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Technologies of low-potential heat utilization on thermal power plants

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Abstract. In this article there are given results of possible efficiency enhancement on thermal power plants with low-potential heat utilization. Intensive usage and restricted stocks of organic fuel creates demand of methods reducing its consumption. Thus, on thermal power plants one of important tasks is increasing of primary energy resources efficiency usage. In the research different thermal schemes based on thermal pumps, thermotransformers and installations using detander-generating aggregates were designed and thermal efficiency of these schemes was determined. Schemes calculation was executed using «Thermoflow» and «Gate Cycle» software products. It is shown, that implementation of various low-potential heat utilization technologies at thermal power plants leads to fuel economy. There are presented financial and economic performance indicators for the researched schemes.

Introduction

According to the Department of Energy [1], at the present time the Russian Federation holds the world's second place for natural gas extraction and the fifth place for power generation stands down China, the United States, India and Japan. Fig. 1 reveals the planned dynamics of natural gas extraction, Fig. 2 – power generation.

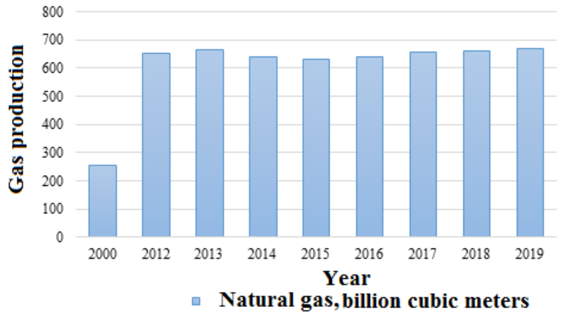

Figure 1. Gas extraction

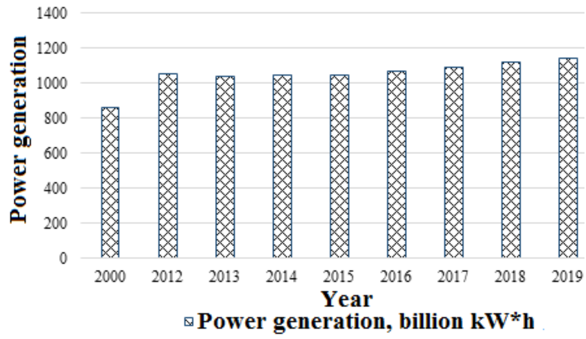

Figure 2. Power generation

Thermal power plants (TPPs) are the basis of Russian energetics. The main TPPs fuel is natural gas. Intensive usage of organic fuels as well as its limited reserves, highlights the need to research methods reducing fuel consumption. One of high-priority tasks of TPPs efficiency maximizing is increasing the efficiency of primary energy resources usage. The possible way is the utilization of various sources low-potential heat at power plants. There are various variants of schemes with low-potential heat utilization are known for both the traditional Rankine cycle and the organic one. In this article, the application of low-potential heat utilization technologies at thermal power plants operating according to the traditional Rankine cycle is considered. It is tend to application of heat pumps and expander-generator installations on its basis for the production of thermal and electric energy.

Application of heat pumps for low-potential heat utilization at TPPs

Heat pump unit (HPU) is designed to convert low-potential heat and to warm secondary coolant. The main HPU types used for industrial purposes are steam compression and sorption types. HPU based on the process of mechanical steam recompression are also known [BREF-LIST].

Heat pump systems are widely used abroad. For example, in 2015 quantity of heat pump plants in Europe amounted to 8.4 million units [http://refportal.com/news/inosmi/european-heat-pump-market-and-statistics-report-216---/]. HPUs of various capacities are installed mainly in Northern Europe, among them are the following [Interrao Report]:

– HPU with total thermal capacity of 180 MW in Stockholm, Sweden;
– HPU with total thermal capacity of 85 MW in Helsinki, Finland;
– HPU with total thermal capacity of 18.4 MW as part of the centralized district heating system in Oslo, Norway;
– absorption HPU at Renova Göteborg, Sweden;
– HPU with a single thermal capacity of 8.8 MW for heat supply to the Swedish scientific center Akalla-Kista.

Heat pumps are also implemented in the Russian Federation at industrial plants. Significant experience in the creation of HPU has been accumulated by the following Russian manufacturers: JSC «VNIIHolodmash», Scientific and Production Company «Triton» (Nizhny Novgorod), company «Energia» (Novosibirsk) [2], company «Teplomash», Kirovsky Zavod (St. Petersburg) and Rybinsk Instrument-Making Plant. In addition, there are a number of companies involved in the design of HPUs and their implementation at industrial facilities, for example, the installation of the SPF «EKIP».

Russian literature highlighted the experience of introducing HPU to industrial and other facilities at following objects: the Chuvash Republic [3], the test results of the industrial stand at CHPP-28 [4], the development of SPF «EKIP» [5]. It should be noted that National Research University "Moscow Power Engineering Institute" has a heat pump unit that operates as part of the MPEI thermal power station [6]. For the conditions of the Russian Federation, the use of heat pumps is limited by a number of factors, the main ones of which are:

– the need to ensure the thermal load in accordance with the required heat schedule;
– increase of the electric auxiliaries at the power plant because of HPU with electric drive;
– the ratio of the fuel cost-to- electricity and heat tariffs.

The problem of ensuring the required heat schedule is related to the properties of HPUs working fluids. The studies shows [7] that it is possible to produce a secondary coolant (heated medium) with maximum temperature 120 ° C from the HPU in the TPP. As it is known, heat supply systems of large cities are designed for a heat schedule with temperatures of 150/70 ° C. In addition, the efficiency of the HPU depends on the temperature of the low-potential heat source, as well as on the temperature required by heat schedule. A large difference between these temperatures leads to a decrease in the efficiency of the heat pump, determined by the conversion factor of the HPU [8].

As an example of the use of HPU for low-grade heat utilization at TPPs, there was carried out the study for the combined-cycle heat power plant (CCHP) unit CCHP-110T. A feature of the CCHP is the dependence of the gas turbine performance on the outside air temperature. Therefore, the study of HPU in the CCHP represents a complex research task with a multitude of technological links. Working in the CCHP, the performance of the HPU can also depend indirectly on the temperature of the outside air. It is known, it affects the customer's heat schedule. A schematic diagram of the plant is shown in Fig. 3.

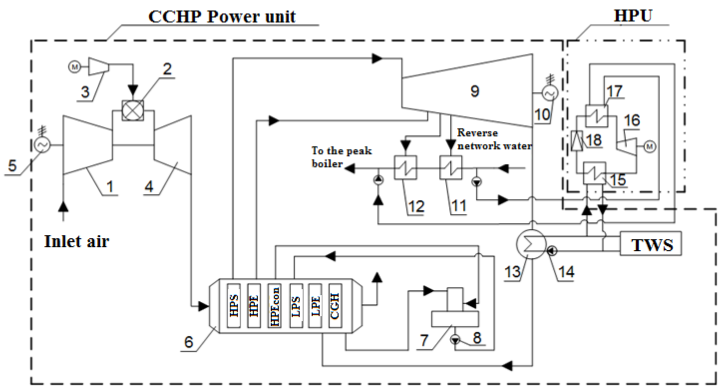

Figure 3. Schematic diagram of the heat cogeneration plant with HPU

Notation on the Fig. 3: 1 – compressor of gas turbine unit (GTU); 2 – combustion chamber; 3 – gas-compression compressor; 4 – gas turbine; 5 – generator of GTU; 6 – heat recovery steam generator; 7 – deaerator; 8 – feed water pump; 9 – steam turbine; 10 – steam turbine generator; 11, 12 – network heaters; 13 – steam turbine condenser; 14 – circulating pump; 15 – evaporator of HPU; 16 – compressor of HPU; 17 – condenser of HPU; 18 – throttling device; HPS – high pressure superheater; HPE – high-pressure evaporator; HPEcon – the economizer of high pressure; LPS – low pressure superheater; LPE – low-pressure evaporator; CGH – condensate gas heater; TVS – technical water supply system.

The purpose of HPU is the production of an additional thermal energy. Butane was chosen as working fluid of HPU. Calculations were made for various regions of the Russian Federation: «Central region», «Ural region» and «South region». CCHP of heating type was designed on the basis of gas turbine 6111 FA produced by General Electric. Heat schedule 150/70 ° C was limiting condition for calculations. However, due to the peculiarities of the study and the working area of the HPU working fluid, there was stated a cut off temperature at 110 ° C. Thermal schemes modelling was implemented using the software product «Thermoflex» developed by the company «Thermoflow».

The study found that the use of heat pumps in the cogeneration plant depending on the operation mode allows to generate a significant quantity of thermal energy in addition to the heating unit (Fig. 4).

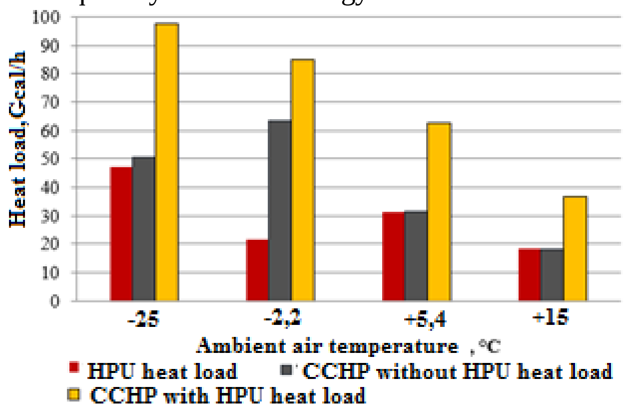

Figure 4. Heat load of CCHP with HPU

At the same time, regardless of the power facility location, the net efficiency and the heat utilization coefficient of the CCHP in considered air temperature range shows a positive trend, despite the increase in the auxiliaries of the power unit (Fig. 5,6). When calculating net efficiency, a physical method was used to divide fuel costs between electric and thermal energy. The diagram at Fig. 7 shows the cost structure for the heat pump plant as part of the CCHP unit. Therefore, in addition to energy costs for the HPU drive, large costs for purchasing energy for the compressor are being a negative factor of the plant's payback period.

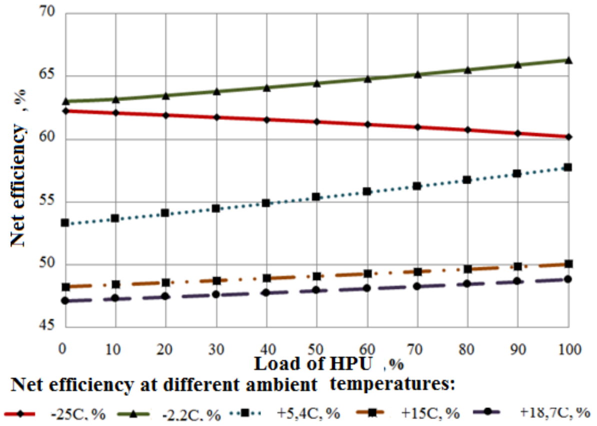

Figure 5. Net efficiency of CCHP with HPU

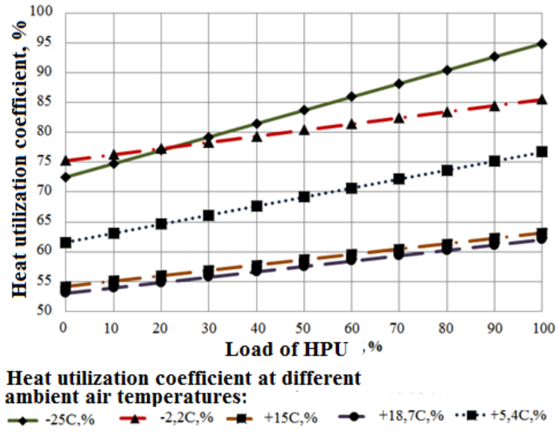

Figure 6. Heat utilization coefficient of CCHP with HPU

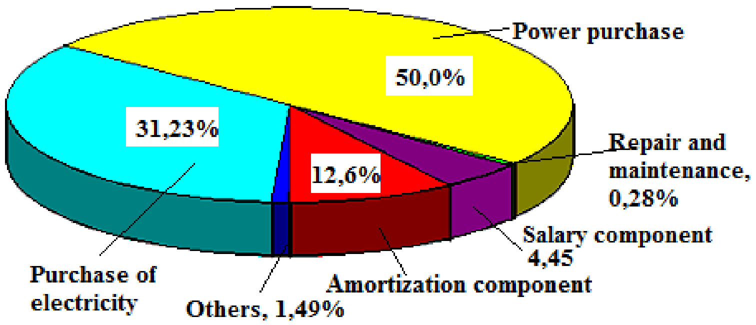

Figure 7. Cost structure of HPU on CCHP

The study determined the minimum values of HPU transformation coefficients under which the installation of a power-driven HPUs pays off, namely: for non-heating period («domestic hot water» mode): for the «Center region» – 5.19, for the «Ural region» – 5.60, the «South region» – 3.00; annual average: for the «Center region» – 2,94,for the region «Ural region» – 3,78, for the «South region» – 3,50.

As an optimization solution, the use of a gas piston drive for HPU compressor was proposed. The results of these study are given in Table 1. Fuel consumption for the CCHP system with HPU with gas piston drive is lower than for the electrical drive installation. The increase in HPU transformation coefficients is about 20–25% in comparison with the electric drive variant.

Table 1. Performance comparison for electric drive and gas piston drive of HPU

Type of HPU drive	Electrical	Gas piston	Gas-piston with a heat recovery system
Electrical gross power, kW		111253	
Net electric power, kW	103277	105239	
Heat utilization load of CCHP with HPU, kW		87923	
Efficiency electric net (physical method),%	73,72	75,12	
Heat utilization coefficient of CCHP with HPU, %		86,67	
Auxiliaries (with TNU compressor when using	7976	6015	

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Type of HPU drive	Electrical	Gas piston	Gas-piston with a heat recovery system
an electric drive), kW			
HPU compressor power, kW		1956,8	
Heat load of HPU, Gcal/h		3,7	
Annual indicators of the CCHP with HPU, calculated at an average ambient air temperature			
Annual fuel consumption, cubic meter/year	69 504 183	69 171 593	67 835 365
Annual electricity output, MW / year	619 662	631 434	
Annual heat output from the power plant with TNU, Gcal / year		453 601	

The expander-generator at TPPs

One of the directions of optimizing schemes using HPU is the use of expander generators at thermal power plants TPPs. The expander-generator units (EGU) is a devices in which the energy of the flow of transported natural gas is converted first into mechanical energy in the expander and then into electric energy in the generator. On the basis of these facilities, it is possible to generate electricity and heat of various temperature levels: high-temperature for heat supply and low-temperature for the construction of refrigeration and air-conditioning systems. Due to the fact that expander-generator technology is offered as an alternative to throttling, all changes in technical and economic indicators introduced by the use of EGU are considered in comparison with throttling.

In the study, the thermal scheme of the power unit with a turbine K-335-240 with the use of EGU and heating of the gas before and after the expander was considered. A schematic diagram of the plant is shown in Fig. 8.

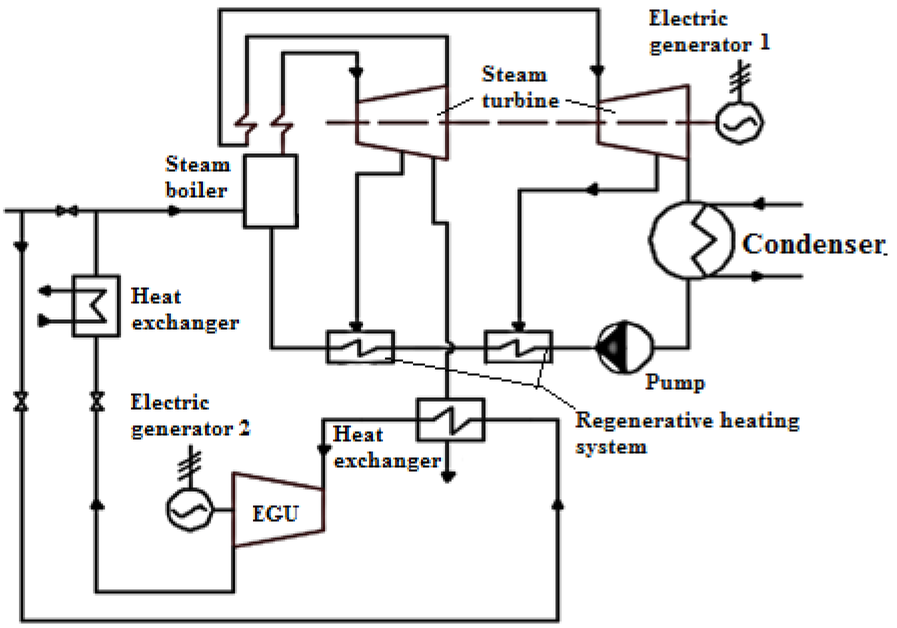

Figure 8. Schematic diagram of the TPP with EGU

As a result of the calculation of the scheme, the indicators for the installation were obtained (Table 2). From the data obtained, it can be seen that the use of the DGA in the scheme makes it possible in addition to obtain 4.3 MW of electric energy. This electricity can be used to drive the TNU compressor. In this case, the heat pump plant can be used to heat the medium in heat exchangers before and after DHA. In addition to producing heat, the consumer releases cold. Since the plant generates three types of energy: heat, cold and electricity, an exergy efficiency is used to compare circuit options.

Table 2. Summary of results

Index	Schematic type	
	Power unit with condensing turbine and gas throttling	Power unit with condensing turbine and EGU
Electrical gross power, kW	335 000	339 288
Cold generation, kW	n/a	230,79
Heat generation, кВт	n/a	4792,39
Exergy efficiency, %	26,96	27,41

Conclusion

1. Perspective schemes for installing a heat pump at TPPs using an electric and gas piston drive are considered. It is also possible to use expander-generator sets for trigeneration systems at TPPs.

2. The studies indicate that for different climatic conditions of Russia the gross unit's efficiency with HPU increased by 10–15 %, net efficiency by 3–5 %, heat utilization coefficient by 15 %.

3. The optimization option with the replacement of the electric drive of the HPU with a gas piston unit with a heat recovery system allows to significantly reduce the fuel consumption at the TPP.

References

[1] The report of the Russian Federation Minister of Energy Novak A.V.: On the main issues of development of the fuel and energy complex at the present stage (2017). Available at: https://minenergo.gov.ru/view-pdf/7692/71278 (accessed 5 June 2017).

[2] Petin Yu.M. Experience of the ten-year production of heat pumps in ZAO Energia / Yu.M. Petin // Energetic policy. Moscow: State Unitary Enterprise, vol. 3. – 2001.

[3] Protsenko V.P., Gorshkov V.G., Osipovich S.V. Experience of implementation and prospects for the development of heat pump plants in the Chuvash Republic / *Energy saving and water treatment*. V.P. Protsenko, V.G. Gorshkov, S.V. Osipovich. – 2003. – No. 3. – P. 37–41.

[4] Devyanin D.N., Pishchikov S.I., Sokolov Yu.N. Development and testing of laboratory stand at TPP-28 of MOSENERGO for approbation of schemes for the use of HPU in the power industry // *Heat supply news*. – 2000. – No. 1. – P. 33–36.

[5] The site of the PC NPF «EKIP» Available at: www.ekip.pro/3/3.shtml (accessed 5 June 2017).

[6] Sukhikh A.A. et al. Thermal Engineering Testing of a Heat Pumping Unit on Carbon Dioxide // *Vestnik MPEI*. – 2011. – No. 3. – P. 10–16.

[7] Investigation of the steam-compression TNU on various refrigerants in the composition of CCGT-TPP / Burov V.D., Dudolin A.A., Oleinikova E.N. // *Materials of the international scientific and technical conference «The state and prospects of development of electrotechnology»*, Ivanovo. – 2013 – P. 203–204.

[8] An analysis of the operation modes of combined-cycle plant-CHPP with TNU / Burov VD, Dudolin A.A., Oleinikova E.N. // *Proceedings of the VII regional scientific and technical conference (with international participation) «Energy – 2012».* T.1. Ivanovo IGEU. – 2012 – C. 9–12.