| 10.0 | 54.352 | 2.120 | 3.90% |

Sample wear volume is determined based on formula (1). The accepted minimum wear value constitutes a compromise between the wear test duration time and the accuracy in estimating the loss in material.

$$V = 0{,}5sr^2\left\{2arcsin\left(\frac{x}{2r}\right) - sin\left[2arcsin\left(\frac{x}{2r}\right)\right]\right\} \qquad (1)$$

where:

- V – sample wear volume [$mm^3$],
- s – sample (the block) width [mm],
- r – counter-sample (the ring) radius [mm],
- x – sample width trace of wear [mm].

In order to determine the wear test duration time ($\tau_t$), one must carry out a series of preliminary tests at different values of this parameter until the assumed minimum wear of 0.5 $mm^3$ has been achieved. An exemplary procedure is shown in **Fig. 2**.

The research concept proposed in this article assumes the realization of these preliminary tests only with the use of oil. However, the oil should interact with air to maintain the predetermined pressure ($p_s$) in the chamber. At this stage, the application of the oil-refrigerant mixture is impossible, because the conditions for the formation of this mixture have not yet been determined. On the other hand, selecting these conditions (according to **Table 1**) already requires the knowledge of the parameter ($\tau_t$).

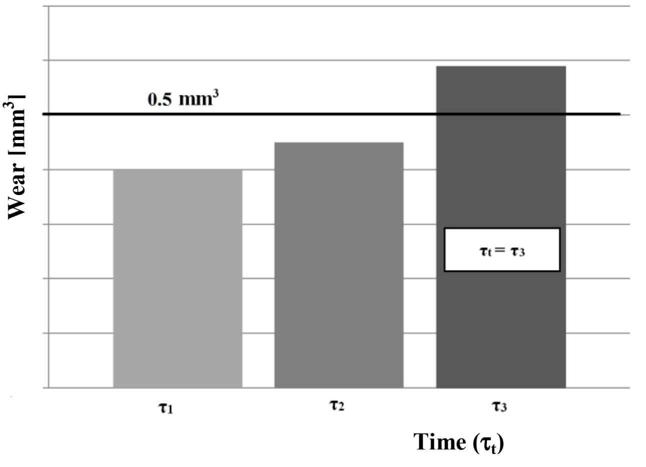


**Fig. 2. The method of selecting the wear test duration time**
Rys. 2. Sposób doboru czasu trwania testu zużyciowego

Once the pressure value ($p_s$) in the test chamber and the prime wear test duration time ($\tau_t$) are determined, one can select the final parameter of the testing method – the mixture formation time ($\tau_m$). In the proposed testing method, the oil-refrigerant mixture is formed due to a direct contact of both substances enclosed in an airtight chamber (**Fig. 1a**). The mixture is formed through absorption without mechanical force.

For determining parameter ($\tau_m$), a series of wear tests must be carried out (for the predetermined duration time ($\tau_t$)) preceded by various periods of mixture formation. In order to realize the prime lubricity tests, one must select the proper mixture formation time ($\tau_m$), after which the sample wear begins to stabilize. Sample wear stability may result from the fact that the oil-refrigerant mixture is in the state approximating the saturation point (the maximum amount of refrigerant in the mixture with oil for the given conditions). The criterion for selecting the mixture formation time became the accomplishment of the state in which enlarging this parameter did not significantly affect the value of sample wear. In terms of quantity, the accepted stability criterion is shown in **Fig. 3**.

According to the presented data, the mixture formation time ($\tau_m$) should amount to ($\tau_2$). As regards the variability of sample wear results ($V_{2,min}$, $V_{2,max}$), for that mixture formation time, there is the mean result of sample wear ($V_3$,sr) for the series of tests preceded by the extended mixture formation time ($\tau_3$). Therefore, it can be concluded that, starting from the value ($\tau_2$), extending the mixing time does not significantly affect the value of sample wear.

The research method proposed by the authors contains certain simplifications to the actual operating conditions of refrigeration compressors. Essentially, however, this method is to be used for comparative assessment of lubricity properties of a group of oils mixed with a given refrigerant.

The compared oils have the same viscosity grade and can be alternately used in a refrigeration system (mutual replacements). Among the tested oils, better lubricity properties are possessed by oil for which the effects (sample wear volume in the block-on-ring matching) caused by the same input forces are smaller.

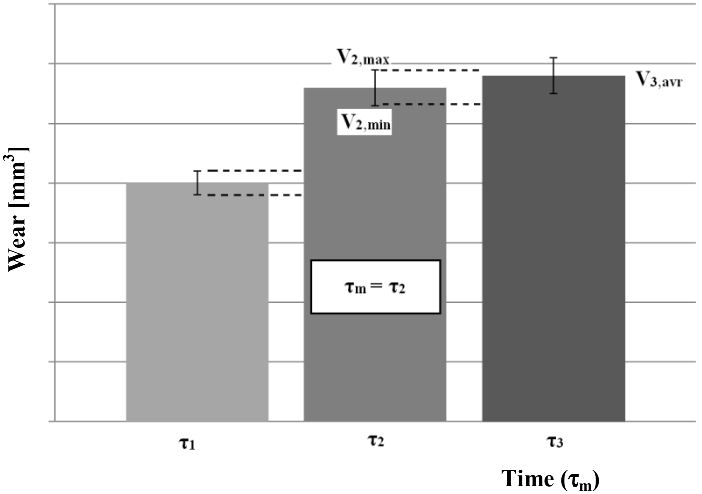


**Fig. 3. The method of selecting the mixture formation time**
Rys. 3. Sposób doboru czasu wytwarzania mieszaniny

## CONCLUSION

The article proposes the concept of a testing method allowing the evaluation of the lubricity properties of oils for refrigeration compressors in a mixture with a refrigerant. The main assessment indicator is sample wear volume in the block-on-ring matching that is determined under the conditions that approximate compressor exploitation after an extended standstill period. The essential elements of the proposed method are the procedure for determining the wear test duration time ($\tau_t$) and the mixture formation time ($\tau_m$).

The proposed procedure for testing the lubricity properties of the oil-refrigerant mixture includes certain simplifications to the actual operating conditions of refrigeration compressors. The described method is to be primarily used for a comparative assessment of compressor oils (comparing lubricity properties determined under the same test conditions). According to this concept, the test conditions are as follows:

– Conditions reflect the interactions existing in the oil-refrigerant system in the compressor during the actual operation in an extended standstill period (the contact of a large quantity of refrigerant with oil at a higher pressure and higher temperature than during the operation of the compressor – the changes determined by the conditions existing in the environment, including the ambient temperature).

– Conditions intensify the negative impact of the refrigerant on the oil achieving a "clear" sample wear in a relatively short time period of the attempt.

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**Streszczenie**

**W sprężarkach chłodniczych problemy ze smarowaniem zazwyczaj spowodowane są obecnością mieszaniny olej–czynnik chłodniczy w węzłach tarcia. Nie można skutecznie ocenić właściwości smarnych oleju do sprężarek chłodniczych w warunkach jego eksploatacji na podstawie wyników badań charakteryzujących tylko olej. W tym celu konieczne jest wykonywanie badań mieszaniny olej–czynnik chłodniczy.**

**W artykule przedstawiono koncepcję metody badań pozwalających na ocenę właściwości smarnych olejów do sprężarek chłodniczych w mieszaninie z czynnikiem chłodniczym. Istotne elementy proponowanej metody to procedura wyznaczania czasu trwania testu zużyciowego ($\tau_t$) oraz czasu wytwarzania mieszaniny ($\tau_m$).**