HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

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V. N. Mel'kumov[1], S. V. Chuikin[2], A. I. Kolosov[3]

DISTRICT HEATING FROM NUCLEAR POWER STATIONS

Voronezh State University of Architecture and Civil Engineering
Russia, Voronezh, tel.: (473)271-53-21, e-mail: teplosnab_kaf@vgasu.vrn.ru
[1]D. Sc. in Engineering, Prof., Head of the Dept. of Heat and Gas Supply and Oil and Gas Business Russia, Voronezh, tel.: (473)271-53-21, e-mail: ser.chu@mail.ru
[2]PhD in Engineering, Assoc. Prof. of the Dept. of Heat and Gas Supply and Oil and Gas Business Russia, Voronezh, tel.: (473)271-53-21, e-mail: teplosnab_kaf@vgasu.vrn.ru
[3]PhD in Engineering, Assoc. Prof. of the Dept. of Heat and Gas Supply and Oil and Gas Business

Statement of the problem. The limited proven reserves of energy resources lead to the need for a wider use of nuclear energy for heat supply of cities. Therefore studying the possible schemes of district heating from nuclear sources is becoming increasingly important and most promising as it is capable of making up for a growing shortage of generating capacity.

Results and conclusions. The article considers thermal schemes of nuclear power plants heat and atomic power plants, as well as lists the parameters of their main units. This data can be used as an input when searching for the most optimal modes of work stations so that through more profound analysis ways to improve the basic circuits of nuclear power stations could be identified. The method of increasing the economic efficiency of nuclear stations of a heat supply based on a joint work with peak boiler-houses lo-cated in the center of heat loads is set forth.

Keywords: heat power engineering, heat supply, nuclear energy, nuclear stations of heat supply, atomic power plant.

Introduction

Currently fuel has become one of the defining factors of production. A good illustration of the key role of fuel and energy base of the global economy is a so-called energy crises that has made this issue one pressing and global. The emerging energy situation is associated with a rapid decrease in the body of non-renewable reserves of oil, and later on gas, which causes increasing costs as they are being sought after. The response to the energy crises was the development of a strategy for the utilization of fuel and energy based on energy saving and optimization of the structure of fuel and energy resources. It is obvious that in these conditions the share of nuclear energy in fuel-energy balance will steadily increase. The decline of the level of confidence in the nuclear energy after the accident at the Chernobyl nuclear power plant and an increasing reliability of modern designs of nuclear reactors contributed to the change in the tendency of the reduction in the share of nuclear energy in the global balance promote its growth.

The most common are power reactors to generate the electricity in nuclear power plants (NPPs). In the process of the development of atomic energy, a number of different thermal schemes of nuclear power plants (NPP) were suggested. However, the experience of the development of heat schemes of nuclear power plants was the foundation of a further improvement of nuclear installations and thermal equipment. At the same time, the thermal energy characteristic of the Northern territories is in growing demand. For example, in addition to the existing nuclear power plants (ATEC) located in the Chukotka Autonomous District (Bilibino NPP), the construction of a plant for the supply of Arkhangelsk and Severodvinsk is being planned. A floating plant for its Northern territories is being developed as well.

These nuclear facilities for the generation of heat associated with the end-point user via a heat exchanger. The principal scheme of such a setup is shown in Fig. 1. The setup includes a reactor, a piping system, relational pump. In a one-contour loop the heat exchanger flows the same coolant installed in the reactor. In this case, the coolant has a large induced radioactivity and in some cases may contain a radioactive fission product. During the decompression of the heat exchanger radioactive materials will penetrate the end-point contour.

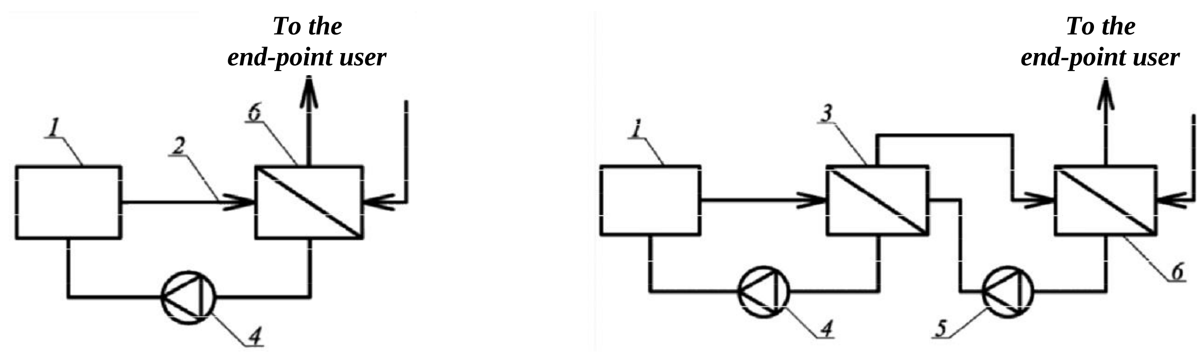

Fig. 1. Single-loop (a) and bypass (b) nuclear power plant for heat supply:
1 — nuclear reactor; 2 — pipe; 3 — intermediate heat exchanger;
4, 5 — circulation pumps of the first and second contours; 6 — end-point exchanger

One-contour setups cannot be used when contamination it is not permitted to pollute a coolant circuit of the consumer. Therefore, the practical use is made of a multi-circuit setup where transfer of heat to the external consumer makes use of two or more coolants not contacting with each other directly. In Fig. 1b the reactor with an intermediate heat exchanger forms the first closed loop and the intermediate heat exchanger, piping and terminal heat exchanger do the second circuit. Each circuit has its own circulating pump.

In multi-loop setups there is hardly any contact of the active coolant of the first circuit to the operating environment of the consumer. However, the implementation of a multi-contour setup is more complicated, since additional hardware is required. In addition to the special stations for heat supply, some nuclear power plants might be utilized. E.g., in Leningrad and Beloyarsk NPP in addition to generating electrical energy there is also a low-grade heat and hot water for adjoining communities. However, the maximum performance of thermal energy is observed for ATEC and nuclear stations of heat supply (NSHS).

1. Schematic diagram of the nuclear steam plant. Nuclear thermal electric pipeline generates electricity and simultaneously through the network heaters releases heat to consumers. The steam for heating water in a network is directed from a heater that is controlled from the selection of the turbine (Fig. 2).

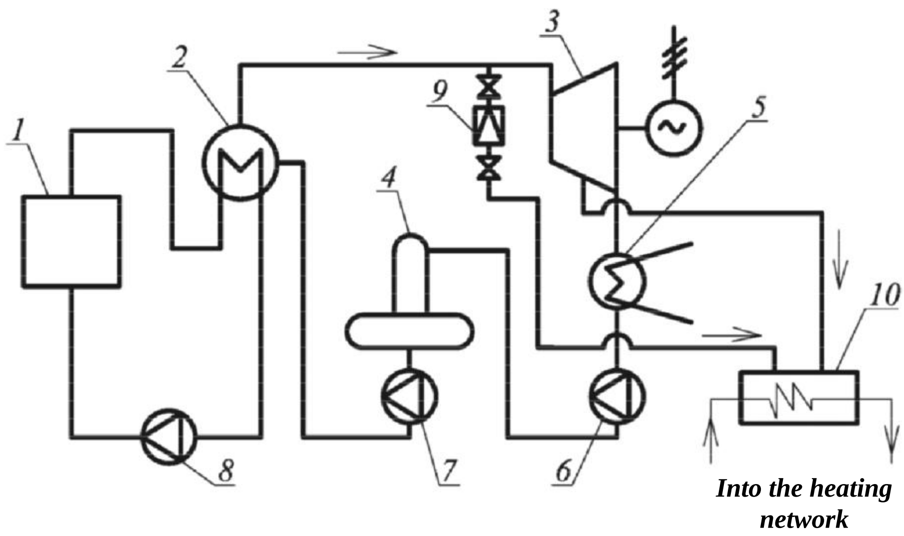

Fig. 2. Scheme of ATEC:

1 is a reactor; 2 is a steam generator; 3 is a turbine; 4 is a deaerator; 5 is a condenser; 6 is a condensation pump; 7 is a feed pump; 8 is a circulating pump; 9 is a reduction-cooling setup; 10 is a heater of nuclear water

To satisfy the peak heat demand a reduction-cooling setup 9 is used. Steam and heat balances of the plant are determined by the following expressions

$$G = G_n + G_k\,, \tag{1}$$

$$N_э = N_n + N_k\,, \tag{2}$$

where G is the total steam flow to the turbine; Gn is the steam consumption selected to meet thermal demands; Gk is the consumption of steam sent to the condenser; N_n is the electrical power produced by the steam selection; N_k is the electrical power produced by the steam entering the condenser.

The most efficient ratio of the produced heat and electric energy is determined by calculating the thermal efficiency using the following expressions. The efficiency of an ATEC:

$$\eta_{АТЭЦ} = \frac{Q_{ИСП}}{Q_{ЗАТР}} = \frac{N_э + Q_{Т.П.}}{Q_p}, \tag{3}$$

where $Q_{T.C.}$ is the amount of heat sent to the consumer; Q_p is the amount of the thermal energy of the power of the reactor.

The efficiency of the production of thermal energy:

$$\eta_{Т.П.} = \frac{Q_{Т.П.}}{Q_{Т.Р.}} = \eta_p \cdot \eta_{пг} \cdot \eta_{тр1} \cdot \eta_{тр2} \cdot \eta_{т.с.}, \tag{4}$$

where $Q_{T.R.}$ is the amount of thermal energy for the production $Q_{T.C.}$; $\eta_{m.\ c.}$ is the amount of heat losses in heating networks;

The efficiency of the production of thermal energy at an ATEC:

$$\eta^{Э}_{АТЭЦ} = \frac{N_Э}{Q_p - Q_{Т.П.} / \eta_{Т.П.}}. \tag{5}$$

In some cases the index of the specific production of thermal energy for meeting a demand for heating is used:

$$ЭТП = \frac{N_{ЭТП}}{Q_{Т.П.}}, \tag{6}$$

where N_{ETC} is the amount of thermal energy that is released by the steam by the selection for a heating demand as well as that for heating provisional water.

In the above scheme the plant thermal energy of nuclear fission is perceived by thermal carriers of the first circuit. Let us consider in more detail the composition of the coolant equipment, e.g. the installation of a reactor VVER-1000 has much in common with the first contours of ATEC for different purposes.

The first contour (Fig. 3) consists of a reactor 1 with four parallel loops (in Fig. there is one loop), each of which includes a steam generator 9, the main circulating pump (MCP) 10, the main isolation valves 8 main circulation pipelines where the organization of several parallel loops makes redundancy of equipment in particular of circulation pumps unnecessary. The water in the reactor is supplied at the pressure of 16.6 MPa with the temperature of 562 K. In the core it is heated up to 595 and is sent to the steam generator where it is cooled giving heat to the secondary coolant. The boiler water enters the main circulation pump which returns it to the reactor. Between the reactor and steam generator there are the main isolation valves that can shut off any loop from the reactor. MCP is installed on the disconnected part of the "cool" pipeline. To create the required pressure for a steam compensator (SC) 6, the steam condensator is used. It also serves to compensate for volume changes of the coolant by heating it at the circuit and the initial pressure. Water in is heated by the heaters 7 and partially vaporized resulting in the necessary pressure. SC is connected to a hot pipe on the side that is kept switched on.

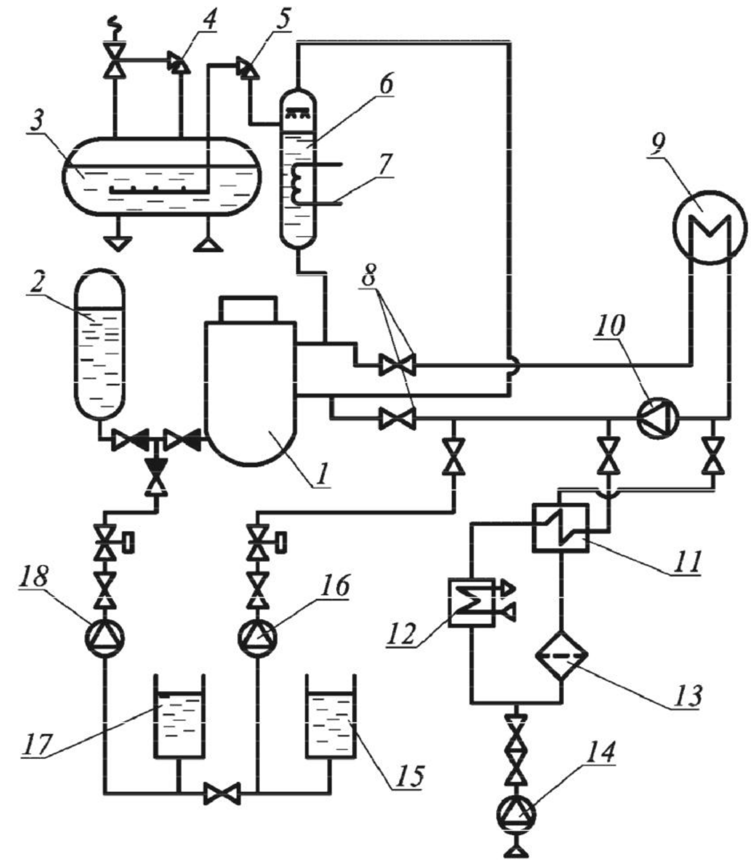

Fig. 3. Scheme of the first circuit of NPP with the reactor VVER-1000:
1 is a reactor; 2 is an accumulator; 3 is a bubbler; 4,5 are safety valves; 6 is a pressure compensator; 7 is a heater; 8 are the main isolation valves; 9 is a steam generator; 10 is a reactor coolant pump; 11 is a heat exchanger; 12 is a refrigerator; 13 is a filter; 14, 16, 18 are pumps; 15, 17 are tanks with boric acid solution

To prevent the pressure SC from exceeding the allowable into the steam space, heat is injected from the cool part of the pipeline. If the injection of the cool keeps resulting in an increase in the pressure, safety valve 5 opens, the output of which is connected to a bubble counter 3. The water temperature in the bubbler is maintained at ~333 K for condensing steam from SC. If the bubbler pressure increases above acceptable, the safety valve 4 in the bubbler will switch on and the heat carrier will be emitted from the first circuit.

The water of the first circuit when the reactor obtains a highly induced radioactivity, as there are always impurities that are activated in the active area. As a result, the first circuit equipment becomes a source of ionizing radiation and thus is placed in unattended areas. To clean the heat carrier off impurities a part of it (a so-called purging) with the flow rate of 22 kg/s with the pressure side coolant is diverted into the filter 13. Before entering the filters, the purge water is cooled down to 318 K. Cooling occurs due to the heating of the purified water in the regenerative heat exchanger 11, after which the filter returns to the loop in the suction branch of the MCP. The final cooling of the purge water is performed using technical water in the fridge 12. Compensation for the losses of the first coolant and the first filling of the circuit produces a charging pump 14 of the special system of the preparation of pure capacitors. Nuclear facilities are equipped with systems of emergency cooling of the active zone of the reactor (ECCS) that provide heat removal from the reactor in case of accidents with the loss of the first coolant. In emergency situations, when the loss of coolant occurs at a slow speed, high pressure pumps are included. At significant depressurization, up to the full instantaneous rupture of a circulation pipe, at first the water is supplied from the accumulator, then high pressure pumps are included, and, if their supply is not enough to maintain the pressure in the circuit a low-pressure pump starts operating.

2. Schematic diagram of the nuclear stations of heat supply. The most cost-efficient use of nuclear fuel is achieved when applied to nuclear power plants. However, in some cases the use of nuclear stations of a heat supply is economically justified. The purpose of the ACT is the production of heat for household and business needs.

The feasibility of the construction of the AST is determined by the following factors:

1) significant facilitation of the conditions for the selection of construction sites for ACT that do not require water resources and additional investments for the construction of systems of technical water supply;

2) great radiation safety of AST compared to the ACEP that allows it to be located at a inconsiderable distance from the consumer;

3) vicinity of AST allows one to avoid significant heat losses during transportation of a heat carrier, to reduce the costs for pumping of a coolant (design of the study the ATEC shows that the costs of transit heat networks is approximately 15 % of the that of the plant);
4) a relatively small value of the required area, less environmental pollution by harmful emissions at the normal and emergency modes of operation.
One of the possible methods of increasing the effectiveness of the AST is to increase the coefficient of the use of its installed capacity that can be achieved by the co-joint operation of AST and peak water-heating boiler stations which provide a covering of the graph of peak thermal load. Providing this part of the graph of the heat load with a peak of sources allows one to increase the duration of the operation of AST at its rated power and to reduce the influence of daily fluctuations of load of hot water supply for its operation mode. The efficiency and reliability of the AST depends on the choice of rational modes of its operation along with peak boilers that must generally be located in the center of thermal loads. In this case, there are two possible schemes of the connection of AST and a peak boiler: the serial and the parallel one. A thermal scheme of the ACT with parallel of a peak boiler is shown in Fig. 4.

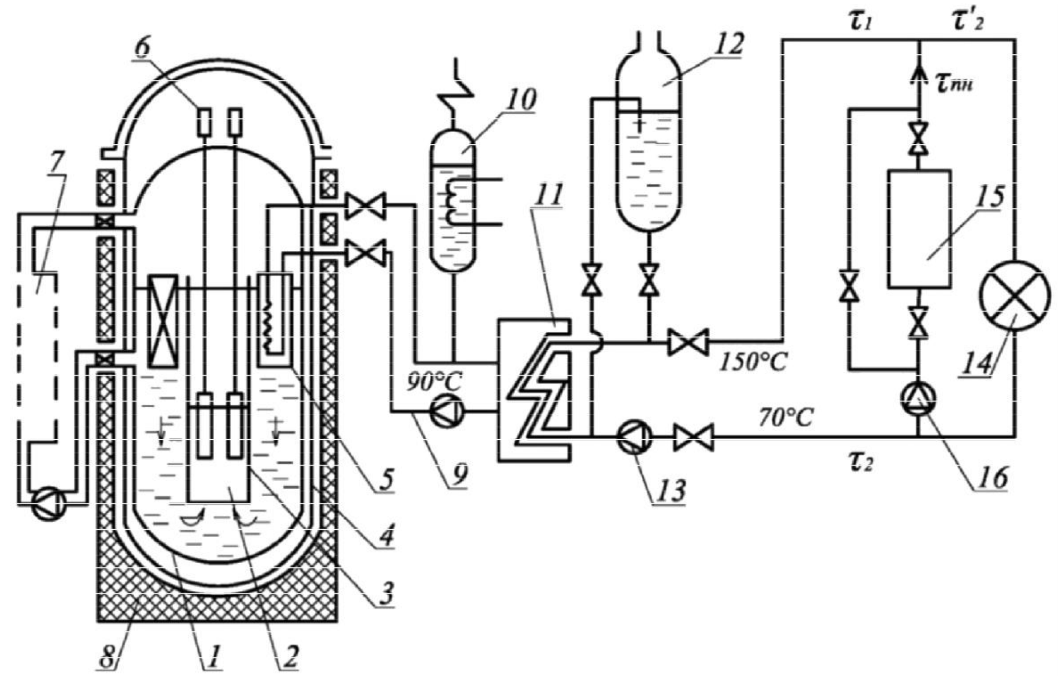

Fig. 4. Scheme of a nuclear power station heating:
1 is a reactor vessel; 2 is a core; 3 is a mine of the contour of a natural circulation; 4 is a safety body; 5 is heat exchanger of the second circuit; 6 is the shutoffs of the control system control and reactor protection; 7 are extra systems of the first circuit; 8 is a ferroconcrete shaft; 9 is the second circuit; 10 is a volume compensator; 11 is network heat exchanger; 12 is a system of emergency cooling; 13 is a pump; 14 is a heat consumer; 15 is a peak boiler; 16 are the pumps of the peak boiler

For the ACT a corpus of pressurized water reactor as more reliable compared to the channel water-graphite reactor. The relatively low pressure inside the reactor leads to a significantly smaller load on the wall and roof of the body of the reactor. To improve the reliability there is a so-called safety case, the main purpose of which is the prevention of coolant leakage of the heat carrier in case of depressurization of the body of the reactor. The concrete shaft is mainly designed to protect against radiation, but it allows one to take additional measures to prevent leaks of the first heat carrier into soil. The heat carrier of the third circuit circulates in the central heating system of residential and public buildings after mixing with water coming from a peak boiler connected with the AST.

Conclusions

1. The thermal schemes of nuclear power plants of heat supply and atomic heat and power plants as well as the parameters of the basic units examined in the article can be used as a source for searching the most optimal modes of operation to allow one to determine the ways of improving the basic circuits of nuclear power plants as a result of more in-depth analysis.
2. An increase in the cost efficiency of nuclear stations of heat supply is possible when they operate jointly with peak boilers located in the centre of thermal loads. At the same time it should be noted that the vicinity of the stations from the city determines higher requirements for the reliability of the station.

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