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## **STUDY OF VARIABLE OPERATION MODES ENERGY ECONOMIC EFFICIENCY OF ENERGY SUPPLY SYSTEMS WITH COGENERATION HEAT PUMP INSTALLATIONS, USING THE HEAT OF THE INDUSTRIAL AND NATURAL SOURCES**

*The results of the research of energy economic efficiency of variable operation modes of energy supply systems (ESS) with peak sources of heat (PSH) and cogeneration heat pump installations (CHPI), using the heat of the industrial and natural sources are presented in the given research, they enable to provide the substantiated determination of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with the combined seasonal usage of low-temperature heat of industrial and natural sources. We suggest the results of the research on the example of ESS with CHPI and PSH for thermal scheme of the health resort boiler house. In our study the application of energy efficient and economically expedient variant of energy supply system with CHPI, based on steam-compressor heat pumps and gas-piston engines-generators (GPE) was suggested in order to improve the operating indices of the thermal scheme of the health resort boiler house. In the study the combined seasonal usage of the boiler house waste flue gases heat in CHPI was foreseen with the usage of utilization equipment as well as the natural heat of the surface waters. It is determined that under the conditions of variable operation modes of ESS with CHPI and combined seasonal usage of the heat of the industrial and natural sources in CHPI, the most efficient by energy, economic and technical indices is the variant of ESS with CHPI application in the thermal scheme of the health resort boiler house with the utilization of 50% of the thermal power of the boiler house waste f gases in utilization equipment and CHPI. If this variant of ESS with CHPI and PSH is used, then energy efficient and economically substantiated operation modes of ESS with combined seasonal usage of low-temperature heat of the industrial and natural sources will be provided. The approach, suggested in the given paper, concerning the study of energy economic efficiency of variable operation modes of ESS with PSH and CHPI, using low-temperature heat of the industrial and natural sources, enabled to provide the substantiated definition of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with the combined seasonal usage of low-temperature heat of the industrial and natural sources.*

**Key words:** energy efficiency, economic efficiency, energy supply system, cogeneration heat pump installation, peak source of heat, variable operation modes, industrial and natural sources of low-temperature heat.

### **Introduction**

Energy supply systems (ESS) with cogeneration heat pump installations (CHPI) and peak sources of heat (PSH) provide high indices of energy conversion efficiency in ESS elements that makes them two times more efficient than the conventional sources of energy supply. Numerous papers consider the problems of energy efficient ESS with CHPI [1 – 9], these papers prove high energy and economic efficiency of the above-mentioned ESS.

**Aim of the research** is the study of energy economic efficiency of variable operation modes of energy supply systems with peak sources of heat and cogeneration heat pump installations, using low-temperature heat of industrial and natural sources, that will enable to provide the substantiated determination of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with combined seasonal usage of low-temperature heat of the industrial and natural sources.

### **Main part**

Energy and economic efficiency of heat pump plants, using natural and industrial sources of low-

temperature heat, on conditions of variable operation modes, is analyzed in [10 – 12]. Our research is aimed at determination of energy efficient and economically substantiated operation modes of ESS with CHPI and PSH with combined seasonal usage of low-temperature heat of the industrial and natural sources.

We suggest the results of the research on the example of ESS with CHPI and PSH for thermal scheme of the boiler house of the health resort. The aim of our research [13] was to carry out technical economic substantiation of energy efficient ESS with CHPI application in the thermal scheme of the health resort boiler house on the base of the results, obtained in the research [14]. Gas-fired hot water boiler house is the source of the health resort heat supply; this boiler house provides the needs of the technological consumers as well as the consumers of the heating and hot water in the health resort. In the studies [13 – 14] the application of energy efficient and economically expedient variant of energy supply system with CHPI, based on steam-compressor heat pumps and gas-piston engines-generators (GPE) was suggested in order to improve the operating indices of the thermal scheme of the health resort boiler house. The operating hot water boiler house of the health resort is planned to use as the peak source of heat in ESS with CHPI. In studies [13 – 14] the combined seasonal usage of the boiler house fuel gases heat in CHPI was foreseen with the usage of utilization equipment as well as the natural heat of the surface waters. Technical economic substantiation of the energy efficient ESS with CHPI usage in the thermal scheme of the health resort boiler house in [13] is performed on the base of studies [1 – 12] results and methodical fundamentals of the assessment of energy and economic efficiency of ESS with CHPI from the studies [1 – 2, 15 – 22].

In our paper, proceeding from the results, obtained in [13], the study of energy-economic efficiency of variable operation modes of ESS with CHPI with combined seasonal usage of waste fuel gases heat of the boiler house and natural heat of the surface waters in CHPI for the thermal scheme of the health resort boiler house. Four variants of ESS with CHPI application in the thermal scheme with following indices of utilization of thermal power of waste fuel gases of the health resort boiler house in utilization equipment and CHPI for the first and the second seasons of the boiler house operation were considered: 1 – 100%; 2 – 75%; 3 – 50%; 4 – 25%. In the third season the usage of natural heat of the surface waters on ESS with CHPI without PSH operating were considered.

The results of the research carried out of energy economic efficiency of variable operation modes of ESS with CHPI with the combined seasonal usage in CHPI of the boiler house waste flue gases heat and natural heat of the surface waters are generalizes in Table 1, were the variants of utilization of the heat power of waste fuel gases of the boiler house in utilization equipment and CHPI are shown: 1 – 100%; 2 – 75%; 3 – 50%; 4 – 25%.

It can be determined from Table 1, that the economy of working fuel by the boiler house in case of usage ESS with CHPI is observed for all the studied variants of application and operation modes of ESS with CHPI with combined seasonal usage in CHPI the heat of industrial and natural sources. The greatest values of seasonal and annual economy of working fuel, in case of using ESS with CHPI in the thermal scheme of the health resort boiler house, will be provided in case of utilization of 100% of the thermal power of the boiler house waste fuel gases in utilization equipment and CHPI. It is seen from Table 1, that the value of the seasonal and annual economy of the working fuel, in case of usage ESS with CHPI in the thermal scheme of the health resort boiler house, will decrease with the decrease of the share of utilization of the thermal power of the waste fuel gases of the boiler house in the utilization equipment and CHPI. In the same way annual cost economy by the boiler house with ESS with CHPI will decrease in case of the decrease of the share of utilization of the thermal power of the boiler house waste fuel gases in utilization equipment and CHPI. Besides, as it is seen from Table 1, the increase of the utilization share of thermal power of the boiler house waste fuel gases in utilization equipment and CHPI stipulates the decrease of boiler house waste fuel gases temperature.

Proceeding from the analysis of the results obtained, it is determined that on conditions of variable operation modes of ESS with CHPI and combined seasonal usage in CHPI the heat of industrial and

natural sources, the variant of using ESS with CHPI in the thermal scheme of the health resort boiler house with 50% utilization of the thermal power of boiler waste fuel gases in utilization equipment and CHPI is the most efficient according to energy, economic and technical indices. If this variant of ESS with CHPI and PSH is realized, energy efficient and economically substantiated operation modes of the above-mentioned ESS with the combined seasonal usage of low-temperature heat of the industrial and natural sources will be provided: the temperature of the waste fuel gases of the boiler house will be 112,8 °C, seasonal economy of the working fuel by the boiler house with ESS and CHPI will vary within the range 10,59...15,43%, annual economy of the working fuel by the boiler house with ESS and CHPI will be 13,64%. For this variant of ESS with CHPI application in the thermal scheme of the health resort boiler house the economy of natural gas will be 593,18 thous. m<sup>3</sup>/yr. and the boiler house will save 5,74 mil. Hrs./yr.

Table 1

**Indices of energy economic efficiency of variable operation modes of ESS with CHPI with combined seasonal application in CHPI of boiler house waste fuel gases heat and natural heat of surface waters**

Index	Application variant											
	1			2			3			4		
	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3
Thermal power of the contact utilization equipment of the heat of boiler house waste fuel gases, kW	1698	1444	---	1346	1146	---	865	737	---	507	427	---
Heat power of CHPI condenser, kW	2252	1916	978	1786	1520	978	1147	977	978	673	566	978
Power of CHPI compressor, kW	554	472	380	440	374	380	282	240	380	166	139	380
Heat power of heat utilization equipment of GPE, kW	765	650	523	606	515	523	389	331	523	228	192	523
General heat power of CHPI, kW	3017	2566	1501	2392	2035	1501	1536	1308	1501	901	758	1501
Temperature of the boiler house waste fuel gases in case of ESS with CHPI application, °C	55	55	---	81,3	81,3	---	112,8	112,8	---	133,8	133,8	---
Economy of the working fuel by the boiler house if ESS with CHPI is used, %	21,20	22,19	15,43	16,73	17,79	15,43	10,59	11,76	15,43	6,05	7,18	15,43

Annual economy of the working fuel by the boiler house if ESS with CHPI is used, %	18,73	16,58	13,64	11,4
Economy of the working fuel by the boiler house if ESS with CHPI is used, thous. m <sup>3</sup> /yr	898,70	769,75	593,18	459,20
Boiler house cost saving if ESS with CHPI is used, mil. Hrs/yr	8,69	7,44	5,74	4,44

The approach, suggested in the given paper, is developed on the base of the results, obtained in [1 – 22], in the process of the research, aimed at studying of energy economic efficiency of variable operation modes of ESS with PSH and CHPI, using low-temperature heat of the industrial and natural sources, enabled to provide the substantiated determination of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with the combined seasonal usage of low-temperature heat of the industrial and natural sources.

### Conclusions

The paper presents the results of the research, dealing with the study of energy economic efficiency of variable operation modes of energy supply systems with peak sources of heat and cogeneration heat pump installations, using low-temperature heat of the industrial and natural sources, aimed at the determination of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with combined seasonal usage of low-temperature heat of the industrial and natural sources.

The results of the research on the example of ESS with CHPI and PSH for the thermal scheme of the health resort boiler house are presented. It is determined that under the conditions of variable operation modes of ESS with CHPI and combined seasonal usage of the heat of the industrial and natural sources in CHPI, the most efficient by energy, economic and technical indices is the variant of ESS with CHPI application in the thermal scheme of the health resort boiler house with the utilization of 50% of the thermal power of the boiler house waste fuel gases in utilization equipment and CHPI. If this variant of ESS with CHPI and PSH is used, then energy efficient and economically substantiated operation modes of ESS with combined seasonal usage of low-temperature heat of the industrial and natural sources will be provided: temperature of the waste fuel gases of the boiler house will be 112,8 °C, seasonal economy of the working fuel by the boiler house with ESS and CHPI will vary within the limits 10,59...15,43%, annual economy of the working fuel by the boiler house with ESS and CHPI will be 13,64%. For this variant of ESS with CHPI application in the thermal scheme of the health resort boiler house the economy of natural gas will be 593,18 thous. m<sup>3</sup>/yr. and cost economy by the boiler house will be 5,74 mil. Hrs./yr.

The approach, suggested in the given paper, is developed on the base the results, obtained in the research [1 – 22], concerning the study of energy economic efficiency of variable operation modes of ESS with PSH and CHPI, using low-temperature heat of the industrial and natural sources, enabled to provide the substantiated determination of energy efficient and economically efficient operation modes of ESS with CHPI and PSH with the combined seasonal usage of low-temperature heat of the industrial and natural sources.

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Editorial office received the paper 10.04.2018.

The paper was reviewed 18.04.2018.

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