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IMPROVING THE RELIABILITY OF HEAT SUPPLY SYSTEMS IN THE CONDITIONS OF POWER OUTAGE

О. Климчук, Г. Позднякова. **Підвищення надійності роботи систем теплопостачання в умовах відключення електроенергії**. В роботі проведено аналіз сучасного стану комунальної теплоенергетики із централізованими системами теплопостачання в умовах аварійних відключень електроенергії. Проведено огляд існуючих підходів до вирішення питання надійного забезпечення електроенергією централізовані джерела теплоти. Наведено актуальність комплексного вирішення проблем надійності енергозабезпечення об'єктів комунального господарства як теплом так і електроенергією. При цьому запропоновано мінімізувати місця розташування генераторів теплоти та електроенергії, узгодити режими споживання різних видів енергоресурсів. Одним із напрямків вирішення поставлених питань запропоновано застосування когенераційних установок, які здатні забезпечувати об'єкти комунального господарства не лише теплотою, а також електричною енергією. Пріоритетом по розташуванню когенераційних установок запропоновано опалювальні котельні, в яких організовано осередкований викид продуктів згоряння, а також система розподілення теплоносіїв. Для вирішення вказаних питань було розроблено схему інтеграції когенераційної установки в централізовану систему теплопостачання на базі районної опалювальної котельні та застосуванням теплових насосів. Порівняний аналіз енергетичної ефективності запропонованих рішень здійснено за величиною коефіцієнта використання теплоти палива. Згідно поставленої задачі проведено аналіз застосування когенераційних установок в системах енергозабезпеченнях комплексів комунального господарства. Запропоновано для підвищення ефективності роботи системи сумісного видобутку теплоти та електроенергії застосовувати теплові насоси. Для обраних режимів роботи запропонованої системи проведено аналіз ефективності комбінованого видобутку теплоти та електроенергії. Показано, що застосування в схемі теплового насосу здатно забезпечити зростання частки додаткових джерел тепла до 50 % у балансі котельні, та, відповідно, збільшити показник енергетичної ефективності у 1,3 рази.
Ключові слова: когенераційна установка, теплові насоси, централізовані системи теплопостачання

O. Klymchuk, G. Pozdnyakova. **Improving the reliability of heat supply systems in the conditions of power outage**. The paper analyzes the current state of municipal heat power engineering with centralized heat supply systems in emergency power outages. An overview of existing approaches to solving the issue of reliable provision of electricity by centralized heat sources is carried out. The urgency of complex solution of problems of reliability of energy supply of communal services objects both heat and electricity is given. At the same time, it is proposed to minimize the location of heat and electricity generators, to coordinate the modes of consumption of different types of energy resources. One of the directions of solving the questions proposed the use of cogeneration plants that are able to provide utilities not only heat, but also electricity. The priority for the location of cogeneration plants is offered by heating boiler houses, which organized a cell release of combustion products, as well as a system of distribution of heat carriers. To solve these issues, a scheme for integrating the cogeneration plant into a centralized heat supply system based on the district heating boiler house and the use of heat pumps was developed. The comparative analysis of energy efficiency of the proposed solutions is carried out by the value of the coefficient of fuel heat use. According to the task, an analysis of the use of cogeneration installations in energy supply systems of communal services complexes was carried out. It is proposed to use heat pumps to improve the efficiency of the system of joint heat and electricity production. For the selected modes of operation of the proposed system, an analysis of the efficiency of combined heat and electricity production was carried out. It is shown that application in the heat pump scheme is able to provide an increase in the share of additional heat sources to 50% in the boiler room balance, and, accordingly, to increase the energy efficiency index by 1.3 times.
Keywords: cogeneration unit, heat pumps, centralized heat supply systems

1. Introduction

The current state of municipal heat power engineering is forced to accept rather tough challenges. It is necessary to provide thermal energy to consumers of different types, both residential areas and critical infrastructure. At the same time, it is necessary to constantly receive electricity to power the main elements of heat supply systems (pumps, boilers, automation, etc.) [1]. In conditions of unstable energy supply, there is a need to install decentralized sources of electricity, which are able to provide electricity to the source of district heating [2].

In practice, there are already a number of solutions to these issues [3, 4]. One of the most popular is the installation of diesel generators. However, this solution has a number of drawbacks, first of all, a significant supply of diesel fuel is needed. More interesting is the installation of gas generators, which are connected to the gas networks of heating systems. This solution is more efficient and environmentally friendly [5].

These solutions are able to provide heat in the winter, which is extremely important for maintaining the regulatory temperature values in the premises and social factor. However, these solutions are

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not able to provide electricity to utilities, including critical infrastructure. It should also be noted that the use of local diesel generators, although partially solve the problem of energy supply of certain objects, but significantly adversely affect the environmental state.

The question arises of a comprehensive solution to the problems of reliability of energy supply of communal services, both heat and electricity [6, 7]. At the same time, it is necessary to minimize the location of heat and electricity generators, to coordinate the modes of consumption of various types of energy resources [8, 9].

One of the directions of solving the questions may be the use of cogeneration plants that are able to provide communal services not only with heat, but also with electric energy.

2. Analysis of literary data and formulation of the problem

The use of cogeneration plants has extensive experience. Usually, cogeneration plants are used for energy independence from external thermal and electrical networks for individual objects and industrial enterprises. In a number of cases, cogeneration plants provide separate settlements, and settlements at enterprises, or at deposits of natural fuel [10, 11].

The issue of coordination of electricity consumption and heat consumption schedules has a number of solutions. The simplest solution is to meet the needs of consumers in electricity, heat production is directed to heat networks, which reduces the total heat production [12, 13]. However, this option is not quite rational for situations where the ratio of electricity production and heat energy is not within effective limits, while it depends quite significantly on the schedules of electricity consumption. This is especially true of decentralized heating systems.

The use of cogeneration plants (CP) as an add-on in district heating boilers has a certain distribution [14]. The main purpose of such application is to provide for the needs of the boiler house in electricity and improve the economic indicators of heat generation by using the recycled heat of the CP.

However, the analysis of the energy balance of such systems shows that for heating boilers for every 100 Gcal/h of installed thermal capacity, on average, 2 MW of electrical power is connected to all its own needs [15]. With electric capacities up to 10 MW, the use of gas piston CP economically has an advantage [16], for which the ratio of electrical and thermal power lies within 1:1.5...1:2.0. That is, at the electric power of KU 2 MW, the recycled heat is 3 Gcal/h.

Since the average heat load of the boiler house is 40…50% of the installed capacity (40…50 Gcal/h with 100 Gcal/h inserted), the share of heat from KU in the total heat balance will be respectively 6…8%, which is relatively insufficient to affect the efficiency of heat generation.

Further increase in the share of recycled heat from the CP requires a corresponding increase in the electrical power of the CP and, accordingly, additional consumers of electricity. External consumers with specific load schedules are undesirable, since this greatly complicates the coordination of the electrical and thermal load of CP I turns the boiler into a mini-CHP, which translates it into another status of energy supply facilities.

A more rational scheme is that provides for the direction of residual electricity to heat production. In this scheme, electricity is regulated taking into account the needs of heat supply and the direction of electricity residues for heat production using electric boilers.

This scheme has a significant drawback – electric boilers are not the most effective in terms of generating heat from electricity. A more effective option is to use heat pumps (HP) as an additional source of heat. With a conversion factor of HP about COP=3.0 for each additional 1 MW of electrical power of CP can be obtained (taking into account the heat) on average 4.5 Gcal/h of thermal power.

That is, with a total electrical capacity of CP 5…7 MW for a boiler room with an average heat load of 40…50 Gcal/h, the share of heat from CP and HP will be 16…25 Gcal/h (40…50%), which will have a significant impact on the efficiency of heat generation while autonomous electricity generation for the boiler room.

3. The purpose and objectives of the research

The main purpose of the study is to develop effective schematic solutions for the implementation of cogeneration plants in existing power supply networks, taking into account the modes of heat energy consumption and electricity.

To achieve this goal, it was necessary to solve the following tasks:

– to analyze the use of cogeneration units in energy supply systems of communal services;

– to develop a scheme for the use of cogeneration plants for joint production of heat and electricity;

– to analyze the effectiveness of the proposed scheme of cogeneration installation.

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4. Methods of conducting research and processing experimental data

The use of cogeneration facilities for municipal utilities of cities with a developed network of both heating systems and electric networks is quite rare.

The peculiarity of cogeneration plants is that it is aimed at generating electricity and the rest of the fuel energy is directed to the extraction of heat. At the same time, the ratio of electricity production to thermal energy varies from 1:1 to 1:4. At the same time, if thermal energy is required more than electricity, the rest of the electricity should be given to external power grids.

Another issue of minimizing the location of cogeneration plants is on the one hand the approach to the main local electric networks, on the other hand to the district heating boiler. The priority for the location is the heating boiler houses, which organized a focal release of combustion products, as well as the distribution system of heat carriers.

To solve these issues, a scheme for integrating the cogeneration plant into a centralized heat supply system based on the district heating boiler (Fig.1) and the use of heat pumps (HP) was developed.

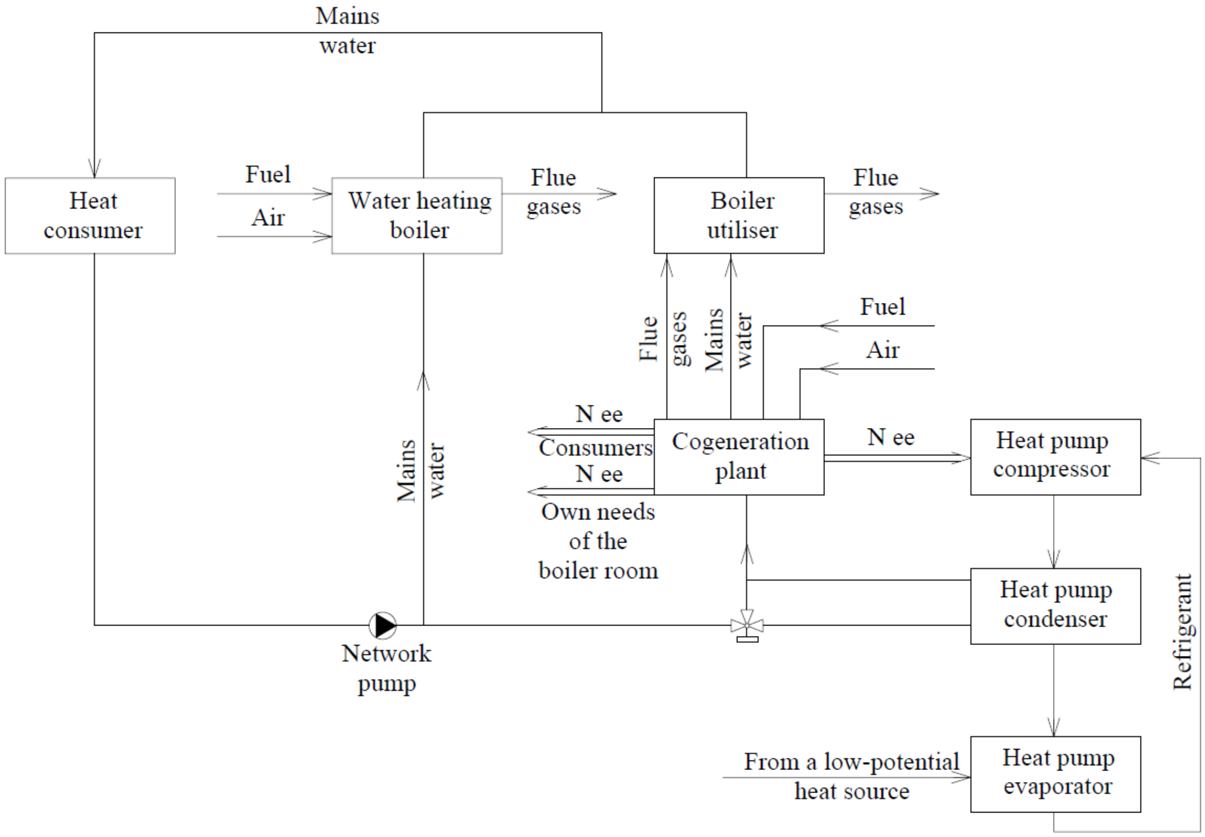

Fig. 1. Thermal scheme of the combined power supply system of the boiler room with a heat pump and cogeneration unit

According to the scheme, the flow of the reverse network water is distributed between the water boiler (WB) and additional heat sources. The first stage of heating network water is HP, since such a temperature regime contributes to its high energy efficiency. The return water temperature at the entrance to the HP t^{r}_{mw} = 50…55 °C, at the output of HP = 60…65 °C. The second stage of heating is the cooling system of the CP engine and the heat exchanger-gas recovery from CP. The second stage of water is about 5…7 °C and thus the temperature of the water at the exit from the system of additional heat sources will be t^{a}_{mw} =70 °C. WB in the scheme plays an important role, because it allows to carry out, if necessary, water heating up to 90 °C.

In addition, thanks to the WB, the main task is solved when using CP – matching the heat and electric load schedules. According to the considered conditions of CP works according to the electric schedule of load (the need for electricity of boiler house and power supply of HP) with the corresponding amount of the disposed heat. Maintaining the thermal balance of the entire system lies on the

WB. At the share of WB in the thermal balance from 50% or more of its capacity is enough to maintain the temperature chart of the boiler room.

A comparative analysis of the energy efficiency of the proposed solutions is proposed to be carried out by the value of η_{cof} the coefficient of fuel heat utilization, which is usually used in assessing the effectiveness of CP [17]:

$$\eta_{cof} = \frac{E + Q_t}{B \cdot Q_l^w} ,$$

where E, Q_t – respectively electric and thermal power of CP;

B – fuel consumption (gas) on the CP;

Q_l^w – heat of burning gas.

For comparison, consider the energy efficiency in three variants of the boiler configuration:

1. Conventional configuration – heat supply from the WB connected electrical power from the external grid;

2. Heat supply from WB, an add-on from CP for autonomous provision of the boiler room needs in electricity with heat utilization of CP;

3. The configuration with a scheme with additional heat sources is proposed in the work.

According to each variant, the expression for the calculation η_{cof} will look like:

$$\eta_{cof}^1 = \frac{Q_{wb} + N_{ce}}{B \cdot Q_l^w + \dfrac{N_{ce}}{\eta_{tpp}}},$$

where Q_{wb} is the thermal power of WB;

N_{ce} – connected electric power to the general needs of the boiler;

η_{tpp} – Electric efficiency of thermal power plants on which electricity is generated taking into account transportation losses:

$$\eta_{cof}^2 = \frac{Q_{wb} + N_{bu}^b + Q_{bu}}{(B_{wb} + B_{bu}) \cdot Q_l^w},$$

where N_{bu}^b, Q_{bu} – respectively electric and thermal power of CP;

B_{wb}, B_{bu} – accordingly, fuel consumption (gas) at the WB and CP:

$$\eta_{cof}^3 = \frac{Q_{wb} + N_{bu}^b + N_{bu}^{hp} \cdot \mathrm{COP} + Q_{bu}}{(B_{wb} + B_{bu}) \cdot Q_l^w},$$

where N_{bu}^b, N_{bu}^{hp} – according to the share of the electric power of the CP for the own needs of the boiler room and the power supply of the HP;

COP – Conversion coefficients of HP.

Input data on the calculation of energy efficiency of the proposed options:

1. Average thermal power of WB Q_{wb} = 40 Gcal/h, when using additional heat sources Q_{wb} = 20 Gcal/h (50% in the heat balance);

2. Combined electric power boiler N_{ce} = 2 MW;

3. Heat of gas combustion Q_l^w = 32 MJ/m^3;

4. Electric efficiency of thermal power plants taking into account transportation losses η_{tpp} = 0.35;

5. The share of the electric power of CP for own needs of the boiler house N_{bu}^b = 2 N_{bu}^{hp} MW and the power supply of HP = 4 MW;

6. Conversion coefficient of HP COP = 3.0;

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7. Thermal power of CP $Q_{bu} = 3$ Gcal/h (when only the boiler room is powered) and $Q_{bu} = 9$ Gcal/h (when the boiler room and TN is powered);

8. Efficiency WB $\eta_{wb} = 0.9$; total efficiency of the CP $\eta_{bu} = 0.9$.

5. Results of experimental bench research

The analysis of the obtained results (Fig. 2) shows that options No. 1 and No. 2 (without CP and, respectively, with CP as only a superstructure) have commensurate values of the fuel heat utilization coefficient – respectively $\eta_{cof}^1=0.845$ and $\eta_{cof}^2=0.9$.

Therefore, the use of CP according to option 2 is important as an autonomous source of electricity for the boiler room with a slight increase in overall thermal efficiency.

Option No. 3 (with CP and HP) has a significantly higher overall thermal efficiency at $\eta_{cof}^3=1.08$, i.e. provides not only autonomous electricity for the boiler room, but also a significant increase in overall thermal efficiency.

The value of η_{cof}^3 greater than 1.0 is conditional for the purpose of comparing options, i.e. during the calculations in the heat balance of the fuel, the heat from the external low-potential energy source at the entrance to the HP was not taken into account, because it is not an organic fuel for heat generation.

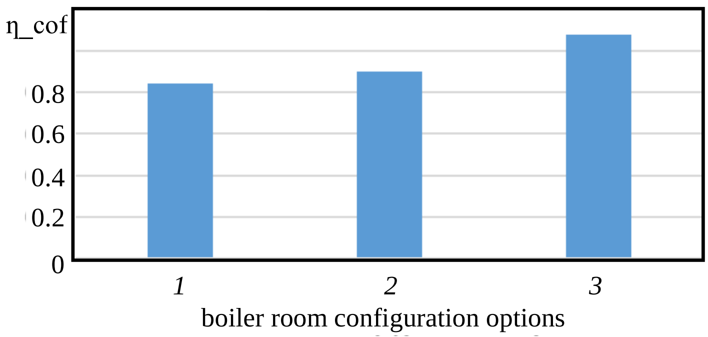

Fig. 2. Energy efficiency of additional heat sources of the heating boiler

These calculations do not take into account the significant dependence of the energy efficiency of the boiler house on the temperature of the external air, but demonstrate a general trend in averaged data. This may be directed further studies of the effectiveness of the proposed scheme.

Conclusions

The paper analyzes approaches to improve the reliability of heat supply systems in the conditions of power outage for district heating boiler with the use of cogeneration and heat pump technologies. According to the task, an analysis of the use of cogeneration plants in energy supply systems of communal services was carried out, schematic solutions for the use of cogeneration plants for joint production of heat and electricity were proposed, an analysis of the effectiveness of the proposed scheme of cogeneration installation was carried out. According to the results obtained, the following conclusions can be drawn:

– The use of cogeneration plants to ensure reliable operation of heat supply systems in the conditions of power outage as an add-on of the boiler house is a very effective and technological solution for autonomous power supply;

– The heat from the cogeneration plant is up to 10% in the heat balance of the heating boiler, so it can not significantly affect the increase in its energy efficiency;

– It is proposed to increase the energy efficiency of the cogeneration plant due to its joint use together with the heat pump, which will increase the share of additional heat sources to 50% in the boiler's balance, and, accordingly, increase the energy efficiency index by 1.3 times.

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