Напрямом дослідження є термодинамічний аналіз схемно-циклового рішення машини для тепло-холодопостачання індивідуального будинку з приводом від автономної сонячної фотоелектричної установки, здатної задовольнити приватних споживачів цілорічним отриманням тепла та холоду в умовах сухого тропічногоклімату.

Для аналізу використано одноступеневу компресорну холодильну машину, яка працює в двох режимах: холодильному для кондиціювання повітря та теплонасосному для опалення, обслуговуючи усі приміщеня будинку. Зміна режимів здійснюється сезонно або на протязі доби в залежності від температури навколишнього середовища. Визначались енергетична ефективність циклу холодильної машини (задача енергетична), пов'язана з властивостями робочої речовини, та габарит циклу (задача транспортна) – пов'язана з схемно-цикловим рішенням,масою устаткування та інвестиційними витратами. В дослідженні використані робочі речовини R404a, R134a, R410, R290,R600a, R32. які не заборонені або термін їх використання ще не вийшов.Розрахунки виконувалися окремо для кожного режиму.Одержані результати визначили, щоробочі речовини R290, R600a мають високу ефективність в обох режимах, R404A, R410, R32 мають однакову енергетичну ефективність, відрізняючись не більше ніж на 10 %, R134a в режимі опалення не конкурентоздатний. З габаритів циклівперевагу мають R32, R410 з значеннями вдвічі меншими за габарити R290, R404A,R600a та R134a до альтернативної групи не входять. Виходячи з термодинамічного аналізу та моніторингу ринку робочих речовин, тільки R32 може бути рекомендованим для реальних проектів. Окремо здійснено термодинамічний аналіз схемно-циклових рішень для CO_2 *– реальної перспективи холодильної техніки*

Ключові слова: холодильна машина, робоча речовина термодинамічний аналіз, енергетична ефективність, габарит циклу

UDC621.57
DOI: 10.15587/1729-4061.2019.167101

THERMODYNAMIC ANALYSIS OF THE SCHEME-CYCLE DESIGN OF A HEATING-COOLINGMACHINEFOR AN INDIVIDUAL HOUSE

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1. Introduction

Production of artificial cold or heat is part of the technological processes of many technical systems. The design of a technical system, which includes a refrigerating machine and/or a heat pump in the technological process of the system, should contain power and environmental analysis of these machines.

World statistics, based on climatic conditions and the level of economic development of different countries, claims that almost 20 percent of electricity consumption goes for cooling (cold production) and heating (heat production) [1]. In this regard, around the world, the specified machines are subject to stringent requirements to saving fuel and energy resources and environmental cleanliness of all types of production.

In recent years, the social effect associated with climaticinfluence on human life and activities has becomesignificant. From this perspective, artificial cold expands its influence. One of the promising ways to solve energy, environmentaland social problems of mankind is the creation of plants for coproduction of three useful effects – electricity, heat and cold. For refrigerating machines and heat pumps there is a prospect for improvement through the use of the heat of a wide temperature potential of fuel power plants or renewable energy sources and creation of new scheme-cycle designs. Among these, small-scale trigenerationsystems with different types of autonomous power plants are the most demanded [2]. Such systems are required for almost 70 percent of the territories of many countries of the world that are nonelectrified and have difficult climatic conditions. Therefore, in the current situation, the transition to power-resource-saving technologies with increasing the social standards of human life becomes an especially relevant scientific and practical task.

2. Literature review and problem statement

The decision on the expediency of using a trigeneration system for a particular customer with the selection of oper-

Received date: 31.03.2019 Accepted date: 02.05.2019 Published date: 21.06.2019

ating parameters, characteristics and equipment requires a detailed analysis and collection of data regarding each element of the system. Data for analysis come from studying the energy, economic, environmental condition of the consumer, monitoring of the operation of available installations in similar conditions and development of modern production in the field of relevant equipment. The general approach to the analysis of the technical system is considered in the work on a specific example of designinga system for the tropical and severely continental climate. The state of such an environment is characterized by high average monthly temperatures in summer (26...40 °C) and relatively low in winter (–10...10 °C), that is, variations of average temperatures of 15...30 degreesduring the year. At the same time, daily temperature fluctuations in all seasons can reach 40 degrees. The paper [3] provides the analysis of climatic and weather conditions of several countries in the Middle East. Information on the constant high solar radiation throughout the year, constant daily fluctuations of ambient temperature, which are superimposed on seasonal,is obtained. All natural phenomena together negatively affect human health and activities. On this basis, the necessity for a year-round, variable, not only seasonal, but also daily airconditioning and heating of premises using solar power plants is proved.

For the implementation of cooling and heating modes in one machine in different seasons of the year, the world market offers small aggregate split systems [4], as well as medium and large rooftop machines [5]. Changes in the temperature modes of airconditioning and heating in premises for both machines are due to the reverse motion of the working fluid through heat exchangers thanks to additional control equipment. This method satisfies the seasonal operation of the machine throughout the year and cannot be used for short-term mode changes during the day. The reasons are the rapid change in thermodynamic processes, operating pressures and temperatures in devices, inertia of the machine. In addition, to provide a comfortable atmosphere in a house, split systems are installed in each room. They work cyclically, control is carried out by starting and stopping a compressor. Large starting currents of several compressors negatively affect the power equipment of the photovoltaic station. Taking into account the outlined [6], the synthesis of the scheme-cycle design of the refrigerating machine with variable modes depending on daily and seasonal fluctuations of ambient temperature is carried out. The temperature connection between the machine and the premiseis made with air from active ventilation.

Intense solar radiation during the year under such climatic conditions makes it possible to use solar energy of both large and small power, that is, local power suppliers [7]. The heat produced by solar devices in a private "solar" house is used only for its intended purpose – hot water supply or heating [8]. Air conditioning by heat recovery refrigerating machines under these conditions is technically difficult and economically inexpedient.

Owners of "solar" houses equipped with autonomous photovoltaic stations of direct solar thermal conversion [9] have the opportunity to use compressor refrigerating machines for air conditioning and heating, high-tech household electronic devices, etc. Such a private house becomes an element of the system, which simultaneously uses three useful energy effects – electricity, heat and cold. This provides energy saving, environmental cleanliness and high social status of the family living in such a house.

The effectiveness of the trigenerationsystem is determined by the machine that provides cold and heatproduction. The results of the energy analysis of the trigeneration systemof tropical type, published in [10], showed that 57 % of the energy produced goes for coldproduction. The energy perfection of the refrigerating machine is due to the properties of the working fluid, and the investment – to thescheme-cycle design and equipment.

In the last 35 years, working fluids of refrigerating machines and heat pumps have been wide open to criticism both for their influence on the earth's protective ozone layer and for their global warming potential. For a long time, R-22 was the most common refrigerant. But now its use is discontinued in accordance with the International Treaty on the Protection of the Earth's Ozone Layer [11].

From 2020, production of the working fluids R21, R124, R142b, R22, R123 and R141b in the developed countries will be ceased. The choice of the working fluid now becomes a compromise between environmental and power parameters, safety and price [12].

Since January 1, 2017, the official document that prohibits charging of new automobile air conditionerswith R134a has come into force in the European Union. New R1234yf that meets all the criteria of modern environmental standardshas been proposed. Representatives of the Mercedes-Benz company have made the statement that R1234yf differs from the predecessor only in the ignition temperature characteristic and no more. In the future, the company plans to use CO_2 as a refrigerant [13]. The main drawback of CO_2, according to experts, is the high cost of the air conditioning system. This is due to the fact that in the new system, gas circulates under high pressure (up to 10.0 MPa), which involves gain of the entire cooling line.

Last year, the United States Court of Appeals for the District of Columbia Circuitprohibited, under the EPA rules [14], the use of the working fluidsR134a, R404A, R407C and R410A in new refrigeration equipment [15].

Propane (R290) as a working fluid of refrigerating machines has been used for a long time. The main scope of application is industrial refrigeration equipment in the heat capacity range from 50 to 200 kW. Due to the abandonment of many popular fluids and strengthening of the norms of refrigerant volume in the system, R290 has been increasingly usedin household refrigerating appliances.

In air/water and direct evaporating heat pumps, R290 has been used relatively recently, thanks to good thermodynamic properties. When designing machines with R290, there are no problems with the choice of structural materials for compressor, condenser and evaporator parts. Propane is well soluble in mineral oils, so when replacing R22 the refrigerator remains unchanged. In this case, the performance falls by no more than 15 % [16].

The results of research on the use of compressor refrigerating machines powereddirectly by the photovoltaic plant are available in various works, but information on working fluids of refrigerating machines is very scanty.

In [17], the feasibility study of the AC-DC conversion of an ordinary household refrigerator with R134a with the no-inverter drive is carried out. The results of the work show that refrigerating machines with DC compressors have the potential to reduce the total cost of the photovoltaic plant by about 18 %. The change of the working fluidis not considered.

In [18], the thermodynamic and economic analysis of the use of solar absorption and compressorchillers poweredbythe photovoltaic station with a refrigerating power of 10 kW for commercial consumers is performed. The analysis highlighted the high thermodynamic efficiency of the compressor machine in combination with the photoelectric installation. Unfortunately, the authors did not give data on the working fluid of the refrigerating machine, having focused on traditional working fluids of the absorption machine.

In [19], a conditioner with the compressor refrigerating machine poweredby the autonomous solar photovoltaic plant is considered. The air conditioner includes a water ice accumulator, a pump and a fancoil. The solar installation had two working models: one with a controller and an inverter, the second – with an additional battery. R134a was used as a working fluid in the refrigerating machine, and the authors pay attention to its positive qualities. The results of the study showed the energy benefits of ice accumulation in the conditioner system, and such conclusions satisfied the authors.

The considered scientific information is necessary for the development of small-scale power generation on the basis of energy saving and environmental safety. The development is associated with the creation of trigeneration systems with autonomous solar photovoltaic plantswith a year-round full load on electricity, constant consumption of cold and heat. Further development of refrigerating machines will be associated with a change in the class of working fluids and emergence of new scheme-cycle designs and equipment.

Solving some of these issues is research of the energy efficiency of compressor refrigeration machines and heat pumps as part of the trigeneration system.

3. The aim and objectives of the study

The aim of the study is the thermodynamic analysis of thescheme-cycle designs of the refrigerating machine powered by a solar photovoltaic plant, based on the determination of energy efficiency and sizes of the cycles. This will provide independent customers with year-round air-conditioning and heating on the basis of energy saving and environmental safety.

To achieve the aim, the following objectiveswere set:

– to carry out the thermodynamic analysis of cycles with medium-temperature working fluids;

– to carry outthe thermodynamic analysis of cycles with CO_2 working fluid.

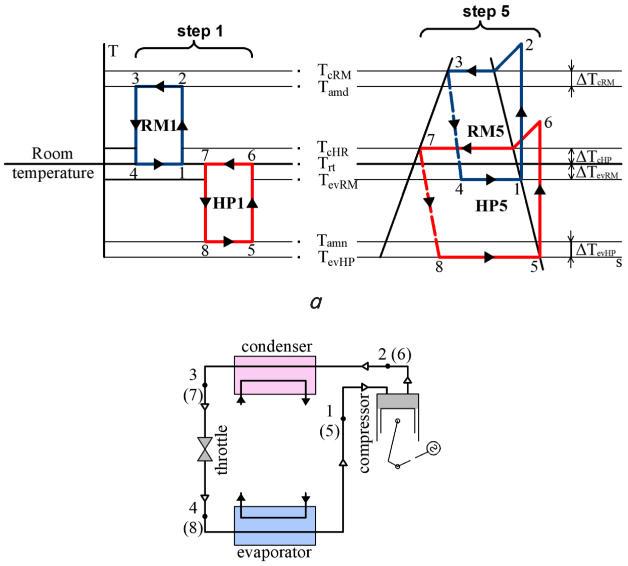
4. Thermodynamic analysis of cycles with medium-temperature working fluids

The thermodynamic analysis of cycles of refrigerating machines and heat pumps is carried out when comparing the actual with the theoretical to determine irreversibilities and to find ways to minimize them. It is the base that supports the solution of more complex tasks, for example, the synthesis of thescheme-cycle designs of special purpose refrigerating machines. This is the "method of cycles" [20].

The classical scheme of analysis by the "method of cycles" represents the logic chain: sample cycle – reference cycle – actual cycle. The sample cycle, as a rule, is used to choose the reverse Carnot cycle. Depending on the problem complexity, samples can be several Carnot cycles related to each other by the original parameters of a future real machine.

In [6], the synthesis of the cycle of a single-stage compressor refrigerating machine for heat and cold supply of an individual house is carried out by the specified method. The machine is an element of the trigeneration system with the autonomous photovoltaic power station.

The solution of the problem is carried out using the *T-s* state diagram. The final result is shown in Fig. 1.



a

b

Fig. 1. Synthesis of the scheme-cycle design of the single-stage compressor refrigerating machinefor heat and cold supply: *a*—sample and reference cycle in the**T**-*s* diagram, *b* — scheme design of the machine

For further analysis,Fig. 1, *a* shows only the samplecycles (*step 1*of the analysis) and the reference cycle (*step 5* of the analysis) of the machine. The reference cycle corresponds to the scheme (Fig. 1, *b*), which includes a compressor, condenser, evaporator (air cooler), throttle. At the first stage of the analysis, specific working fluids were not discussed. The initial conditions were medium-temperature working fluids with high critical temperature, as shown by the arrangement of the saturationcurves in the field of temperature modes.

In the presence of the reference cycle, it is possible to continue the analysis, select working fluids and solve two problems:

– "energy", estimation of the energy efficiency of the machine (COP) associated with the thermodynamic properties of working fluids;

– "transport", estimation of the cycle size and associated mass and sizecharacteristics of the compressor.

The reference cycle consists of two Planck cycles, refrigerating 1234 and heat pump 5678, for the working fluids R404A, R134a, R410, R290, R600a, R32. Those are included that are neither prohibited nor expired. The cooling capacity of the machine in the airconditioning mode – 10 kW, temperature mode: evaporatingtemperature – 15 °C, condensingtemperature– 50 °C. The heating capacityin the heating mode – 7 kW, temperature mode: evaporatingtemperature– 5 °C, condensingtemperature– 30 °C. For the analysis, average statistics for buildings up to 150 m^2 in tropical climates were taken.

The basic characteristics of the cycles, obtained in the thermal calculations of the two modes by the methods [20], are given in Table 1.

Table 1

Basic characteristics of cycles for different working fluids

Characteristic	Units	R290	R600a	R134a	R32	R404a	R410a
Airconditioningmode							
Cooling capacity	kW	10.0	10.0	10.0	10.0	10.0	10.0
Specific mass cooling capacity	kJ/kg	256	255	135	219.5	93.47	137.8
Specific condenserload	kJ/kg	295	292	155	255.6	110	161.5
Specific compressorwork	kJ/kg	39	37	20	36.1	16.99	23.7
Refrigerant mass flow rate	kg/s	0.039	0.039	0.074	0.046	0.107	0.072
Volumetric efficiency	–	0.879	0.81	0.879	0.873	0.877	0.87
Compressor theoretical displacement	$m^3/s, 10^3$	2.8	7.0	3.5	1.4	2.5	7.3
Effective compressor power		1.7	1..61	1.82	2.04	2.29	2.12
Condenserthermal load	kW	11.7	11.61	11.82	12.04	12.29	12.12
Coefficient of performance, COP	–	5.88	6.2	5.49	4.9	4.36	4.71
Sample cycle coefficient of performance		8.22	8.22	8.22	8.22	8.22	8.22
Degree of thermodynamic perfection of the reference cycle		0.793	0.747	0.438	0.697	0.676	0.591
Heating mode							
Condenserthermal load	kW	7.0	7.0	7.0	7.0	7.0	7.0
Specific mass cooling capacity	kJ/kg	291	279	83	258.8	120	172.2
Specific condenser load	kJ/kg	357	321	107	300.68	140.3	200.4
Specific compressorwork	kJ/kg	46	42	24	41.8	20.3	28.2
Refrigerant mass flow rate	kg/s	0.0196	0.022	0.065	0.023	0.05	0.035
Volumetric efficiency	–	0.869	0.87	0.87	0.866	0.866	0.866
Compressor theoretical displacement	$m^3/s, 10^3$	2.7	6.9	6.1	1.4	2.6	1.4
Effective compressor power	kW	1.072	1.14	1.94	1.22	1.47	1.44
Cooling capacity	kW	5.928	5.86	5.06	5.78	5.53	5.56
Coefficient of performance, COP		6.52	6.14	3.6	5.73	5.56	4.86
Sample cycle coefficient of performance		8.657	8.657	8.657	8.657	8.657	8.657
Degree of thermodynamic perfection of the reference cycle		0.753	0.709	0.416	0.662	0.642	0.591

The comparative analysis of the results of solving the energy problem is graphically illustrated in Fig. 2.

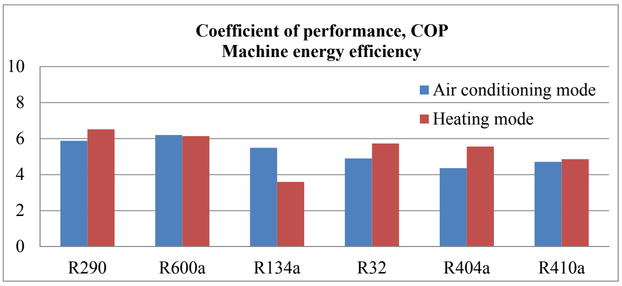


Fig. 2. Comparative analysis of thermodynamic efficiency of cycles

The results of solving the «energy» problem indicate that R404A, R410, R32 in the airconditioning and heating modes have the same energy efficiency, differing by no more than 10 %. Theworking fluids R290, R600a havea high efficiency in both modes, and R134a is inefficient in the heating mode.

The comparative analysis of the results of solving the «transport» problem isgraphically illustrated in Fig. 3.

In the “transport”problem, R32, R410 with the minimum cycle size (compressor theoretical displacements) have the advantage, followed by R290, R404. Others are not included in the alternative group. R134a requires different sizesof the cyclesin operating modes, which means that in the airconditioning mode the compressor will be loaded only by 50 %.

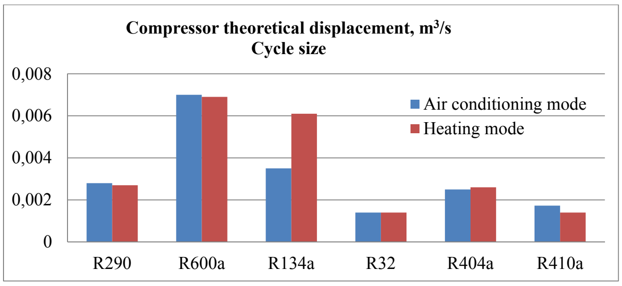
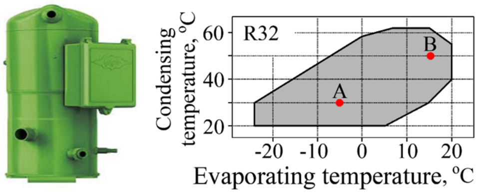


Fig. 3. Comparative analysis of mass and size characteristics of the machine

Based on the thermodynamic analysis and market monitoring of working fluids, only R32 can be recommended from this group of fluids for real projects. The reason is the new serialscrollcompressors of the BITZER company (Germany), the appearance and temperature modes of the machine (points A and B) are presented in Fig. 4 [21].



a *b*

Fig. 4. ORBIT scroll compressor of the BITZER company (Germany) [21]: *a* — general view, *b* — operating modes A and B on R32

New ORBIT models of the BITZER company are equipped with permanent-magnetacross-the-line motorsproviding a high level of energy efficiency. For greater flexibility in load control, a frequency converter can be included inthe system.

In COPLANDSCROLL compressors, start unloadingand smooth control of cooling capacityranging from 10 to 100 percent are accomplished by changing the time of effective compression. Unloading is achieved by means of vertical motion of the fixed spiral. In this case, the DC motor operates continuously with low power consumption. The compressors are fully compliant with the requirements to poweringfrom the solar photovoltaic plant.

The thermodynamic analysis shows that for a particular case the choice of the working fluid has great limitations.

5. Thermodynamic analysis of cycles with CO_2 working fluid

We carried out the synthesis of the scheme-cycle design for machineswith CO_2 using the “methodof cycles” (Fig. 5).

The Carnot-Carnot set (*step 1* of the analysis) remains the sample cycle. At a low critical temperature of CO_2, saturation curves with a critical point are detected in the operating temperature zone of the actual cycle. Then the heat removal processes should be carried out in the transcritical region (*step 5* and *step 6*).

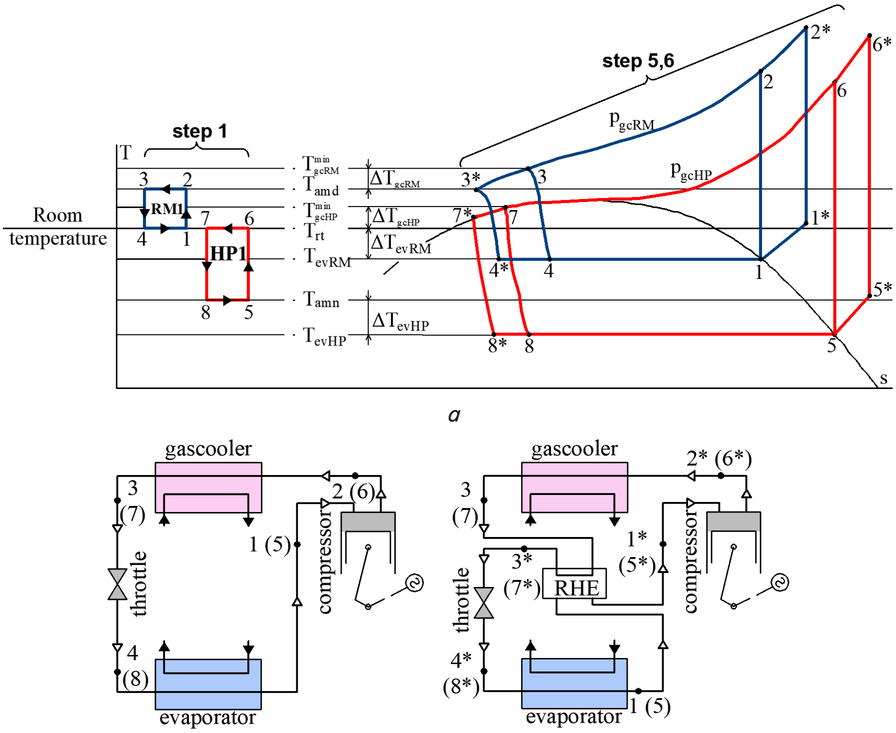
In the scheme, the traditional condenser is replaced by a gas cooler. Reference cycles, refrigerating 1234 and heat pump 5678, are constructed provided that the working fluid at the compressor inletisdry saturated vapor, the temperature in front of the throttle is equal to the condensingtemperature of the previous working fluids. The schemeof the machine for the reference cycles is given in Fig. 5, *b*. Calculated characteristics of the reference cycles with CO_2 are given in Table 2.

The results of the calculations showthe low energy efficiency of the reference cycles with CO_2 in comparison with the previous working fluids.

Traditionally, the energy efficiency of the cycles can be increased by using internal heat regeneration. The new scheme designis shown in Fig. 5, *c*, the new cycle design (1*2*3*4* and 5*6*7*8*) is shown next to the reference (*step 6*) in Fig. 5, *b*.

The result of internal heat recovery is the reduction of energy efficiency (Table 2), and this does not contradict past research [20]. In the «transport» problem, the cyclesizesof the machine with CO_2 are 3...4 times less than those of the previous group of working fluids, and these are significant advantages.

For the practical implementation of the machine, BITZER (Germany) compressors can be recommended[22]. The appearance and temperature modes of the machine (points A and B) of one of them are presented in Fig. 6.



a

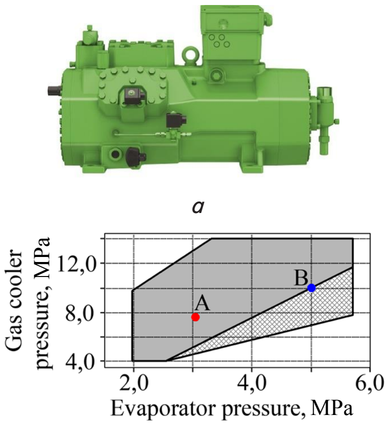
b *c*

Fig. 5. Synthesis of the scheme-cycle design of the compressor refrigerating machine with CO_2 for heat and cold supply: *a* — cycles in the **T**-*s*diagram, *b* — scheme design for the reference cycle, *c* — scheme design for the real cycle

Table 2

Basic characteristics of the cycles for CO_2

Characteristic	Units	Airconditioning-mode		Heating mode	
		Reference cycle	Actual cycle	Reference cycle	Actual cycle
Cooling capacity,	kW	10.0	10.0	5.2	5.4
Specific mass cooling capacity	kJ/kg	103.26	128.3	140.49	154.3
Specific gas cooler load	kJ/kg	127.82	151	177.21	197
Specific compressor work	kJ/kg	24.56	27	36.72	42.72
Refrigerant mass flow rate	kg/s	0.0968	0,0779	0.039	0.0335
Volumetric efficiency	–	0.88	0.80	0.866	0.76
Compressor theoretical displacement	m^3/s, 10^3	0.68	0.72	0.542	0.62
Effective compressor power	kW	2.95	2.87	1.8	2.15
Thermal load on the gas cooler, (heating capacity)	kW	12.37	11.76	7.0	7.0
Coefficient of performance, COP		3.38	3.48	3.88	3.25



a

b

Fig. 6. BITZER (Germany) ECOLINE+ semi-hermetic displasment compressor [22]: *a* – general view, *b* – operating modes A and B on CO_2

In the ECOLINE+ compressors, to achieve the highest energy efficiency, a new technology of permanent-magnetacross-the-line electric motorwith the possibility of operating with frequency converters was developed. The compressorsare equipped with a new system of mechanical control of the cooling capacityof 10 to 100 percent. Together with the mechanical capacity control, which is also new to transcritical cycles with CO_2, the efficiency of the system increases significantly at full and partial load. The compressor fully complies with the requirements to poweringfrom solar photovoltaic plants.

If low-capacity refrigeration compressors for R290will appear on the market, it will have advantages over all alternatives.

6. Discussion of the results of the thermodynamic analysis of the scheme-cycle design of the heating-cooling machine foran individual house

Theoretical researches of the scheme-cycle designs of a single-stage compressor heating and cooling machine are carried out. There are several prerequisites:

– availability of a group of working fluids that meet the current operation requirements to refrigerating machines and create an alternative to each other;

– availability of serial equipment and its characteristics according to manufacturers.

In the course of the research, two problems were solved: "energy" with determination of the energy efficiency of the cycles and "transport" with determination of the cycle sizes (compressor theoretical displacement), which is associated with mass and size characteristics. Two temperature modes were considered: air conditioning and heating with constant cooling and heatingcapacities for the R134a R404A, R410, R290, R600a, R32 working fluids.

The solution of the energy problem found that the cycles with all the working fluids in the heating and coolingmachine have equally high energy efficiency (COP=4.0...6.0 in the airconditioning mode, COP=5.0...6.5 in the heating mode). This is due, firstly, to the fact that the interval of operating temperatures of the cycles is small and does not exceed 35 degrees, and secondly, the energy efficiency of the cycles of refrigerating machines and heat pumps (reverse thermodynamic cycles) depends only on the temperature difference, and the properties of the fluids (internal cycleirreversibilities) will not affect it [20].

For refrigerating machines, compressor dimensions are determined by the value of the specific volume of the working fluid at the compressorinlet. It is clear that one of the main properties of refrigerants is the theoretical displacement, which varies in a fairly wide range for different working fluids. Consequently, in order to achieve the minimum dimensions of the compressor cylinder at a given coolingcapacity, it is necessary to find a working fluid with a high value of specific displacement.

Considering the set of the cycles limited by the upper and lower temperatures, one can distinguish one of them, which has the smallest cyclesize. In the "transport"problem, R32 and R410have the advantage.

A separate analysis of the scheme-cycle designwith CO_2 is carried out considering the transcritical cycles in the machine, and in general CO_2 is not considered as an alternative but as the future of the refrigeration technology.

The obtained theoretical results testify to the potential possibilities of using the considered working fluids in the heating and coolingmachine with high energy efficiency and satisfactory weight and size characteristics. Environmental requirements and availability of single-stage compressors in the market of equipment for theconsidered temperature modes are the basis for recommending only CO_2 and R32 for real projects. If low-capacity refrigerating compressors for R290will appear in the market, it will have advantages over all others.

The presented results can be considered as the beginning of the study of single-stage compressor refrigerating machines in trigeneration systems with autonomous solar photovoltaic plants. The development is aimed at finding new heating and cooling facilities with expanding working temperature intervals and finding new working fluids for their practical implementation.

7. Conclusions

1. The thermodynamic analysis foundthat the cycles with the R134a R404A, R410, R290, R600a, R32 working fluids in the heating and coolingmachine have high energy efficiency (COP=4.0...6.0 in the airconditioning mode, COP=5.0... 6.5 in the heating mode). The thermodynamic analysis recommended that R134a and R600a be excluded from the consideration of the «transport» problem as uncompetitive by cyclesizesthat are 3...4 times greater than others.

2. The thermodynamic analysis foundthat the thermodynamic efficiency of the cycles with $CO_2$is 50 % lower than with the previous working fluids. The cycle sizesare 3...4 times less, and such indicators, together with environmental safety, make machines with CO_2 promising to meet the energy, social and environmental needs of the population of regions with difficult climatic conditions.

References

1. Razvitie mirovoy holodil'noy promyshlennosti. URL: http://znakka4estva.ru/dokumenty/ekonomika/razvitie-mirovoy-holodil-noy-promyshlennosti/
2. Performance assessment of cogeneration and trigeneration systems for small scale applications / Angrisani G., Akisawa A., Marrasso E., Roselli C., Sasso M. // Energy Conversion and Management. 2016. Vol. 125. P. 194–208. doi: https://doi.org/10.1016/j.enconman.2016.03.092
3. Denysova A., Alhemiri Saad A., Morozyuk L. Discussion of the possibility of creating trigeneration systems in the climate of the Middle East // Kholodylna tekhnika i tekhnolohiya. 2018. Vol. 54, Issue 5. P. 36–43. doi: https://doi.org/10.15673/ret.v54i5.1249
4. Split/Multi-Split Type Air Conditioners. URL: https://www.daikin.com/products/ac/lineup/split_multi_split/
5. York Rooftop Units Heatingand Air Conditioning. URL: https://www.master.ca/en/professionnal/rooftop-units
6. Schemes, design and technological features of trigeneration systems for the conditions of the Middle East / Denysova A., Morozyuk L., Alhemiri Saad A., Tsurkan A. // Bulletin of the National Technical University «KhPI». Series: Innovation researches in students' scientific work. 2018. Issue 40. P. 10–16. doi: https://doi.org/10.20998/2220-4784.2018.40.02
7. Klyuev P. G. Solnechnaya energetika: 2014. URL: http://www.nanometer.ru/2010/08/23/12825909129704_216802.html
8. Bellos E., Tzivanidis C. Parametric analysis and optimization of a solar driven trigeneration system based on ORC and absorption heat pump // Journal of Cleaner Production. 2017. Vol. 161. P. 493–509. doi: https://doi.org/10.1016/j.jclepro.2017.05.159
9. Ghafoor A., Munir A. Worldwide overview of solar thermal cooling technologies // Renewable and Sustainable Energy Reviews. 2015. Vol. 43. P. 763–774. doi: https://doi.org/10.1016/j.rser.2014.11.073
10. Medved D. Trigeneration units // Intensive Programme "Renewable Energy Sources". 2011. P. 47–50.
11. Monreal's'kiy protokol pro rechovini, scho ruynuyut' ozonoviy shar. URL: https://zakon.rada.gov.ua/laws/show/995_215
12. Coulomb D. The refrigerants future: the phase down of HFCsand its consequences // Nizkotemperaturnye i pischevye tekhnologii v XXI veke: materialy VI MNTK. Sankt-Peterburg. Sankt-Peterburg: NIU ITMO, IHiBT, 2013. P. 3–6.
13. Zapret hladagenta R134a v Evrope. 2017. URL: http://www.automaster.net.ua/artykuly/zapret-hladagenta-r134a-v-evrope,49721?wyslij=49721
14. Regulation (EU) No. 517/2014. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&-from=EN
15. California approves original SNAP rules // Cooling Post. 2018. URL: https://www.coolingpost.com/world-news/california-approves-original-snap-rules/
16. Environmentally friendly and efficient propane heat pump. 2018. URL: https://phys.org/news/2018-09-environmentally-friendly-efficient-propane-burning.html
17. Comparative techno-economic assessment of a converted DC refrigerator and a conventional AC refrigerator both powered by solar PV / Opoku R., Anane S., Edwin I. A., Adaramola M. S., Seidu R. // International Journal of Refrigeration. 2016. Vol. 72. P. 1–11. doi: https://doi.org/10.1016/j.ijrefrig.2016.08.014
18. Infante Ferreira C., Kim D.-S. Techno-economic review of solar cooling technologies based on location-specific data // International Journal of Refrigeration. 2014. Vol. 39. P. 23–37. doi: https://doi.org/10.1016/j.ijrefrig.2013.09.033
19. Experimental investigation of solar photovoltaic operated ice thermal storage air-conditioning system / Xu Y., Li M., Luo X., Ma X., Wang Y., Li G., Hassanien R. H. E. // International Journal of Refrigeration. 2018. Vol. 86. P. 258–272. doi: https://doi.org/10.1016/j.ijrefrig.2017.11.035
20. Morozyuk T. V. Teoriya holodil'nyh mashin i teplovyh nasosov. Odessa: Studiya «Negociant», 2006. 712 p.
21. Scroll Compressors // BITZER. URL: https://www.bitzer.de/gb/en/scroll-compressors/?country=gb
22. Porshnevye kompressory // BITZER. URL: https://www.bitzer.de/ru/ru/поршневые-компрессоры/