Improving the Efficiency of Autonomous Heat Supply Systems by Implementing Integrated Control Systems

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Abstract. In this paper we studied the actuality of the problem of optimal control of the heat supply system as a single complex object on the basis of a generalized mathematical model that takes into account the dynamics of the fuel combustion process, heat generation, its transmission through the heat network and that takes into account the dynamics of heat energy consumption and various external factors.

1. Introduction

Autonomous heat supply systems provide heat energy in the form of heating and hot water supply to the population living both in small settlements and in separated city districts. On the Russian Federation territory, due to natural and territorial conditions autonomous heat supply systems often have no alternatives, but at the same time, the implementation of new technologies in these systems lags behind scientific and technological progress. This lag is due to the inertia of thinking and the established tradition of introducing simple but reliable solutions, and on the other hand, the lack of well-developed solutions that guarantee an increase in the energy efficiency of power equipment.

Steam boilers used in autonomous heat supply systems, as a rule, due to their increased risk during operation, have standard automatic control systems that ensure both energy efficiency and operational reliability. Hot water boilers, especially boilers with manual fuel supply, are either completely manually controlled, or automatic control systems are responsible for only part of the energy equipment (for example, fuel supply and air supply). When manually controlling power equipment in boiler rooms in autonomous heating systems, measuring instruments are used as simple as possible, intended only for visual control. Therefore, the issue of increasing the energy efficiency of autonomous heat supply systems is a systemic one, requiring an integrated scientific approach.

At large thermal power plants, various automated control systems are successfully used, which ensure the reliability and high energy efficiency of heat and electricity generation. The high cost and excessive for autonomous heat supply systems functionality makes it impossible to implement them in boiler houses of medium and low power.

For gas and liquid fuel boilers of medium and low power, there are compact automatic control systems, including those that allow the operation of such boilers without the continuous presence of maintenance personnel. The high energy efficiency of such boilers is due to the type of fuel burned, since both liquid and gaseous fuels can be accurately dosed. The combustion process of fuel in gas and liquid fuel boilers is generally uniform, without drastic changes, which makes it possible to build a control system based on simple PID controllers.
In autonomous heat supply systems, gas and liquid fuel boilers are not widely used for two reasons: the high cost of liquid fuel and the limited ability to connect to a gas supply source. Therefore, in autonomous heat supply systems, solid fuel boilers using wood or coal as fuel are most widespread. Fuel supply to such boilers, as a rule, is carried out periodically manually or automatically.

The combustion of fuel in solid fuel boilers is fundamentally different from the combustion process in gas and liquid fuel boilers: it has a periodic dependence on the supply system, therefore it is characterized by both uneven heat release and uneven air volume required for combustion. This increases the complexity of the combustion control system for solid fuel boilers, as well as the impossibility of applying existing algorithms and models used in control systems for boilers with a continuous uniform fuel supply.

In addition to the direct source of heat supply, autonomous heat supply systems are also characterized by the presence of a strong connection through the heat carrier with the system for transporting heat energy to consumers. Autonomous heat supply networks have less inertia in comparison with central heating networks in cities, also they are more susceptible to the influence of consumers and weather conditions. Therefore, increasing the energy efficiency of autonomous heat supply systems only at the expense of automating the control of boilers at boiler houses is impractical.

Increasing the energy efficiency of autonomous heat supply systems is a complex task that cannot be reduced to the sum of private decisions due to the strong mutual influence of both the heat source on the heat supply network, and vice versa, as well as the strong influence of external factors.

Based on a generalized model of an autonomous heat supply system, an integrated solution is required. In the current economic conditions, increased requirements for energy saving and environmental friendliness, the issue of developing automated control systems (ACS) for the systems at hand becomes relevant. Modern measuring and microprocessor devices make it possible to implement an economically viable solution for autonomous heat supply systems, but currently there is no scientific basis for the development of effective control systems for such systems. Currently, private non-systemic solutions of individual management problems, which can be used as the basis for solving the problem exist and have been tested.

Increasing the energy efficiency of autonomous heat supply systems will improve the environmental friendliness of such autonomous systems, reduce fuel consumption for heat generation and, as a result, reduce the "carbon footprint" of autonomous heat supply systems.

2. Relevance

Until 1991, in our country there was an active interest in improving the energy efficiency of heat supply systems and, in particular, boilers of various designs used in such systems. During this period, various designs of boilers and the organization of the furnace space were actively considered, various control and regulation systems were proposed at the level of the circuitry of that period [1-7]. Later, interest in low-capacity boilers practically ceased for economic reasons: the cost of theoretically achievable fuel savings in autonomous heat supply systems was many times less than the cost of developing and implementing control systems. With the rise in fuel prices, increased interest in energy-saving and environmentally friendly technologies, the issue of developing energy-efficient heat supply systems again became relevant [8-12, 14, 17, 18].

Nevertheless, as the scientific search on this problem has shown, work to improve the energy efficiency of autonomous heat supply systems is aimed, as a rule, at solving individual problems and are not of a systemic nature. The main directions of research by various authors and teams are devoted to improving the efficiency of coal combustion by organizing various combustion systems, including changing the shape of the furnace, the method of coal supply and the organization of air flows in the furnace [10, 12, 13, 15, 16].

All proposed solutions are focused on application at the design stage of heat supply systems and have significant limitations for use in existing systems. In addition, the proposed devices and systems of automatic control and management are focused either on gas boilers [9, 15], or on solid fuel boilers with a continuous screw feed of fuel into the boiler furnace [10, 17, 18].
In world science, similar trends are observed: with an increase in fuel prices, increase in interest in energy-saving and environmentally friendly technologies, researches in methods for reducing harmful emissions from coal-fired power plants and utilizing heat from flue gases have appeared [19-24]. But due to the low prevalence abroad of systems similar to our autonomous heat supply systems, the problem we are considering is not significant for them. The main specificity of foreign works is to consider either large coal-fired power plants or individual boilers.

3. Problem statement
A large number of autonomous heat supply systems are in operation in our country. Only in the Khabarovsk Territory alone there are 248 such systems with a total installed capacity of more than 1200 Gcal/hour and a total fuel consumption of 300 thousand tons of standard fuel a year. The average value of the efficiency of heat supply sources for the supply of heat energy is only 65%, while the passport efficiency of boilers, according to manufacturers, is 80..85% for solid fuel boilers and 90..95% for gas and liquid fuels. Therefore, the task of increasing the energy efficiency of autonomous heat supply systems is topical.

Modernization of boiler houses by replacing equipment with more energy efficient ones does not significantly improve the problem of low efficiency of solid fuel boilers, since the problem with such boilers is not in design flaws, but in the absence of effective control systems for the process of generating and transporting heat energy.

4. Research results
All solid fuel boilers have a lower efficiency than gas and liquid fuel boilers: the efficiency of gas and liquid fuel boilers is in the range of 90..96%, and solid fuel in the range of 70..86%. At the same time, the passport efficiency of solid fuel boilers with periodic fuel loading, as a rule, is indicated by the maximum achievable efficiency at peak modes. The actual efficiency of solid fuel boilers with periodic fuel loading in the process of fuel combustion varies widely and these fluctuations can reach 20..25%, which leads to the fact that the average efficiency per fuel loading cycle is in the range of 60..75% [16, 25]. The periodicity of fuel loading complicates the process of controlling the auxiliary equipment of the boiler, in comparison with boilers with continuous fuel supply: if for boilers with continuous fuel supply, it is enough to know the rate of fuel supply to the furnace in order to calculate the optimal air supply rate and ensure minimum losses with flue gases, then for boilers with periodic fuel loading, it is required to measure many additional parameters, including the determination of the combustion mode (fuel combustion, its combustion and burnout) and, therefore, to estimate the amount of fuel currently burning. This leads to the complication of control algorithm of the auxiliary equipment of the boiler and to the increase in the complexity of the control system as a whole due to the increase in the number of measurement points. Various studies in the field of increasing the efficiency of the fuel combustion process in boilers with periodic fuel loading [9, 15, 26] are aimed to solve the problem of regulating the air entering the boiler furnace and allow to increase the average boiler efficiency per cycle by 2..5%. There are also solutions in the field of building adaptive systems that can be used to improve the efficiency of existing control systems for the combustion process in solid fuel boilers, for example, [32, 13, RFBR grant No. 12-07-00252-a, No. 13-08-00532-a].

As well as the analogue, one can consider the current state of research in related fields, for example, the control of annealing furnaces. In this area or research there is a similar problem of controlling periodic heating and cooling, but associated not with a periodic change in the amount of burning fuel in the stove, but with the frequency of the annealing process. Nevertheless, there are a number of works confirming the relevance of the problem of controlling processes with time-varying parameters [28, 29].

The main disadvantage of the above studies is that they consider the boiler without connections with the heat supply system in which it is integrated [30]. Thus, for this problem there are solutions to particular tasks of varying degrees of elaboration, but at the same time there is no comprehensive solution to increase the energy efficiency of the heat supply system as a single object. In a systematic consideration of the process of generating heat energy, there is a connection between the boiler, the
group of network pumps and the heat supply network through the heat carrier. In some cases, this relationship can be reverse positive and lead to negative consequences. For example, fluctuations in the combustion of fuel in solid fuel boilers with periodic fuel loading leads to fluctuations in heat release, which, in turn, leads to fluctuations in the temperature of the coolant, including fluctuations in the amount of heating of the coolant in the boiler jacket. Since water has different density at different temperatures, fluctuations in its temperature lead to pressure fluctuations in the heat circuit. If the control system of a solid fuel boiler with periodic fuel loading and the control system of a group of network pumps operate independently (which is typical for most boiler houses), then under certain modes of sharp dumping or power gain of the heat supply source in the boiler-pump system, a positive feedback arises, leading to instability of the system regulation of the heat carrier pressure in the heat supply system. This confirms that when building a control system for a heat supply system, an integrated solution to the problem is required, taking into account system connections, and the mutual influence of various equipment of the boiler house and the heat supply network.

5. Conclusions
The task of effective management of autonomous heat supply systems should be based on an integrated approach to automation and effective management of autonomous heat supply systems as a single object, including the research methodology, formalized description, optimization and simulation of autonomous heat supply systems functioning [31]. The solution to this problem will make it possible to systematically increase the energy efficiency of autonomous heat supply systems through the creation, on a scientific basis, of an automated control system for the generation and transmission of heat energy with the integration into a single system of all elements of the autonomous heat supply system.

This research showed that at present there are no systemic effective solutions to increase the energy efficiency of existing autonomous heat supply systems, which leads to an increase in the specific fuel consumption for the supplied heat energy and, as a result, reduces the environmental friendliness of autonomous heat supply systems.

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