DOI: 10.58224/2618-7183-2022-5-2-43-50

Orlov P.A., Applicant,
Il`ina T.N.,* Doctor of Engineering Sciences (Advanced Doctor), Professor,
Belgorod State Technological University named after V.G. Shukhov, Russia,
Orlov K.P.,
National University of Science and Technology University Moscow Institute of Steel and Alloys, Russia
*Corresponding author E-mail: ilina50@rambler.ru

TEST OF HEAT PUMP UNIT WITH MOVEBIT ANTI-ICING SYSTEM

Abstract: use of heat pump units is one of the directions for introducing energy-saving technologies into engineering systems. Air heat pumps are more promising than geothermal ones, but their use in cold climates is limited by formation of frost on the evaporator heat exchanger. This paper presents a heat pump unit with a system for breaking ice with using oscillatory circuits. The air heat pump unit with MOVEBIT anti-icing system, including the oscillatory circuit, has been developed. It was tested in the temperature range from -26℃ up to +10℃. The transformer ratio is determined as the ratio of the heat received to the operation expended. The calculation of heat output was carried out using a computer program that includes the flow main parameters. The calculated and experimental values of the coefficients are compared. Studies have shown that a change in the temperature of the air entering the evaporator of the pumping unit with the anti-icing system does not significantly affect the energy efficiency of the equipment under test. The MOVEBIT outdoor air heat pump allows to obtain a conversion factor in the range of 4-6 when operating in areas with outdoor temperatures down to -27℃ and can compete with geothermal heat pumps. Measurements of the sound impact of the anti-icing system showed the need to reduce it by 30 %.

Keywords: heat pump, evaporator, frost, MOVEBIT system, transformer ratio, heat output

Introduction

The Russian government is taking consistent measures at the legislative level to stimulate introduction of energy-saving technologies. The Ministry of Energy of the Russian Federation has prepared a strategy for development of the country until 2050, in which the priority is transition to low-carbohydrate and renewable energy sources, by 2035 their share will increase eightfold [1].

In Western Europe, heat pumps currently heat about 10 % of all buildings. Nevertheless, so far three-quarters of the heating equipment produced is produced by units operating on fossil energy sources. To stimulate the market for heat pumps, economically developed countries introduce government support programs, for example, in China, subsidies under the "Action Plan for the Prevention of Air Pollution" the Ministry of Environmental Protection of China introduced subsidies for air source heat pumps in various provinces from 24,000 to 29,000 yuan per family, similar measures exist in almost all countries of Europe and the USA, reducing the costs of households for purchase of energy-saving equipment, while at the same time tightening the requirements for performance of heat transfer equipment [2].

Since 2021 a new energy efficiency standard for heat pumps has been introduced, the European seasonal performance labels for heat pumps also use the same scale as for fossil fuel boilers, which allows comparison of their performance. In European countries and China, heat pumps are classified as renewable energy sources, which leads to various incentives such as tax, depreciation and customs benefits [3].

The demand for heat pumps motivates the emergence of productive, installation, service companies that require highly qualified specialists.

Geothermal heat pumps (GHP) are the most efficient sources of low-potential heat today. Their main advantage is the ability to operate at low outdoor temperatures, but along with the high COP – Coefficient of Performance – the value showing how many times the heat pump produces more energy than it consumes. GHP have a number of significant disadvantages, such as high price, the need to have a land plot for laying a horizontal collector or drilling wells with a depth of 150-200 m, as well as problems that arise during operation, such as freezing of heat-removing elements of the collector or wells, use of arable land, and etc. [4].

The most promising are air heat pumps. However, their use is limited in countries with a cold climate as a result of ice formation. An analysis of ways to prevent icing of the heat exchangers of the outdoor evaporative unit showed that the most effective is use of mechanical vibrations [5, 6]. Moreover, it is preferable to manufacture the emitters of the oscillatory circuit using certain materials [7, 8]. Development of heat pump units using various sources of renewable and recyclable energy is an urgent task in heat supply systems of engineering systems [9-13].

Materials and Methods

As part of an air heat pump development project, in order to create an alternative heating source that can compete with the energy efficiency of geothermal heat pump units, a laboratory copy of an air heat pump with the heat exchanger with MOVEBIT anti-icing system was made.

The MOVEBIT anti-icing system includes the heat exchanger of the evaporative unit with the magnetostrictive emitter fixed in the certain way, which supplies vibrations of the given frequency to the surface of the heat exchanger to destroy ice.

The diagram of the air heat pump is shown in figure 1.

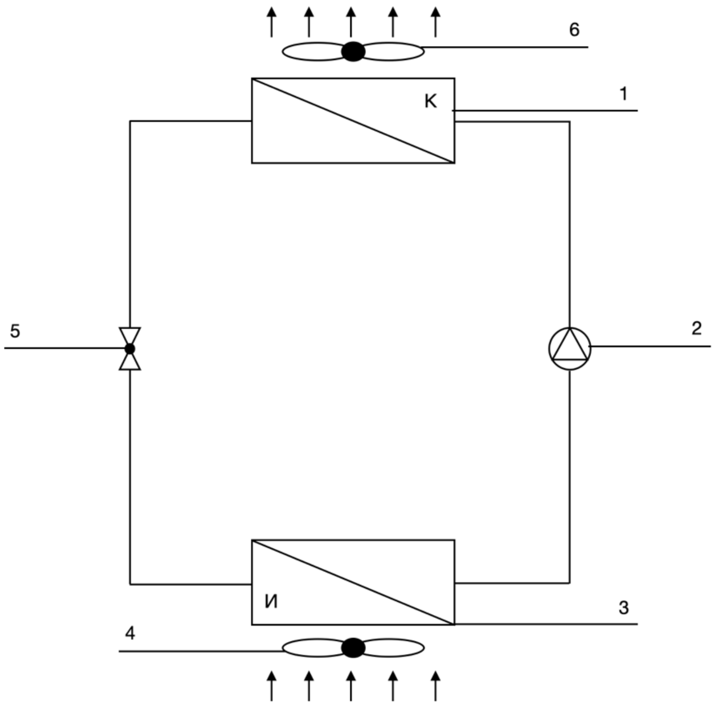

Figure 1. Scheme of the heat pump unit

The outdoor unit (3) consists of the aluminum evaporator with emitters of mechanical vibrations operating in the low-frequency range with the predetermined time interval, which is a derivative of the temperature and humidity indicators of the outdoor air and the surface temperature of the heat-removing evaporator lamellas. From the refrigeration chamber, through the duct fan (4) with the capacity of 400 $^{m^3}$/h, the cooled air enters the outdoor unit with the aluminum heat exchanger that acts as the evaporator. In the outdoor unit, the air is humidified using an ultrasonic steam generator within the range of 76-84% humidity. Humidified air, passing through the heat transfer elements of the evaporator, gives off heat to the refrigerant in the vapor-liquid state, and makes the phase transition, absorbing heat and turns into gas. Then the gaseous refrigerant through the inlet tube enters the accumulator chamber (liquid separator), where the refrigerant boils. Then it enters the compressor (2), which, according to the principle of operation, belongs to the class of volumetric compressors with a rotating rotor (rotary ones) in the sealed body with the built-in single-phase electric motor 230 V-50 Hz. Manufacturer MATSUI (Japan); power 920 W; CAPACITY-9300 BTU/h – (thermal power-2,724.9 W); working substance – coolant R-410a. The compressor outlet temperature is 68 -70℃. Then the gaseous refrigerant at the high pressure of 1.2-1.4 MPa (12-14 bar) enters the condenser with the series-parallel movement of the refrigerant through 3/8" (9.525 mm) copper pipe line. The fin-tube heat exchanger is made by fitting fins made of aluminum plates onto smooth copper tubes. The condenser is mounted on the same frame as the compressor.

The movement of the air flow is carried out by the radial fan (6) with the capacity of 700 m^3. The power consumption is 50 Wh, the flow is arranged in such a way that the air used for cooling the compressor is mixed with the warm air coming after the condenser and is also used for space heating. After the gaseous refrigerant has condensed and given off heat to the room, it enters the throttling device (5), the role of which is performed by the ECV (electronic control valve) CAREL E^2 V. The ECV is controlled by the EVD series controller (Italy), the temperature sensor takes readings of the refrigerant on the low pressure pipeline after the evaporator, wherein, the low pressure sensor transmits readings to the controller. The controller sends an electrical signal to the stepper motor, which drives the needle cone stem, increasing or decreasing the valve flow area: opening the valve increases the flow of liquid refrigerant, the pressure in the circuit rises, therefore, the boiling point of the refrigerant increases. The ability of the evaporator to absorb heat from the outside air decreases, and vice versa, closing the valve lowers the pressure in the circuit, respectively, the value of the boiling point of the refrigerant decreases, as a result of which the evaporator absorbs heat from the air with the lower temperature.

The experiment was carried out in two stages:

1 – without the use of the oscillatory circuit with the plate heat exchanger, air-freon type, bimetallic design, copper tubes with aluminum fins;

2 – using an outdoor unit with MOVEBIT technology at the outdoor air humidity of 76-84%.

Within the testing of the heat pump, the sound load was measured using TESTO 816 sound level meter that complies with the requirements of IEC 61672. After calibration, the natural noise level was up to 36 dB, the noise level from the operation of the indoor unit, which includes the compressor and fan, was 56.7 dB. The external unit with the fan and the oscillatory circuit showed the noise level within the following limits: natural background of 30 dB; noise from the fan 50 dB, the noise from the operation of the oscillating circuit of 101 dB. Within the operation of the external unit, oscillating circuit, compressor, fan, the measurements of the sound effect inside the room amounted to 86 dB.

Tests of operation without the oscillatory circuit (first stage) showed that critical frostbite of the lamellas began after 15 minutes of operation, the liquid refrigerant did not boil away at the viewing window and entered the liquid separator in the liquid state, overheating in this mode of operation showed values of 0°K. To defrost the evaporator, it was necessary to completely stop the heat pump and turn on the 3 kW heater for 10 minutes of continuous operation. Therefore, within production of thermal energy of 525 W, it took 500 W to fight the icing. In view of the danger of liquid refrigerant entering the compressor and its failure due to water hammer, further tests were suspended.

The second stage of testing was carried out using the oscillatory circuit evaporator of the MOVEBIT system. In order to be able to conduct the more accurate analysis of the operation of various consumers of electricity: (compressor, fan, operation of the oscillating circuit electronics, controller and ECV, ultrasonic steam generator) were carried out separately.

Results and Discussion

The tests were carried out for four hours with the outdoor temperature of +10 to -28.9℃ , more than two thousand values were received. The above example shows how to calculate the heat output of the heat pump at the outdoor temperature of -26.4℃. The average values of the test results are provided in the table 1.

Table 1

Test results of the heat pump unit at various temperatures of outside air in the evaporator circuit, ℃

Ser. No.	Measured values	Unit	10	5	0	-5	-10	-15	-20	-26.4
1	Low pressure	bar	4.4	3.08	2.9	2.21	1.82	1.66	1.39	1.42
2	Liquid temperature	°C	-11.6	-19.3	-20.5	-25.6	-28.8	-30.2	-32.7	-32.4
3	Gas pipeline temp.	°C	-3.4	-10.8	-11.8	-21.6	-24.3	-26.7	-28.4	-26.8
4	Overheat	K	8.2	8.5	8.7	4	4.6	3.5	4.3	5.6
5	Air temperature upstream the evaporator	°C	9.2	5.4	0.8	-4.9	-9.3	-17.1	-20.2	-26.4
6	Air temperature downstream the evaporator	°C	1.9	-3.4	-6.5	-12.8	-12.3	-20.5	-21	-28.6
7	High pressure	bar	13.95	13.5	13.48	13.17	12.49	12.49	12.42	12.09
8	Gas temperature	°C	21.2	20.1	20	19.2	17.5	17.5	17.3	16.4
9	Liquid pipeline temp.	°C	18.8	15.7	15.6	13	11.4	10.8	10.7	10.7
10	Subcooling	K	2.4	4.4	4.4	6.2	6.1	6.7	6.6	5.7

Continuation of Table 1

11	Air temperature upstream the condenser	°C	8.6	8.7	9	9.4	7.8	8.5	8.6	7.6
12	Air temperature downstream the condenser	°C	18.9	18.2	18.3	17.6	16.3	15.9	15.7	15.3
13	Refrigerant temperature downstream the compressor	°C	32.9	49.7	51.9	67.4	67.4	68.2	68.5	68.6
14	Indoor humidity	%	43.7	41.2	41.4	41.6	43	42	41.6	42.5
15	Air flow rate downstream the condenser	m/sec	14.6	15.0	15.0	14,8	14.9	14,8	15.0	14.9
16	COS Φ		0.75	0.52	0.54	0.4	0.48	0.37	0.46	0.43
17	Active power, R	W	363.1	336	347	276	305	238	308	276
18	Heating capacity	W	2,251	2,130	2,085	1,816	1,894	1,633	1,595	1,711
19	COP		6.2	6.34	6.01	6.58	6.21	6.86	5.18	6.2

The heat output was calculated using the computer program that included the following quantities:

a) variables: air flow velocity V (m/s); inlet air temperature T_N (°C); temperature of the air leaving the condenser T_K (°C); indoor air humidity, relative humidity *F* (%); atmospheric pressure P (atm).

b) constants: cross-sectional area of the duct $S=\pi R^2=3.14 \cdot 6.15^2=116.8\ cm^2=0.0118\ m^2$

p – density at the temperature of 7.6 is 1.258 kg/m^3 , at the humidity of 45% *p* = 1.262 kg/m^3

Air flow velocity of 14.91 m/s, air volume flow of 0.177 m^3/s, mass flow of 0.223 kg/s. Heat output $Q_P = m \cdot (T_K - T_N) = 0.223 \cdot (15.3 - 7{,}6) = 1.71$ kJ/s = 1.71 KW

The max of COP, provided in the table, is based on the electricity consumed by the compressor P_K (W) and the production of the body Q_P (W) by the air heat pump.

Active power P (W) is the power consumed by the compressor, $P = I \cdot U \cdot \cos\varphi$ [14, 15].

$COP_K = Q_P / Pk = 1711/276 = 6.199$, this is an indicator of the transformation ratio without considering the power consumption for the fan, ECV, oscillatory circuit in total they are approximately: 68 W and as a result we get COP = 4.9.

Electricity costs for the operation of additional equipment are further taken into account as constant due to their low volatility and stochasticity. Used control and measuring equipment complies with DIN EN ISO 7726; DIN EN ISO 14644-3.

The transformation ratio is the ratio of the heat output of the unit to the energy consumed by the compressor. As can be seen from the table, when the temperature drops from +10°C up to -26.4°C heating capacity Q_P has decreased accordingly from 2,251 W to 1,711 W, however, the average value of the COP_K coefficient is within 6.2 and does not change due to the decrease in outside temperature. This is due to the fact that the active power consumed by the compressor decreases with decreasing temperature and depends on the current strength and $\cos\varphi$,($P = I \cdot U \cdot \cos\varphi$).

The developed air heat pump unit with the MOVEBIT anti-icing system (figure 2) worked for several days in real conditions at the outdoor air temperature from -6.4°C up to -10.4°C. The efficiency of the unit corresponded to the values provided in the table.

Figure 2. Heat pump unit with MOVEBIT system

The conversion factor of the refrigeration process was also calculated on the logP-i diagram for the refrigerant R-410a in the considered temperature range. Refrigerant pressure, bar, specific enthalpy, kJ/kg. (Figure 3 shows a diagram of the refrigeration cycle at -20°C, Figure 4 shows a diagram of the refrigeration cycle at 0 °C, Figure 5 shows a diagram of the refrigeration cycle at +10°C.)

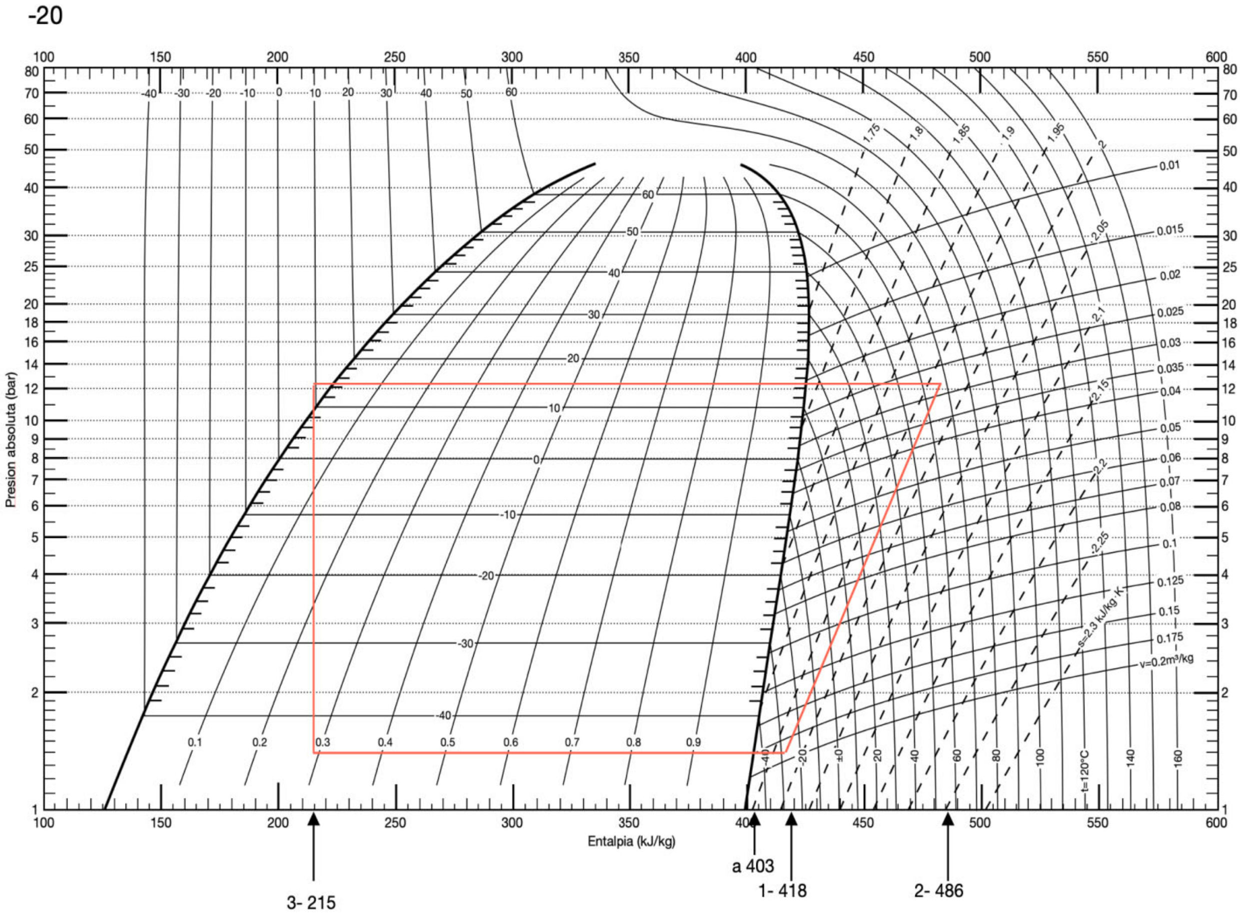

Figure 3. Refrigeration cycle diagram in logP-i coordinates at -20°C

0

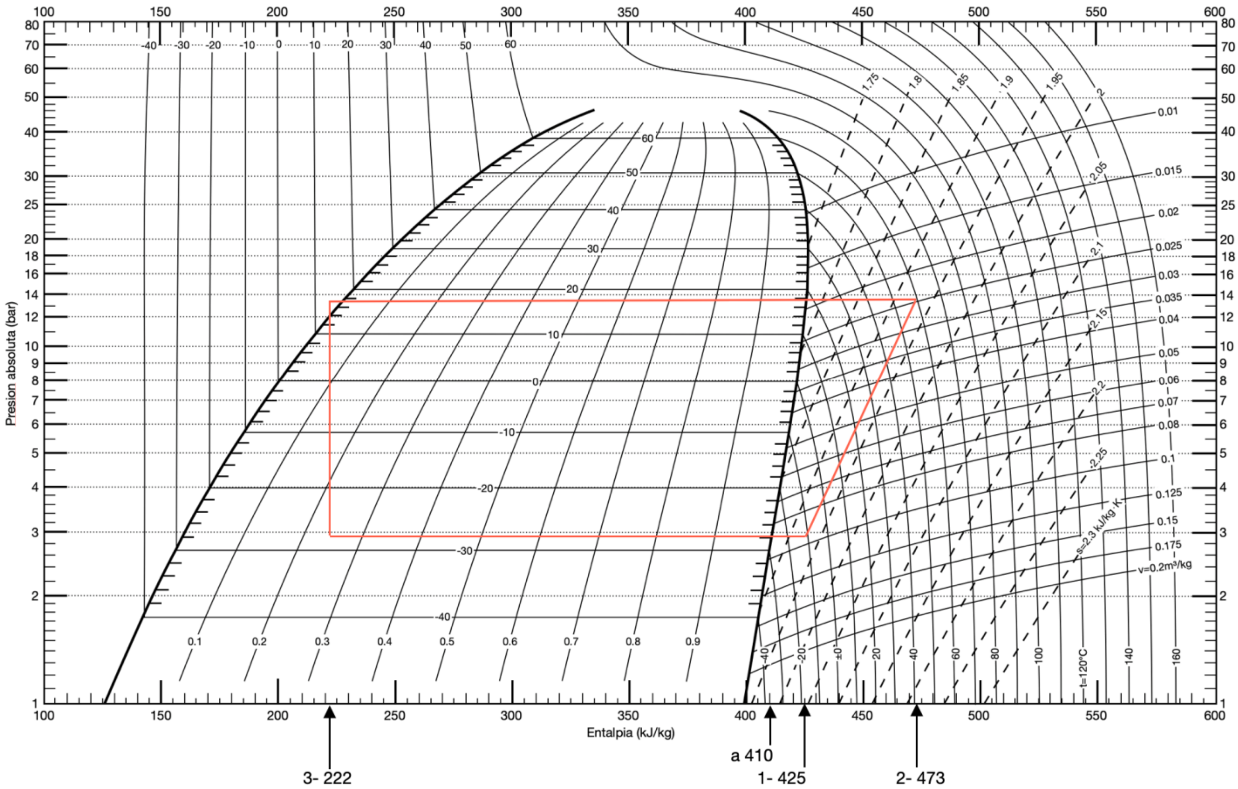

Figure 4. Refrigeration cycle diagram in logP-i coordinates at 0°C

10

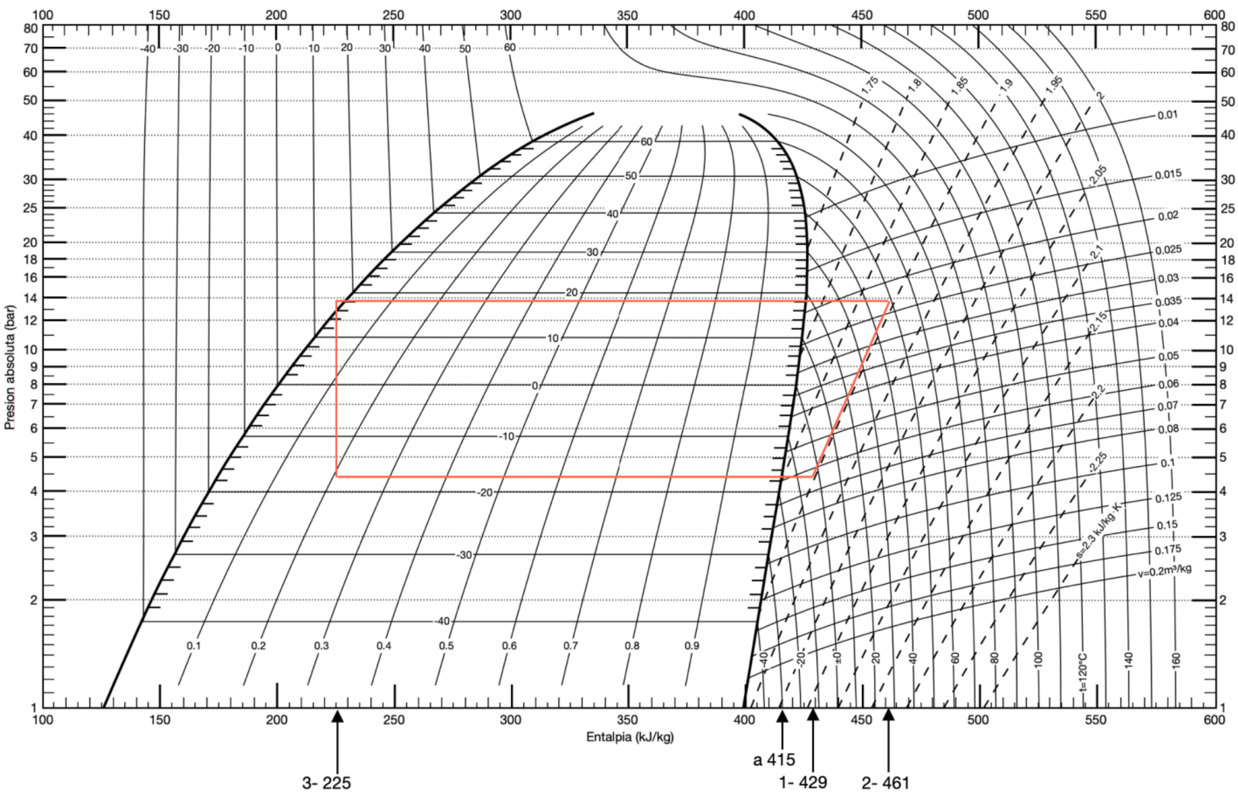

Figure 5. Refrigeration cycle diagram in logP-i coordinates at +10°C.

According to the results presented in the diagrams, the cooling capacity of the plant, the heat output in kJ/kg of refrigerant, the refrigerating coefficient and the transformation coefficient (COP) are calculated.

As the figures (3-5) show, the condenser operates at basically the same high pressure (12-14 bar), regardless of the air temperature during the test. The pressure at the evaporator block (low pressure area) increases with increasing temperature from 1.5 to 4.5 bar. Accordingly, the theoretical work of the refrigeration cycle decreases from 68 to 32 kJ/kg, which leads to an increase in the transformation ratio from 2.98 to 7.37 (figure 6).

Comparisons of real heat output and calculated one showed that refrigerant flow rate is 1.20...1.40 kg/s. Obtained data correspond to the real content of the refrigerant in the experimental heat pump unit.

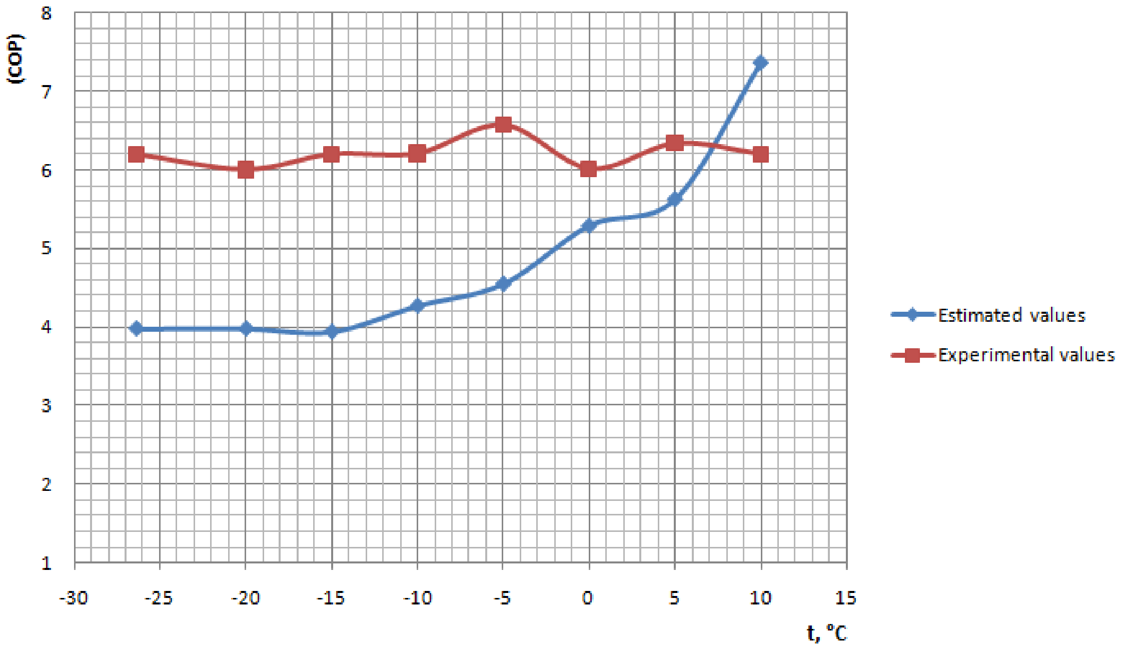

Figure 6. Dependence of the transformation coefficient of a heat pump unit (COP) on the out side temperature.

Figure 6 shows the temperature dependence of the calculated transformation coefficient and the one actually obtained in the test of the heat pump system with the MOVEBIT anti-icing system. The values of the calculated coefficient were obtained by processing the refrigeration cycle diagrams at the outside air temperatures in the evaporator circuit, given in the table.

The conversion factor of the refrigeration process was also calculated on the logP-i diagram for the refrigerant R-410a in the considered temperature range. It was found that with decreasing temperature, the coefficient decreases from 6.5 at +10℃ up to 4.0 at the temperature of -26.4℃.

This indicates that the operation of the heat pump unit at negative temperatures is possible only with use of an anti-icing system, but its efficiency can also be increased by inverter control of the compressor.

Conclusions

The heat pump air unit with the outdoor unit of the MOVEBIT anti-icing system has been developed. The unit was tested in laboratory and real conditions at various air temperatures in the heat-removing evaporative unit. The processing of the large amount of experimental data (more than 2,000) was carried out in the computer program. Tests have shown that the unit only works when the anti-icing system is used. Analysis of the data obtained showed that when the outside air drops to -27℃ the transformation ratio is 4…6, which corresponds to the operation of the heat pump at positive outdoor temperatures. The change in the outdoor temperature did not significantly affect the energy efficiency of the equipment under test. The data obtained showed that air source heat pumps with the outdoor unit of the MOVEBIT anti-icing system are able to effectively compete with geothermal heat pumps.

References

1. Department of Energy. Energy strategy of the Russian Federation for the period up to 2035 https://minenergo.gov.ru/node/10269. P. 1 – 20. (rus).

2. USA Corporate Sales Global Market Insights Inc kgufhttps://www.nachedeu.com/global-market-insights-inc-european-market-tep. P.5-20.

3. Report on the dynamics of the heat pump market from the IEA. https://www.iea.org/reports/heat-pumps. P.1-20.

4. Orlov P.A., Uvarov V.A., I1`ina T.N., Orlova V.A., Orlov K.P., Orlov S.P. The impact of the unit and use of geothermal heat pumps on the environment: Interuniversity International Congress. Higher School: Scientific Research. Moscow: Infiniti Publishing. 2020. 1. P. 136 – 147. (rus).

5. Orlov P.A., Il`ina T.N., and Orlov K.P. Promising methods of ice control of air heat pump evaporators. Journal of Physics: Conference Series. 2021.1926. 012017. https:// doi:10.1088/1742-6596/1926/1/012017

6. Patent for invention 2724661, the Russian Federation. The method of protection against icing of refrigeration and ventilation units. K.P. Orlov, application dated June 19, 2019, No. 2019119135. (rus).

7.Orlov P.A., Il`ina T.N., Orlov K.P. The impact of mechanical vibrations on the icing of air heat pumps. Bulletin of BSTU named after V. G. Shukhov. 2021. 6. P. 36 – 44. https://DOI:10.34031/2071-7318-2021-6-6-36-44. (rus).

8. Il`ina T.N., Orlov P.A., Chizhov A.V. Influence of material structure on the magnetostrictive properties of a radiator for defrosting heat exchangers of ventilation equipment. Constructions materials and productions. 2021. 4. P. 5 – 10.

9. Serikov S.V., Il`ina T.N.. Utilization of waste heat from the boiler plant in the air heating system. Bulletin of BSTU named after V.G. Shukhov. 2013. 4. P. 53 – 55. (rus).

10. Il`ina T.N., Belmaz, D.N. Analysis and methods of utilization of the secondary energy resources of an oil refinery. Bulletin of BSTU named after V.G. Shukhov. 2014. 3. P. 170 – 173. (rus).

11. Orlov P.A., Il`ina T.N., Kolesnikov M.S., Echina A.O. Integration of heat pumps in the heat supply of engineering systems. Proceedings of the Intern. scientific pract. conf "Energy in the modern world". 2021. Chita, FGBOU Zab GU.P. 88 – 92. (rus).

12. Kolesnikov M.S., Il`ina T.N., Orlov P.A. Modern methods of heat supply for buildings for various purposes. Proceedings of the Intern. scientific pract. conf "Energy in the modern world". 2021. Chita, FGBOU Zab GU. P. 106 – 110. (rus).

13. Il`ina T.N., Mukhamedov R.Yu., Verevkin O.V. Prospects for use of heat pumps in heating systems for low-rise residential buildings in the Belgorod region. Bulletin of BSTU named after V.G. Shukhov. 2009. 3. P. 142 – 146. (rus).

14. Power Quality in Power Systems and Electrical Machines. Authors: Ewald Fuchs, Mohammad A. S. Masoum Publisher: Academic Press; 1st edition (March 7, 2008). P. 150 – 165.

15.Dynamic Harmonic Mitigation and Power Factor Correction https://ieeexplore.ieee.org/document/4424144. P. 5 – 10.

Для цитирования: Orlov P.A.,Il`ina T.N., Orlov K.P. Test of heat pump unit with movebit anti-icing system // Строительные материалы и изделия. 2022. Том 5. № 2. С. 43 – 50. DOI: 10.58224/2618-7183-2022-5-2-43-50

For citation: Orlov P.A., Il`ina T.N., Orlov K.P. Test of heat pump unit with movebit anti-icing system. Construction Materials and Products. 2022. 5 (2). P. 43 – 50. DOI: 10.58224/2618-7183-2022-5-2-43-50

Поступила в редакцию 12 января 2022 г.
Принята в доработанном виде 10 марта 2022 г.
Одобрена для публикации 22 апреля 2022 г.

Received: January 12, 2022.
Revised: March 10, 2022.
Accepted: April 22, 2022