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A. Mazurenko, DSc, Prof.,
O. Klymchuk, DSc, Prof.,
G. Pozdniakova,
A. Pustovit,
V. Shavrov
Odessa Polytechnic National University, 1 Shevchenko Ave., Odesa, Ukraine, 65044; e-mail: klymchuk@op.edu.ua

PROBLEMS OF RELIABLE HEAT SUPPLY PROVIDING IN THE CONDITIONS OF NON-GUARANTEED ELECTRICITY SUPPLY TO HEAT-GENERATING ENTERPRISES

А. Мазуренко, О. Климчук, Г. Позднякова, А. Пустовіт, В. Шавров. **Проблеми забезпечення надійного теплопостачання в умовах негарантованого електропостачання теплогенеруючим підприємствам.** В роботі проведено аналіз сучасного стану централізованих систем теплопостачання. Розглянуті проблеми, що виникають при більш тривалому відключені електроживлення наприклад через стихійні негоди чи руйнування електричних станцій, підстанцій та мереж. Проведено аналіз наслідків тривалих зупинок джерел централізованого теплопостачання в зимовій період при екстремально низьких температурах, що призводить до виведення з ладу основного та допоміжного устаткування, теплових мереж та внутрішньо домових систем опалення. Розглянуто декілька реальних варіантів резервування, або повного власного забезпечення потреб котельні теплопостачання в електроживленні для найбільш розповсюджених типів котельні, а саме – з водогрійними котлами та безпосереднім підключенням до теплової мережі і з паровими котлами та пароводяними бойлерами. Запропоновано впровадження елементів власної електрогенерації на постійній основі, як частини технологічного процесу системи теплопостачання чи окремої котельні середньої та великої потужності, що при раціональному їх поєднанні, може призвести до значного економічного ефекту. Показано, що найперспективнішим є резервування за рахунок вбудованої в основну схему генерації тепла, систему генерації електроенергії, тобто повної або часткової когенерації. Виявлено, що при використані в системі когенерації тепла та електроенергії газових турбін, доцільно використовувати агрегати з невисокою температурою до 800 °С та тиском газу перед турбіною до 0,8 МПа, які відрізняються високою надійністю, невисокою вартістю та забезпечують найбільший відпуск утилізованого тепла.
Ключові слова: централізовані системи теплопостачання, надійність енергообладнання, електропостачання котелень

A. Mazurenko, A. Klymchuk, G. Pozdniakova, A. Pustovit, V. Shavrov. **Problems of reliable heat supply providing in the conditions of non-guaranteed electricity supply to heat-generating enterprises.** The paper analyzes the current state of centralized heat supply systems. Considered problems that arise when the power supply is turned off for a longer period of time. For example, due to natural disasters or the destruction of power stations, substations and networks. An analysis of the consequences of long-term shutdowns of centralized heat supply sources in the winter period at extremely low temperatures, which leads to the failure of the main and auxiliary equipment, heat networks and domestic heating systems, was carried out. Considered several real options for reservation or full self-sufficiency of boiler room heat supply needs in power supply for the most common types of boiler room. Namely, with water heating boilers and direct connection to the heating network and with steam boilers and steam water boilers. It is proposed to introduce elements of own power generation on a permanent basis, as part of the technological process of the heat supply system or a separate boiler house of medium and large capacity, which, with their rational combination, can lead to a significant economic effect. It is shown that the most promising is the redundancy due to the built-in heat generation scheme, the electricity generation system, i.e. full or partial cogeneration. It was found that when gas turbines are used in the cogeneration system of heat and electricity, it is advisable to use units with a low temperature of up to 800 °C and a gas pressure before the turbine of up to 0.8 MPa, which are characterized by high reliability, low cost and provide the greatest release of utilized heat.
Keywords: centralized heat supply systems, reliability of power equipment, power supply of boiler houses

Introduction

The work of existing heat generation enterprises is practically impossible without a stable power supply, which is necessary for automation and control systems, pumps, fans, lighting, etc. The level of reliability of electricity supply to consumers in most developed countries is taken at the level of 0.999, which corresponds approximately to a simultaneous interruption in energy supply for 24 hours in 2.75 years, or, on average, less than 9 hours per year [1, 2, 3]. In case of such a short-term loss of power supply, the existing safety systems of heat supply systems prevent severe emergency situations and preserve the possibility of prompt restoration of boiler room equipment.

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However, in the case of a much longer power outage, for example due to natural disasters or the destruction of power stations, substations and networks, which is currently the case in Ukraine, the consequences can be quite serious. Prolonged stoppage of boiler heating during the winter period at extremely low temperatures can lead to failure of the main and auxiliary equipment, heat networks and domestic heating systems of multi-apartment residential buildings, hospitals, educational institutions and, as a result, suffering of the population. Ensuring high reliability of power systems is possible at the expense of high reliability indicators of the equipment used, and at the expense of the appropriate structure and redundancy of electric and heat generation systems.

Analysis of literary data and statement of the problem

In the current conditions in Ukraine, power supply backup measures due to the installation of mobile generators definitely increase the reliability of heat supply systems. However, this is an urgent and emergency solution to the problem, which, to a large extent, became possible due to international aid. Nevertheless, this forced solution requires significant expenses for diesel fuel or gasoline in case of their use, and in the case when there is no need to connect them, these are "frozen" resources and assets, that is, it is a forced, but the most ineffective solution [4].

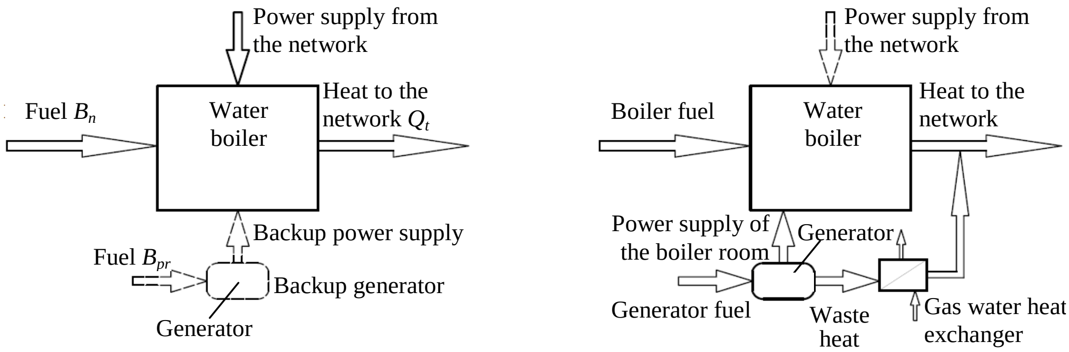
In our opinion, it is more appropriate to introduce elements of own power generation on a permanent basis, as part of the technological process of the heat supply system or a separate boiler house of medium and large capacity. In addition, combining the processes of heat and electricity generation (cogeneration), with their rational combination, can lead to a significant economic effect [5, 6].

Let's consider several real options for backup, or complete self-support of the needs of the boiler room's heat supply in power supply. For comparison, let's take the most common types of boiler rooms – with water heating boilers and direct connection to the heating network and with steam boilers and steam water boilers [7].

In the option of a gas boiler room with water heating boilers, the following reservation options are possible:

– a backup generator with an internal combustion engine (ICE), which works only in the absence of power supply from the network. The fuel is most often liquid (Fig. 1, *a*);

– a generator of full or partial own power supply, which works constantly with utilization in the thermal network of the heat of the output gases of the internal combustion engine through a gas-water heat exchanger. The fuel, as well as for the boiler, can be gas (Fig. 1, *b*).



a *b*

Fig. 1. Power supply backup schemes of a boiler room with water heating boilers: *a* – the fuel is most often liquid; *b* – the fuel, as well as for the boiler, can be gas

The listed options for backup power supply are also possible for boiler rooms with steam boilers. However, the presence of steam makes it possible to consider, as a perspective, a scheme with a steam turbine (ST) of small power and back pressure, with the discharge of steam after the turbine into steam-water heat exchangers for supplying additional heat to the network [8, 9].

Such a turbine is very reliable and inexpensive, as it works at low steam parameters, does not require a low-pressure cylinder and a condenser with a cooling system. At the same time, the efficiency of such a solution can be quite high due to the mode of cogeneration of heat and electricity. With a small power (up to hundreds of kilowatts), it is possible to use a variety of steam turbines - a bladeless steam turbine (BST) of the Tesla type [10, 11], which is characterized by a simple design, high reliability and economy, including operation on wet steam.

In Fig. 2 shows the diagram of energy flows of a boiler room with a steam boiler and a steam turbine power generator. The steam after the turbine can be discharged into the main steam-water heat exchanger (boiler) or into a separate one.

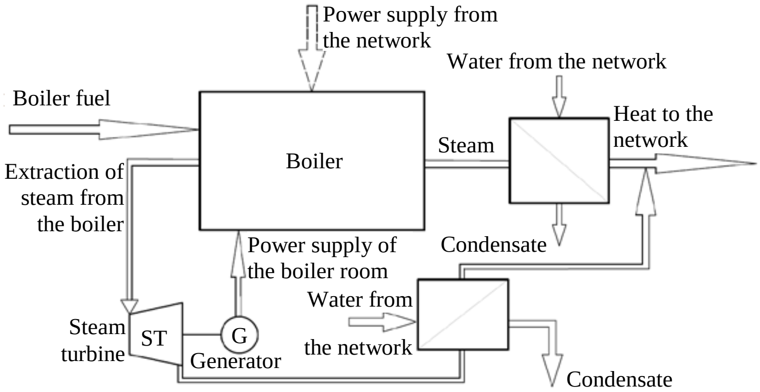


Fig. 2. Steam boiler for heat supply with a steam turbine autonomous power supply

The purpose and objectives of the research

The purpose of this work is to solve the problem of reliable heat supply of communal heat energy facilities in modern conditions of Ukraine, taking into account various factors that destabilize the work of the energy industry.

To achieve this goal, the following tasks must be solved:

– analysis of the current state of heat supply systems in Ukraine;

– research of different ways of reserving power supply for different types of heat supply sources;

– determining the efficiency of various energy sources to ensure the reliability of electricity supply of centralized heat supply systems.

Materials and methods of research

The results of the analysis of electricity consumption by most boiler plants in Odessa show that the specific electricity consumption is 20…30 kWh/Gcal, which, accordingly, indicates the required power of electricity consumers – 20…30 kW per 1 Gcal/h of boiler capacity:

$$k = \frac{N_{\text{T}}}{Q_{\text{B}}} = (0.025....0.035),$$

or kW/kW. For the variant of the heat supply scheme with a steam boiler presented in Fig. 2, we will determine the necessary parameters for a steam turbine of autonomous power supply.

Steam consumption in the boiler to obtain the required amount of heat – Q_{B} can be determined as:

$$G_{\text{B}} = \frac{Q_{\text{B}}}{(h_{\text{s}} - h_{\text{c}}) \cdot \eta_{\text{B}}},$$

where: h_{s} and h_{c} are, respectively, the enthalpy of steam at the boiler outlet and the enthalpy of condensate in the boiler, and the η_{B} efficiency of the boiler, which is quite high, is 0.99.

The consumption of steam in a turbine with a capacity of N_{T} can be determined by the formula:

$$G_{\text{T}} = \frac{N_{\text{T}}}{(h_{\text{s}} - h_{\text{s}}^{\text{в}}) \cdot h_{\text{T}} \cdot h_{\text{M}} \cdot h_{\text{E}}},$$

where $h_{\text{s}}^{\text{в}}$ – enthalpy of saturated or wet steam behind the turbine,

$\eta_{\text{T}}, \eta_{\text{M}}, \eta_{\text{E}}$ – respectively, the internal efficiency of the turbine, the mechanical efficiency of the turbogenerator and the electrical efficiency of the generator.

Thus, with the total steam productivity of the boiler $G_{\text{TB}} = G_{\text{T}} + G_{\text{B}}$, and the percentage of boiler steam – μ, which will go to the turbine, will be:

$$\mu = \frac{G_{\text{T}}}{G_{\text{B}} + G_{\text{T}}} \cdot 100 = \frac{1}{\frac{G_{\text{B}}}{G_{\text{T}}} + 1} \cdot 100\ \%.$$

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Taking into account the formulas for determination G_B and G_T :

$$\mu = \frac{1}{\frac{(h_s - h_s^{в}) \cdot \eta_T \cdot \eta_M \cdot \eta_E}{k \cdot (h_s - h_c) \cdot \eta_B} + 1} \cdot 100\ \%.$$

If we take as an example a steam boiler of the DKVR 4-13 (ДКВР 4-13) type [3] with steam parameters of 1.3 MPa and 194 °C, which is widespread in heat supply systems, then with an average value of k = 0.030 and with generally accepted efficiency values of system elements, we will obtain the percentage of steam extraction per turbine:

$$\mu = \frac{1}{\frac{(2793 - 2250) \cdot 0.8 \cdot 0.85 \cdot 0.9}{0.03 \cdot (2793 - 813) \cdot 0.99} + 1} \cdot 100 = 15\%.$$

When bladeless turbines are used, which allow much higher steam humidity at the outlet, the percentage of steam used to drive the turbine can be reduced to 8…10%.

The required estimated electrical power of the steam turbine generator when working in the heat supply system of the boiler selected for the example is about 45 kW.

For large-capacity heat supply systems, especially when there are heat consumers for heating, hot water supply or industrial needs throughout the year, it is more appropriate, in our opinion, to use own electricity generation based on gas turbine units (GTU). In Ukraine, there are many enterprises that manufacture or are able to manufacture power gas turbines and turbines for special purposes (ship, aviation, transport and others), which, with appropriate modernization, can also be used for power generation. In international practice, there are many examples of the use of aircraft engines that have worked out the estimated flown resource, they are inexpensive, but they are successfully used in energy production for a long time [12], and this is also promising for the conditions of Ukraine. GTUs are quite compact, mobile from the point of view of starting and changing operating modes, they can work on gas or liquid fuel (kerosene, gas turbine fuel).

Due to the fact that when the capacity of the gas turbine is increased, its specific cost per 1 kW decreases, it seems appropriate to implement them for the power supply of more powerful heat supply enterprises, the system of several smaller boiler houses, or to use the electricity generation for sale to the external power system in cases where redundancy is necessary, or at times of its peak load.

It should be noted that the autonomous operation of the gas turbine in the mode of electricity generation only is quite inefficient and has an efficiency of about 30%, since the heat loss with exhaust gases, which have a temperature after the turbine, depending on the parameters of the working body in front of the turbine, is 300…500 °C. However, if you use the heat of these gases in a fairly simple and inexpensive gas-water heat exchanger to a temperature of, for example, 100…120 °C, then the fuel energy utilization factor of such a gas turbine increases to 60%. At the same time, more than half of the energy of the used fuel was transformed into the most expensive and relevant form of it – electricity, and the other part – into heat for heating or hot water supply.

Fig. 3 shows the diagram of the energy flows of a boiler house with a gas turbine power supply unit and a gas-water heater for heat utilization of waste gases after the gas turbine for the needs of heat supply to consumers.

It should be noted that the characteristics of the gas turbine installation in the mode of electricity generation only are quite well studied depending on the schematic solutions and parameters. However, in the conditions of the combined mode of electricity generation and heat release in a single system with heating boiler rooms, the analysis method and its conclusions may differ from the classical ones.

The analysis of the efficiency of such a heat supply system with a gas turbine installation of autonomous power supply is more complicated than with a steam turbine, so it is advisable to conduct it using a software product developed for this purpose in the Visual Basic environment. The general view of the working window of the program for calculations and analysis of the gas turbine installation in the heat supply system is shown in Fig. 4. However, if necessary, this program can be used for pure energy gas turbines without heat recovery or a gas turbine plant with heat regeneration of the outgoing gases in the heat exchanger after the compressor for additional air heating.

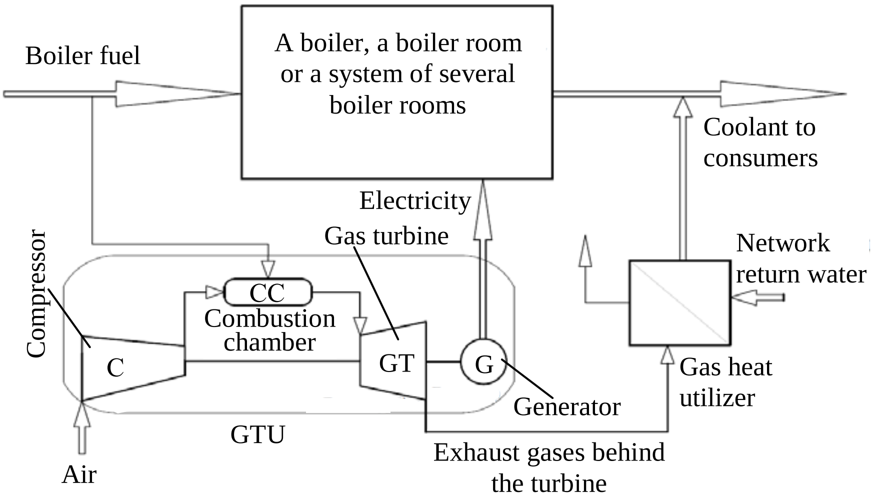

Fig. 3. Heat supply system with a gas turbine power plant

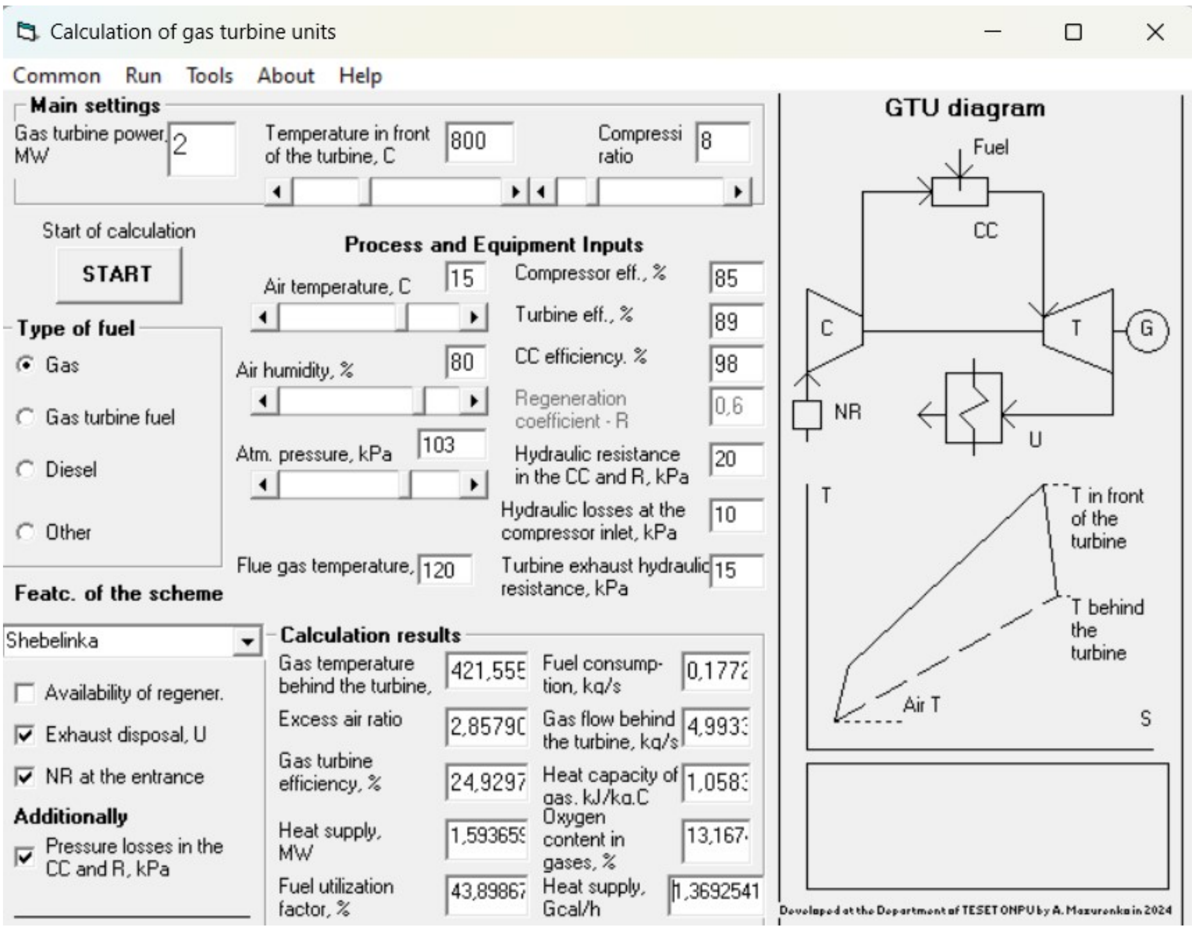

Fig. 4. Working window of the program for calculations and analysis of the gas turbine installation in the heat supply system

Fig. 5 shows the scheme of the gas turbine installation and the corresponding process in T-S coordinates of the option using a gas-air heat exchanger-regenerator, however, despite the higher efficiency of electricity generation, this option is not attractive for heat supply needs, since there is no use of the heat of waste gases for heat supply needs, and it should also be noted that the gas-air heat exchanger-regenerator is inefficient due to the low value of the heat transfer coefficient. In the case of using a gas turbine installation in a heat-generating system in cogeneration mode, it is possible to

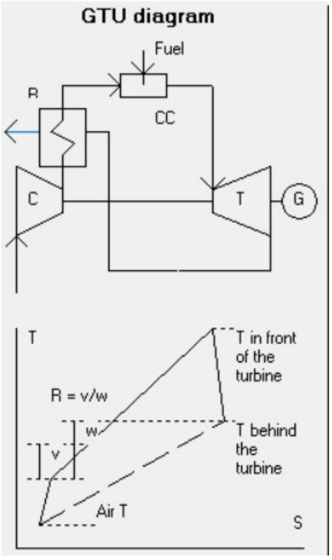

Fig. 5. Scheme of a gas turbine installation with heat regeneration without its utilization

change the parameters and characteristics of the elements of such a system, including boilers, in a wide range, in order to choose optimal solutions. Factors that have the greatest influence on the parameters of the gas turbine installation in the heat supply system include the parameters of the gas in front of the turbine – its temperature and pressure, the temperature of the air in the external environment, as well as the temperature to which cooling of the gas in the heat exchanger - regenerated gas is allowed.

Research results

The possible range of gas temperature changes in this program is from 400 to 1600 °C, pressure - from 3 to 30 bar, and outside air temperature –30 to +35 °C. The result of the calculation of the release of heat to consumers is given both in MW and in Gcal/hour. The temperature of the outgoing gases after the gas-hydrogen gas heat utilizer is also important. The lower it is, the more complete the heat utilization will be. In our case, it is considered in the range of 80…140 °C, but a lower temperature can lead to intensive corrosion of the corrosion-resistant material of the heat exchanger under the conditions of the dew point on its surface and the presence of corrosively aggressive components in the working gas.

As can be seen from the results of the presented Fig. 6 by determining the influence of the temperature and the correspondingly agreed pressure of the working gas in front of the turbine on the possibility of heat utilization at different temperatures at the outlet of the heat exchanger-utilizer, there is a clearly defined maximum of heat release at temperatures downstream of the utilizer of 120 and 140 °C. At lower temperatures, the maximum thermal efficiency shifts to lower initial parameters. It is very important that the optimal gas temperature in front of the turbine does not exceed 800 °C, which means that there is no need to use high-temperature GTUs, which are extremely expensive due to the need to use unique heat-resistant materials for the blades of the flow part of the turbines, as well as complex and expensive technologies for manufacturing turbine blades that are cooled by air taken from the compressor.

For the energy balance of the system, the ratio of electric power, efficiency of the gas turbine and the corresponding release of heat to consumers is important, depending on the parameters of the main equipment of the GTU and external factors. In Fig. 7 shows the value of the efficiency of the gas turbine depending on the parameters of the gas in front of the turbine and the air temperature of the external environment. The influence of these parameters is determined by the well-known formula for the thermal efficiency of the equivalent Carnot cycle $\eta_T = 1 - \frac{T_{2m}}{T_{1m}}$, where T_{1m} and T_{2m} average thermodynamic temperatures, respectively, in the process of heat supply to the cycle and heat removal from the cycle to the external environment. That is what determines the nature of the dependence of the efficiency on the specified parameters.

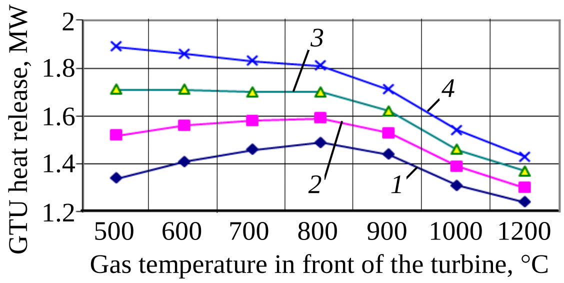

Fig. 6. Influence of the parameters in front of the GTU with a capacity of 2 MW on the amount of utilized heat at the selected temperature behind the heat exchanger: 80 (*1*); 100 (*2*); 120 (*3*); 140 (*4*)

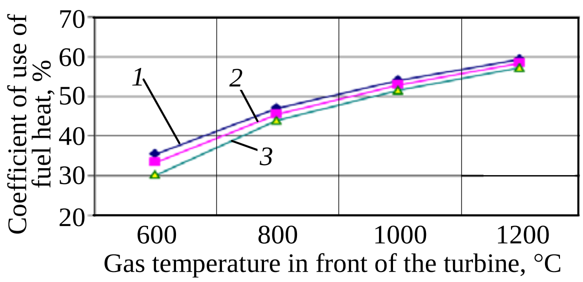

Fig. 7. Electrical efficiency of the gas turbine installation depending on the parameters of the gas in front of the turbine and the air temperature: –15 (*1*); 0 (*2*); 15 (*3*)

For the case of using a GTU in the heat supply system, the fuel energy utilization factor is more informative, as it takes into account its costs not only for electricity generation, but also for heat generation.

As can be seen from Fig. 8., the temperature of the outside air affects the fuel utilization ratio to a lesser extent than the efficiency. In addition, and this is particularly important, increasing the parameters in front of the gas turbine does not lead to a rapid, or even proportional increase in the efficiency of fuel use, which once again emphasizes the impracticality of using gas turbines with high initial temperature and pressure in heat supply systems, as with extremely high parameters the cost of such turbines increases several times, and sometimes by orders of magnitude.

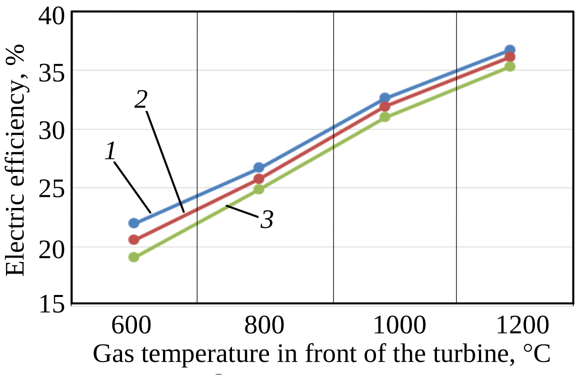

Fig. 8. Influence of gas parameters before the gas transport facility and air temperature on the fuel utilization rate; –15 (*1*); 0 (*2*); 15 (*3*)

It should be noted that depending on the nature of the heat supply enterprise – local, district, district or city boiler house, its structure will be different, including from the point of view of the use of power supply backup systems. If there is a large number of boilers in the boiler room, it is impractical to equip all of them with autonomous power-generating superstructures.

The boiler house can have one or two (if backup is necessary) generation systems. Moreover, when using relatively powerful gas turbines, it is possible to organize an independent power supply of a group of compactly located boiler houses of small or medium capacity, which will reduce costs both for the equipment and for its maintenance.

Conclusions

Under the influence of external factors caused by natural disasters, military actions or other factors that destabilize the operation of the energy industry, the presence of electricity supply of heat-generating enterprises has a significant impact on the possibility of stable heat supply. The lack of possibility of operation of boiler rooms for a long time in the winter period can lead to catastrophic consequences for the entire heat supply system - from the boiler room to the final consumer. Based on the research, the following conclusions can be drawn:

– depending on the type of heat supply enterprise and the nature of its equipment, redundancy is possible at the expense of own electricity generation, based on internal combustion engines, steam or gas turbines;

– the most promising is redundancy due to the built-in heat generation scheme, electricity generation system, i.e. full or partial cogeneration;

– for small, in particular, individual heat supply systems with a maximum power consumption of up to 5…10 kW, it is possible to use inexpensive autonomous electricity generators based on gasoline or diesel generators. However, given the high cost of fuel for such generators, their use is appropriate only in the absence of external power supply. And therefore, as a rule, most of the time of operation of boilers, they do not operate.

– about autonomous power supply systems built into the technological cycle, in the case of steam boilers for heat supply of medium capacity, the use of steam turbines working with back pressure is promising. Depending on the type of turbines (classical or bladeless with the required power up to 50…100 kW), they can take 8…18% of the steam produced by the boiler for operation.

– the use of gas turbines is advisable for large power consumption capacities in the boiler room of a heat-generating enterprise, in boiler rooms with water-heating boilers of medium capacity, or for independent power supply of a heat-generating complex from smaller boiler rooms.

– it is important to note that when gas turbines are used in the cogeneration system of heat and electricity, it is advisable to use units with a low temperature of up to 800 ^{o}C and a gas pressure in front of the turbine of up to 0.8 MPa, which are characterized by high reliability, low cost and provide the greatest release of utilized heat.

– it is necessary to assess the possibility of lowering the gas temperature behind the boiler by the heat exchanger to less than 140 ^{o}C, of course, if it is possible to ensure its reliable long-term operation.

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Мазуренко Антон Станіславович; Anton Mazurenko, ORCID: https://orcid.org/0000-0002-0165-3826
Климчук Олександр Андрійович; Oleksandr Klymchuk, ORCID: http://orcid.org/0000-0002-5207-7259
Позднякова Ганна Іванівна; Ganna Pozdniakova, ORCID: https://orcid.org/0009-0003-1132-094X
Пустовіт Анатолій Васильович; Anatoliy Pustovit, ORCID: https://orcid.org/0009-0008-4320-953X
Шавров Віктор Вікторович; Viktor Shavrov, ORCID: https://orcid.org/0009-0006-1023-0725

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