EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF FULLERENES ADDITIVES TO THE WORKING FLUID ISOBUTENE/COMPRESSOR OIL ON REFRIGERATION SYSTEM PERFORMANCE

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Abstract – *Promising ways to improve the energy efficiency of vaporcompression refrigerators is an addition of the nanoparticles into the working fluid. The effect of metal oxides nanoparticle additives into the compressor oil to the coefficient of performance of the refrigeration system has been investigated by researchers by now. The problem of the influence of fullerenes additives to the working fluid on the performance of the refrigeration system is still studied insignificant.*
The experimental values of the cooling capacity, power consumption and coefficient of performance for the compressor refrigerating system using isobutane / compressor oil and isobutane / compressor oil/ fullerenes as working fluids have been presented in the paper. The fraction of fullerene in compressor oil was 0.5 mass %. Experimental measurements are carried out on the original experimental setup with compressor from domestic refrigerator. The experiments have been performed for several values of the working fluid mass flow. The reduction of the compressor power consumption and invariance of cooling capacity with using the isobutane / compressor oil/ fullerenes as working fluid in comparison with using the traditional working fluid have been observed. The prospects of fullerene additives into compressor oils for using in refrigeration systems have been considered in paper.
Keywords – *fullerenes, refrigeration system, coefficient of performance, working fluid*

CERCETĂRI EXPERIMENTALE PRIVIND INFLUENŢA ADAOSURILOR DE FULERENI ÎN CORPUL DE LUCRU IZOBUTAN/ULEI DE COMPRESIE ASUPRA INDICILOR DE EFICIENŢĂ A SISTEMULUI DE REFRIGERARE

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Rezumat – *una din metodele de perspectivă pentru sporirea eficienţei energetice a maşinilor de refrigerare cu abur compresat este adaosul nanoparticulelor în corpul de lucru. De un şir de întreg de cercetători a fost efectuată studierea influienţei adaosului de nanoparticule a oxizilor de metal în uleiurile de compresie asupra indicilor de eficienţă energetică a sistemului de refrigerare. Totodată, în present problema impactului adaosurilor fulerenilor în corpul de lucru a maşinilor de refrigerare asupra caracteristicilor energetici de funcţionare este studiată insufficient.*
În raport sunt prezentate rezultate a cercetărilor experimentale a productivităţii frigorifice, puterii consumate şi a coeficientului de răcire a sistemului de compresoare în cazul funcţionării cu corp de lucru – izobutan/ulei de compresiune/fulereni în comparaţie cu indicii de eficienţă utilizând corp de lucru izobutan/ulei de compresiune. Concentraţia fluerenilor în uleiul de compresiune constituia 0,5% masă. Cercetări experimentale au fost efectuate la o instalaţie originală, dotată cu compresor de la frigiderul de uz casnic la câteva valori a consumului în masă a corpului de lucru. Cercetările efectuate au demonstrat reducerea puterii consumate de către compresor la maşina de refrigerare cu corpul de lucru lichid de răcire/ulei/fulereni la productivitate frigorifică a sistemului aproape neschimbată. Conform rezultatelor cercetărilor efectuate sunt făcute concluzii de existenţă a perspectivei de implementare în industria frigorifică a uleiurilor de compresori cu adaosuri de fulereni.
Cuvinte cheie – *fulereni, sistem frigorific, coeficient frigorific, corp de lucru.*

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ВЛИЯНИЯ ДОБАВОК ФУЛЛЕРЕНОВ В РАБОЧЕЕ ТЕЛО ИЗОБУТАН/КОМПРЕССОРНОЕ МАСЛО НА ПОКАЗАТЕЛИ ЭФФЕКТИВНОСТИ ХОЛОДИЛЬНОЙ СИСТЕМЫ

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Реферат – *Одним из перспективных способов повышения энергетической эффективности парокомпрессионных холодильных машин является добавка в рабочее тело наночастиц. Рядом исследователей уже проведено изучение влияния добавок наночастиц оксидов металлов в компрессорные масла на показатели энергетической эффективности холодильной системы. Причем, на сегодняшний день вопрос влияния добавок фуллеренов в рабочее тело холодильных машин на энергетические характеристики ее работы изучен недостаточно.*

В докладе приводятся результаты экспериментального исследования холодопроизводительности, потребляемой мощности и холодильного коэффициента компрессорной системы при работе на рабочем теле изобутан/компрессорное масло/фуллерены в сравнении с показателями эффективности при использоании рабочего тела изобутан/компрессорное масло. Концентрация фуллеренов в компрессорном масле составляла 0,5 % масс. Экспериментальные исследования были выполнены на оригинальной установке с компрессором бытового холодильника при нескольких значениях массового расхода рабочего тела. Проведенные исследования показали снижение потребляемой компрессором мощности для холодильной машины на рабочем теле хладагент/масло/фуллерены при почти неизменной холодопроизводительсности системы. По результатам проведенных исследований сделан вывод о перспективности внедрения в холодильную промышленность компрессорных масел с добавками фуллеренов.

Ключевые слова – *фуллерены, холодильная система, холодильный коэффициент, рабочее тело*

1. INTRODUCTION

The nanotechnologies introduction into the refrigeration industry is a prospective direction of the increasing energy efficiency and decreasing environmental impact of the equipment. The influence of nanoparticles additives on the thermophysical properties of the refrigerants, compressor oil, and refrigerant/oil solutions (ROS) was studied in [1]. It was shown that the nanoparticles additives influence positively as well as negatively on the properties of ROS. Quantitative ratio between mentioned factors will determine the perspectives of the nanotechnologies application in the refrigeration equipment.

Only few papers are devoted to study the influence of the nanoparticle additives to working fluid on the efficiency of the vapor compression refrigeration system [2-7]. Analysis of reported data shows that using the compressor oil with nanoparticle additives mainly leads to increase the refrigeration equipment energy efficiency. However, it was also shown that positive effects from nanoparticles additives varied in different studies, and sometimes it lies within range of the experimental uncertainty. Therefore, the prospects of nanotechnology applications in refrigeration equipment are ambiguous.

It should also be mentioned that additives of the nanoparticles in compressor oil lead to increase the oil viscosity [8], and, consequently, the viscosity of the working fluid of the vapor compression refrigeration system increases as well. It is assumed that the additives of nanoparticles such as fullerenes in compressor oil can both lead to viscosity increase and to friction loss decrease in compressor [9, 10].

The effect of fullerene additives to the working fluid on the coefficient of performance or energy consumption of refrigeration equipment is investigated very poorly. Only one paper, which contains the experimental date for energy efficiency of the refrigeration equipment that using the compressor oil with fullerenes, has been found [6]. In this paper it was shown that the coefficients of performance of two compressors for domestic refrigerators were improved by 5.6% and 5.3%, respectively, when the nano-oil was used instead of pure mineral oil. The fraction of fullerenes in compressor oil was 3 g/l of oil.

Therefore, the present paper is dedicated to investigation of the influence of fullerene C_{60} nanoparticle presence in the real working fluid (isobutane R600a with impurities of mineral compressor oil) on the efficiency of vapour compression refrigeration system.

2. MATERIALS, NANOFLUIDS PREPARATION AND STABILITY INVESTIGATION

An important issue before the start of the study of the prospects of nanofluid application is estimation of its aggregation stability (stability the disperse composition for a time). Fullerenes can be dispersed in solution as single molecules in contrast to metal oxides nanoparticles. Simultaneously, the fullerenes in solution can exist as clusters, the size of which depends from the fullerenes mass fraction in liquid and the basic liquid physicochemical properties.

The solubility of fullerenes in different liquids reported in many papers, one of the first studies was performed by Ruoff [11]. Since fullerene molecule is non-polar, it can be dispersed very well in non-polar fluids such as mineral oil which was used in our study. Therefore, many researchers demonstrated good stability of nanooil with fullerenes without surfactants [10]. In spite of this fact, the nanooil with fullerenes was prepared by the authors of the paper [6] with using the surfactants span-40 and tween-60.

In present research the nanoparticles of fullerene C_{60} (CAS # 99685-96-8) and compressor oil (ISO VG 19.5) were used. On the first stage two oil samples with tween-80 surfactant (CAS # 9005-65-6) and without surfactant at the mass fraction of fullerenes of 0.13 mass% were prepared for the study of aggregation stability.

The nanofluids for experiment were prepared in the following way. While preparing the nanooil the required mass of the fullerenes was weighed on the electronic balance Model GR 300 with the accuracy of 0.5mg. The required mass of the oil was weighed on the technical laboratory scales with the accuracy of 5 mg. After balancing the nanoparticles and oil, the mixture was dispersed by ultrasonic bath Codison CD 4800 with frequency 42 kHz during 9 hour.

The estimation of nanooil stability was based on the ability of fullerenes to absorb the light flux proportionally the fullerenes mass fraction in solution. Measurement of the light absorption by the nanooil with fullerenes in the cell with optics path length of 1.1 mm at the light wavelengths from 360 to 800 nm was realized with using the spectrophotometer Shimadzu UV-120-02. The excellent stability of the obtained samples of nanooil with surfactant tween-80 and without surfactant for two months has been observed. For charging into compressor refrigeration system the nanooil was prepared without surfactant.

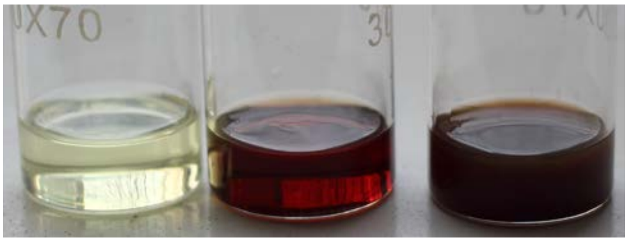
The required mass of the fullerenes and oil were weighed to obtain 320 ml of the nanooil with a concentration of the nanoparticles 0.5 mass % in oil. Obtained nanooil was charged to the crankcase of the compressor. After evacuation of the inner volume of the refrigeration compressor system, it was filled with a required quantity of the isobutane (R600a). The average mass fraction of components in ROS after charging the compressor system was:

oil mass fraction w_{oil}=70,53 mass%,

refrigerant mass fraction w_{ref}=29.11 mass%,

fullerenes mass fraction w_{C60}=0.36 mass%.

Foto of the samples of compressor oil and nanooil with fullerenes are shown in Fig. 1.



a b c

Fig. 1. Foto of the samples of compressor oil and nanooil with fullerenes:
a – compressor oil without fullerenes; b – compressor oil with 0.13 mass% of fullerenes; c - compressor oil with 0.5 mass% of fullerenes.

3. AN EXPERIMENTAL INVESTIGATION OF THE COMPRESSOR REFRIGERATION SYSTEM ENERGY EFFICIENCY

The series of the experiments have been carried out by aythors in order to estimate the prospects of using the working fluid with fullerene additives for refrigeration equipment. The schematic diagram of the experimental setup (compressor refrigeration system with compressor from domestic refrigerator Atlant CKN 150) and experimental technique are presented in [7].

The cooling capacity and power consumption of the compressor refrigeration system has been investigated at the following parameters:

- range of the mass flow rate of working fluid G_{ROS}=0,202·10^{-3} – 0,404·10^{-3} kg/s;
- range of the evaporation temperature T_0=254.9 - 255.8 K;
- range of the condensing temperature T_C=300.7 - 301.0 K;
- superheating of the working fluid (relatively to saturation temperature of pure R600a) in the evaporator ΔT=3 K.

The calorimetric method with using a secondary refrigerant (ISO 917-89) was used for determination the cooling capacity of the experimental refrigeration setup. The compressor energy consumption was measured with an uncertainty of 0.1%.

The experimental values of the cooling capacity and power consumption of the refrigeration compressor system were obtained at specified steady-state conditions. The experimental conditions were characterized by specified refrigerant flow rate, evaporation and condensing pressure values, value of refrigerant vapor superheating in the calorimeter and power consumption of the heater of the calorimeter.

The sampling of the ROS before throttling device at different mass flow was carried out in order to determine the oil mass fraction in the different parts of the refrigeration system. The concentration of the oil impurities in the refrigerant was calculated according to the values of the flow rate of the working fluid those determined by the calorimetric flowmeter [12].

The obtained experimental results are presented in Figs. 2 - 4.

The Fig.3 demonstrated that the additives of fullerenes in the compressor oil lead to reduce the energy consumption of the compressor refrigeration system up to 9 %. It probably can be explained by improving compressor oil lubricity [9, 10].

The absence of the effect of fullerenes additives on cooling capacity (see Fig. 2) can probably be explained by low mass fraction of fullerenes in working fluid in the evaporator. In the compressor refrigeration system the fullerenes circulate only jointly with liquid phase of working fluid. Leaving the compressor the fullerenes are presented only in the compressor oil, not in the refrigerant vapor. Small amount of the compressor oil is always circulating in the compressor refrigeration system. The compressor oil mass fraction in the ROS in the different parts of refrigeration compressor system depend from the design of the compressor, thermodynamic properties of the working fluid and values of the mass flow rate [13].

The results of sampling of the ROS before throttling device at the different values of the mass flow and specified operational parameters were used for determination of compressor oil and fullerenes mass fractions in the ROS - see Fig. 5. This information was also used to determination of the mass fraction of compressor oil and fullerenes in different parts of the compressor refrigeration system. For example, fullerenes mass fraction in the ROS in the evaporator of the compressor refrigeration system was insignificant – 0.016 mass% at mass flow rate of the ROS of 0.25·10^{-3} kg/s. However, fullerenes mass fraction in the compressor was 0.36 mass%. The analysis of the variation of fullerenes mass fraction in the ROS in different parts of the compressor refrigeration system explains significant reducing the compressor power consumption and insignificant effect on the cooling capacity of the system with working fluid R600a/mineral compressor oil/fullerenes compared to the such working fluid without fullerenes.

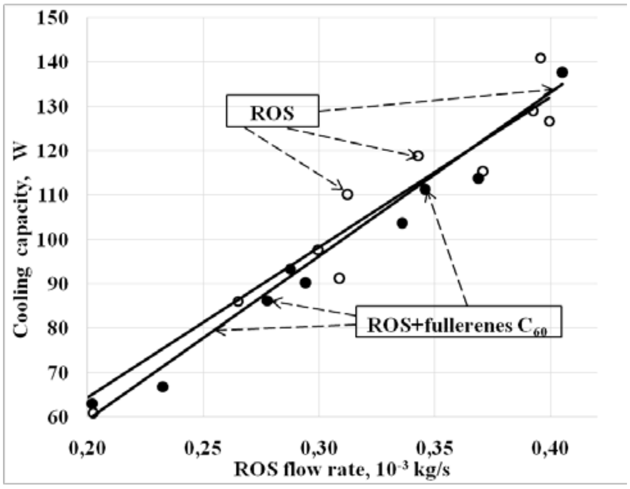


Fig. 2. Cooling capacity of the compressor refrigeration system as a function of mass flow rate of the working fluid.

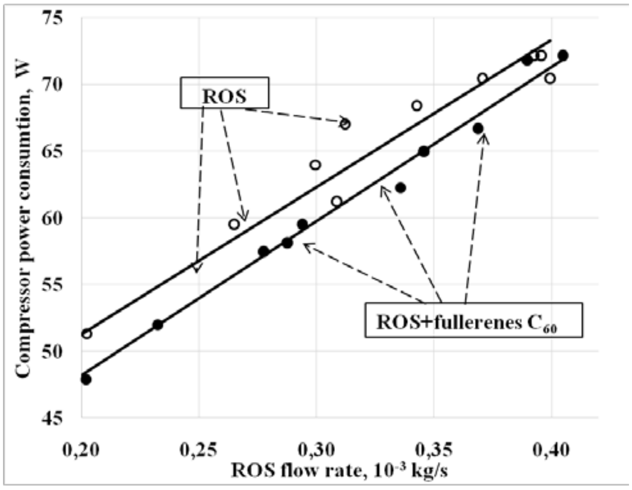


Fig. 3. Power consumption of the compressor of the refrigeration system as a function of mass flow rate of the working fluid.

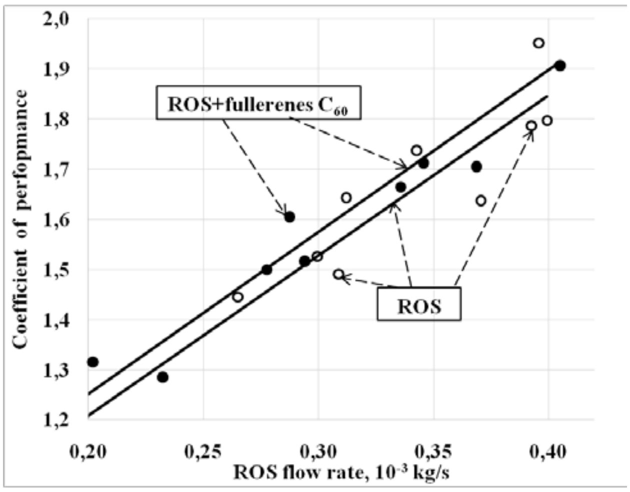


Fig. 4. Coefficient of performance of the compressor refrigeration system as a function of mass flow rate of the working fluid.

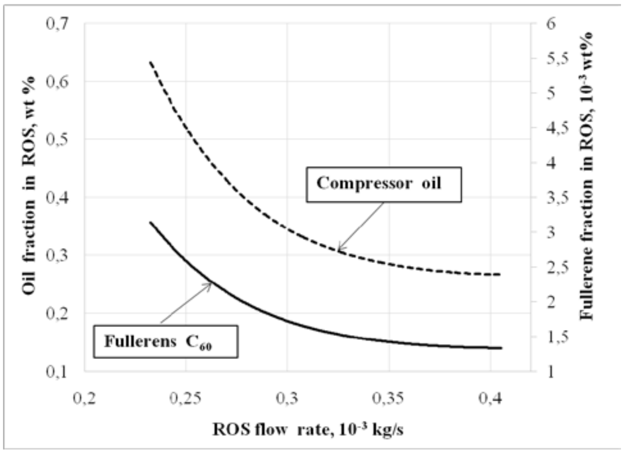


Fig. 5. Mass fraction of compressor oil and fullerenes in ROS before the throttle valve

4. CONCLUSIONS

The implementation of the nanotechnologies in new generation of refrigeration equipment has not been studied well for today. The main reasons are a complexity of determination of numerous positive as well as negative factors and effects related to nanoparticles influence on the compressor refrigeration system efficiency.

In present study was shown that additives of fullerenes in the compressor oil lead to reduce the power consumption of the compressor refrigeration system up to 9 % that probably can be explained by improving the compressor oil lubricity. It has been found experimentally that the mass fraction of fullerene in evaporator of the refrigerator system was insignificant and therefore the effect of fullerenes additives on cooling capacity was not observed.

It can be concluded that obtained results will contribute to evaluation the prospects of the nanotechnologies application in the refrigeration technique. The further study in the mentioned field will favor the enhancement of the eco-energy efficiency of the refrigeration equipments.

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