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Universal dependence for determining exergetic output-input ratio of air split-conditioner heat pump

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Today, in air conditioning and heating systems for small rooms of industrial, public, and residential buildings, the use of heat pumps of air split-conditioners is becoming more common. However, heat pumps of air split-conditioners are energy-intensive equipment, and, therefore, the need to increase their energy efficiency arises. It is important to reduce energy consumption during the refrigeration machines operating in the mode of heat pump in air split-conditioners, which is possible using a modern method of thermodynamics — *an exergetic one*. Exergetic analysis allows for establishing the maximum thermodynamic capabilities of the system, determining the losses of exergy in it, and substantiating recommendations for improving some of its elements. The exergetic method of analysis of the operation of one-stage steam-compressor freon heat pumps of air split-conditioners developed by the authors is used in this article. As a result, the universal dependence for determining the exergetic output-input ratio (OIR) for the air split-conditioner heat pump by "Mitsubishi Electric" with a heating capacity of 3200 W has been established, which makes it possible to select the parameters of its operation with the maximum exergetic OIR. The described algorithm for obtaining such a universal dependence can be used for heat pump air split-conditioner of any firm and any heating capacity.

Keywords: *heat pump of air split-conditioner, exergy balance, exergy efficiency, same internal temperature conditions, universal dependence for exergetic output-input ratio.*

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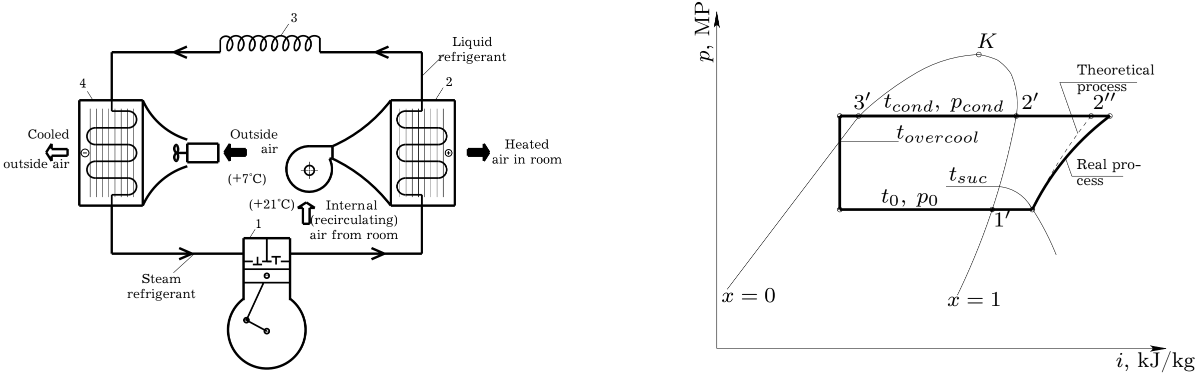
1. Introduction

Refrigeration machines that operate in the mode of a heat pump in local autonomous air conditioners need to reduce energy consumption improvement, which is possible using a modern method of thermodynamics — *the exergetic method* [1, 2].

Exergetic analysis allows for establishing the maximum thermodynamic capabilities of the system, determining the losses of exergy in it, and substantiating recommendations for improving some of its elements [3–12]. And for this, you need to study all aspects of the heat pump of local autonomous air conditioners thoroughly.

Therefore, the authors developed the exergetic method for analyzing the operation of one-stage steam-compressor freon heat pumps (*without efficient compressor cooling*) for local autonomous air conditioners, described in detail in [13–15]. This method uses the principle scheme of the heat pump, which is shown in Fig. 1*a*, and, accordingly, the construction of the processes of its work on the (p, i) diagram in Fig. 1*b* and the refrigerant freon-32 (R32) [16]. Computational and quantitative experiments were performed using a mathematical model developed by the authors using the computer program in Excel [13].



a ***b***

Fig. 1. Scheme of heat pump of air split-conditioner (***a***): 1 is compressor; 2 is condenser; 3 is capillary tube (throttle); 4 is evaporator and construction of the processes of its work on (p, i) diagram (***b***): 1, 2, 3, 4 are characteristic points of the thermodynamic cycle of the heat pump.

Therefore, based on the analysis of available literature data, the reduction of energy consumption consumed by heat pumps of air split-conditioners can be achieved by obtaining a universal dependence to determine the exergetic output-input-ratio (OIR) of heat pump of split-conditioner of any firm of a certain heat capacity, which will allow you to choose the parameters of its operation with the maximum exergetic efficiency.

2. Purpose and tasks of the investigation

The purpose of the work is to establish the universal dependence of the exergetic OIR of the heat pump of air split-conditioner on various factors that affect its operation. To do this, you need to identify:

- exergetic OIR of the heat pump of air split-conditioner of the company “Mitsubishi Electric”, for example with a heat capacity of 3200 W under various factors influencing its operation [13–15];
- analytical relationship between the exergetic OIR of the received heat pump of air split-conditioner and various factors that affect its operation.

3. Methods, materials and results of research

The exergetic analysis was performed for the “Mitsubishi Electric” air split-conditioner heat pump with the highest exergetic OIR, which was determined under the standard temperature conditions (standard refrigeration capacity $Q^{\mathrm{st}}_{\mathrm{heat}} = 3200\,\mathrm{W}$; standard power consumption $N^{\mathrm{st}}_{\mathrm{cons}} = 780\,\mathrm{W}$; standard evaporation of condensate $W^{\mathrm{st}}_{\mathrm{cond}} = 1.10\,\mathrm{l/h}$) [17].

To establish the universal dependence of exergetic OIR on various factors that affect its work, the following initial data were adopted:

- the ambient temperature (outside air) $t_{C_1} = +7\ldots-15^\circ\mathrm{C}$ (for standard process was accepted $t_{C_1} = 7^\circ\mathrm{C}$);
- the temperature of indoor (recirculation) air in the room was taken as constant $t_{H_1} = 21^\circ\mathrm{C}$ (for the standard process was also accepted $t_{H_1} = 21^\circ\mathrm{C}$);
- the air flow in the condenser $L_{\mathrm{cond}} = 300\ldots1000\,\mathrm{m^3/h}$ (for the standard process was accepted $L_{\mathrm{cond}} = 490\,\mathrm{m^3/h}$);
- the air flow rate in the evaporator $L_{\mathrm{ev}} = 500\ldots5000\,\mathrm{m^3/h}$ (for the standard process was accepted $L_{\mathrm{ev}} = 1020\,\mathrm{m^3/h}$);
- the final temperature difference in the condenser (condensing refrigerant and outside air at the outlet of the condenser) $\Delta t_{\mathrm{cond}} = 3.0\ldots5.0^\circ\mathrm{C}$ (for the standard process was accepted $\Delta t_{\mathrm{cond}} = 4.2^\circ\mathrm{C}$);

- the final temperature difference in the evaporator (internal air at the outlet of the evaporator and boiling refrigerant) $\Delta t_{\text{ev}} = 2.0\ldots4.0°\text{C}$ (for the standard process was accepted $\Delta t_{\text{ev}} = 2.8°\text{C}$);
- the difference of overcooling temperatures in the condenser $\Delta t_{\text{overcool}} = 3.0\ldots5.0°\text{C}$ (for the standard process was accepted $\Delta t_{\text{overcool}} = 5.0°\text{C}$);
- the difference of overheating temperatures in the evaporator $\Delta t_{\text{overheat}} = 5\ldots15°\text{C}$ (for the standard process was accepted $\Delta t_{\text{overheat}} = 10°\text{C}$);
- the electromechanical efficiency of the compressor $\eta_{\text{em}} = 0.70\ldots0.95$ (for the standard process was accepted $\eta_{em} = 0.9$);
- the adiabatic (indicator) compressor efficiency $\eta_{\text{ad}} = 0.70\ldots0.90$ (for the standard process was accepted $\eta_{\text{ad}} = 0.8$).

The following dependences for the exergetic OIR of the studied air split-conditioner on the indicated factors influencing its work were consistently obtained [13–15]:

$$\eta_{\text{e}} = 0.435 - 0.0088 \cdot t_{C_1}, \tag{1}$$

$$\eta_{\text{e}} = 0.3956 + 6.43 \cdot L_{\text{cond}}^{-1} - 36.42 \cdot L_{\text{ev}}^{-1}, \tag{2}$$

$$\eta_{\text{e}} = 0.4251 - 0.0074 \cdot \Delta t_{\text{cond}} - 0.0075 \cdot \Delta t_{\text{ev}}, \tag{3}$$

$$\eta_{\text{e}} = 0.361 + 0.0024 \cdot \Delta t_{\text{overcool}}, \tag{4}$$

$$\eta_{\text{e}} = -0.2982 + 0.4151 \cdot \eta_{\text{em}} + 0.372 \cdot \eta_{\text{i}} \tag{5}$$

and, finally, the universal dependence to determine exergetic efficiency:

$$\begin{aligned}\eta_{\text{e}} = {} & -0.0088 \cdot t_{C_1} + 6.43 \cdot L_{\text{cond}}^{-1} - 36.42 \cdot L_{\text{ev}}^{-1} - 0.0074 \cdot \Delta t_{\text{cond}} - 0.0075 \cdot \Delta t_{\text{ev}} \\ & + 0.0024 \cdot \Delta t_{\text{overcool}} + 0.4151 \cdot \eta_{\text{em}} + 0.372 \cdot \eta_{\text{i}} - 0.1739.\end{aligned} \tag{6}$$

Table 1. The results of the calculations exergetic OIR of air split-conditioner heat pump of the company "Mitsubishi Electric" with a heat capacity of 3200 W due to various factors influencing its operation.

t_{C_1}, °C	L_{cond}, m^3/h	L_{ev}, m^3/h	Δt_{cond}, °C	Δt_{ev}, °C	$\Delta t_{\text{overcool}}$, °C	$\Delta t_{\text{overheat}}$, °C	η_{em}	η_{i}	$\eta_{\text{e cons}}$	η_{e}	Δ, %
1	2	3	4	5	6	7	8	9	10	11	12
7	*490*	*1020*	*4.2*	*2.8*	*5*	*10*	*0.9*	*0.8*	*0.3730*	*0.373*	*0*
8	490	1020	4.2	2.8	5	10	0.9	0.8	0.3642	0.363	−0.3
−15	490	1020	4.2	2.8	5	10	0.9	0.8	0.5666	0.567	0.1
7	**300**	1020	4.2	2.8	5	10	0.9	0.8	0.3814	0.378	−0.9
7	**1000**	1020	4.2	2.8	5	10	0.9	0.8	0.3664	0.363	−0.9
7	490	**500**	4.2	2.8	5	10	0.9	0.8	0.3359	0.339	0.9
7	490	**5000**	4.2	2.8	5	10	0.9	0.8	0.4015	0.405	0.9
7	490	1020	**3.0**	2.8	5	10	0.9	0.8	0.3819	0.382	0
7	490	1020	**5.0**	2.8	5	10	0.9	0.8	0.3671	0.367	0
7	490	1020	4.2	**2.0**	5	10	0.9	0.8	0.3790	0.379	0
7	490	1020	4.2	**4.0**	5	10	0.9	0.8	0.3640	0.364	0
7	490	1020	4.2	2.8	**3**	10	0.9	0.8	0.3680	0.368	0
7	49	1020	4.2	2.8	**5**	**5**	0.9	0.8	0.3730	0.373	0
7	49	1020	4.2	2.8	5	**15**	0.9	0.8	0.3730	0.373	0
7	490	1020	4.2	2.8	5	10	**0.70**	0.8	0.2900	0.290	0
7	490	1020	4.2	2.8	5	10	**0.95**	0.8	0.3938	0.394	0.1
7	490	1020	4.2	2.8	5	10	0.9	**0.70**	0.3358	0.336	0.1
7	490	1020	4.2	2.8	5	10	0.9	**0.90**	0.4102	0.410	0
7	**350**	**2500**	**3.0**	**2.0**	**5**	**10**	**0.95**		**0.4723**	**0.479**	**1.4**

The results of the calculation of exergetic OIR according to the universal formula (6) $\eta_{\text{e calc}}$ and the actual η_{e} and relative error Δ are given in Table 1 (in *italics* marked technical characteristics of the air conditioner in the standard process, **bold** is for the proposed).

4. Conclusions

Analyzing the obtained universal dependence (6) and the data in Table 1, we can draw the following conclusions. The air flow in its evaporator L_{ev} has the greatest influence on the exergetic OIR of the heat pump of the air split-conditioner η_{e}, and the difference in overheating temperatures in its evaporator $\Delta t_{\mathrm{overheat}}$ does not affect the exergetic OIR at all. The universal relationship between the exergetic OIR of the heat pump of the air split-conditioner and various factors (6) makes it possible to install it quickly and correctly with a maximum error of up to 1.4%. The proposed process of using the heat pump of the air split-conditioner is quite energy-efficient because it leads to an increase in its exergetic OIR by $(0.479 - 0.373) \cdot 100/0.373 = 28.4\%$.

Reduction of energy consumption by heat pumps of air split-conditioners can be achieved by obtaining a universal dependence for determining the exergetic OIR of the air split-conditioner heat pump of any company of a certain heat capacity, which will allow choosing the parameters of its operation with maximum exergetic OIR.

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Універсальна залежність для визначення ексергетичного ККД теплової помпи split-кондиціонера

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Сьогодні у системах кондиціювання та опалення невеликих приміщень промислових, громадських та житлових об'єктів використання теплових помп (ТП) повітряних split-кондиціонерів стає все розповсюдженішим. Але теплові помпи повітряних split-кондиціонерів належать до енергоємного обладнання, а тому потребують підвищення їх енергоефективності. Тому стає актуальним зменшення енергозатрат під час експлуатації холодильних машин, які працюють в режимі теплової помпи в split-кондиціонерах, що можливе з використанням сучасного методу термодинаміки — *ексергетичного*. Ексергетичний аналіз дозволяє встановити максимальні термодинамічні можливості системи, визначити втрати ексергії в ній та обґрунтувати рекомендації з вдосконалення окремих її елементів. Для цієї статті використано розроблений авторами ексергетичний метод аналізу роботи одноступеневих хладонових теплових помп split-кондиціонерів. У результаті встановлено універсальну залежність для визначення ексергетичного ККД теплової помпи split-кондиціонера фірми "Mitsubishi Electric" теплопродуктивністю 3200 Вт, яка дає можливість підібрати параметри її роботи з максимальним ексергетичним ККД. Описаний алгоритм отримання такої універсальної залежності можна використати для теплової помпи split-кондиціонера будь-якої фірми та будь-якої теплопродуктивності.

Ключові слова: *теплова помпа, split-кондиціонера, ексергетичний баланс, ексергетична ефективність, універсальна залежність для ексергетичного ККД.*