Marta MARTYNYAK-ANDRUSHKO
Marta KUZNETSOVA
Institute of Engineering and Systems Management
National University "Lviv Polytechnic", Ukraine

METHOD OF DETERMINATION THE EFFICIENCY OF WORK CENTRALIZED HEATING SYSTEM

Problem statement

Today, district heating is central to the total heat supply of objects in many countries of the world. The advantages of district heating over decentralized are obvious: high thermal efficiency, the ability to burn low-cost fuels of local origin, small fuel transport costs, less pollution of the environment, through the introduction of highly effective equipment systems, etc.

Over the past 15 years, most of Ukraine's neighboring countries have modernized their district heating systems to provide high-quality centralized heat and hot water supply at affordable prices based on financial stability. Ukraine did not make this transition.

The current state of the existing district heating systems of the country is conditioned by the fact that its main technologies and equipment were created in the 60's and 80's of the last century. They correspond to optimal conditions of the "era of cheap fuels", in which most of the progressive but costly technologies of insulation of housing, the effective transformation of primary energy into heat, its transportation, distribution, and regulation were beyond the limits of economic feasibility. Therefore, the specific heat consumption of Ukrainian households per 1 m^2 of living space, as well as the specific expenditures of primary energy for holidays and transport of heat, exceeds the corresponding indicators of economically developed countries of western and northern Europe, and in recent years – and indicators of countries – former members of the camp that began earlier to implement measures of insulation of buildings.

Today, large funds are required for efficient and economical operation of district heating systems in Ukraine, for their modernization with the installation of high-tech and environmentally sound equipment.

The state of the vast majority of district heating systems, in particular, the closed type, can now be characterized as insufficiently effective. This is primarily due to the fact that they have installed morally and physically obsolete equipment. There are a high failure rate and low-quality control of the release of coolant, as a result – excess fuel, which leads to excessive heat losses or (more often than not) low supply of heat energy to the consumer.

In the sphere of municipal heat and power utilities, about 60% of boiler-houses have already worked out their normative term, and 38% of boiler houses exploit inefficient and obsolete boilers with low efficiency, which results in significant losses of fuel. Almost 40% of thermal points are in an emergency, which leads to constant interruptions in hot water supply and over-consumption of fuel and energy resources. Heat networks in their majority also have a significant degree of wear and are not equipped with modern types of thermal insulation, 15.8% of the total length of the networks is an emergency [3].

Analysis of recent research and publications

In scientific publications [1, 2, 5] you can find different approaches to problem-solving and regulation of the situation. The practice of European countries [3] testifies to the highest effectiveness of mechanisms of state regulation in indirect methods, namely: the establishment of tax rates and the provision of tax privileges, depreciation rates, regulation of the interest rate discount rate, norms of mandatory redundancy, state guarantees under granted or received loans, introduction export-import duties, credit privileges, open market operations and, most importantly, modern approaches to the calculation.

To date, Ukraine has not developed a methodology for calculating heat losses, taking into account all elements in the path of "generation of energy – the heat consumer", there is no methodology for assessing the state of the systems which are based on indicators of fuel, heat, water and electricity meters. Problems of improving the energy efficiency of systems and their connected buildings [3] are considered separately, without taking into account the mutual techno-economic impact of measures implemented in these interconnected heat engineering systems, therefore the development and implementation of these methodologies become a priority task.

Setting objectives

The purpose of the article is to develop a method of analysis and calculation of the efficiency of the closed-loop system of district heating, which will allow simultaneously analyzing the state of the district heating system in general and its components, in particular, depending on the mode of operation of the system.

Presentation of the main research material

In real conditions, the release of thermal energy from thermal power plants (CHP) to external thermal consumers takes place in two fundamentally different schemes: open and closed, namely the closed circuit, household and industrial facilities are an important component of the overall energy supply of the state.

In open systems, circulating water is partially or completely disassembled by subscribers, which leads to a large amount of feed that reaches 50% or more of the amount of circulating water against 1-3% in closed systems. The choice of a closed or open system depends primarily on the water supply conditions of the generating facility and the heat sources. An analysis of the functioning of open-source district heating systems is given in [4].

In the closed scheme of thermal energy release, the transfer of heat energy to the thermal consumer occurs through an intermediate heat exchanger. The steam coming from the turbine selections in the intermediate heat exchanger is only a heating medium for the coolant that is fed to the external heat carrier. The steam that gave its heat energy, returns to CHP.

Consider the centralized heat supply system (Fig. 1), which consists of a heat source (CHP or boiler house) (1), a heat exchanger (2), pipelines for supplying energy to the heat exchanger and the water supply pipelines to the heat exchanger, as well as to the heat consumer (3).

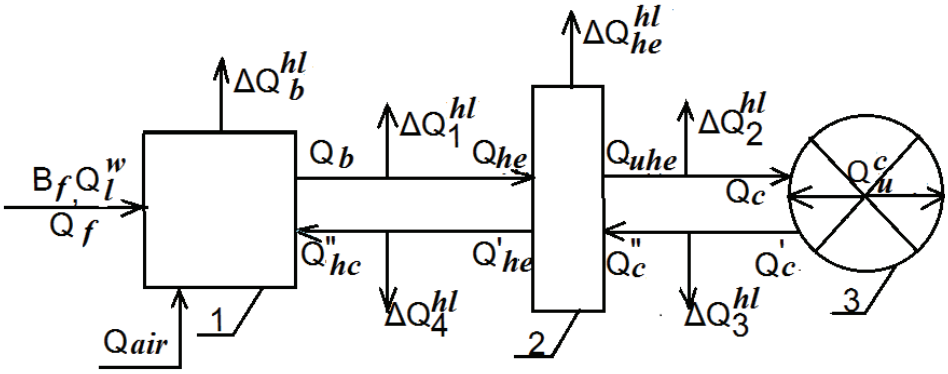

Figure 1. *Principal scheme of the system of centralized heat supply of the closed type: 1 – a source of energy (boiler house or CHP), 2 – heat exchanger, 3 – heat consumer*

For a heat supply system, the amount of the thermal energy entering the fuel boiler with fuel Q_f is considered and it can be determined by the equation:

$$Q_f = Q_{uh} + \Delta Q_{hl} \tag{1}$$

where: Q_{uh} – useful heat generating by boiler, ΔQ_{hl} – heat loss in the boiler.

If to express heat losses in a boiler in units of unit, then they will be as follows: $q_2 + q_3 + q_4 + q_5 + q_6$, (where: q_2 – heat loss with waste gases, q_3 – heat loss with chemical incomplete combustion, q_4 – heat loss with mechanical underburning, q_5 – heat loss in the environment, q_6 – heat loss with physical heat of the ash).

The amount of heat entering the fuel boiler will consist of the sum:

$$Q_h^{sum} = Q_f + Q_{air} + Q_{hc}^{"} \tag{2}$$

where: Q_{air} – the amount of heat that enters with the air; Q_f – the amount of heat of fuel; $Q_{hc}^{"}$ – the amount of heat which is coming with energy (condensate).

The components of heat Q_{air} and $Q_{hc}^{"}$ introduced into the boiler are sometimes not considered in the engineering calculations, as their share of heat in the overall component is insignificant.

To calculate the efficiency of the system, we introduce correctional energy coefficients to the total amount of heat supplied to the boiler fuel. For a small amount of heat that is added in addition to air and condensate, we introduce the correctional energy coefficients

The correction factor K_{air} for the heat supplied to the boiler with air is determined by:

$$K_{air} = \frac{Q_h^{sum}}{Q_f + Q_{hc}^{"}} \tag{3}$$

and the correction factor for the heat supplied with the condensate:

$$K_{hc}^{"} = \frac{Q_h^{sum}}{Q_f + Q_{air}} \tag{4}$$

Then the total amount of heat entering the boiler is determined:

$$Q_h^{sum} = Q_f \cdot K_{air} \cdot K_{hc}^{"} \tag{5}$$

The amount of useful heat generated by the boiler for the period τ can be written down as:

$$Q_{uh} = \int_0^{\tau} Q_i d\tau \tag{6}$$

where Q_i is amount of heat generated by the boiler per unit of time.

When n boilers operate, the amount of heat generated by the boiler house (CHP) will be recorded as the amount of heat generated by each boiler:

$$Q_{uh}^n = \sum_{i=1}^{i=n} \int_0^{\tau} Q_i d\tau \tag{7}$$

where n is the number of boilers.

The heat loss of the boiler will be determined by the equation:

$$\Delta Q_b^{hl} = Q_n^{sum} \sum_{i=2}^{i=6} q_i \tag{8}$$

During the boiler period of work τ, heat loss can be determined as:

$$\Delta Q_b^{hl} = \int_0^{\tau} \Delta Q_b^{hl} \cdot d\tau \tag{9}$$

When n boilers are working, we will find total losses for the period τ in boiler-house:

$$\Delta Q_{sum\ b}^{hl} = \sum_{i=1}^{i=n} \left(Q_f^{sum} \sum_{i=2}^{i=6} q_i \right)_i \tag{10}$$

or

$$\Delta Q_{sum\ b}^{hl} = \sum_{i=1}^{i=n} \int_0^{\tau} \Delta Q_{b,i}^{hl} d\tau \tag{11}$$

The total amount of the heat entering the boiler house will be determined by the heat losses and useful heat of the boiler, with the summing up of the useful heat and losses:

$$Q_h = \sum_{i=1}^{i=n} \int_0^{\tau} Q_i d\tau + \sum_{i=1}^{i=n} \int_0^{\tau} \Delta Q_{b,i}^{hl} d\tau \tag{12}$$

The efficiency coefficient η_b of the boiler will be determined from the equation:

$$\eta_b = \frac{Q_b}{Q_h^{sum}} = \frac{\int_0^{\tau} Q_{b,i} d\tau}{\int_0^{\tau} Q_{b,i} d\tau + \int_0^{\tau} \Delta Q_{b,i}^{hl} d\tau} \tag{13}$$

Amount of the heat entering the heat exchanger:

$$Q_{he} = Q_h^{sum} - \left(\Delta Q_b^{hl} + \Delta Q_1^{hl} \right) \tag{14}$$

and the coefficient of transport of the heat from the boiler-house to the heat exchanger will be determined as follows:

$$\eta_{b-he}^{tr} = \frac{Q_{he}}{Q_b} = \frac{Q_b - \Delta Q_1^{hl}}{Q_b} = 1 - \frac{\Delta Q_1^{hl}}{Q_\kappa} \tag{15}$$

To determine the heat loss in the heat exchanger:

$$\Delta Q_{he}^{hl} = Q_{he} - Q_{uhe} \tag{16}$$

and the useful heat that gives the heat exchanger Q_{uhe} will be found as follows:

$$Q_{uhe} = Q_{he} - \Delta Q_{he}^{hl} \tag{17}$$

During the period of operation, τ, the amount of the heat that the heat exchanger gives to the consumer will be determined

$$Q_{uhe}^{\tau} = \int_0^{\tau} Q_{he,i} d\tau - \int_0^{\tau} \Delta Q_{he,i}^{hl} d\tau \tag{18}$$

In this case, the heat load of heat exchangers from the side of the supply of heat from the boiler house (CHP) will be determined as follows:

$$Q_{he}^{b} = Q_{he} - Q_{hc}^{'} \tag{19}$$

and from the side of the heat consumer:

$$Q_{uhe}^{c} = Q_{uhe} - Q_{c}^{"} \tag{20}$$

where: Q_{he}^{b} – the amount of the heat received by the heat point from the side of the boiler-house (CHP); Q_{uhe}^{c} – the amount of the heat used by the heat consumer.

The coefficient of efficiency of the heat exchanger will be found as:

$$\eta_{he} = \frac{Q_{uhe}^{c}}{Q_{he}^{b}} = \frac{\int_0^{\tau} Q_{uhe}^{c} d\tau}{\int_0^{\tau} Q_{he}^{b} d\tau} \tag{21}$$

For the modern heat exchangers, without the addition of additional energy sources, the efficiency is quite high and is at a level of 97-99%.

The heat transfer coefficient of heat from condensate from the heat exchanger to the boiler for modern heat-insulated pipes is quite high and it is often not taken into account in engineering calculations.

When the heat transporting from the heat exchanger to the consumer there is a loss of it ΔQ_2^{hl}.

The coefficient of transport is determined similarly to the transport of the heat from the boiler to the heat exchanger η_{uhe-c}^{tr}, namely:

$$\eta_{uhe-c}^{tr} = \frac{Q_c}{Q_{uhe}} = \frac{Q_{uhe} - \Delta Q_2^{hl}}{Q_{uhe}} = 1 - \frac{\Delta Q_2^{hl}}{Q_{uhe}} \tag{22}$$

When the return energy from the heat consumer to the heat exchanger supplying in heat networks there is a loss of heat. Depending on the temperature of the return energy of the heat consumer, these losses can vary in absolute value. At the same time, they can be determined by the coefficient of transport of the return energy carrier of the heat consumer:

$$\eta_{c-uhe}^{tr} = \frac{Q_c^{"}}{Q_c^{'}} = \frac{Q_c^{'} - \Delta Q_3^{hl}}{Q_c^{'}} = 1 - \frac{\Delta Q_3^{hl}}{Q_c^{'}} \tag{23}$$

Then we can find the coefficient of efficiency of the district heating system with a closed-circuit heat exchanger:

$$\eta_{dh} = \frac{Q_c}{Q_h^{sum}} = \frac{Q_b}{Q_h^{sum}} \cdot \frac{Q_{he}}{Q_b} \cdot \frac{Q_{uhe}}{Q_{he}} \cdot \frac{Q_c}{Q_{uhe}} \tag{24}$$

or

$$\eta_{dh} = \eta_b \cdot \eta_{b-he}^{tr} \cdot \eta_{he} \cdot \eta_{uhe-c}^{tr} \tag{25}$$

The amount of the heat that the heat consumer receives will be determined as follows:

$$Q_c = Q_h^{sum} - \left(\Delta Q_b^{hl} + \Delta Q_1^{hl} + \Delta Q_{he}^{hl} + \Delta Q_2^{hl} \right) \tag{26}$$

With known coefficients of efficiency of the boiler, heat exchanger and energy carrier, the amount of heat supplied to the heat consumer, we will find from the equation:

$$Q_c = Q_h^{sum} \cdot \eta_b \cdot \eta_{b-he}^{tr} \cdot \eta_{he} \cdot \eta_{uhe-c}^{tr} \tag{27}$$

For a period τ, the amount of heat that the heat consumer will receive will be determined:

$$Q_c^{\tau} = \eta_b \cdot \eta_{b-he}^{tr} \cdot \eta_{he} \cdot \eta_{uhe-c}^{tr} \int_0^{\tau} Q_h^{sum} d\tau \tag{28}$$

The developed method is partly implemented on modernized sections of LCCE "Lvivteploenergo", where was investigated that for the modern systems of district heating, the efficiency of the boiler η_b, heat exchanger η_{he} and transport of energy carriers η_{b-he}^{tr} and η_{uhe-c}^{tr} high enough to transport heat to a heat consumer with low losses. So at $\eta_b = 0.94$, $\eta_{he} = 0.98$, $\eta_{b-he}^{tr} = 0.99$ and $\eta_{uhe-c}^{tr} = 0.99$ amount of heat from the total amount of heat entering the boiler fuel Q_h^{sum} expressed in fractions of unit will consume 0.9 or 90% and more, and for district heating systems that have worked their technical resource with low boilers Efficiency and high heat losses in transport systems the amount of heat supplied to the heat consumer in comparison with the total heat entering the boiler will be 70% or less.

Conclusions

1. An analysis of the work of the centralized heat supply systems in Ukraine shows that most of them are sufficiently worn out, do not meet the current technical level, and therefore require significant capital investments, both in transport systems and in sources of thermal energy generation.
2. The proposed method of analysis and calculation of the efficiency of the system of centralized heat supply of the closed type with the heat exchanger allows to analyze the state of its components and the system as a whole, to determine their profitability, depending on the mode of operation of the system, structural changes in the system and the duration of its operation.

References

[1] Воінов О.П., *Перспективи оновлення котлів у малих системах* / О.П. Воінов, С.О. Воінов, М.М. Полунін [Текст] // Енергетика та електрифікація. 2013. №4, с. 11-13.

[2] Долинський А.А., *Основы энергоэфективной модернизации коммунальной теплоэнергетики Украины на базе региональных програм (опыт Донецкой области)* [Текст] / А.А. Долинський, Б.М. Басюк, Е.Т. Базеев // Энергетик. 2013. №2. с. 43-46.

[3] Корчміт О.Ю., *Державне регулювання енергоефективності сфери теплопостачання в україні* [Електронний ресурс] / Електронне наукове фахове видання "Державне управління: удосконалення та розвиток". № 12, 2011.

[4] Мартыняк М.А., *К анализу функционирования систем централизованого теплоснабжения* [Текст] / М.А. Мартыняк, И.С. Мысак // Энергетик. 2014. №8, с. 43-44.

[5] Шидловський А.К., *Енергетичні ресурси та потоки* [Текст]/ за загальною ред. А. К. Шидловського. // К.: Українські енциклопедичні видання, 2003 – 468 с.