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EVALUATION OF LUBRICATING PROPERTIES OF MIXTURES OF MINERAL OILS WITH REFRIGERANT R600A

OCENA WŁAŚCIWOŚCI SMARNYCH MIESZANIN OLEJÓW MINERALNYCH Z CZYNNIKIEM CHŁODNICZYM R600A

Key words:

oil/refrigerant mixture, lubricity properties

Słowa kluczowe:

mieszanina olej/czynnik chłodniczy, właściwości smarne

Abstract

Current legal regulations concerning ozone-depleting substances and greenhouse gases result in a dynamic return to the use of natural refrigerants such as hydrocarbons. However, they are gases included in the A3 (combustible) security group, and that is why they are now mainly used in devices with low performance (mainly in household refrigerators). The most widely used hydrocarbon as a refrigerant in this group of devices is R600a (isobutene).

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The article presents a comparative assessment of the lubricity properties of oil-refrigerant mixtures of three mineral oils with R600a. The assessment was based on a sample wear volume of the block-on-ring node under the conditions approximating the operation of the compressor after an extensive standstill period. The oil/refrigerant mixture was obtained as a result of an appropriately extended mutual contact of both substances in a closed chamber.

INTRODUCTION

The refrigerant in refrigeration equipment always comes in contact with lubricating oil. Depending on the values of pressures and temperatures prevailing in a particular part of the system, there forms the oil-refrigerant mixture. Such a situation may adversely affect the cooperation of friction nodes in the refrigeration compressor, which can manifest itself through an excessive wear of movable elements.

The selection of the oil for a refrigeration compressor is determined by the type of the refrigerant. Among the presently used refrigerants, the agents that have a destructive impact on the ozone layer have practically been eliminated. Currently, the refrigerants with a high potential for triggering global warming are also being eliminated. The refrigerants that are still commonly used are the ones from the group of hydrofluorocarbons (HFCs), such as R134a. However, future efforts are aimed at a successive replacement of these agents with natural substances having a negligible impact on the climate change. The prospective refrigerants include hydrocarbons (HCs), such as R600a (isobutene) **[L. 1]**.

Pure isobutene primarily constitutes a replacement for R12 in devices of low performance, mainly in household refrigerators. It is estimated that, among all household refrigeration appliances in EU, 98% of them use isobutene as the working medium **[L. 2]**.

Replacing refrigerants with more environmentally friendly ones results in the necessity for selecting appropriate compressor oil. The selection of lubricating oil should be supported by studies enabling an assessment of the lubricity properties of oil-refrigerant mixtures. For this purpose, test benches of the block-on-ring type have been used frequently in recent years **[L. 3–7]**. Some of these studies have addressed mixtures of oils with refrigerants from the HFC group (mainly R134a) **[L. 4**, **6]**. On the other hand, mixtures of oils with refrigerants from the HC group (mainly R600a) have been tested less frequently **[L. 3**, **7]**. Individual researchers formed the oil-refrigerant mixture in different ways. Most frequently, they maintained a permanent supply of refrigerant of a constant pressure **[L. 3**, **5–7]**, or a portion of the refrigerant was supplied to oil several times **[L. 4]**. In many cases, the process of mixture formation was not carried out or its parameters, such as the pressure of the refrigerant and the oil-refrigerant mixture formation time, were not stated.

The aim of this article is the following:

- To select test parameters for the assessment of the lubricity properties of mixtures of mineral oils with R600a – wear test duration time (τ_t) and mixture formation time (τ_m), and
- To carry out wear tests enabling an assessment of the lubricity properties of oil-refrigerant mixtures obtained for R600a, which is ecological and recommended for wider future application refrigerant with mineral oils.

THE TEST METHOD

In order to evaluate lubricity properties of an oil-refrigerant mixture, the wear of block from block-on-ring node was used. The description of the model block-on-ring friction node was presented in **[L. 8]**. All tests were carried out while loading the node with the force of 120 N and the sliding velocity of 0.5 m/s. These parameters allow one to achieve a clear loss in material in a relatively short period of time. The wear tests should be preceded by determining the following parameters:

- Refrigerant pressure in the test chamber (p_s),
- Wear tests duration time (τ_t), and
- Oil-refrigerant mixture formation time (τ_m).

The refrigerant pressure in the test chamber (p_s) should be the saturation pressure of the given refrigerant at the ambient temperature. This parameter is dependent on the tested refrigerant itself. The wear test duration time should be selected in the preliminary tests in which the oil interacts with air at the previously selected pressure. Further testing should include the shortest wear test duration time (τ_t) that guarantees the loss in material greater than $0.5mm^3$. Then the relative uncertainty of estimating wear volume calculated by the total differential is less than 15%. Subsequently, one must determine mixture formation time (τ_m). For this purpose, a series of wear tests (for the previously set realization time (τ_t)) must be performed, preceded by various periods of mixture formation. For primary tests on lubricity, the mixture formation time (τ_m) should be selected after which sample wear starts to stabilize. A detailed description of the procedure for selecting parameters p_s, τ_t and τ_m has been presented in **[L. 9]**. During the primary tests, but prior to each one, the samples must be cleaned in acetone in an ultrasonic bath for 15 minutes and then mounted in the test chamber. In order to form the oil-refrigerant mixture, one must first remove the air from the test chamber and supply it with oil in the amount providing the level of half the height of the ring. Next, the chamber with the oil is supplied with the refrigerant of a selected pressure (p_s), and such conditions are maintained for a specified time (τ_m). Following the formation of the oil-refrigerant mixture, one should perform the wear test of the duration time (τ_t). After each testing, it is necessary to recover the refrigerant and dismantle the samples. Subsequently, one should measure the width trace of wear on the sample in the form of the block and calculate the wear volume in accordance with the guidelines contained in **[L. 8, 9]**.

DETERMINING TEST PARAMETERS FOR MINERAL OILS AND R600A MIXTURES

The primary testing of lubricity properties of oil-refrigerant mixtures was preceded by preliminary tests. Their aim was to determine the following parameters of the main test: the wear test duration time (τ_t), and the mixture formation time (τ_m). During the tests that were necessary to assess the lubricity properties of mineral oils (MO) and their mixtures with isobutene (R600a), the pressure in the test chamber was maintained at the level of approximately 0.21 MPa. This value is equivalent to the saturation pressure of R600a at the temperature of 23°C.

Figure 1 presents the results of wear tests performed in mineral oil at the air pressure value of 0.21 MPa above the liquid surface, at different wear test duration times, τ_t. According to the presented concept, the minimum sample wear of 0.5 mm^3 can be achieved after 40 minutes.

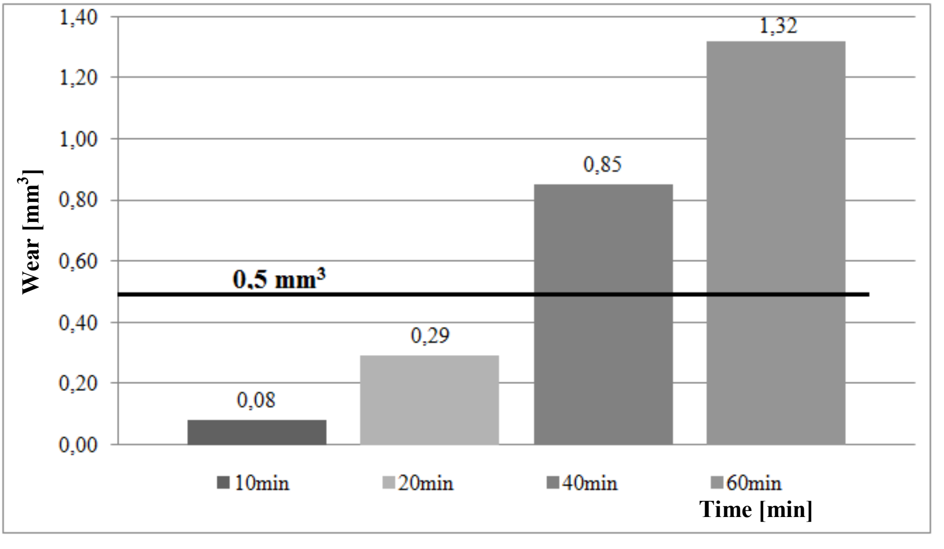

Fig. 1. Wear tests duration time selection for mineral oils (p_s = 0.21 MPa)
Rys. 1. Selekcja czasu trwania testu zużyciowego dla olejów mineralnych (p_s = 0,21 MPa)

The second series of preliminary tests concerned the assessment of MO/R600a mixture formation time (τ_m). For this purpose, several wear tests were carried out. In subsequent tests, the mixture formation time was lengthened (from 40 min to 30 hours). The results achieved are presented in

Fig. 2. In accordance with the accepted criterion, the time (τ_m) of MO/R600a mixture formation should amount to 20 hours. The large value of this parameter is caused by the fact that the mixture in the tested system is formed as a result of molecular diffusion exclusively.

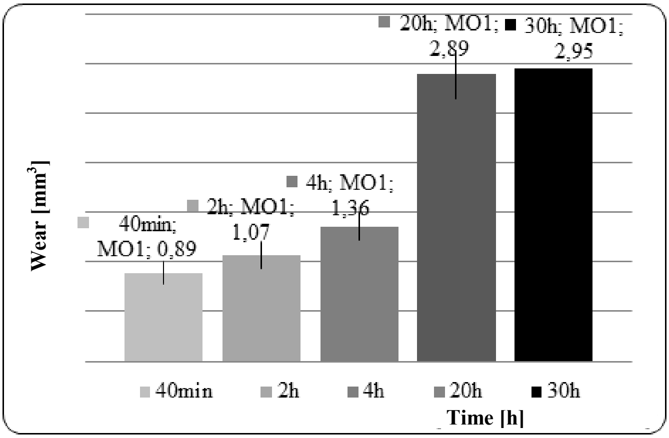

Fig. 2. Oil-refrigerant mixture formation time selection for mineral oils and R600a (p_s = 0.21 MPa, τ_t = 40 min)
Rys 2. Selekcja czasu wytwarzania mieszaniny dla olejów mineralnych z R600a (p_s = 0,21 MPa, τ_t = 40 min)

Test parameters for lubricity properties of MO/R600a mixtures are shown in **Table 1**.

Table 1. Individually selected test parameters for MO/R600a mixtures
Tabela 1. Zestawienie parametrów badań dla mieszanin olejów mineralnych z czynnikiem chłodniczym R600a (MO/R600a)

Parameter	Unit	Value
Sliding velocity	[m/s]	0.5
Friction node load	[N]	120
Method of forming oil-refrigerant mixture	-	Without limiting supply of refrigerant
Refrigerant pressure	MPa	0.21
Wear tests duration time	[min]	40
Oil-refrigerant mixture formation time	[min]	1200

TEST RESULTS

Two series of tests were carried out for each of the tested oils (**Table 2**). The series consisted of three wear tests. In the first series, the lubricity properties of oils were evaluated. During the tests, pressure (p_s) was maintained by means of air. The obtained results became the basis for an analysis of the impact of the refrigerant on lubricity properties of oil. During the second series of tests, lubricity properties of the oil-refrigerant mixture were analysed.

Table 2. Properties of the examined mineral (MO) oils [L. 10–12]
Tabela 2. Właściwości badanych olejów mineralnych (MO) **[L. 10–12]**

Type of oil	Properties				
	Kinematic viscosity [$mm^2 s^{-1}$]		Density in 15°C [$kg\ m^{-3}$]	Ignition temperature [°C]	Flow temperature [°C]
	40°C	100°C			
MO1	32	4.8	889	185	-45
MO2	29,5	4.31	909	178	-40
MO3	32	4.4	910	190	-42

The obtained results are presented in **Figs. 3** and **4**. The graphs show the mean values of sample wear volume. The ranges of variations of results are also indicated in the form of standard deviation.

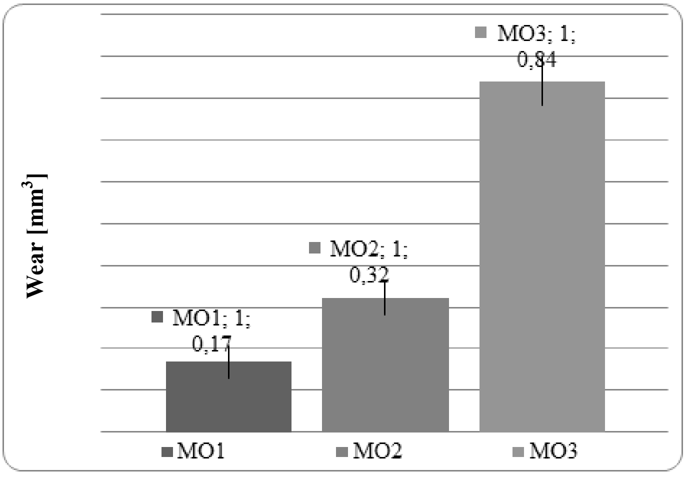

Fig. 3. Wear volume results after the tests in mineral oils
Rys. 3. Zużycie objętościowego próbek po testach w olejach mineralnych

Figure 3 illustrates the values of sample wear volume after tests in mineral oils. It is MO1 that has the best lubricity properties in the analysed group. This oil's wear volume amounts to 0.17 mm^3. The worst lubricity properties resulting in the highest wear (approximately 0.84 mm^3) were noticed for MO3. The identified differences can be considered important, because all the wear results obtained for MO2 are beyond the range of the test results for MO1. The order of tested oils resulting from the rising value of sample wear volume is as follows: MO1, MO2, and MO3.

Figure 4 lists the sample wear volume test results for particular mineral oils mixed with R600a. The lowest wear of 2.26 mm^3 and the best lubricity properties were observed for MO1/R600a mixture. The mean wear for MO2/R600a mixture stood at approximately 2.57 mm^3. Whereas, in the case of MO3/R600a mixture, the wear amounted to 2.89 mm^3. The order of oil-isobutene mixtures resulting from the rising value of wear is then the same as the order of MO1, MO2, and MO3 alone.

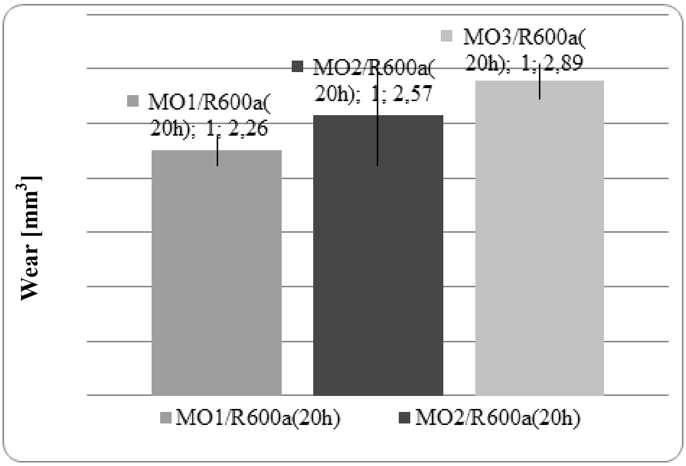

Fig. 4. Wear volume results after the tests in MO/R600a mixtures
Rys. 4. Zużycie objętościowe próbek po testach w mieszaninach MO/R600a

DISCUSSION OF RESULTS

In all analysed cases, it was found that sample wear after tests in the oil-refrigerant mixture was clearly higher (from 3 to over 13 times) than for the oil alone. Therefore, lubricity properties of refrigeration compressor oil should be evaluated by testing mixtures of a particular oil with a refrigerant. The achieved results enable a conclusion to be drawn that the developed method and applied test bench adequately reproduce the impact of the refrigerant on lubricity properties of oil (oil-refrigerant mixture). Moreover, the proposed criterion, sample wear volume, may constitute an effective indicator allowing one to compare lubricity properties in the following relations:

- Oil and the oil-refrigerant mixture, and
- A group of oils being the replacement in the application with a particular refrigerant.

The presence of R600a in MO1 caused over a thirteen-fold growth in sample wear volume. On the other hand, the sample wear volume for MO2 mixture increased over eight times, and for MO3 mixture it increased over four times. In the case of mineral oil and isobutene, the mixture is formed by molecular diffusion. The obtained results (**Figs. 3** and **4**) indicate that the applied method of assessing lubricity properties is effective, because it allows one to map the impact of the refrigerant on lubricity properties.

SUMMARY

The currently on-going process of eliminating refrigerants of a high global warming potential results in an increasing use of natural substances of a negligible impact on climate changes. The prospective refrigerants include hydrocarbons, such as isobutene R600a. The replacement of refrigerants with more ecological ones triggers the need of selecting a proper compressor oil. For this purpose, one must assess the lubricity properties of oil-refrigerant mixtures.

This article presents the following:

– The selection of parameters to evaluate lubricity properties of oil-R600a mixtures: the wear test duration time (τ_t) and the mixture formation time (τ_m); and,
– The test results of the lubricity properties of oil-refrigerant mixtures obtained for R600a, which is ecological and the recommended refrigerant for wider application with mineral oils in the future.

The test results presented in the article indicate that the impact of a refrigerant on the lubricating oil is an individual property of the examined substance. The diversity of the impact of R600a on the lubricity properties of mineral oils allows the conclusion that one cannot adequately assess the lubricity properties of oil in its operating conditions based on results characteristic for the oil alone.

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Streszczenie

Aktualne regulacje prawne dotyczące substancji zubożających warstwę ozonową oraz gazów cieplarnianych powodują dynamiczny powrót do stosowania naturalnych czynników chłodniczych, takich jak węglowodory. Są to jednak gazy zaliczane do grupy bezpieczeństwa A3 (palne), przez co znajdują obecnie głównie zastosowanie w urządzeniach o małej wydajności (głównie w chłodziarkach domowych). Najpowszechniej stosowanym czynnikiem chłodniczym w tej grupie urządzeń jest R600a (izobutan).

W artykule przedstawiono ocenę porównawczą właściwości smarnych mieszanin trzech olejów mineralnych z czynnikiem chłodniczym R600a. Oceny dokonano na podstawie zużycia objętościowego próbki w węźle rolka – klocek w warunkach zbliżonych do eksploatacji sprężarki po długim okresie wyłączenia. Mieszaninę olej – czynnik chłodniczy uzyskano w wyniku odpowiednio długiego wzajemnego kontaktu obu substancji w zamkniętej komorze badawczej.