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COMPARISON OF HEAT SUPPLY SYSTEM EFFICIENCY FROM HEATING BOILER AND HEAT PUMP PLANTS

There had been conducted the comparison exergetic analysis of operation efficiency of heat supply system from boiler house and steam compressor heat pump plants.

Key words: *boiler, heat net, heating device, heat pump, evaporator, condenser.*

Introduction

Today with constant increase in price on organic fuel, the economy on fuel and energy resources is of priority significance. Following the statistic data, heat supply consumes 91 mln.tons of equivalent fuel. At the same time, production of electricity consumes only 33 mln. tons. In view of this, it becomes obvious that the main attention in solution the problem of efficiency in using fuel resources has to be paid to heat supply sector.

One of the priority methods in fuel economy and environmental protection is the use of low temperature energy source. The developed countries pay much attention to criteria and implementation of heat pump plants (HPP) which are designed for heating, heat water supply, drying etc [1, 2]. There is an experience in using HPP in the systems of central heating by creation of heat pump stations [3]. One of the significant factor is the HPP universality which means that they may be used as heater and coolers at the same time, transferring heat exhausters into the conditioned thermal energy, heating the heat carrier теплоносій up to the temperature, acceptable for heat supply.

Many foreign and native specialists consider HPP to take the main place in low temperature heat supply systems. Introduction of HPP into the thermal balance of the country allows not only to save the losses of initial energy resources for producing heat but also to decrease the environmental pollution. Unfortunately, in Ukraine there is no definite scale and spheres for HPP efficient use. Papers [4 – 6 and others] present controversial data as for the evaluation of efficiency in using HPP in the heat supply systems. The analysis shows that these differences may be explained by different conditions of experiments, in particular, temperatures in heat bearers in evaporator and in condensator of heat and pump plant, different methods for processing experimental data and different thermal and physical peculiarities of working bodies. The above sets the task to compare the efficiency of heat supply systems from boiler houses and heat and data pump plants.

Main results

It is known [7], that the power efficiency in operation of heating plants is evaluated by values of specific consumption of fuel equivalent for producing the unit of energy (b_c, kg/GJ). If the production of thermal energy is made by boiler the specific consumption of fuel equivalent makes up

$$b_c^{wb} = 1/(\eta_к \cdot Q_н^p), \qquad (1)$$

where $\eta_к$ – energetic factor of efficiency of the boiler; $Q_н^p$ - bottom heat of burning of equivalent fuel, which equals $29.3 \cdot 10^{-3}$ GJ/kg.

HPP, producing thermal energy, consumes electric power, which equals the consumed capacity of the compressor drive N. It is clear that the equivalent consumption of equivalent fuel, used for production of electric energy with he capacity N is the power network makes up

$$B_c = N/(\eta_{es} \cdot \eta_{en} \cdot Q_н^p), \qquad (2)$$

where η_{es} – average efficiency of electric power station netto; η_{en} – electric efficiency.

Then the specific consumption of equivalent fuel for the unit of the produced thermal energy in

HPP equals

$$b_c^{TPU} = 1/(\varphi \cdot \eta_{ec} \cdot \eta_{eg} \cdot Q_н^р), \quad (3)$$

where $\varphi = Q/N$ - factor of energy transformation in HPP (heating factor); Q – produced thermal energy.

Fig. 1 presents the calculating values of the specific consumption of equivalent fuel in boiler (line 1) and in heat and pump plant (line 2) following the data: $\eta_к$ = 0.9; η_{es} = 0.34; η_{eg} = 0.9. Fig. 1 shows that under the specific conditions the specific consumption of equivalent fuel by HPP becomes significantly lower that in the boiler.

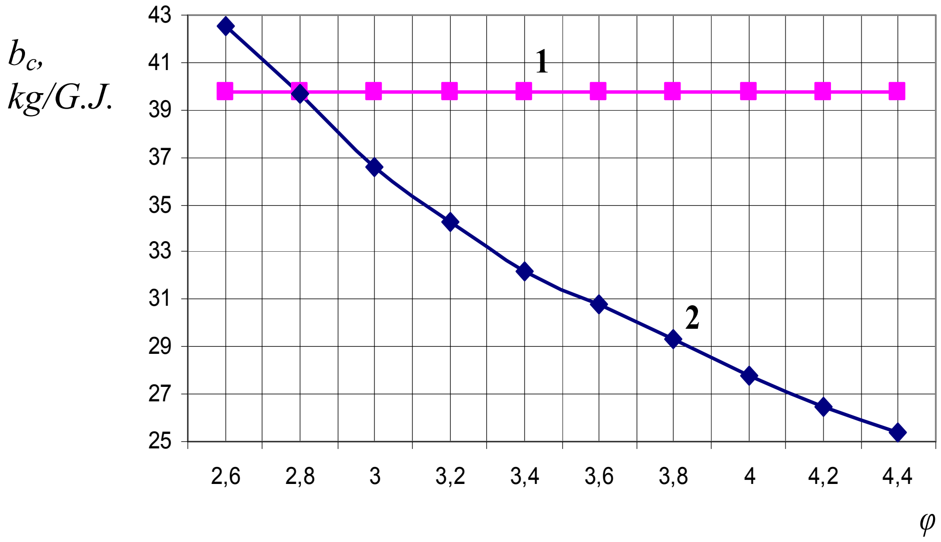

Fig. 1. Current values b_c

It is also known [8], that the perfection of thermal processes and plants is expedient to evaluate on the exergetic efficiency factor η_{ex}. Deviation η_{ex} from the maximum value (η_{ex} = 1) is the measure of irreversible losses of energy, which may be removed in case of rational execution of technological processes. The values of exergetic efficiency depend on the exergetic temperature function (Karno factor), which equals

$$\eta_c = 1 - T_0 / T_{av}, \quad (4)$$

where T_0 – absolute temperature of environment; $T_{av} = (h_2 - h_1)/(s_2 - s_1)$ - medium thermodynamic temperature of heat input and output; $(h_2 - h_1)$ -change in enthalpy in the process of heat exchange; $(s_2 - s_1)$ - change of enthalpy in thermal process.

The [9] reveals the ambiguous character of changing the exergetic efficiency of heat and pump plants depending on medium thermal-dynamic temperatures of heat input and output. The meanings of Karno factors for different values T_0 and T_{av} are presented in Table 1.

Table 1

Values of Karno factors

T_{av}, K	Temperature of environment, K							
	248	253	258	263	273	278	283	288
293	0.1535	0.1365	0.1194	0.1023	0.0853	0.0682	0.0512	0.0341
298	0.1677	0.1500	0.1342	0.1174	0.1006	0.0839	0.0671	0.0533
303	0.1815	0.1650	0.1485	0.1320	0.1155	0.0990	0.0825	0.0661
308	0.1948	0.1785	0.1623	0.1461	0.1298	0.1136	0.0974	0.0811
313	0.2070	0.1917	0.1757	0.1597	0.1437	0.1278	0.1118	0.0958
318	0.2201	0.2044	0.1886	0.1729	0.1572	0.1415	0.1257	0.1100
323	0.2322	0.2167	0.2012	0.1857	0.1702	0.1548	0.1393	0.1238
328	0.2439	0.2286	0.2134	0.1982	0.1829	0.1676	0.1524	0.1372

333	0.2552	0.2402	0.2252	0.2102	0.1952	0.1802	0.1615	0.1501
338	0.2662	0.2514	0.2366	0.2219	0.2071	0.1923	0.1775	0.1627
343	0.2769	0.2624	0.2478	0.2332	0.2186	0.2041	0.1895	0.1749
348	0.2873	0.2729	0.2586	0.2442	0.2298	0.2155	0.2011	0.1867
353	0.2974	0.2832	0.2691	0.2550	0.2407	0.2256	0.2154	0.1983
358	0.3072	0.2933	0.2793	0.2653	0.2514	0.2374	0.2234	0.2095
363	0.3168	0.3030	0.2892	0.2754	0.2617	0.2479	0.2341	0.2204
368	0.3261	0.3125	0.2989	0.2853	0.2717	0.2581	0.2445	0.2309
373	0.3351	0.3217	0.3083	0.2949	0.2817	0.2681	0.2546	0.2413
378	0.3439	0.3306	0.3174	0.3042	0.2910	0.2777	0.2645	0.2513
383	0.3524	0.3394	0.3263	0.3133	0.3002	0.2872	0.2741	0.2611

Heat supply system includes: boiler or thermal pump, heat and electric nets, heating devices. Let us first determine the exergetic efficiency of boiler and thermal pump. In accordance with [8] the exergetic efficiency of boiler is determined according with the formula

$$\eta_{ex}^{\kappa} = (Q_{н}^{p} / e_{xe}) \cdot \eta_{\kappa} \cdot \eta_{c}^{\kappa}, \tag{5}$$

where e_{xe} – exergy of fuel; η_{κ} – exergy efficiency of boiler; η_{c}^{κ} – Karno factor, determined according to (4) for average thermodynamic temperature of heat bearer (net water) in boiler.

The first cofactor in (5) when boiling gas like or flued fuel equals, as rule, 0.94 – 0.97 [8]. Fig. 2 presents dependences of change in exergetic boiler efficiency for different temperature modes of net operation under condition $(Q_{n}^{p} / e_{xe}) = 0.95$ and $\eta_{\kappa} = 0.9$.

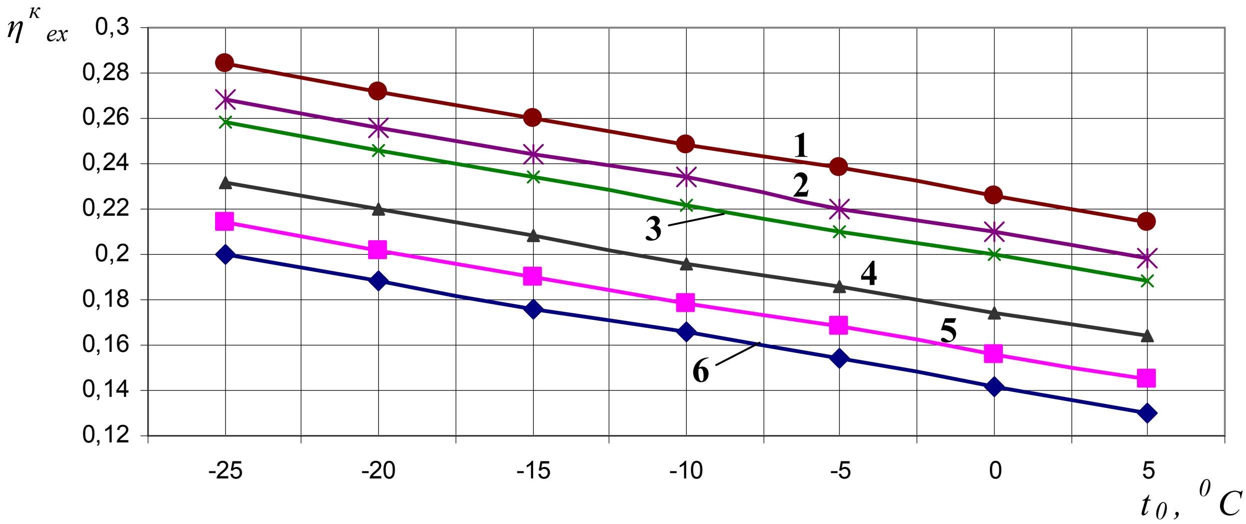

Fig. 2. Values of boiler exergetic efficiency: 1 – t_{dnw} / t_{rnw} = 130/70, ^{0}C; 2 – 120/60; 3 – 100/60; 4 – 90/50; 5 – 80/40, 6 – 70/40; t_{dnw} *i* t_{rnw} – temperature of direct and reverse net water correspondingly

Fig. 2 shows that the value of exergetic boiler efficiency increases when the temperature of environment decreases and the temperature mode of net water heating increases. The exergetic losses in boiler make up from 70% to 80%. These losses are possible to decrease at the cost of increasing the medium thermodynamic temperature of supplying heat to the net water.

The exergetic efficiency of thermal pump is calculated according to the formula

$$\eta_{ex}^{tp} = E_{XQ} / N = Q \cdot \eta_{c}^{c} / N = \varphi \cdot \eta_{c}^{c}, \tag{6}$$

where E_{XQ} – exergy of heat; $\eta_{c}^{кн}$ – Karno factor for medium thermodynamic temperature of net water in condenser of thermal pump.

In [9] states that the factors of energy transformation φ depend on medium thermodynamic temparatures of heat carriers in the process of heat supply in evaporator T_{av}^{e} and heat discharge, in condenser T_{av}^{c} as well as heat physical peculiarities of working bodies in heat and pump plant (freon). The calculating values φ for steam compression of heat and pump plant are presented in

Fig. 3. These dependences testify that These dependences testify that the values φ increase when temperature T_{av}^{e} increases and temperature T_{av}^{c} decreases.

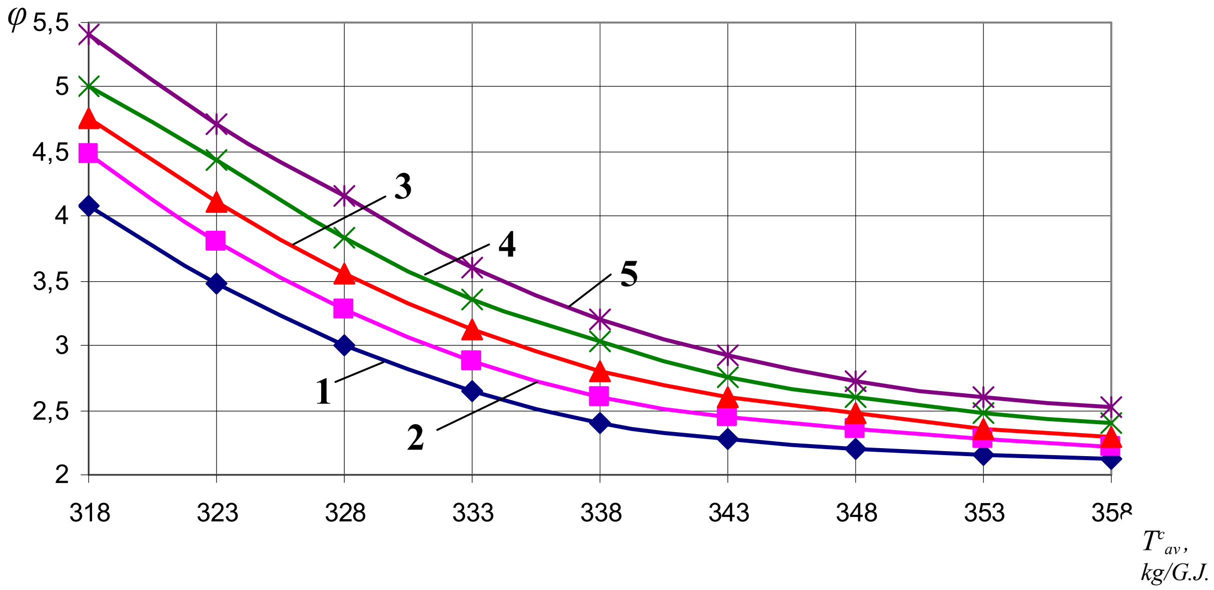

Fig. 3. Values φ: 1 - T_{av}^{e} = 278 K; 2 – 283; 3 – 288; 4 – 293; 5 - 298

Heating devices (radiators) are recuperatives thermal exchanging devices which emit heat in the room with temperature t_r. If we neglect the exergetic losses on friction of heating carrier in radiator, than the exergetic efficiency of the latter will equal [10]

$$\eta_{ex}^{R} = (1 - T_0 / T_r)/(1 - T_0 / T_{av}^{R}) = \eta_c^{r} / \eta_c^{R}, \qquad (7)$$

where T_{av}^{R} – medium thermodynamic temperature of heat carrier (net water) in radiator; T_r – absolute temperature in the room.

Fig. 4 presents the calculating values of exergetic efficiency of heating devices under condition: $t_r = 20\ ^0C$. It is seen that the higher the η_{wb}^{R} the lower the temperature t_0 and T_{av}^{R}.

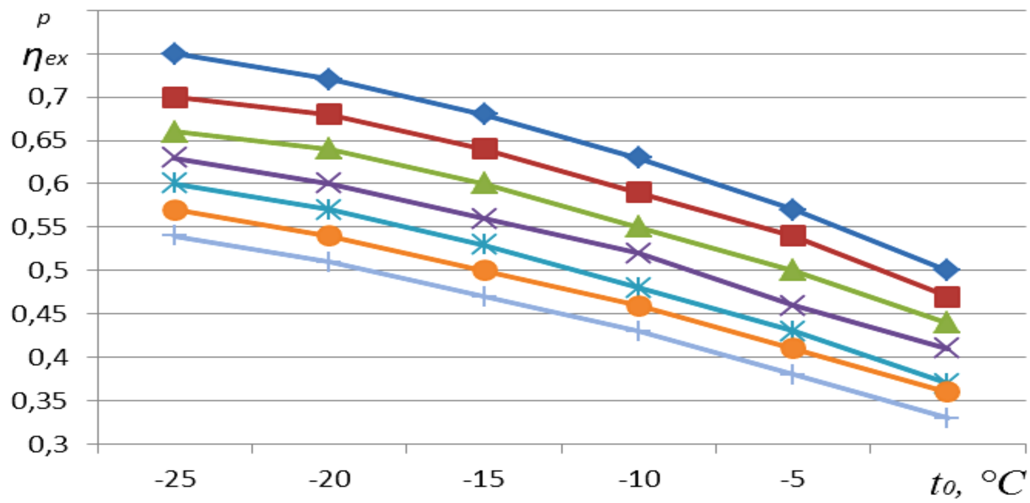

Fig. 4. Dependences $\eta_{ex}^{p} = f(t_0)$: 1 - T_{av}^{r} = 313 K; 2 – 318; 3 – 323; 4 – 328; 5 – 333; 6 – 338; 7 – 343

It is clear that the operating efficiency of heat supply systems and boilers with heat and pump plants may be compared under conditions: equal thermal capacity, equal temperature modes of operating and heating devices. Considering the above, the formulas for the comparison as for exergetic efficiency of these heat supply systems will look like:

$$\eta_{ex}^{wb} = \eta_{ex}^{b} \cdot \eta_{ex}^{R}, \quad (8)$$

$$\eta_{ex}^{HPU} = \eta_{ex}^{HP} \cdot \eta_{ex}^{R}, \quad (9)$$

where values η_{ex}^{b}, η_{ex}^{HP}, η_{ex}^{R} are determined according to (5), (6) and (7) accordingly. According to the correlations (8) and (9) for an example there had been built the calculation dependences of exergic efficiency in heat supply systems, which are shown in Fig. 5 and 6.

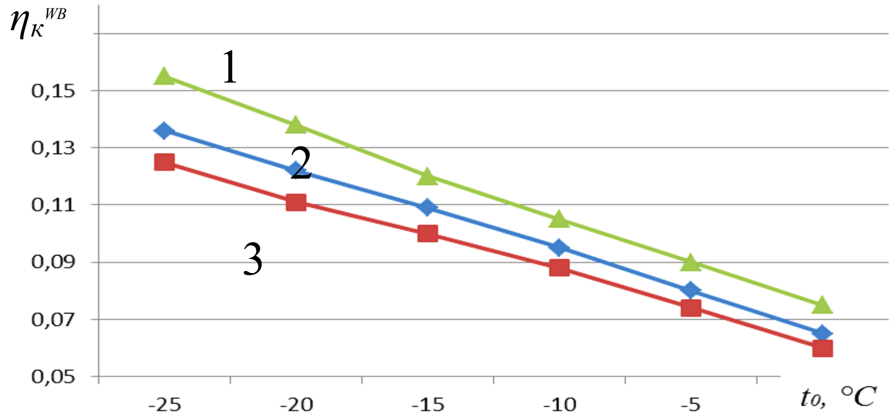

Fig. 5. Values of exergic efficiency in heat supply systems from water-heating boiler plant: 1 – η_b = 0.9, T_{av}^{R} = 328 K; 2 – η_b = 0,85, T_{av}^{R} = 328 K; 3 – η_b = 0.9, T_{av}^{R} = 318 K

Fig. 5 shows, that the exergic efficiency of heat supply system from water-heating boiler plant increases with the decrease in temperature of the environment, medium- thermodynamic temperature of heat extraction from the heating device and increase the energetic efficiency of the boiler. Temperature decrease T_{av}^{R} by 10° C increases the exergic efficiency by 11.25%. Approximately by the same values increases η_{ex}^{wb} under condition T_{av}^{R} = const with the increase of the efficiency of the boiler. by 10 %.

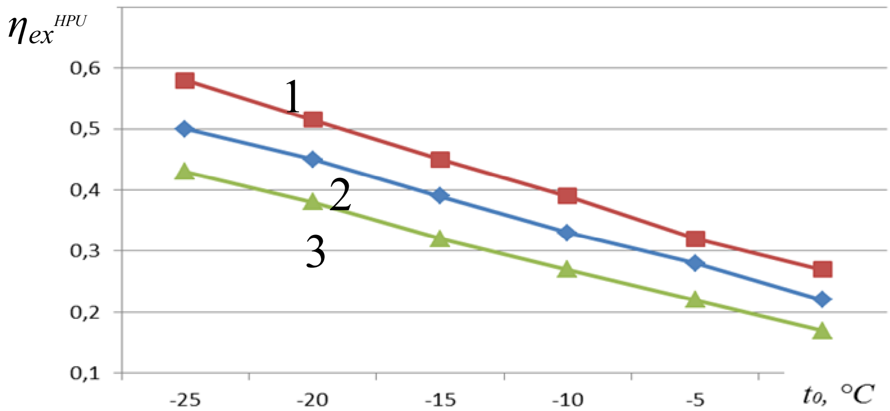

Fig. 6. Exergic efficiency of heat supply system from heat pump system: 1 – φ = 3, T_{av}^{R} = 328 K; 2 – φ = 3,5, T_{av}^{R} = 328 K; 3 – φ = 3, T_{av}^{R} = 338 K

Fig. 6 presents the dependences in changing the exergic efficiency of heat supply system from heat pump system.

Comparing the dependences, presented in Fig. 5 and 6, we see that the values of exergic efficiencies for heat supply system from heat pump unit is 3 – 3.5 times higher than the values of exergic efficiency for heat supply system from boilers. The values of exergic efficiency in Fig. 6 increase with the decrease in temperature t_0 and T_{av}^{R} and with the increase in coefficients of energy transformation φ. Thus, with the increase of φ by 0,.5 the values of the exergic efficiency increase on average by 11.3 %. The exergic efficiency increases by the same value with the decrease of the temperature T_{av}^{R} by 10° C. It is seen (see Fig. 1), that with the increase of φ from 3 to 3.5 the discharge intensity of the conventional fuel for the production of energy b_c also decreases by 11.3 %. This means that the value b_c adequately evaluates the operating efficiency of heat-and-power systems and plants, heat pump system in particular.

Despite some advantages of the heat supply system from heat pump systems in comparison with heat supply systems from boilers, it should be noted that the investment on heat pump systems increase sufficiently. Using the heat pump systems in heat supply systems is expedient with the availability of low-temperature heat source with relatively high temperature of dump coolant and high fuel prices. The expediency of using heat pump systems in each specific case may be determined on the base of engineering economic analysis.

Conclusions

1. The efficient operation of heat supply system from heat pump unit, in comparison with heat supply system from boilers takes place when the energy conversion ratio in heat pump system exceeds 2.9.
2. Temperature of the environment influences the operation efficiency of heat supply systems. Its decrease causes the increase in exergic efficiency factors.
3. The increase in energy transformation factor in heat pump systems is achieved with the increase in coolant temperature in evaporator and the decrease in temperature of heat abstraction from the condenser.
4. The value of the energy rate adequately characterizes the energy efficiency of heat supply system operation.

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