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Modern requirements for refrigeration agents in transport air conditioners

The Scientific advances, changes in national legislation in the field of combating the effects of global warming and market requirements have stimulated the development of fourth generation refrigerants. In contrast to the first and second generation refrigerants, which provided, along with the principle possibility of achieving a refrigerating effect, such qualities as durability and operational safety, the third and fourth generations include environmental constraints in a significant way. The identification of a link between leaks of traditional second-generation chlorofluorocarbon (CFC)-based refrigerants and the destruction of the protective atmospheric layer of ozone gave rise to the third generation of refrigerants. The Vienna Convention and the Montreal Protocol were the reaction of the world community, leading to the banning of ozone-depleting substances (ODS). At the same time, hydrochlorofluorocarbons were considered as temporary or transient and hydrofluorocarbons (HFCs) as long-term working bodies. Interest in the natural refrigerants ammonia, carbon dioxide, hydrocarbons and water has increased dramatically.

Keywords: *railway transport, refrigerant, transportation air conditioners, greenhouse effect, alternative refrigerants, passenger car, refrigeration machine.*

Introduction. Exploring the trade-offs between new refrigerants, their environmental goals, safety and material compatibility.

According to international forecasts, with the existing rates of greenhouse effect growth, the average temperature of the Earth's atmosphere by 2050 may increase by 3...5 K, which may lead to an increase in the level of the world ocean by 20 cm and thereby cause irreversible environmental consequences.

The analysis of the most probable scenarios of transition to environmentally safe working bodies in refrigeration technology indicates that two main approaches to the search for substances compatible with environmental requirements are now competing, these are [5, 6]:

1. The use of natural refrigerants, which eliminates ozone-depleting substances in air-conditioning refrigeration systems;

2. Increasing the environmental safety of alternative refrigerants - fluorocarbon hydrocarbons, which have non-zero global warming potential, by adding natural components as an intermediate goal.

The development of the second scenario is unlikely, as industrialized countries, which play a significant role in the global economy, have decided to accelerate the phase-out of ozone-depleting substances compared to the timeframe stipulated by the Montreal Protocol. In particular, industrialized countries reduced production and consumption of ozone-depleting substances by 75% in 2010 and 90% in 2015 compared to the baseline year of 1987. The final deadline for the elimination of environmentally hazardous substances is 2020.

For developing countries, this period has also shortened by 10 years and ends in 2030. Given the time required to develop and introduce new working bodies with non-zero global warming potential into industry, the prospect of using fluorocarbons and mixtures based on them seems doubtful.

The choice of future refrigerants depends to a large extent on changes in the political and legislative environment. At the end of 2007, the international community endorsed the "Bali Action Plan" (the so-called "Bali Roadmap") for discussion in 2009, much more stringent requirements to mitigate climate change after the end of the Kyoto Protocol (2008-2012). The Action Plan envisioned greenhouse gas emission reductions of 25 to 40% by 2020 and 50% (other proposals as high as 80%) by 2050. These ambitious plans contrasted with the collective commitments for 2008-2012, according to which the relative reduction of greenhouse gas emissions relative to the 1990 level will be on average about 5% for developed countries, and for some of them the specified targets were not fulfilled.

The generally accepted view is that hydrofluorocarbons - HFCs, as one of the six groups of greenhouse gases (GHGs) defined by the Kyoto Protocol contribute little to total GHG emissions compared to energy-intensive air conditioning and refrigeration systems. In 2006, HFCs and PFCs contributed slightly less than 2% to total GHG emissions. By 2010, this share had increased as R-22 was phased out and prioritized for replacement with the HFC - R - 410A refrigerant blend in new air conditioners.

Taking into account that historically the refrigerant consumption for service exceeds the factory norms, it should be expected that the HFC share will increase by 7-10%, corresponding to a two or threefold increase in HFC emissions, equivalent to the complete elimination of R-23 emissions in R-22 production. This contribution becomes quite competitive with a 50% reduction in emissions of the other greenhouse gases. The influence of factors related to energy efficiency (indirect contribution to greenhouse gas emissions) remains dominant, despite the increase in the direct contribution from refrigerant leaks.

Analysis of recent research and problem statement. The following parameters are used to analyze the environmental feasibility of refrigerant use: ODP (Ozon Depletion Potential); GWP (Global Warming Potential) or HGWP (Halocarlon Global Warming Potential) [7, 17].

Ozone depletion potential ODP is determined by the presence of chlorine atoms in the refrigerant molecule and is taken as one for R11 and R12. For CFC group refrigerants ozone destruction potential ODP≥1, for HCFCs ODP < 0.1, and for HFCs ODP = 0.

The global warming potential GWP is taken as one for carbon dioxide ($C0_2$) with a time horizon of 100 years, and the HGWP is calculated relative to the value of this parameter for R11, also taken as one.

According to the degree of activity of destruction of the Earth's ozone layer, haloid derivatives of hydrocarbons are divided into three groups:

- refrigerants with high ozone-depleting activity are chlorofluorocarbons (CFCs) R11, R12, R13, R 113, R114, R115, R502, R503, R12B1, R13B1 (or by international designation CFC12, CFC13, etc.)[3] and others. In accordance with the requirements of the Montreal Protocol, the countries are divided into 2 groups. The group consisting mainly of developed countries (so-called "non-article 5") stopped using CFC refrigerants in 1996. The "article 5" countries did it in 2010;
- refrigerants with low ozone-depleting activity are hydrochlorofluorocarbons (HCFCs) R21, R22, R141b, R142b, R (or by international designation HCFC21, HCFC22, HC, etc.), etc., whose molecules contain hydrogen. These substances are characterized by a shorter time of existence in the atmosphere compared to CFCs, and as a consequence, they have a smaller impact on ozone layer depletion. The Montreal Protocol provides for a phased reduction in their production from 1996, 2010, 2015 and 2020, with a complete phase-out by 2030 in "non-Article 5" countries, and in "Article 5" countries requires a "freeze" of 2016. Different countries have taken different decisions on this process. Most countries in Western and Central Europe have accelerated the phase-out of HCFCs, while most other developed countries have established regulations for the early use of these substances as an alternative to CFCs;

- refrigerants not containing chlorine atoms (fluorocarbons FC (FC) hydrofluorocarbons HFC (HFC), hydrocarbons (HC), etc.) are considered to be completely ozone-safe. Such are refrigerants R134, R134a, R152a, R143a, R125, R32, R23, R218, R116, RC318, R290, R600, R600a, R717 and others.

The ozone recovery trend is in direct in direct contrast to the worsening climate change situation. The new data on global warming published in the First Report of the Intergovernmental Panel on Climate Change reflects the unanimous position of the scientific community that "climate warming is undeniable; this is evident from the observed increase in the observed increase in the ozone layer.

The new global warming data published in the Intergovernmental Panel on Climate Change I report reflects the consensus of the scientific community that "climate warming is undeniable, evident from observed increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels". The scientists' assessment is that "it is most likely that the global warming observed since the mid-twentieth century is driven by increases in anthropogenic greenhouse gases" and that "the discernible effects of human activity are now spreading to other aspects of climate change, including ocean warming, increases in continental mean temperatures, and shifting winds."

The selection criteria for the fourth generation of refrigerants included, in addition to the existing criteria of safety and material compatibility, minimum ozone depletion potential (ODP), the requirement of low global warming potential GWP values (less than 150 for a cumulative 100-year period). Another environmental selection criterion is the rational lifetime of the refrigerant in the atmosphere, which is important for fluorine-containing chemical compounds. Along with this, the new generation of refrigerants should have high energy efficiency in order to avoid a cumulative increase in greenhouse gas emissions.

The Kyoto Protocol, ratified by Ukraine in accordance with the International Framework Agreement on Climate Change, sets some benchmarks for greenhouse gas (GHG) emissions based on the calculated equivalents of carbon dioxide, methane, nitrogen oxides, HFCs, perfluorocarbons (PFCs) and sulfur hexafluoride. It does not address ODS (the Montreal Protocol deals with them), although some of them are very potent GHGs. National laws and regulations on the application of the Kyoto Protocol differ, but, in general, they prohibit emissions of refrigerants.

In 2006, the European Parliament set a timetable to ban the use of fluorinated refrigerants (F-gases) with a GWP of more than 150 per 100 years in air-conditioners for new car models from 2011 and from 2017 for all new vehicles. In addition, the new rules require periodic inspection of stationary systems where HFCs are used. The European Parliament rejected a recommendation that would have banned the use of HFCs in aerosols by 2006, by 2009 for foaming, and by 2010 as refrigerants for stationary air-conditioning and refrigeration. Sufficiently strong intergovernmental support for greenhouse gas risk reduction measures predicts revised conditions in the future, especially in view of recent scientific discoveries indicating accelerating climate change.

As a direct result, the ban on the use of R134 in transportation air conditioners. The adopted low GWP deliberately allows the use of HFCs such as R152a despite its flammability.

Alternative refrigerants are generally less energy efficient than their predecessors [8]. With few exceptions, the efficiency gains of equipment using alternative refrigerants depend not on the properties of the new working fluid but on the design improvements in the equipment. Increasing constraints lead to new trade-offs between environmental performance, safety, cost and other parameters.

The emergence of new refrigerants raises questions about the trade-offs between conflicting environmental objectives and between environmental, safety and material compatibility. The rejection of ODS reduces the ability to combat climate change from direct or indirect effects, such as energy-related emissions. As an example of mutually conflicting goals, consider R1311 (CF31 (CEZl - fluorojodurocarbon, FIU), a potential low-potential refrigerant of R123 (HCFC). Both refrigerants have GWP and short atmospheric lifetime, low GWP value, low toxic by inhalation, non-flammable, can be effectively used for flame suppression. However, both have a low but not zero value of 0.011 to 0.018 for R1311 and a semi-empirical value of 0.02 for ODP R123. As an additive in mixtures of fluorinated olefins (unsaturated alkenes), to suppress their flammability and simultaneously reduce ODP and GWP, R1311 seems promising.

As an ODS, although not subject to the low ODP value, R1311 of the Montreal Protocol, as it has not been used commercially since 1992, when the protocol was last amended. R123 is the most efficient refrigerant for water chillers, apart from R11 and R141b, but the latter two have significantly higher ODP and GWP values. Nevertheless, the use of R123 as an ODS has long been banned in Europe. In addition, there is a ban on its use in new chillers in countries not specified in section 5 of the protocol by 2020, and in specified countries - by 2040. And this is despite the fact that R123 has very low environmental impact due to low ODP, very low GWP, very short lifetime in the atmosphere, low leakage from modern chillers, and is also highly efficient. The Montreal Protocol authorizes its limited use for service purposes until 2030 in countries not listed in Section 5. These examples demonstrate the conflict between two environmental goals: preserving the ozone layer and preventing climate change.

Another example of an environmental trade-off is the most common refrigerant R22. It is known that to replace R22, it is recommended, first of all, R410A - a mixture of two HFCs (R32 and R125). Although ODP of this mixture is practically equal to zero, GWP increases by 16% (from 1800 to 2100 for a century interval of time) [2].

Technology, market and policy changes affecting the choice of new refrigerants are transforming extremely rapidly. Recent toxicity tests have excluded from further consideration at least three refrigerant blends (AC-1, DP-1 and JDH) that were claimed to replace R134a. In particular, its stability and actual ozone depletion potential were questioned. These circumstances ruled out the R 1234yf/R1311 mixture, which is known as H-liquid [3, 5], as a candidate. The four blends listed above, which were named as candidates for Global Alternative Refrigerant, very quickly went from very promising testing in early 2007 to complete rejection in late 2007.

Most manufacturers also stopped looking for opportunities use of R-152a as a global alternative in direct expansion systems because, despite its limited flammability, this refrigerant is "not suitable for use in vehicles that are not specifically designed to use flammable refrigerants.". Research continues for indirect systems where the effectiveness of R-152a is not in doubt [6], particularly for smaller vehicles and in hot climates.

The main studies of efficiency of carbon dioxide and other natural refrigerants utilization are carried out on stationary installations. Typically, CO_2 is used in the low-temperature circuit of cascade systems in industrial artificial refrigeration production, displacing ammonia.

The use of carbon dioxide is increasing, especially in European countries, both as a common refrigerant in industrial artificial refrigeration and as an intermediate coolant in systems (UNEP, 2007b). In the latter case, significant reductions in refrigerant charge weight are achieved and further prospects are opened for the use of ammonia, ammonia mixtures (e.g. R-723 mixtures of ammonia with dimethyl ether R-E170), hydrocarbons (UNEP, 2007b).

The hydrocarbon refrigerants R- 600a (isobutane) and its blends replaced R-12 and later R-134a in home refrigerators manufactured in Europe.

The search for a compromise solution among many alternative refrigerants requires the choice of an objective criterion for comparing the proposed options. There are several approaches to the problem of thermodynamic, selection of such criterion on the basis of thermodynamic, energy or technical and economic analysis. Each of the approaches is correct within the framework of appropriate assumptions. The main difficulty in selecting an objective criterion for the selection of the refrigerating system working body for vehicles is to find a compromise between pollution reduction and price, reliability and safety [3].

The concept of sustainable refrigeration adopted by the International Refrigeration Institute requires a balance between baseline characteristics such as physical (safety, functionality, risk of failure, technical support), economic (life cycle costs, return on investment, costs, profits), environmental (greenhouse gas emissions, water, air, soil pollution) and social (health, consumer safety, consumer prices) over the product life cycle.

There is no unambiguous solution or universal evaluations to ensure a trade-off between the baseline characteristics of a refrigeration machine, so the final choice is reached through agreements or demand.

The International Institute of Refrigeration has recommended the LCCP life cycle climate characteristic as a sustainability criterion. This value is expressed in CO_2-equivalent units and takes into account the impact of direct and indirect greenhouse gas emissions on the climate during the entire life cycle (production of components, assembly, operation and disposal) of a product, in our case, a vehicle refrigeration system. LCCP criterion is a generalization of the widespread TEWI criterion (Total Equivalent Warming Impact), which considers the direct contribution from greenhouse gas emissions into the environment and only the part of indirect CO2 emission, which is a consequence of energy consumption during vehicle operation. Obviously, a detailed analysis of vehicle interactions and their impact on the climatic characteristics of the environment should reflect the full life cycle, for which an assessment should be made not only of carbon dioxide emissions during operation, but also during production and disposal processes.

To find the LCCP, the total equivalent warming impact, TENWI, is pre-calculated

$$TEWI = GWPR \cdot MR + GWPBA \cdot MBA + a \cdot E_O \cdot L, \quad (1)$$

where MR – refrigerant mass;
MBA – foaming agent weight;
E_O – average annual energy consumption during operation (kW·h);
L – the useful life of the vehicles;
a – conversion factor of energy units to CO_2, - equivalent, taken for Ukraine equal to 0.48 kg CO_2/kWh;
$GWPR$ – global warming potential of refrigerant;
$GWPBA$ – global warming potential of the foaming agent.

When calculating the LCCP, only the contribution of indirect components (E_p and E_i, i=1...N) of greenhouse gas emissions during the life cycle was taken into account, neglecting the contribution of direct effects, which are related to direct leakages due to their smallness. life cycle, neglecting the contribution of direct effects associated with direct leakages due to their smallness.

The calculated dependence has the form

$$LCCP = TEWI + a \cdot \left[\left(E_p - E_o \right) \cdot L + E_i \right]. \quad (2)$$

The TEWI calculation methodology was developed by the International Institute of Refrigeration. The TEWI parameter for a particular substance is the sum of the direct greenhouse effect potential due to the emission of this substance into the atmosphere and the indirect potential due to the emission of carbon dioxide during the production of electricity, which is required for the operation of refrigeration plants.

Currently, the choice of an alternative refrigerant for refrigeration systems depends on changes in the political and legislative environment, technology and market. The Vienna Convention and the Montreal Protocol leading to the ODS ban treat hydrochlorofluorocarbons (HFCs) as temporary or transitional and hydrofluorocarbons (HFCs) as long-term working bodies. Given these changes, R134a refrigerant is used to replace R12 refrigerant in transportation air conditioners.

The refrigerant Freon R-134a is non-toxic and not susceptible to ignition in the operating temperature range. Although when air penetrates into the working system and compresses it, mixtures of flammable gases are formed.

Unlike other refrigerants, which contain chlorofluorocarbons, which causes significant harm to the ozone layer of the Earth, the refrigerant Freon R-134a does not contain chlorine. And when it is used in air-conditioning and cooling systems, no harmful chlorine-containing compounds capable of destroying the Earth's ozone layer are emitted. This contributes to an environmentally friendly approach.

Low toxic effect is a significant characteristic of Freon R-134a refrigerant. This means that with proper use and maintenance of systems that operate on Freon R-134a, minimizes the risk of negative impact on human health and the environment. Which is essential at refrigerant sources, when small amounts of the substance may be released into the atmosphere.

Due to its low toxicity, Freon R-134a is suitable for use in enclosed spaces where people are present and does not pose a significant hazard under regulatory operating conditions.

Freon R-134a has excellent thermal properties, which makes it attractive for use in air conditioning systems. Since its high thermal conductivity allows efficient heat transfer from one part of the system to another, providing optimal cooling. Specific heat capacity of the refrigerant Freon R-134a, plays an important role in maintaining a stable temperature, which is important in processes where precise control of parameters is required.

It is not recommended to mix R-134a with R-12, due to the formation of a high-pressure azeotropic mixture, where the mass fraction of these components is one to one. The saturated vapor pressure of R-134a (1.16 MPa at 45 ºC) is slightly higher than that of R-12 (1.08 MPa at 45 ºC). According to ASNRAE classification R-134a refrigerant belongs to A1 class. Operational characteristics in medium-temperature equipment, where boiling point is -7 ºC and higher, R-134a is close to R-12.

Energy performance of R-134a in refrigeration systems, which operate at boiling point of the refrigerant below -15 ºC, is slightly inferior to R-12 (about 6% at -18 ºC). It is advisable to use refrigerants with lower boiling point or compressor with increased hourly volume, which describes the piston.

In hermetic refrigeration systems, through significant global warming potential, it is recommended to use R-134a.

When working with R-134a refrigerant it is recommended mainly only polyester refrigeration oils, which have increased hygroscopicity.

R-134a molecule has smaller sizes than R-12 molecule, which considerably increases the danger of refrigerant leaks.

R-134a is used in all countries of the world as a priority replacement of R-12 in refrigeration equipment operating in the range of average temperatures. The refrigerant is also used for retrofit of equipment operating at lower temperatures. In this case, replacement of the compressor of the refrigeration system is required to increase the cooling capacity.

For comparison of indicators and properties of refrigerant R134a with R12 we use the main requirements for modern refrigerants [7, 17]:

- environmental (ozone safety, low global warming potential, non-flammability and non-toxicity);
- thermodynamic (high volumetric cooling capacity;

low boiling point at atmospheric pressure; low condensation pressure; good thermal conductivity; low density and viscosity of the refrigerant, providing reduction of hydraulic friction losses and local resistances during its transportation; and local resistance during its transportation;

- maximum approximation to the replaced refrigerants (for alternative ozone-safe refrigerants) in terms of pressures, temperatures, specific volumetric cooling capacity and refrigeration coefficient);
- operational (thermochemical stability, chemical compatibility with materials and refrigeration oils, sufficient solubility with oil to ensure its circulation, processability of application; non-flammability and non-explosiveness; ability to dissolve water, insignificant fluidity; odor, color, etc.);
- economic (availability of commercial production, affordable (low) prices).

Thermodynamic requirements determine the performance of the refrigerant. To analyze the performance qualities we use the most important thermodynamic indices:

- differential value;
- value of temperature at the end of compression process t, °C;
- value of specific mass cooling capacity q_0, kJ/kg;
- value of specific volumetric cooling capacity q_υ, kJ/m^3;
- adiabatic work of compression l, kJ/kg;
- COPε value.

Refrigerant differential is the ratio of pressure in condenser Pk to pressure in evaporator P_0 (Pk/P_0).

The greater the difference between the condenser pressure and the evaporator pressure, the more severe the compressor operating conditions are. Consequently, the absolute pressures and their difference determine the reliability and efficiency of the refrigeration machine.

The temperature values at the end of the compression process t.

The higher the temperature of the refrigerant at the end of compression, the more loads arise in the compressor, the greater the friction forces in the mating pairs increase, and the reliability and efficiency of the refrigeration machine decrease.

The values of specific mass cooling capacity q_0 are the amount of heat removed from the cooled body by one kilogram of refrigerant

$$q_0 = i_1 - i_4, \tag{3}$$

where i_1 – enthalpy of refrigerant at the end of boiling process in the evaporator, kJ/kg;

i_4 – enthalpy of the refrigerant at the beginning of the boiling process in the evaporator, kJ/kg.

The value of specific volumetric cooling capacity q_υ is the amount of heat removed from the body being cooled to reach one-meter cubic saturated vapor of refrigerant

$$q_\upsilon = \frac{q_0}{\upsilon}, \tag{4}$$

where υ – specific volume of refrigerant vapor at suction to the compressor, m^3/hour.

Adiabatic work of compression is the work that must be applied to compress one kilogram of refrigerant.

$$l = i_2 - i_1, \tag{5}$$

where i_2 – enthalpy at the end of compression process, kJ/kg;

i_1 – enthalpy at the beginning of the compression process, kJ/kg.

The value of CORε is the ratio of cooling capacities to the consumed work.

The values of thermodynamic indicators of refrigerants R12 and R134a are determined and compared at a fixed cycle of the refrigerating machine corresponding to the conditioning conditions:

- boiling point of the refrigerant in the evaporator, t_0 = +5°C;
- temperature of refrigerant suction into the compressor, t_{vc} = +20°C;
- refrigerant condensation temperature, t_c = +35°C;
- subcooling temperature of the refrigerant before the evaporator, t_p = +30°C.

By means of computer modeling of refrigerants R12 and R134a indicators in a fixed cycle of the refrigerating machine corresponding to the conditioning conditions, the following results were obtained:

- refrigerant differential in the fixed cycle of the refrigeration machine corresponding to the conditioning conditions when using R134a refrigerant is greater than R12 by 0.18% (Fig. 1);
- the temperature at the end of the compression process in the fixed cycle of the refrigeration machine corresponding to the conditioning conditions when using R134a refrigerant is 1.0% higher than R12 (Fig. 2);
- specific mass cooling capacity in the fixed cycle of the refrigerating machine corresponding to the conditions of conditioning when using refrigerant R134a is 34,8% higher than R12 (Fig. 3);
- specific volumetric cooling capacity in a fixed cycle of the refrigeration machine corresponding to the conditions of air conditioning when using refrigerant R134a is 2.8% higher than R12 (Fig. 4);
- adiabatic work of compression in a fixed cycle of the refrigerating machine corresponding to the conditions of conditioning when using R134a refrigerant is 2.81% more than R12 (Fig. 5);
- The value of COPε in the fixed cycle of the refrigerating machine corresponding to the conditioning conditions when using R134a refrigerant is higher than R12 by 0,72% (Fig. 6).

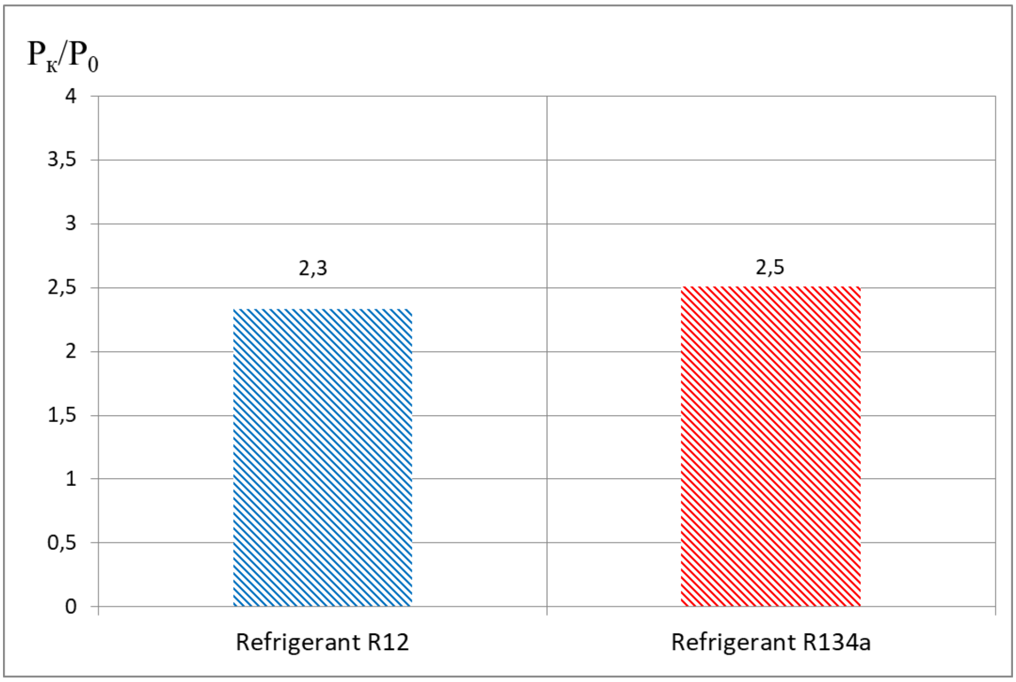

Fig. 1. **Refrigerant differential in a fixed cycle of the refrigeration machine corresponding to the conditioning conditions, using refrigerants R12 and R134a.**

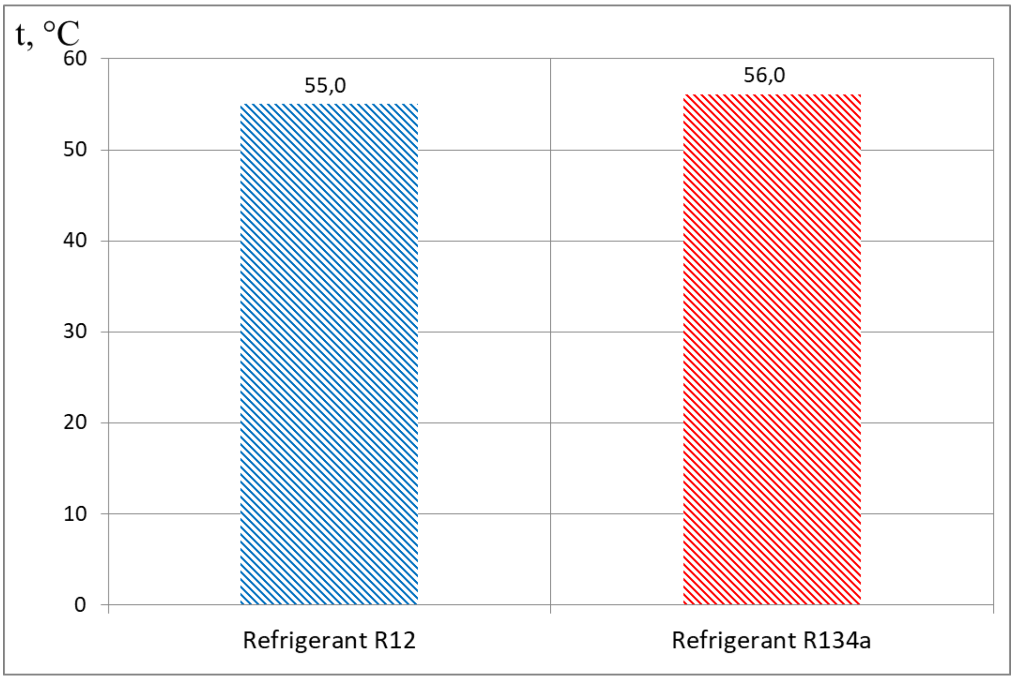

Fig. 2. **Temperature at the end of the compression process in a fixed cycle of the refrigeration machine corresponding to the conditioning conditions, when using refrigerants R12 and R134a.**

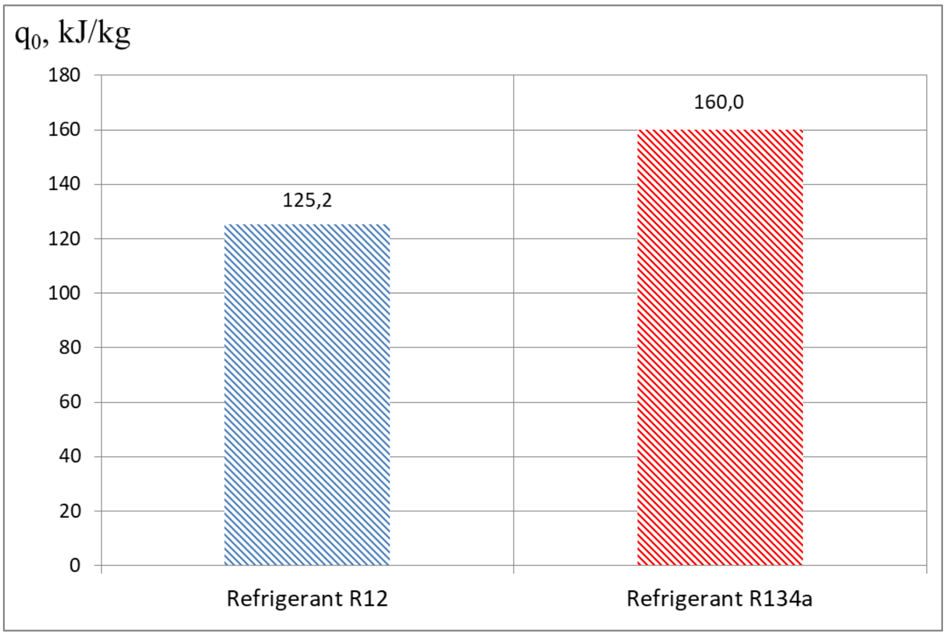

Fig. 3. **Specific mass cooling capacity in a fixed cycle of the refrigeration machine corresponding to conditioning conditions, using refrigerants R12 and R134a.**

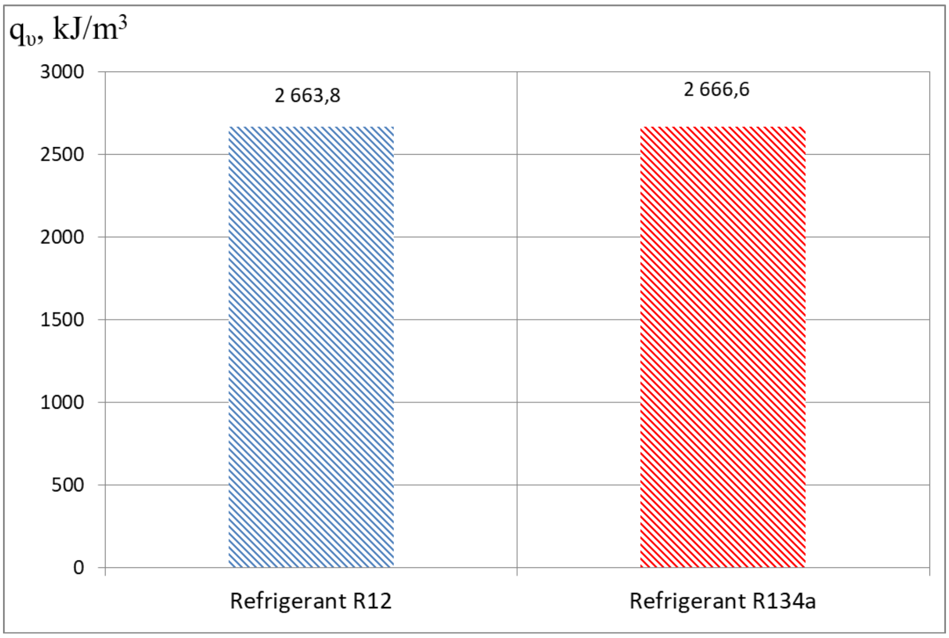

Fig. 4. **Specific volumetric cooling capacity in a fixed cycle of the refrigeration machine corresponding to conditioning conditions, using refrigerants R12 and R134a.**

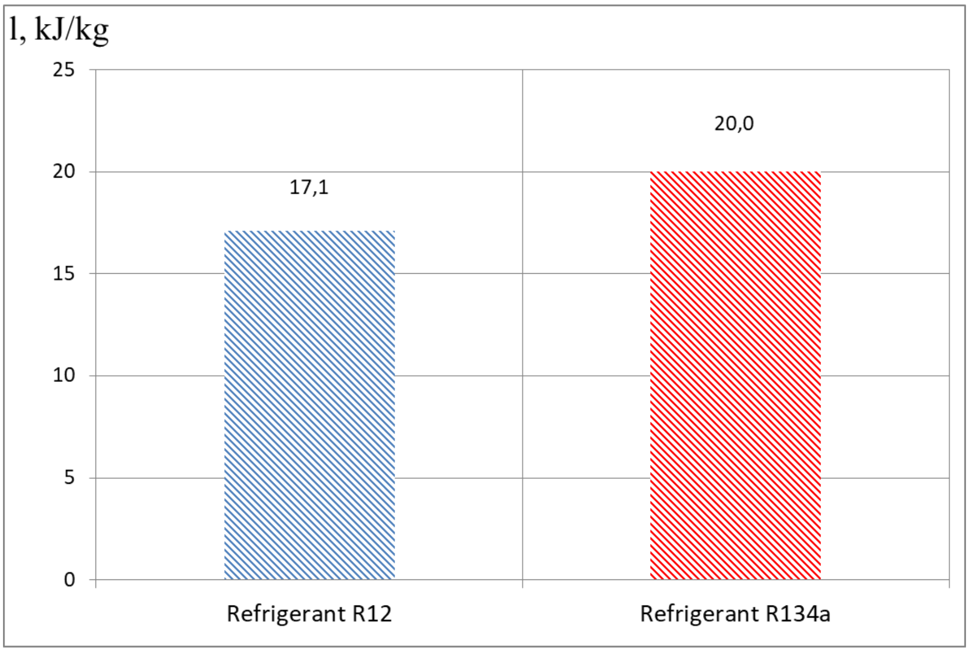

Fig. 5. **Adiabatic compression work in a fixed cycle of the refrigeration machine corresponding to conditioning conditions, using refrigerants R12 and R134a.**

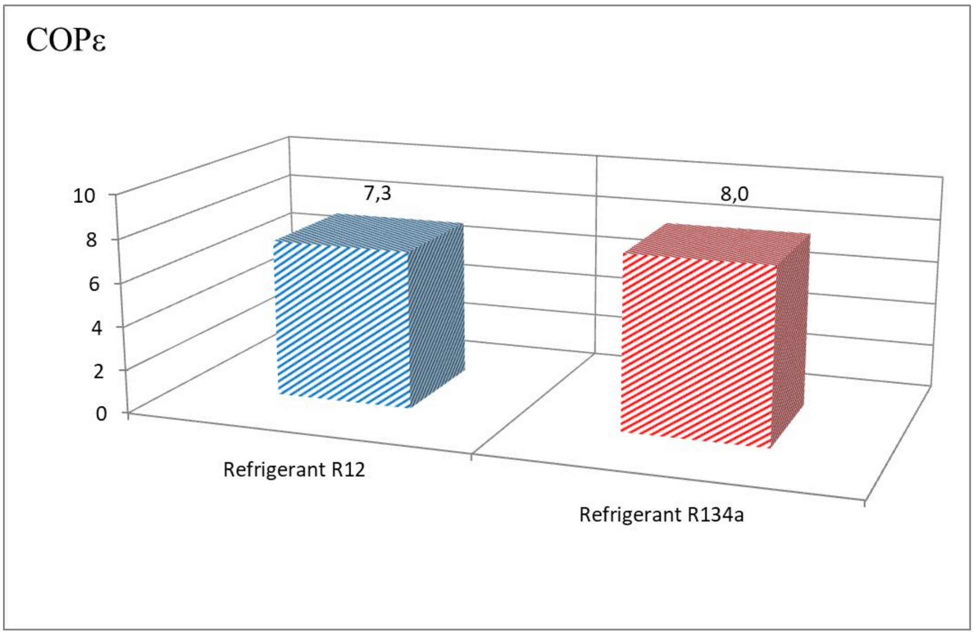

Fig. 6. **COPε value per fixed cycle for air conditioning condition, using refrigerants R12 and R134a.**

The conducted analysis of the values of weighty thermodynamic parameters of refrigerants R12 and R134a in the conditions of the fixed cycle of the refrigerating machine, corresponding to the conditioning conditions, has revealed insignificant deviations given in table 1 and has shown an insignificant discrepancy of the weightiest thermodynamic parameters. The results of the conducted thermodynamic analysis of working qualities of refrigerants R12 and R134a in the fixed cycle corresponding to the conditioning conditions, satisfies the use of refrigerant R134a as an alternative R12.

Values of refrigerant indices at fixed cycle corresponding to conditioning conditions are given in

Table 1.

Table 1. Values of indicators of refrigerants R12 in R134a in a fixed cycle corresponding to conditioning conditions

№	Parameter	Dimensionality	Refrigerant		
			R12	R134a	Divergence Δ, %
1	Differential refrigerant differential (Pк/Po)	-	2,33	2,51	0,18
2	Temperature at the end of the compression process t	°C	+55	+56	1
3	Specific mass cooling capacity q_0	kJ/kg	125,2	160	34,8
4	Specific volumetric cooling capacity $q_υ$	kJ/m^3	2663,8	2666,6	2,8
5	Adiabatic work of compression l	kJ/kg	17,15	20	2,81
6	Value COP$_ε$	-	7,28	8,0	0,72

Practical relevance. The most important task of railway transport is the mass transportation of goods and passengers. When operating a passenger railcar fleet, it is necessary to ensure not only traffic safety but also comfortable conditions for passengers. Creating and maintaining comfortable conditions in passenger cars is achieved by air conditioning with transport air conditioners. Transport air conditioners of MAB-II type of passenger cars, which are in operation of passenger car fleet, are equipped with ventilation, water and electric heating, cooling and automatic regulation and control systems [7, 17]. A feature of these systems is the ability to adjust the air temperature in each compartment by the passengers themselves, while in other air-conditioned cars the temperature is regulated simultaneously in all rooms of the car from one temperature sensor.

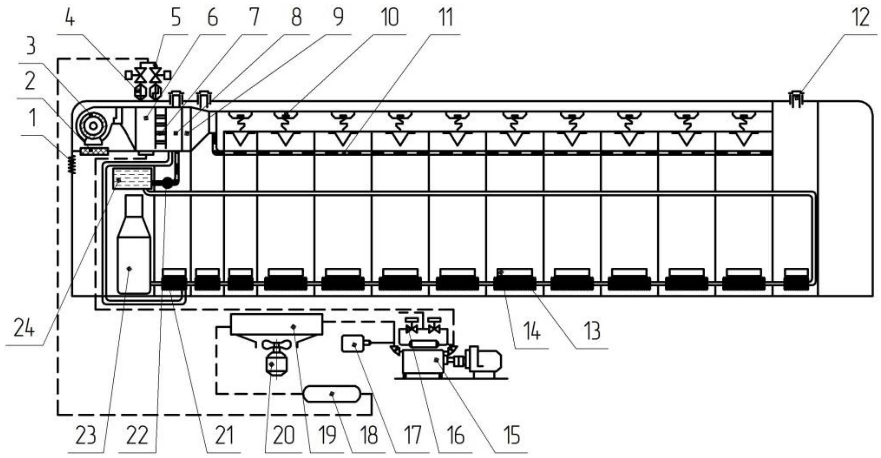

Fig. 7. **Diagram of the transport air conditioner type MAB-II:**
1 - grilles for external air; 2 - filter; 3 - ventilation unit; 4 - thermostatic valves; 5 - solenoid valves; 6 - air cooler; 7 - droplet separator; 8 - water heater; 9 - electric heater; 10 - outlet control device; 11 - perforated grille; 12 - deflector; 13 - heating battery; 14 - electric furnace; 15 - compressor; 16 - solenoid valves; 17 - pressure difference switch; 18 - receiver; 19 - condenser; 20 - condenser fan; 21 - circulation pump in the heating network; 22 - circulation pump of the heater; 23 - boiler; 24 – expander.

The refrigeration machine in the air conditioner cooling system cools the air supplied to the car by the ventilation system.

The refrigeration machine of the transport air conditioner MAB-II is a vapor compression, single-stage compression, automated, has an aggregate design, designed for refrigerant Hladon 12 (R12). Compared to other types of refrigeration machines, this machine has a number of advantages: simple design, easy to operate, maintain and repair, and the use of alternative refrigerants. The scheme of the refrigeration machine (Fig. 8).

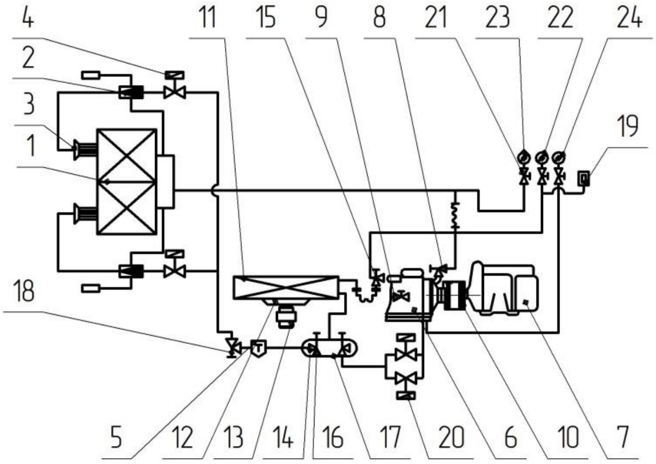

Fig. 8. **Diagram of the refrigeration machine of the transport air conditioner type MAB-II:**
1 - evaporator; 2 - thermostatic valve; 3 - liquid distributor; 4 - solenoid valve; 5 - filter-dryer; 6 - compressor; 7 - compressor motor; 8 - compressor suction shut-off valve; 9 - valve for filling the compressor crankcase with oil; 10 - flywheel coupling; 11 - condenser; 12 - condenser fan; 13-fan motor; 14-receiver; 15-compressor discharge shut-off valve; 16-angle shut-off valve at the receiver outlet; 17-angle shut-off valve of the receiver; 18-angle shut-off valve of the liquid line; 19 - high-pressure relay; 20 - electromagnetic valve for compressor capacity control; 21 - shut-off valves for pressure gauges; 22 - discharge pressure gauge; 23 - suction pressure gauge; 24 - oil pressure gauge.

By comparing the parameters of the compressor operating process and the values of COPε under operating conditions at the refrigerant boiling temperature in the evaporator t_0 = +5°C, condensation temperature in the condenser t_k = +55°C, which corresponds to the outside air temperature of more than +36°C, the following results were obtained (Fig. 9).

The refrigeration machine uses a V-type reciprocating compressor. The compressor is a 4-cylinder, V-axis, single-stage compression, block-crankcase, stuffing box, air-cooled cylinder, with a combined lubrication system, equipped with a device for regulating cooling capacity. The device for reducing the cooling capacity ensures the shutdown of two or three compressor cylinders using devices located in the cylinder heads. The cylinder diameter is 80 mm, the piston stroke is 58 mm, the crankshaft speed is 24.16sec^{-1}, and the volume described by the pistons per unit time is 112 m^3/h.

The crankshaft of the V-type compressor is connected to the shaft of a 13 kW electric motor.

The compressor is equipped with a device for reducing the cooling capacity of the unit by disconnecting two or three cylinders using lifting devices placed in their heads, and an oil heating device that facilitates start-up at low ambient temperatures.

At present transport air conditioners of MAB-II type of passenger cars are transferred to alternative refrigerant R134a.

By comparing the compressor refrigeration machine operating process parameters and COPε values on operating conditions at the refrigerant boiling temperature in the evaporator t_0 = +5°C, condensation temperature in the condenser t_k = +55°C, which corresponds to the outside air temperature of more than +36°C, in computer modeling the following results of using refrigerants R12 and R134a (Fig. 9)

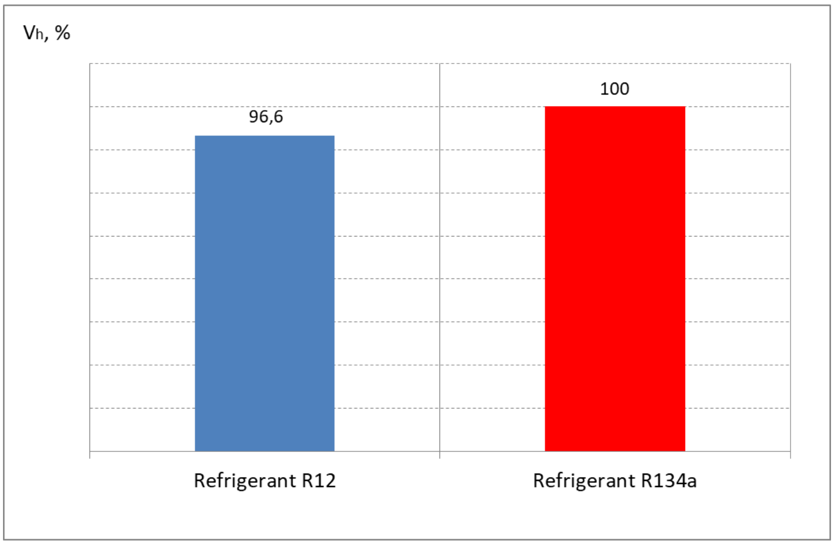

Fig. 9. **Volume described by pistons of the compressor type V for the operating mode t_0 = +5°C, t_k = +55°C when using refrigerants R12 and R134a.**

The volume described by the pistons of the compressor type V for the considered operating mode when using R134a is 100%, and when using R12 it is less by 3.4% (Fig. 9).

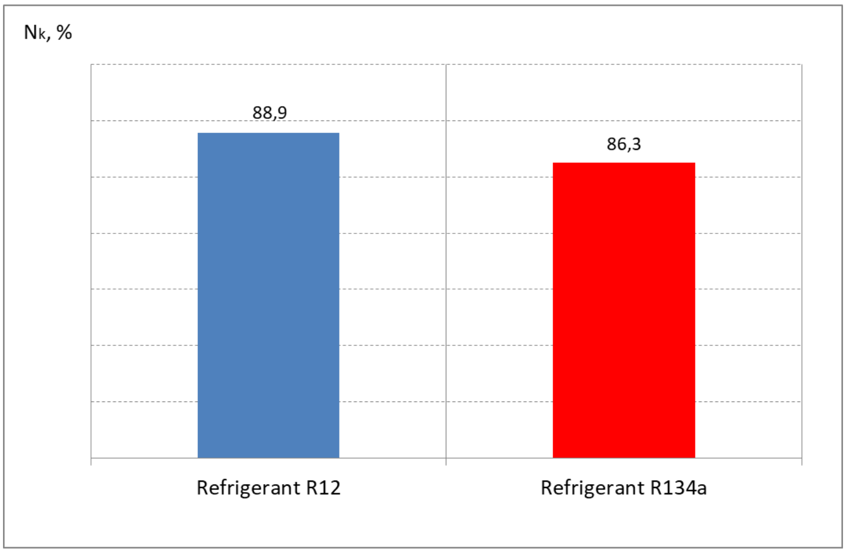

Fig. 10. **Power consumed by V type compressor for operating mode t_0 = +5°C, t_k = +55°C when using refrigerants R12 and R134a.**

The power consumed by the V type compressor for the considered operating mode when using R134a is less than R12 by 2.6% (Fig. 10).

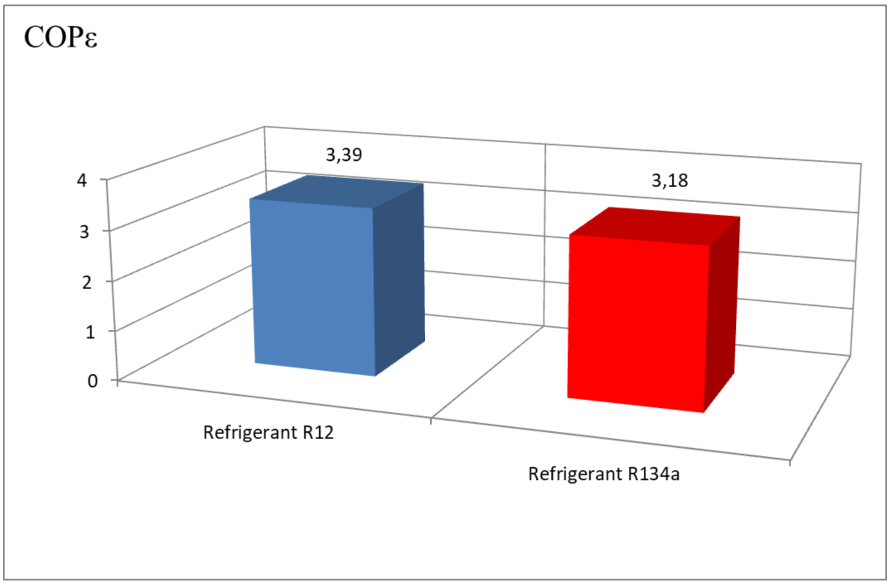

Fig. 11. **COPε value for operating mode t_0 = +5°C, t_k = +55°C when using refrigerants R12 and R134a.**

The value of COPε for the considered temperature mode when using R134a is less than R12 by 0.21% (Fig. 11).

Analysis of operating parameters of V type compressor and COPε value of refrigerating machine of transport air conditioner MAB-II of passenger car when using alternative refrigerant R134a instead of refrigerant R12 for operating conditions showed insignificant differences, which gives the reason for expediency of its application in transport air conditioner.

At present passenger cars with transport conditioners of MAB-II type, which are in the passenger car fleet, are transferred to alternative refrigerant Freon R-134a. Railway transport production enterprises have developed measures on retrofit of the refrigeration system of the transport air conditioner of MAB-II type of passenger car to the alternative refrigerant R-134a and conducted bench tests. Operational tests of passenger cars with transport conditioners of MAB-II type when using alternative refrigerant R-134a gave the confirmation about expediency of its application.

Conclusions. The following trends are currently prevailing in the development of refrigeration systems due to the risk of climate change, leading to the development of 4th generation refrigerants:

1) reduction of refrigerant emissions from refrigeration systems;

2) reducing the amount of refrigerant charged into the system;

3) increased requirements to the quality of assembly of refrigeration machines and equipment;

4) improvement of existing refrigeration machines in order to increase their energy efficiency and development of new refrigeration machines;

5) at present, the choice of alternative refrigerant for operating refrigeration machines depends on changes in the political and legislative environment, technology and market;

6) in transportation air conditioners of passenger coaches, freon R134a, which does not deplete the ozone layer, is used as an alternative refrigerant to replace refrigerant R12, but at the same time, further research on the use of natural component additives as an intermediate target is needed to reduce greenhouse gas emissions.

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Сучасні вимоги до холодильних агентів транспортних кондиціонерів

Наукові досягнення, зміни національних законодавств у сфері боротьби з наслідками глобального потепління і вимоги ринку, стимулювали розробку холодоагентів четвертого покоління. На відміну від холодоагентів першого і другого поколінь, які забезпечували поряд із принциповою можливістю досягнення холодильного ефекту, такі якості як довговічність і безпека експлуатації, третє і четверте покоління істотно включають екологічні обмеження. Виявлення зв'язку між витоками традиційних холодоагентів другого покоління на основі хлорфторвуглеводнів (ХФВ) та руйнуванням захисного атмосферного шару озону спричинило появу третього покоління холодоагентів. Віденська конвенція і Монреальський протокол були реакцією світового співтовариства, що призвела до заборони озоноруйнівних речовин (ОРВ). При цьому ГФХУ розглядали як тимчасові або перехідні, а гідрофторвуглеці (ГФУ) - як довготривалі робочі тіла. Різко зросла зацікавленість до природних холодоагентів аміаку, діоксиду вуглецю, вуглеводнів і води.

Ключові слова: *залізничний транспорт, холодоагент, транспортні кондиціонери, парниковий ефект, альтернативні холодоагенти, пасажирський вагон, холодильна машина.*