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A METHOD OF DECISION SUPPORT FOR THE SELECTION OF LUBRICANTS FOR REFRIGERATION COMPRESSORS ON THE BASIS OF TRIBOLOGICAL TESTS

METODA WSPOMAGANIA DECYZJI DOBORU ŚRODKÓW SMARNYCH DO SPRĘŻAREK CHŁODNICZYCH NA PODSTAWIE BADAŃ TRIBOLOGICZNYCH

Key words: oil/refrigerant mixture, Bellinger's method, decision support tool.

Abstract The article presents a simple and clear decision support method for use when selecting lubricants for refrigeration compressors on the basis of tribological tests. The Bellinger method has been chosen. Moreover, the article shows the process of decision support for the selection of lubricants for various mechanisms of the mixing lubricating oil with refrigerant. For the mixing mechanism of a simultaneous intermolecular diffusion and natural convection, the mixture of polyester oils and R134a was selected, whereas, for the mixing mechanism of intermolecular diffusion alone, it was the mixture of mineral oils with R290 that was selected. There were simulations of several decision-making situations due to the decision maker's attitude, such as economic, qualitative, and balanced. In each variant, the importance of particular criteria was subjectively assigned trying to reflect the decision maker's attitude. The presented analysis indicates that the lubricity properties of oils and refrigeration mixtures must be taken into account; otherwise, disregarding them can have serious operational consequences. The decision on the selection of the proper lubricant for refrigeration compressors should be preceded by tribological tests allowing one to assess lubricity properties of oils and their mixtures with a refrigerant.

Słowa kluczowe: olej/czynnik chłodniczy, metoda Bellingera, narzędzie wspomagające podejmowanie decyzji.

Streszczenie W artykule przedstawiono propozycję wykorzystania prostej i przejrzystej metody wspomagania decyzji doboru środków smarnych do sprężarek chłodniczych na podstawie badań tribologicznych. Wybrano metodę Bellingera. Zaprezentowano również proces wspomagania decyzji doboru środków smarnych dla różnych mechanizmów mieszania się oleju smarowego z czynnikiem chłodniczym. Dla mechanizmu mieszania poprzez jednoczesną dyfuzję międzycząsteczkową oraz naturalną konwekcję masową wybrano mieszaninę olejów poliestrowych z czynnikiem chłodniczym R134a, natomiast dla mechanizmu mieszania jedynie poprzez dyfuzję międzycząsteczkową wybrano mieszaninę olejów mineralnych z czynnikiem chłodniczym R290.
Przeprowadzono symulacje kilku sytuacji decyzyjnych zależnych od nastawienia decydenta: ekonomiczny, jakościowy i zrównoważony. W każdym z wariantów subiektywnie przypisano wagi poszczególnym kryteriom, starając się odzwierciedlić nastawienie decydenta.
Przedstawiona analiza wskazuje, że nieuwzględnianie właściwości smarnych olejów i mieszanin chłodniczych może mieć poważne konsekwencje eksploatacyjne. Decyzję o wyborze odpowiedniego środka smarnego do sprężarek chłodniczych powinny poprzedzać badania tribologiczne pozwalające ocenić właściwości smarne olejów i ich mieszanin z czynnikiem chłodniczym.

INTRODUCTION

Due to the use of new ecological refrigerants enforced by legal provisions **[L. 1]**, it is necessary to match them to the new or existing lubricating oils. The selection should be supported by the assessment of lubricity properties of mixtures of oils with a refrigerant.

Previous analyses **[L. 2, 3]** have allowed one to state that, in the friction pairs of refrigeration compressors, there is always a mixture of lubricating oil with refrigerant. Its composition depends on the temperature of oil, the pressure of the refrigerant, and the time of their mutual interaction.

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Hitherto, publications have concerned the research method and the test bench for the model tribological tests in the operating conditions of refrigeration compressors **[L. 4, 5]**. There were also a series of tests that allowed assessing the lubricity properties of mixtures of lubricating oils and refrigerants **[L. 6, 7]**. These test results can facilitate the selection of the proper lubricating oil.

The purpose of this work was the following:

– Recommending the use of a simple and clear decision support method for the selection of lubricating agents for refrigeration compressors on the basis of tribological tests, and
– Carrying out the process of decision support for the selection of lubricating agents for various mechanisms of the mixing process of lubricating oils with refrigerant.

In order to compare the tested oils, there were simulations of several decision situations, depending on the decision maker's attitude: economical, qualitative, and balanced ones. In each variant, the importance of particular criteria was subjectively assigned trying to reflect the decision maker's attitude.

DESCRIPTION OF TRIBOLOGICAL TEST RESULTS

In the previous works concerning lubricating agents for refrigeration compressors and their mixtures with a refrigerant **[L. 4–9]** two basic mechanisms of mixing these substances were defined. In the subject literature **[L. 10–13]**, one can find reports related to the following two cases of refrigerant behaviour on the surface of liquid oil (at the inter-phase boundary):

– The density of refrigerant vapours increases above the density of oil, and the penetration occurs through intermolecular diffusion and natural mass convection **(Fig. 1a)**.
– The density of refrigerant vapours is lower than the density of oil, and the penetration occurs only through intermolecular diffusion **(Fig. 1b)**.

In the first case, the transfer of mass (particles of refrigerant into the oil) results from the thermal movement of the particles, and in the second case, it is also the result of gravitational forces. The impact of these forces considerably accelerates the process of obtaining the mixture.

Two types of oil/refrigerant mixtures corresponding to two types of mixing mechanisms were used for comparative tests as follows:

– Through simultaneous intermolecular diffusion and natural mass convection – POE/R134a mixtures, and
– Through intermolecular diffusion alone – MO/R290.

In the tribological tests, the block-on-ring matching of the concentrated contact was used. Samples in the form of rings were made from EN-GJL-250 grey cast iron, and the block was in the form of PA6 aluminium. These materials are used to make sliding friction pairs of the bearing shell of the connecting rod and crankshaft

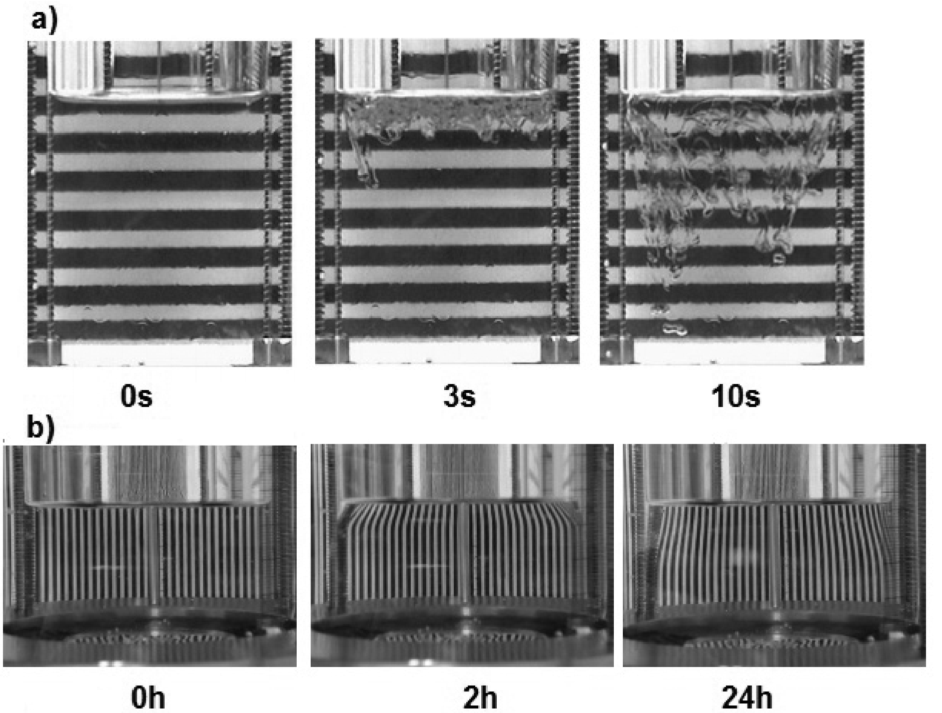

Fig. 1. Photographs of the mixing process of the refrigerant with oil through (a) intermolecular diffusion and natural mass convection, and (b) through intermolecular diffusion alone [L. 10, 11]

Rys. 1. Zdjęcia procesu mieszania czynnika z olejem poprzez a) dyfuzję międzycząsteczkową oraz naturalną konwekcję masową, b) tylko dyfuzję międzycząsteczkową **[L. 10, 11]** in piston refrigeration compressors **[L. 14, 15]**. For the formation of the oil/refrigerant mixture, the amount of oil was used that allowed immersion lubrication system for the friction node (the level of half the height of the roll) and an unlimited access to the refrigerant of the pre-selected saturation pressure **[L. 7]**.

A set of test parameters was used selected so as to obtain a measurable material reduction in a relatively short period of time. In order to achieve the assumed effect, forces were used that are characteristic for operational conditions of refrigeration compressors, i.e. a large amount of refrigerant in oil, a high load in the node, and a low relative speed of the matching elements (parameters corresponding to the start of the compressor after a long stand-still period) **[L. 9]**. **Table 1** presents a set of series and test parameters. For each combination of oil and refrigerant and the oils alone, there were a minimum of three test runs carried out.

Table 1. Test parameters for POE and MO and for POE/R134a and MO/R290 mixtures [L. 7]
Tabela 1. Parametry badawcze dla olejów POE i MO oraz dla mieszanin POE/R134a i MO/R290 **[L. 7]**

Lubricant	Friction node load [N]	Sliding velocity [obr/min]	Refrigerant pressure [MPa]	Oil – refrigerant mixture formation time [min]	Wear tests duration time [min]
POE	120	500	0.5	0	20
POE/R134a	120	500	0.5	40	20
MO	120	500	0.75	0	20
MO/R290	120	500	0.75	3600	20

Table 2 shows the final test results that were the basis for the description of the decision support process for the selection of lubricants for refrigeration compressors on the basis of tribological tests. The results mentioned above concern sample wear in the tests with oil, sample wear in the test with the oil/refrigerant mixture, and the mean value of the coefficient of friction in the tests with the oil/refrigerant mixture. **Table 3** presents additional information to support the process of selecting the lubricant. These additional parameters mentioned above constitute the multiplicity of wear increase (mixture/oil) and the price of the lubricating oil.

Table 2. Test results being the basis for the description of the decision support process for the selection of lubricants for refrigeration compressors on the basis of tribological tests [L. 6–8]
Tabela 2. Wyniki testów będące podstawą do opisania procesu wspomagania decyzji doboru środków smarnych do sprężarek chłodniczych na podstawie badań tribologicznych **[L. 6–8]**

Parameter	Lubricant					
	MO1	MO2	MO3	POE1	POE2	POE3
Sample wear in the tests with oil [mm^3]	0.59	1.10	0.92	0.96	1.78	5.43
Sample wear in the test with the oil/ refrigerant mixture [mm^3]	1.61	2.50	2.71	31.25	49.43	67.90
The average coefficient of friction in the tests with the oil/refrigerant mixture [-].	0.08	0.17	0.21	0.11	0.12	0.15

Table 3. Additional information to support the process of selecting the lubricant [L. 6–8]
Tabela 3. Dodatkowe informacje mające wspomóc proces doboru środka smarnego **[L. 6–8]**

Parameter	Lubricant					
	MO1	MO2	MO3	POE1	POE2	POE3
The multiplicity of wear increase (mixture/oil) [-]	1.73	1.27	1.95	32	27	12
The price of the lubricating oil [% of price in relation to the cheapest oil]	141	102	100	100	120	107

TEST METHOD

Among the methods of multi-criteria decision support for the selection of lubricants for refrigeration compressors on the basis of tribological tests, the following methods were taken into account: the Electre, Promethee, AHP, and Bellinger.

The Electre method belongs to the group of the most advanced multi-criteria methods and is based on the relation of surpassing, which makes it possible to select the best decision variation by ordering the variations from the point of view of the decision-maker expressed by his/her preferences. The Electre method is characterized by quite a high sensitivity to the change in the number of options and thus adding or removing any variant can result in the change of interaction among the remaining ones, as well as a change in their position in the final ranking. Despite the fact that the Electre method gives the opportunity to precisely model the decision maker's preferences relative to each criterion and the detailed determination of criteria significance, it was rejected in the context of the selection of lubricants for refrigeration compressors on the basis of tribological tests.

In turn, due to the inconveniences for the analyst and the decision maker, the Promethee method was also abandoned for the selection of lubricants for refrigeration compressors on the basis of tribological tests. The main reasons for giving up this method are the difficulty in determining the equivalence threshold and preferences by the evaluators. In addition, this method requires a large number of operations to process data to obtain results.

Another approach, the AHP (the Analytic Hierarchy Process), is a multi-criteria decision-making analysis which enables sequencing the decision problem by presenting it in the form of a hierarchical structure and allocating specific significance to particular criteria **[L. 16]**. In this method, it is the decision maker that evaluates the variants due to the selected criteria on the basis of his/her knowledge and recognition based on experience **[L. 17]**. The fact that, at some stage of the analysis, criteria assessment is performed by the decision maker who compares pairs of criteria on the basis of subjective findings may significantly affect the result of the final ranking.

Another approach to decision support is the Bellinger method. In this method, objects are sequenced on the basis of the total assessment value determined from the pre-defined partial criteria **[L. 18]**. The method involves bringing the assessment of decision variants relative to all criteria to the possible comparison. The basic dependences of Bellinger algorithm concern the distance between the upper and lower limits of the desired values. Due to the possibility of comparing a small number of variants and bringing the decision variants relative to all criteria to the possible comparison, the method was selected for decision support for the selection of lubricants for refrigeration compressors on the basis of tribological tests.

The Bellinger method involves the following eight successive stages **[L. 18]**:

– Defining the requirements and limitations for solution variants of the analysed problem;
– Defining the decision options available in a given situation;
– Defining, in detail, the adopted assessment criteria, the adoption of measurement units and the desired direction of changes within a given criterion (stimulus and inhibitor) and the lower and upper limits of changes for the analysed partial criteria;
– Determining the weights (priorities) that are given to the adopted assessment criteria by the decision maker;
– Developing matrices containing the real values of the analysed criteria in relation to particular variants,
– Presenting all of the numbers from the matrix from the preceding stage as the percentage of the "progression" from the least to the most desired state;
– Multiplying all of the numbers obtained in stage six by the weights adopted in stage four; and,
– Specifying the best option on the basis of the sum of assessments awarded to particular variants including all the criteria analysed.

In the Bellinger method, the assessment of the decision variant on the basis of the variant of grade $O_{x_{ij}}$ is determined in accordance with the following relationships **[L. 19]**:

– for stimulus:

$$O_{x_{ij}} = \frac{\sup X - X_i}{\Delta j} \cdot 100\%$$

– for inhibitor:

$$O_{x_{ij}} = \frac{\inf X - X_i}{\Delta j} \cdot 100\%$$

where

$O_{x_{ij}}$ – assessment of the decision-making variant on the basis of assessment variant,
X_i – the numerical value determined by the decision maker for a given decision variant,
Δj – the distance between the upper and lower extremities of the set of values of the j-th assessment criterion of the decision variants,
supX – the most desired value,
infX – the least desired value.

The distance between the upper and lower extremities of the set of values of the j-th assessment criterion of the decision variants Δj is expressed by the following relationship **[L. 19]**:

$$\Delta j = |\sup X - \inf X|$$

The final assessment of the decision variant O_{x_i} is determined on the basis of the dependence where the weight of the given criterion determined by the decision maker is taken into account **[L. 19]**:

$$O_{x_i} = \sum_{j=1}^{m} O_{x_{ij}} \cdot w_j$$

where

- O_{x_i} – the final assessment of the decision variant,
- w_j – the weight of the assessment criterion according to the decision maker's preferences.

It was the Bellinger method that was selected from the considered methods, because it can enable selection in quite a simple and clear way, on the basis of tribological tests of a lubricant from among substances which constitute mutual replacements for use in refrigeration compressors.

APPLICATIONS OF THE BELLINGER METHOD FOR DECISION SUPPORT FOR THE SELECTION OF LUBRICANTS FOR REFRIGERATION COMPRESSORS

Below is a way of applying the Bellinger method for decision support for the selection of lubricants for refrigeration compressors on the basis of tribological tests.

The analysis was performed taking into account the stages of the Bellinger method discussed above. First, the requirements and limitations for the solution variations of the analysed problem were determined. It was decided to apply tribological tests of lubricating oils for refrigeration compressors compatible with R134a (polyester oils of the same viscosity grade ISO VG 32 marked POE1, POE2, POE3, respectively) and with R290 (also of the same viscosity grade ISO VG 32 marked MO1, MO2, MO3, respectively). The solution variants are then the tested lubricants.

The decision variants are the tested lubricants. The choice is made of three polyester compressor oils for use with R134a and three mineral oils for use with R290.

The adopted assessment criteria are the following:

- Sample wear in tests with oil – ideal working conditions (K1) [mm^3],
- The multiplicity of the wear increase (mixture/oil) (K2) [-],
- Sample wear in the tests with the mixture – real working conditions (K3) [mm^3],
- The price of lubricating oil (K4) [percentage of the price in relation to the cheapest oil], and
- The mean value of the coefficient of friction (K5) [-].

All of the selected criteria were matched so that they constituted inhibitors within a given criterion. This means that the most desired ones are the lowest numerical values within the given criterion. The lower and upper limits of each criterion are the smallest and the largest numerical value, respectively.

Three exemplary attitudes of the decision maker were adopted (the economical, qualitative, and balanced ones) in which the weights of particular criteria differ depending on the decision maker's preferences. **Table 4** shows a set of weights (priorities) for the types of decision maker's attitudes discussed above.

Table 4. A set of weights for the decision maker's different attitudes

Tabela 4. Zestaw wag dla różnych rodzajów nastawienia decydenta

Criterion	Decision maker's preferences		
	Economic	Qualitative	Balanced
K1	0.10	0.20	0.10
K2	0.10	0.10	0.20
K3	0.20	0.50	0.30
K4	0.50	0.10	0.30
K5	0.10	0.10	0.10

While making the decision in the economic variant, the main focus was on K4 price criterion (50% influence on the decision). The next adopted criterion was K3 concerning the wear in the mixture of oil and refrigerant (20% influence on decision-making). The other criteria (K1, K2, and K5) were assigned the smallest influence on the selection decision (10% each).

As for the qualitative variant, the main focus during the decision-making was the K3 criterion of wear in the mixture of oil and refrigerant (50% influence on decision-making). A subsequent criterion was K1, constituting the sample wear in the tests with the same lubricating oil (20% influence on decision-making). The other criteria (K2, K4, and K5) were assigned the weight at the level of 10%.

On the other hand, in the balanced variant, the main focus in the decision-making process was on the following criteria: K3 – the wear in the mixture of oil and refrigerant, and K4 – price criterion (30% influence on decision-making each). The K2 wear increase multiplicity criterion was assigned 20% influence on decision making. The least influence on decision-making in this variant was assigned to K1 and K5 (10% influence on decision-making each).

The next stage involved developing a matrix containing the real values of the analysed criteria with particular variants in mind and results from the combination of information from **Tables 2 and 3**.

Table 5 presents the actual collective summary of the analysed criteria for the problem of selection from the groups of mineral oils for R290 and polyester ones for R134a.

Table 5. The matrix of real values of the analysed criteria in terms of particular variants
Tabela 5. Macierz rzeczywistych wartości analizowanych kryteriów pod kątem poszczególnych wariantów

Criterion	Variants					
	MO1	MO2	MO3	POE1	POE2	POE3
K1	0.59	1.10	0.92	0.96	1.78	5.43
K2	1.73	1.27	1.95	32	27	12
K3	1.61	2.50	2.71	31.25	49.43	67.90
K4	141	102	100	100	120	107
K5	0.08	0.17	0.21	0.11	0.12	0.15

The next stage involved making a list of all numbers from the matrix of real values of the analysed criteria for particular variants as the percentage of the "progression" from the least to the most desired states **(Table 6)**. When making the combination, proper formulas were used for an inhibitor.

Table 6. The matrix of real values as the percentage of the "progression" from the least to the most desired states
Tabela 6. Macierz rzeczywistych wartości jako procent tzw. drogi od stanu najmniej do najbardziej pożądanego

Criterion	Variants					
	MO1	MO2	MO3	POE1	POE2	POE3
K1	100.00	0.00	35.29	100.00	81.66	0.00
K2	32.35	100.00	0.00	0.00	25.00	100.00
K3	100.00	19.09	0.00	100.00	50.40	0.00
K4	0.00	95.12	100.00	100.00	0.00	65.00
K5	100.00	30.77	0.00	100.00	75.00	0.00

Next, the final calculations were made aimed at decision support for the selection of lubricants for refrigeration conditions based on tribological tests. **Tables 7–9** show the products of weights of particular criteria and the percentage values of the so-called progression from the least to the most desired states for the three exemplary attitudes of the decision maker. Next, the best variant was selected on the basis of the total ratings granted to particular variants with all the criteria taken into consideration. The variants for the decision maker's individual attitudes were lined up in rankings.

Table 7. Ratings awarded to individual options taking into account all the analysed criteria with the economic attitude of the decision maker
Tabela 7. Oceny przyznane poszczególnym wariantom z uwzględnieniem wszystkich analizowanych kryteriów przy ekonomicznym nastawieniu decydenta

Criterion	Variants					
	MO1	MO2	MO3	POE1	POE2	POE3
K1	10.00	0.00	3.53	10.00	8.17	0.00
K2	3.24	10.00	0.00	0.00	2.50	10.00
K3	20.00	3.82	0.00	20.00	10.08	0.00
K4	0.00	47.56	50.00	50.00	0.00	32.50
K5	10.00	3.08	0.00	10.00	7.50	0.00
Total rating	43.24	64.46	53.53	90.00	28.24	42.50
Ranking	3	1	2	1	3	2

For R290 in the economic variant, the decision is to choose MO1 (score – 64.46). The subsequent oils in the decision maker's comprehensive assessment from this variant are MO3 (score – 53.53) and MO1 (score – 43.24). In the economic attitude, the sequence is not identical to the one resulting from the K3 sample wear criterion in the mixture of oil and refrigerant. It should also be noted that, in this variant, the compared oils obtained relatively similar ratings, and the choice of the third oil was not determined by the K4 price criterion.

The decision in the economical option for R134a is the choice of POE1 (score – 90.00). The consecutive oils in the decision maker's comprehensive evaluation from this option are POE3 (score – 42.50) and POE2 (score – 28.24). In the economic approach, the sequence is, in this case, identical to the sequence resulting from K4 price criterion.

Table 8. Ratings awarded to individual options taking into account all of the analysed criteria with the qualitative attitude of the decision maker
Tabela 8. Oceny przyznane poszczególnym wariantom z uwzględnieniem wszystkich analizowanych kryteriów przy jakościowym nastawieniu decydenta

Criterion	Variants					
	MO1	MO2	MO3	POE1	POE2	POE3
K1	20.00	0.00	7.06	20.00	16.33	0.00
K2	3.24	10.00	0.00	0.00	2.50	10.00
K3	50.00	9.55	0.00	50.00	25.20	0.00
K4	0.00	9.51	10.00	10.00	0.00	6.50
K5	10.00	3.08	0.00	10.00	7.50	0.00
Total rating	83.24	32.13	17.06	90.00	51.53	16.50
Ranking	1	2	3	1	2	3

In the qualitative variant, MO1 was selected (score – 83.24). The subsequent oils in the decision maker's comprehensive evaluation are MO2 (score – 32.13) and MO3 (score – 17.06). In the qualitative approach, the sequence is identical to the sequence resulting from the K3 wear criterion in the mixture of oil with refrigerant. On the other hand, the ranking is different than in the case of the economic approach, which may indicate the selection of oil of worse lubricity properties when one focus on the price exclusively.

In turn, for R134a, the decision in the qualitative variant is to choose POE1 (score – 90.00), as well as it is in the economical variant. The other oils in the comprehensive evaluation of the decision maker are POE2 (score – 51.53) and POE3 (score – 16.50). In the case of the qualitative approach, the sequence is identical to the one resulting from the K3 wear criterion in the mixture of oil with refrigerant.

Table 9. Ratings awarded to individual options taking into account all of the analysed criteria at the balanced attitude of the decision maker

Tabela 9. Oceny przyznane poszczególnym wariantom z uwzględnieniem wszystkich analizowanych kryteriów przy zrównoważonym nastawieniu decydenta

Criterion	Variants					
	MO1	MO2	MO3	POE1	POE2	POE3
K1	10.00	0.00	3.53	10.00	8.17	0.00
K2	6.47	20.00	0.00	0.00	5.00	20.00
K3	30.00	5.73	0.00	30.00	15.12	0.00
K4	0.00	28.54	30.00	30.00	0.00	19.50
K5	10.00	3.08	0.00	10.00	7.50	0.00
Total rating	56.47	57.34	33.53	80.00	35.78	39.50
Ranking	2	1	3	1	3	2

In the balanced variant, MO2 was selected (score – 57.34). The other oils in the decision maker's comprehensive rating are MO1 (score – 56.47) and MO3 (score – 33.53). The differences in the ratings of the first two oils are insignificant.

For R134a, the decision in the balanced variant is the selection of POE1 (score – 80.00). The next oils in the decision maker's comprehensive evaluation from this variant are POE3 (score – 39.50) and POE2 (score – 35.78). In the case of the balanced approach, the sequence is identical to the one in the economical approach. The differences in the ratings of the last two oils are insignificant.

CONCLUSIONS

The use of the Bellinger method has numerous advantages. The computational algorithm consists of simple, uncomplicated calculations. The decision maker is not required to have a wide knowledge of multi-criteria optimization, nor is special software needed. Due to its simplicity and speed of calculation, the Bellinger method can be successfully applied in decision support for the selection of lubricants for refrigeration compressors based on tribological tests.

When selecting oil for R134a in each of the analysed variants (economical, qualitative, and balanced ones), the Bellinger method pointed to POE1. It is worth noting that POE1 had the best lubricity properties at the lowest price, which determined its selection in the analysed variants. The results concerning the selection of oil for R290 were more varied. The Bellinger method pointed to MO2 as the one to be selected in both the economic and balanced variants, whereas, in the qualitative one, it indicated MO.

The above-mentioned approach in making decisions concerning the selection of lubricating oil for cooperation with a given refrigerant is an example of the use of test results obtained in the course of previous studies on the wear of friction nodes in the oil – refrigerant mixtures. It should be noted that the result achieved by the Bellinger method is closely related to the decision maker's preferences and the weights of individual criteria that result from them.

The presented analysis shows that the selection of lubricants for refrigeration compressors based on generally available information for the decision maker (i.e. the applied oil base, viscosity grade, and price) may be incorrect. The failure to take into account the lubricity properties of oil and refrigeration mixtures in the decision process may lead to faster damage to refrigeration compressors. The decision on the selection of the proper lubricant for refrigeration compressors should be preceded by tribological tests allowing one to assess the lubricity properties of oils and their mixtures with a refrigerant.

REFERENCES

1. Rozporządzenie Parlamentu Europejskiego i Rady nr 517/2014 z dnia 16 kwietnia 2014 r. w sprawie fluorowanych gazów cieplarnianych i uchylenia rozporządzenia (WE) nr 842/2006.
2. Górny K., Tyczewski P., Zwierzycki W.: Problem powstawania mieszaniny oleju smarowego i czynnika chłodniczego w węzłach tarcia sprężarek chłodniczych. Tribologia nr 5, (2011), s. 59–68.
3. Górny K., Tyczewski P., Zwierzycki W.: Specyficzne właściwości oleju sprężarkowego w układach chłodniczych, Inżynieria Rolnicza, Z 1 (141), T. 1, (2013), s. 65–74.
4. Górny K., Stachowiak A., Tyczewski P., Zwierzycki W.: Wear test stand for oils applied in refrigerating compressors. Problemy Eksploatacji, nr 2, (2014), pp. 53–60.
5. Górny K., Tyczewski P., Zwierzycki W.: Wear tests of sliding surfaces in the environment of mixtures of lubricating oils and refrigerants. Advances in Science and Technology – Research Journal, Vol. 8, No. 21, (2014), pp. 49–53.
6. Górny K., Stachowiak A., Tyczewski P., Zwierzycki W.: Zużycie tribologiczne węzłów tarcia sprężarek chłodniczych smarowanych olejami poliestrowymi. Chłodnictwo: organ Naczelnej Organizacji Technicznej, nr 7, (2014).
7. Górny K., Stachowiak A., Tyczewski P., Zwierzycki W., Lubricity evaluation of oil-refrigerant mixtures with R134a and R290, International Journal of Refrigeration 69 (2016), pp. 261–271.
8. Górny K., Stachowiak A., Tyczewski P., Zwierzycki W.: Przyczyny różnic zużycia w olejach poliestrowych oraz w ich mieszaninach z czynnikiem chłodniczym R134a, Tribologia 3/2015, pp. 33–42.
9. Górny K., Stachowiak A., Tyczewski P., Zwierzycki W.: Research idea and methodology for determining test parameters for the lubricity evaluation of oil/refrigerant mixtures, Tribologia 3/2016, pp. 87–98.
10. Barbosa J.R., Ortolan M.A.: Experimental and Theoretical Analysis of Refrigerant Absorption in Lubricant Oil. HVAC&R Research, vol. 14 (2008), pp. 141–158.
11. Neto M., Thoma S.M., Moise´s A., Barbosa J.R: Absorption of Isobutane (R-600a) in Lubricant Oil. International Compressor Engineering Conference, Paper 1991 (2010).
12. Fukuta M., Yanagisawa T., Omura M., Ogi Y.: Mixing and separation characteristics of isobutane with refrigeration oil, International Journal of Refrigeration, vol. 28/7 (2005), pp. 997–1005.
13. Prata A.T., Barbosa J.R.: The Thermodynamics, Heat Transfer And Fluid Mechanics Role of Lubricant Oil in Hermetic Reciprocating Compressors. HEFAT 2007 5th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics Sun City, South Africa Paper number: K6 (2007).
14. Warczak W.: Tłokowe sprężarki ziębnicze. WNT, Warszawa 1972.
15. Kobayashi M., Hayashi A., Yoshimura T.: Experimental Study on Journal Bearing Characteristics in Reciprocating Compressors for HFC-134a. International Compressor Engineering Conference. Paper 1258, (1998).
16. Garvin T., Schniederjans M.: Using the Analytic Hierarchy Process and multiobjective programming. European Journal of Operational Research, no. 100, (1997).
17. Piliński M., Rutkowska D., Rutkowski L.: Sieci neuronowe, algorytmy genetyczne i systemy rozmyte. Wydawnictwo Naukowe PWN, Łodź 1997.
18. Górny P.: Elementy analizy decyzyjnej, Akademia Obrony Narodowej. Warszawa 2004.
19. Duchaczek A., Skorupka D., Szleszyński A.: Optymalizacja doboru środków transportowych w logistyce magazynowej, Zeszyty Naukowe Wyższej Szkoły Oficerskiej Wojsk Lądowych im. Gen. Tadeusza Kościuszki, nr 4, 2012.