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To cite this article: Anatoliy Kolienco and Rasul Akhmednabiev 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1491** 012014

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# Study of the efficiency of cogeneration plant based on an internal combustion heat engine (ICE)

Anatoliy Kolienko<sup>1,2</sup> and Rasul Akhmednabiev<sup>1</sup>

<sup>1</sup>National University "Yuri Kondratyuk Poltava Polytechnic", Pershotravneva Ave., 24, Poltava, 36011, Ukraine

<sup>2</sup>Corresponding author: agkolienko@gmail.com

**Abstract.** The results of thermal and environmental tests of a cogeneration plant (CP) based on a gas-piston internal combustion engine with a total nominal thermal capacity of 2.46 MW are presented, of which 1.26 MW is nominal thermal capacity and 1.2 MW is electrical. Russian aggression against Ukraine led to significant losses of both basic and shunting generating capacities of thermal power plants and to a decrease in the production of electrical energy in nuclear and hydroelectric power plants. In this regard, work on the introduction of distributed sources of electric energy, including CPs based on internal combustion heat engines as gained considerable importance. Given the sufficiently long economic life of such devices, their implementation should be carried out on the basis of acceptable energy efficiency. The article deals with the issue of developing a methodology for surveying the energy efficiency of CPs, determining the technical and economic indicators of their work, researching the factors influencing the energy efficiency indicators of CPs and ways to increase of their efficiency. The work is based on the results of regulatory and corrective works performed by the authors at CPs, analysis and generalization of the results of CPs surveys.

## 1. Introduction

A significant part of the electrical energy in Ukraine is produced, as a rule, by sufficiently powerful condensing (CS) and heating (HS) stations. In the conditions of military operations on the territory of Ukraine and the destruction of energy facilities by the aggressor, the low stability of such powerful stations of the centralized system and vulnerability to airstrikes led to a significant negative impact on the country's energy industry as a whole [1].

Therefore, from the point of view of experts [2], the transition from centralized generation facilities to decentralized distributed generation is the most likely scenario for the development of the energy industry. At the same time, the objects of distributed generation include electric stations with a capacity of 20 MW and less, which are connected to the electric energy distribution system. The development of such systems involves the wider use of cogeneration plants based on gas piston and gas turbine plants and renewable energy sources: solar energy, biomass, wind turbines. According to [3], the share of distributed generation is expected to grow by at least 15% of the total installed capacity by 2025.

The generation deficit of 3,500 MW, which is 3,500 container megawatt stations and two hundred cogeneration plants, does not solve the issue of stable energy supply of the country and will not provide the city with heat. But they are able to increase the stability of critical infrastructure systems.

When using cogeneration units of distributed generation, the issue of their efficiency, which refers to the technical and economic indicators of their operation, is of great importance [4].

The thermodynamic efficiency of modern internal combustion engines (ICE) and generators for the



production of electrical energy, which are used in cogeneration plants (CP) of various manufacturers, is at the level of 34-42% when working on natural gas, and this does not contribute to obtaining a high efficiency production of electrical energy at CP and, accordingly, high efficiency of fuel use. This is due to the thermodynamic limitations that exist for the internal combustion heat engine cycle [5,6]. In the case of generating only electrical energy, 64-58% of the primary fuel energy supplied to the CP are lost aimlessly. The indicator of the specific consumption of natural gas per 1.0 kW/h of generated electrical energy will be about 0.4 m<sup>3</sup> or 0.37 l of diesel fuel. Therefore, it is impossible to call such a method of generating electrical energy efficient enough.

It is difficult to agree with such technical and economic indicators of the operation of equipment that generates electrical energy for a long period of time. Rather, it is possible to accept such efficiency only in the case of emergency short-term operation of the generator to support vital infrastructure facilities (boiler plants, health care facilities, production with an uninterrupted technological cycle), or in emergency cases.

To improve the overall efficiency of operation, the composition of the CP includes utilization heat exchangers, which are installed on the line of waste products of combustion of fuel from the engine and the cooling circuit of the oil and the engine itself [7]. They utilize and make useful use of waste heat. For example, heating water with waste high-temperature combustion products from the CP. The obtained water can be used for heating or hot water supply to heat consumers. The efficiency of heat generation in such a heat exchanger reaches 45-54% relative to the energy of the input primary fuel, or 80-88% of the energy of the waste products of combustion of internal combustion engines for machines of various manufacturers. In this way, the useful release of energy from the CP increases and the overall efficiency of the installation increases to 80-89% relative to the energy of the input fuel.

In addition to the combustion products, there is another source of waste heat in the CP, which is oil heated in the engine and hot water in the cooling circuit of the engine itself [8]. This water must be cooled in order to ensure the safe operation of the engine and avoid its overheating. If this heat is not usefully used, then it should be released into the environment with the help of a cooler-cooling house. In this case, the energy that will be obtained from the cooling circuit cannot be considered as useful in the process of determining the energy efficiency of the CP operation.

According to [9], the harmonized reference value of the efficiency of thermal energy generation in CP commissioned after 2016 should be at least 90% when operating on natural gas, liquefied petroleum gas, liquefied natural gas, and biomethane relative to the energy of the waste products of combustion and the working fluid of the engine cooling circuit (in case of using hot water). This corresponds to the thermal efficiency of the CP operation of about 52-59% (relative to the input fuel energy). Thus, the overall coefficient of cogeneration for the category of highly efficient CP, as declared by [10], should be 93-94%. In addition to the production and useful use of circulating hot water during the disposal of waste products of combustion from CP, it is also possible to generate steam, or directly use the heat of waste products of combustion from CP (for example, for drying processes).

Therefore, due to the combined production of useful thermal and electrical energy in CP, it is possible to achieve a significant increase in the efficiency of fuel use, a reduction in irreversible losses of the original primary fuel, and a reduction in greenhouse gas emissions into the atmosphere.

In view of the above, it is extremely important to ensure the beneficial use of waste heat from CP and turn it into a liquid product for consumers.

Considering the global processes of climate change on Earth, the ecological effect of using cogeneration is no less important than the economic one [11].

The purpose of the work is research of the energy and thermal efficiency of cogeneration plants and the development of recommendations for calculating their efficiency.

## 2. Methods

The study of the efficiency of cogeneration plants based on internal combustion engines was carried out in the following sequence:

- selection of indicators that characterize the efficiency of cogeneration plants;

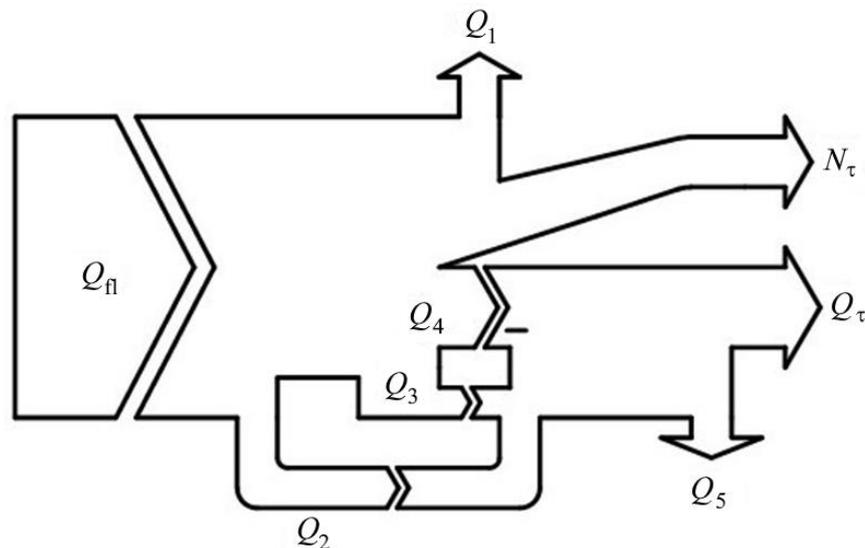
- study of passport data on the efficiency of the CP;  
 - study of the conditions of use and operation of CP in the context of their adaptation in the public utility and industrial sectors.

Analysis of possible schemes for joining CP to existing thermal energy generation systems;

- the selection of factors that affect the effectiveness of the use of CP;  
 - development of a methodology for researching the effectiveness of CP work;  
 - carrying out tests of CP in real operating conditions;  
 - analysis of test results and assessment of factors that affect the technical and economic efficiency of using internal combustion engine-based CP for distributed generation of electrical and thermal energy.

### 3. Results and their discussion

The graphic display of energy flows during the combined production of thermal and electrical energy in the CP based on the ICE is presented in figure 1.



**Figure 1.** Energy flows of CP.  $Q_{fl}$  - input energy of the fuel supplied to the CP;  $N_{\tau}$  - produced amount of electrical energy;  $Q_{\tau}$  - produced amount of heat;  $Q_1$  - heat loss with cooling of the surface of the equipment and pipelines of the CP;  $Q_2$  - heat loss with the engine cooling circuit (with coolant);  $Q_3$  - heat loss with heated oil;  $Q_4$  - heat loss with hot exhaust gases from internal combustion engines;  $Q_5$  - other unproductive heat losses (including exhaust gases).

The assessment of the technical and economic efficiency of the CP operation according to the passport data of such equipment is carried out using two thermodynamic efficiency indicators, namely two coefficients of useful action: one - for the production of electrical energy -  $KEE_N$  and the second - the coefficient of useful action for the production of thermal energy -  $KTE_Q$  [8 ,12,13]. The value of  $KEE_N$  during a certain period of time of operation of the CP for the production of electrical energy is estimated relative to the input energy of the fuel:

$$KEE_N = \eta_N = \frac{N_{\tau}}{Q_{fl\tau}} \cdot 100 = \frac{N \cdot \tau_1}{Q_{lh}^c \cdot B_{\tau}} \cdot 100, \% \quad (1)$$

where  $\tau_1$  - the period of time of operation of the CP for the production of electrical energy, for which the energy efficiency assessment is performed, h;  $B_{\tau}$  - fuel consumption for the CP during the period of

evaluation of the efficiency of the CP in the production of electric energy,  $m^3$  under normal conditions;  $Q_{\text{th}}^c$  – the lower heat of combustion of fuel,  $\text{kJ}/m^3$  under the conditions of using a non-condensing heat exchanger of a combustion products disposer;  $N_\tau = \sum N \cdot \tau_1$  – the amount of electrical energy produced during the period of evaluation of work efficiency,  $\tau$ , in kWh;  $Q_{\text{th}\tau} = \sum Q_{\text{th}} \cdot \tau_1$  – the amount of heat received during the combustion of the input fuel during the period of evaluation of work efficiency, in kWh.

But the passport data of CP indicates the instantaneous value of  $KEE_N$ , which can be achieved under the nominal (optimal) operating conditions of the unit. In this case, dependence (1) is written in the form:

$$KEE_N = \eta_N = \frac{N}{Q_{\text{hff}}} 100, \% \quad (2)$$

where  $N$  – the capacity of the CP from the generated electrical energy, kW;  $Q_{\text{hff}}$  – heat flow obtained with the input fuel, kW.

The difference in the results of calculations according to equations (1) and (2) will occur as a result of the fact that the operating conditions of the electric power generation installation during the evaluation period  $\tau$  may differ from the nominal (optimal) conditions. The result of the efficiency calculations for a certain period of time will be less than the instantaneous performance indicators of the CP.

When evaluating the energy efficiency from the useful production of another type of energy – heat, the thermodynamic efficiency ( $KTE_Q$ ) can be determined relative to different values:

- relative to the total input flow of heat to utilization heat exchangers from cooling water from CP –  $Q_2$ ; hot oil –  $Q_3$  and waste products of combustion –  $Q_4$ :

$$Q_{\text{ifh}} = Q_2 + Q_3 + Q_4$$

- relative to the input fuel energy.

At the same time, the dependences for determining the values of  $KTE_Q$  during a certain period of useful heat production in the CP and the instantaneous nominal value of  $KTE_Q$  will differ, as well as the values of the obtained  $KTE_Q$ . This is caused by different operating conditions of the CP at the nominal mode of operation and during a certain period of time of useful heat production  $\tau_2$ .

Determination of the value of  $KTE_Q$  for the generation of thermal energy during a certain time of operation of the installation can be determined, on the one hand, relative to the input amount of heat coming from the internal combustion engine to the utilization heat exchangers. In this case, the dependence for calculating the value of thermal  $KTE_Q$  is written as

$$KTE_Q = \eta_Q = \frac{Q_\tau}{Q_{\text{ihf}\tau_2}} 100 = \frac{Q \cdot \tau}{Q_{2\tau_2} + Q_{3\tau_2} + Q_{4\tau_2}} 100, \% \quad (3)$$

The instantaneous value of efficiency under certain operating conditions of the CP unit is determined according to the dependence

$$KTE_Q = \eta_Q = \frac{Q_\tau}{Q_{\text{ihf}}} 100 = \frac{Q \cdot \tau}{Q_2 + Q_3 + Q_4} 100, \% \quad (4)$$

where  $Q_\tau$  and  $Q$  are the useful heat obtained during the time period  $\tau_2$  in kWh and the instantaneous value of the useful heat output of the heat recovery system of the CP in kW, respectively;  $\tau_2$  is the period of time of the CP operation for useful heat generation, for which the energy efficiency is assessed  $Q_{\text{ihf}\tau_2}$  and  $Q_{\text{ihf}}$  are the input amount of heat entering the CP heat recovery system in kWh and the instantaneous heat flow entering the heat recovery system in kW, respectively.

Note that the duration of the CP operation for generating electric energy –  $\tau_1$  and the duration of the period of useful heat generation in the heat recovery system –  $\tau_2$ , most often, will not coincide. This is

due to the fact that heat extraction by consumers is of a changing nature and heat generation in the CP does not always correspond to the need for useful heat on the part of consumers. The time period  $\tau_1 - \tau_2 = \Delta\tau$  of the CP unit will be operated due to full or partial cooling of oil, cooling water and combustion products in the cooling tower, which is equivalent to production irrecoverable energy losses, and not to useful heat generation. The energy efficiency of the CP unit during this period will be significantly reduced to a value that characterizes the generation of only electrical energy. For most CP units, this value is 37-43% depending on the CP unit operating mode.

This is important both for assessing the overall efficiency of the CP unit and the process of planning fuel consumption and setting tariffs. This is primarily due to the fact that tariffs for gas for generating thermal energy for different categories of consumers and for generating electrical energy differ significantly.

Determining the overall efficiency of the CP unit for combined generation of electrical and thermal energy by compiling the corresponding efficiency values -  $KEE_Q$  and  $KEE_N$  cannot be considered correct and proper. Firstly, they are defined relative to different input energy flows and secondly, for different periods of time of generation of thermal and electrical energy. The balance points for assessing the completeness of use of input energy and the units themselves are also different. The engine and electric generator produce electrical energy, and the heat exchangers-utilizers generate useful thermal energy.

For a comprehensive assessment of the efficiency of the combined production of two types of energy (thermal and electrical) in a CP, it is proposed to use the concept of "fuel utilization factor" -  $FUF$ . And the definition of such a value should be performed according to the relationship:

$$FUF = \frac{N_{\tau} + Q_{\tau}}{Q_{fl\tau}} 100 = \frac{\sum(N \cdot \tau_1 + Q \cdot \tau_2)}{Q_{lh}^c \cdot B_{\tau}} 100, \% \quad (5)$$

where  $\tau$  is the total period of the CP unit operation time for which the efficiency indicator is determined. It is possible that  $\tau_1 \neq \tau_2$ , and  $\tau \neq \tau_1 \neq \tau_2 \neq \tau_1 + \tau_2$ . The time periods of useful heat generation -  $\tau_2$ , electrical energy -  $\tau_1$  and the total period of the CP unit operation time -  $\tau$  are determined during the installation survey.

As can be seen from (5), the value of the  $FUF$ , as a complex indicator of the efficiency of the CP, characterizes the relationship between the amount of produced electrical  $N_{\tau_1}$  and useful thermal  $Q_{\tau_2}$  energy on the one hand and the potential of the used fuel  $Q_{fl\tau}$  on the other.

To estimate the instantaneous value of the efficiency of combined production, it is suggested to use dependence (6) with the instantaneous values of energy flows (heat productivity and electric power):

$$FUF = \frac{N + Q}{Q_{hff}} 100, \% \quad (6)$$

To increase the efficiency of combined heat and power generation, it is important to ensure the beneficial use of waste heat from the CP.

In the absence of a fuel metering unit supplied to the CP, it is possible to determine the supplied input energy potential based on the enthalpy values of the combustion products and their consumption according to the relationship:

$$Q_{hff} = \frac{(i_{ecf} - i_{eac})V_{vcp}}{3600}, \text{ kW} \quad (7)$$

where  $i_{ecf}$  - enthalpy of combustion products at fuel combustion temperature,  $\text{kJ/m}^3$ ;  $i_{eac}$  - enthalpy of air supplied for combustion,  $\text{kJ/m}^3$ ;  $V_{vcp}$  - is the specific volume of combustion products  $\text{m}^3$  of combustion products/ $\text{m}^3$  of combustible gas.

The obtained values of the efficiency of the engine and generator ( $KEE_N$ ) for the production of electrical energy and the efficiency of heat generation ( $KEE_Q$ ) allow us to achieve the main goal of the

work – to determine the values of specific costs of conventional fuel for the release of electrical and thermal energy in a cogeneration plant based on an internal combustion engine.

This was done according to the relationship:

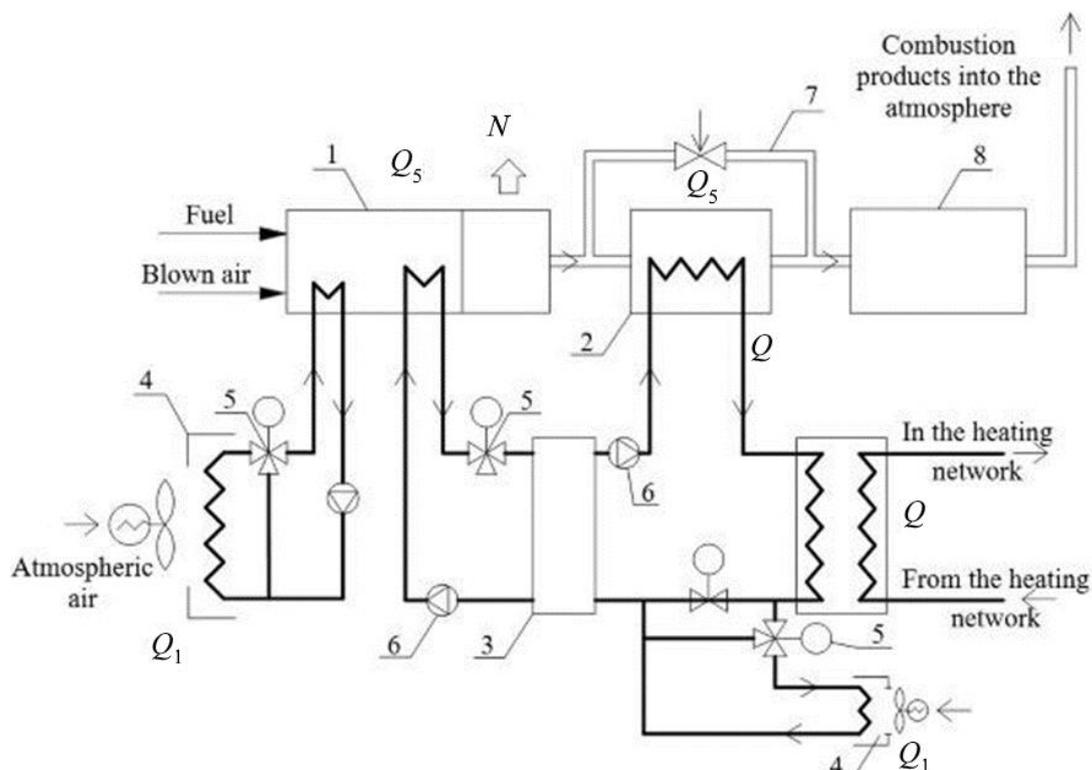
- specific consumption of equivalent fuel (kg.e.f.) for the release of 1 kWh of electrical energy:

$$b_N = \frac{0.123}{KEE_N}, \text{ kg.e.f./kWh}; \quad (8)$$

- specific consumption of equivalent fuel for the release of thermal energy:

$$b_Q = \frac{0.123}{KEE_Q}, \text{ kg.e.f./kWh}. \quad (9)$$

The field studies of the efficiency of the CP operation, according to the given dependencies, were carried out on the basis of the TEDOM Caterpillar G 3512E machine, installed in the boiler house of the municipal enterprise of centralized heat supply. The basic diagram of the CP is presented in figure 2.



**Figure 2.** Schematic diagram of the piping of the combined heat and power plant: 1 - engine and electric generator; 2 - heat exchanger-utilizer of combustion products; 3 - automatic control system of coolant flows (hydraulic manifold); 4 - additional atmospheric heat exchangers-coolers of the engine without useful heat utilization; 5 - three-way control valves; 6 - circulation pump; 7 - bypass; 8 – muffler.

The flue gas duct after the waste heat exchanger was adopted as the balance point (BP) during the tests.

During the tests, the temperature of the combustion products and their composition, as well as the excess air coefficient in them, were determined. Water is used as a heated working fluid in the engine cooling circuit of the coolant, the parameters of which were determined during the tests.

When the engine operating parameters deviate from the nominal ones, the systems of additional heat extraction from the engine using cooling towers are automatically switched on. Utilization and useful

use of heat in them is assumed - heat is discharged into the atmosphere. Thus, the priority of stable, efficient and reliable engine operation is realized. Increasing the efficiency of the engine cooling system allows to increase the thermal efficiency of its operation in generating electric energy, to achieve an increase in the electric power of the CP unit and, accordingly, to increase the amount of generated electric energy, which is the main task of the unit.

But the discharge of heat obtained during engine cooling to atmospheric coolers (heat exchangers of cooling tower) reduces the amount of utilized heat and the efficiency of the system as a whole.

This has a negative impact on the technical and economic performance of the plant. The thermodynamic analysis of the operation of the internal combustion engine cycle indicates the dependence of not only the comprehensive FUF indicator, but also the efficiency of the engine and  $KEE_N$  for the production of electrical energy of the CP on the factor of the intensity of heat extraction from the engine and the efficiency of its cooling system.

The operating parameters of the CP were studied under different operating conditions. The results of the examinations are presented in table 1.

**Table 1.** Results of the study of the work of the CP.

The name of the parameter that characterizes the work of CP	Unit of meas.	Modes of work of CP			
		No. 1	No. 2	No. 3	No. 4
Consumption of natural gas with a heat of combustion of 9.39 kW h/m <sup>3</sup>	m <sup>3</sup>	194	210	43200 in 240 hours	21120 in 96 hours
The heat flow obtained with the input fuel ( $Q_n$ )	kW	1821.6	1971.9	1690	2066
The flow of useful heat generated by the heating heat exchanger	kW	836.9	607.1	660	595
Heat flow discharged to cooling tower coolers (heat loss)	kW	0	240.8	230	293
Power from generated electrical energy	kW	705.0	680.2	808	954
The amount of heat obtained with the input fuel	kW h	-	-	405648 in 240 hours	198317 in 96 hours
The amount of received electrical energy	kW h	-	-	173920 in 240 hours.	91600 in 96 hours
The amount of received useful thermal energy	kW h	-	-	105600 in 160 hours	32130 in 54 hours
The amount of heat discharged to cooling tower coolers	kW h	-	-	18400 in 80 hours.	12306 in 42 hours
The amount of heat lost with exhaust gases	kW h	-	-	88600 in 240 hours	51840 in 96 hours
The amount of heat that is lost from the surface of the engine, generator, heat exchanger and pipelines.	kW h	-	-	19128 in 240 hours	10440 in 96 hours
Thermal flow of heat loss from the surface of the engine, generator, heat exchanger and pipelines.	kW	134.0	160.8	-	-
Heat flow with exhaust gases into the atmosphere	kW	145.5	283.0	-	-
$KEE_N$ on the production of electric energy	%	38.7	34.5	42.8	46.1
$KTE_Q$ on thermal energy production	%	45.9	30.8	26.0	16.2
Fuel utilization factor $FUF$	%	84.6	65.3	68.9	62.3

The analysis of the survey results allows us to draw the following conclusions:

- the highest efficiency of the CP unit operation is observed in the absence of heat discharge to the

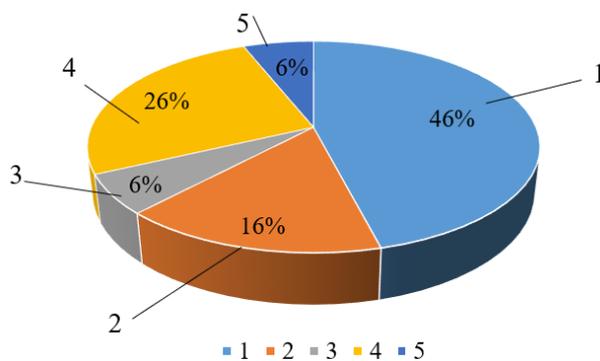
cooling tower-cooler and the possibility of realizing the heat obtained in the waste heat exchangers as useful;

- any operation of the CP unit for a certain period of time other than one hour leads to the need to discharge part of the produced heat to the cooling tower heat exchangers due to the fact that the main priority of the scheme is the reliable and efficient operation of the unit's engine;

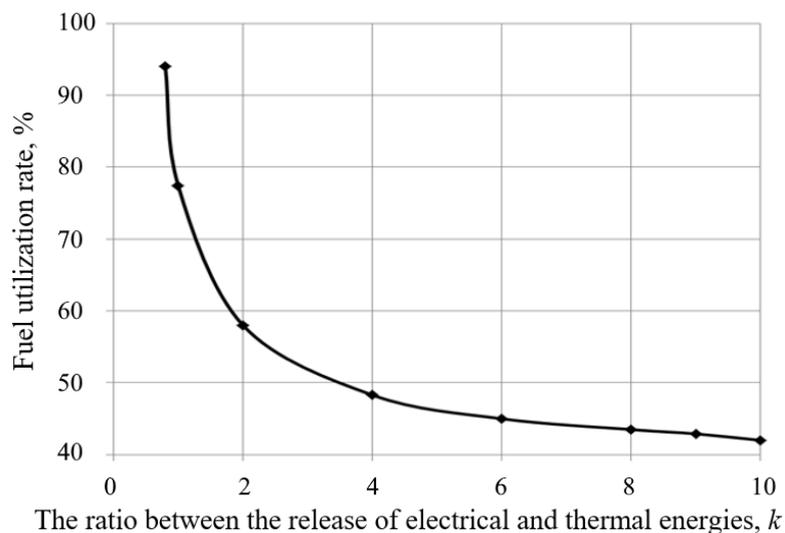
- a decrease in the useful amount of heat produced in the waste heat exchangers leads to a significant increase in heat losses with the exhaust gases of the unit and losses in the cooling towers-coolers. With a ratio between useful and lost heat of about  $\frac{1}{2}$ , the fuel utilization factor in the unit did not exceed 62%, and the structure of the energy balance of the unit is shown in figure 3;

- a decrease in the release of useful and liquid heat during the operation of the CP leads to a decrease in the efficiency indicator of the unit - the fuel utilization factor. The graphical view of the dependence of the FUF on the ratio between the release of electrical and thermal energy is shown in figure 4.

- the specific value of fuel consumption for the operation of the CP to generate thermal and electrical energy depends significantly on the ratio between the release of electrical and useful thermal energy.



**Figure 3.** Energy balance of the CP operation with the ratio of useful and lost heat of  $\frac{1}{2}$ : 1 - useful generation of electrical energy - 46%; 2 - useful generation of thermal energy - 16%; 3 - heat losses in the cooling tower - 6%; 4 - heat losses with exhaust gases - 26%; 5 - heat losses with heated surfaces of the equipment - 6%.

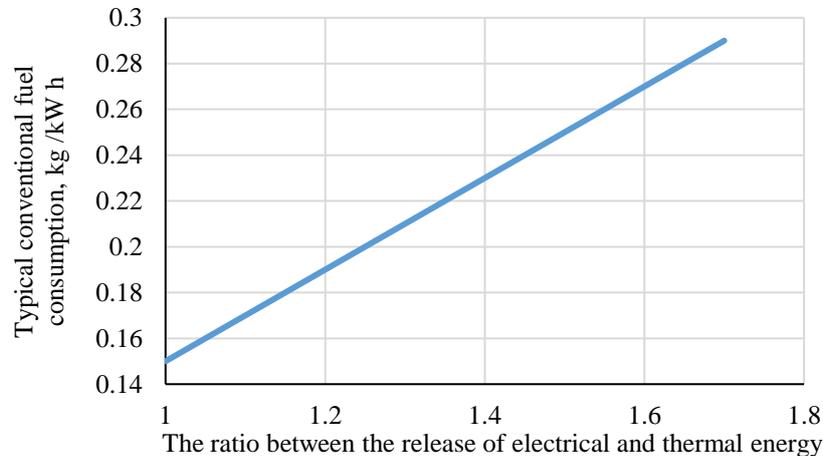


**Figure 4.** Dependence of the FUF on the ratio between the release of electrical and useful thermal energies.

Figure 5 shows a graph of the dependence of specific consumption of equivalent fuel for the CP, obtained as a result of tests.

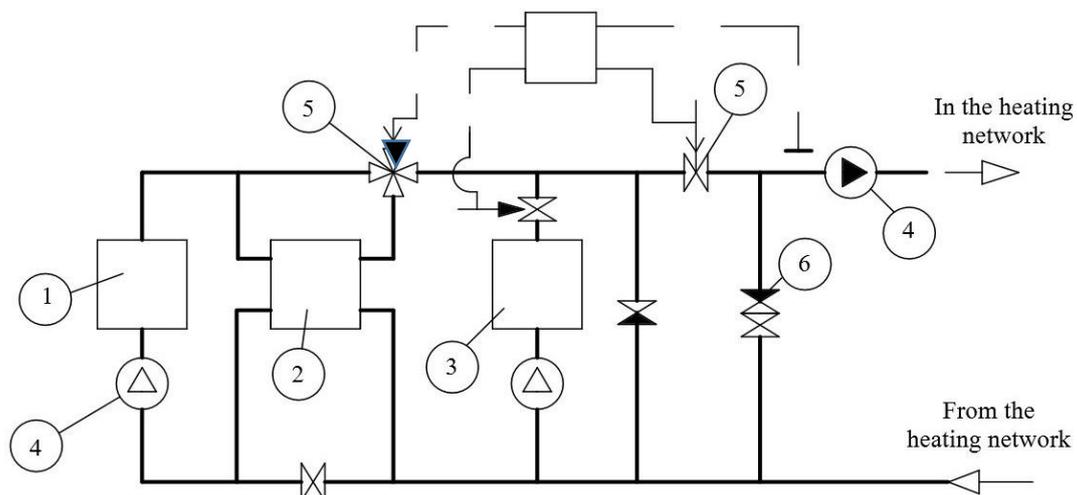
Reduction of useful thermal energy supply to consumers in relation to electric energy leads to a sharp increase in specific fuel consumption and deterioration of the economic performance of the CP. The influence of the value of the supplied electric energy itself remains important. Increasing the supply of

electric energy and bringing this value closer to the nominal passport setting leads to a decrease in specific fuel consumption.



**Figure 5.** Dependence of specific fuel consumption on the ratio between the release of electric and useful thermal energy.

To achieve high energy efficiency indicators, the method of connecting the CP to heat consumers is also important. The most common and simple scheme is the connection to the return pipeline of the heating networks, before switching on to the main boilers of the boiler room. The coolant is supplied according to the following scheme from the return pipeline of the heating networks and is supplied to it again, after which it is sent to the boiler. But as studies have shown, such a connection scheme leads to an increase in the temperature at the inlet to the boilers, which is one of the important negative factors for the operation of the boilers, since it leads to a decrease in their efficiency. Therefore, the CP connection scheme shown in figure 6 is proposed.



**Figure 6.** Connection diagram of CP to district boiler house system of centralized heat supply: 1- cogeneration plant; 2- heat accumulator; 3- boiler of district boiler house; 4- circulation pumps; 5- regulators; 6- check valve.

The scheme provides for the possibility of increasing the production of useful heat due to the placement of the heat accumulator, it is impossible to increase the temperature of the water at the boiler inlet, automatic regulators ensure the operation of the boiler in peak mode and adapt the CP to the main cycle of release and regulation of heat supply.

#### 4. Conclusions

The studies allowed us to determine the influence of the main factors on the efficiency of the CP as distributed sources of electric energy.

The obtained data show that one of the main factors influencing the parameters of the CP operation is the possibility of supplying consumers with useful thermal energy.

1. It is shown that the most common way to use waste heat energy from the CP is to transform it into hot water energy. The resulting hot water is sent to the heating and hot water supply systems of consumers. When using the CP to increase the stability of boiler houses of centralized heat supply systems (HS), it is advisable to supply the resulting hot water to the HS heating networks. But in this case, the warm period of the year is the most intense for those heat supply systems that do not have a hot water supply service. The need for heat in the HS system decreases sharply. To achieve the highest possible performance indicators of the CP, it is necessary to increase the useful heat consumption and achieve the CP capacity for thermal energy up to the nominal. Another way to ensure a stable heat load on the unit is to include heat accumulators in the heating circuit of the boiler house.

In the absence of demand for thermal energy by consumers, a forced measure for the operability of the CP is cooling the water heated in the engine circuit in atmospheric cooling towers. Such heat will be lost and the overall efficiency of the CP will be significantly reduced. Such heat is classified as non-cogeneration. And high-temperature combustion products after the internal combustion engine, in the absence of demand for heat, have to be discharged into the atmosphere without cooling. This heat also becomes an irrecoverable loss, which contributes to a decrease in the efficiency of the unit.

2. A good option for operating the CP unit during such a period may be to obtain cold in an absorption refrigeration unit using waste heat energy from the CP unit with subsequent useful use of it (if necessary). For example, to create the necessary characteristics of the microclimate of premises or the necessary characteristics of the operation of technological devices during the warm period of the year. It is also possible to combine the operation of the CP unit with a heat pump. In this case, the excess electrical energy produced in the CP unit will also come in handy.

Optimal operation of the CP unit (with the lowest possible specific fuel consumption) will be achieved when it operates for a longer period of time at a constant nominal power close to the rated power, without frequent adjustment of the supply of thermal and electrical energy to the network.

In order to determine the average performance indicators of the CP for a certain period of the year, it is necessary to control the duration of operation of the installation under a certain load, and further determine the specific consumption depending on the amount of load and subsequent averaging of efficiency indicators over time.

3. During the operation of the CP, it is necessary to prevent a decrease in the temperature of the combustion products at the balance point (after the heat exchanger-utilizer) below 100-110 °C to prevent condensation of water vapor in the combustion products, avoiding the need to remove condensate from the flues and chimney with combustion products.

When the temperature of combustion products decreases below the dew point, the calculations of the technical and economic characteristics of the CP operation should be made with the correction of the value of the combustion heat of the fuel. For this, it is necessary to use the value of the higher combustion heat specified in the gas quality certificate. Thus, the heat of condensation of water vapor in the composition of the combustion products will be taken into account.

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