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Improving the energy efficiency of NPP

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Abstract

The objective of the present study is the analysis and assessment of potential ways for enhancing the energy efficiency of nuclear power generation.

Currently used and promising advanced thermodynamic cycles of nuclear power plants in power generation are examined. Ways for enhancing parameters of working agents in the NPP steam-turbine plants are suggested. Thermodynamic assessment was made of enhancement of thermal efficiency of NPP equipped with fast reactors due to the increase of coolant temperature at the reactor core outlet and, correspondingly, the increase of temperature and pressure of steam generated by steam generator. Analysis of efficiency of utilization of waste low-potential heat at the NPP using heat pumps was performed.

Contemporary level of development of machine building industry for power generation, development of high-efficiency high-temperature gas turbines and steam compressors allow addressing the possibility to achieve high conjugated parameters of steam at NPPs equipped with conventional light-water reactors without exceeding the permissible conditions for operation of reactor cores with fuel cladding made of zirconium alloys.

Application of heat pumps within the cooling circuit of the main condenser of steam-turbine power plant for the purpose of enhancement of financial indicators is not justifiable. As it was demonstrated by estimation calculations, the use of heat pumps within the main condenser loop is promising only for reducing heat discharged by NPPs in the environment. Utilization using heat pumps of low-potential heat removed by equipment cooling systems is the efficient way to improve NPP efficiency. Non-productive extraction of steam from the thermal cycle of the power unit is reduced in this case which results in the additional power generation as well as reduces heat disposal in the environment.

Keywords: Thermal efficiency; Conjugated parameters; Fired superheating; Waste heat; Heat pump.

Introduction

Enhancement of energy efficiency of the national economy is one of the priority tasks [1–3]. The following approaches to achieving this goal are examined in the present paper:

- Increase of nuclear fuel burnup;
- Increase of installed capacity of nuclear power units by upgrading the equipment;
- Increase of thermal efficiency of nuclear power plants by improvement of the balance of heat and thermodynamic cycles;
- Increase of duty factors (DF) of nuclear power units;
- Reduction of thermal and electric power used for coverage of inherent plant power consumption;
- Reduction of non-productive expenditures and losses of energy;
- Use of low-potential heat energy.

Along with the above tasks addressed and solved in evolutionary ways numerous innovation projects [4] capable to radically enhance the environmental, energy and financial efficiency of nuclear power generation are examined.

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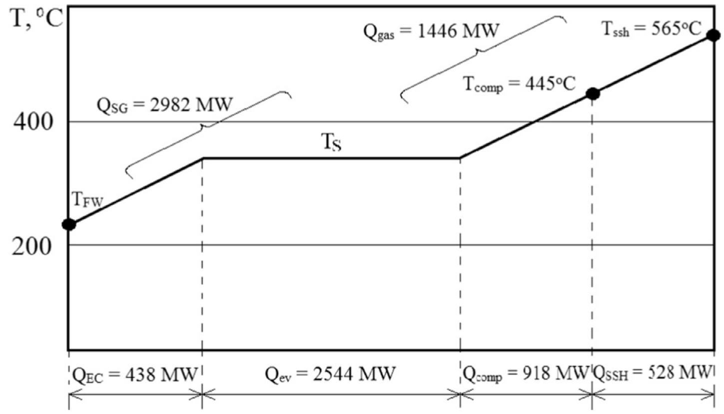

Fig. 1. *T-q*-diagram of processes of heat transfer in the combined nuclear-thermal cycle of NPP on the basis of VVER-1000 reactor.

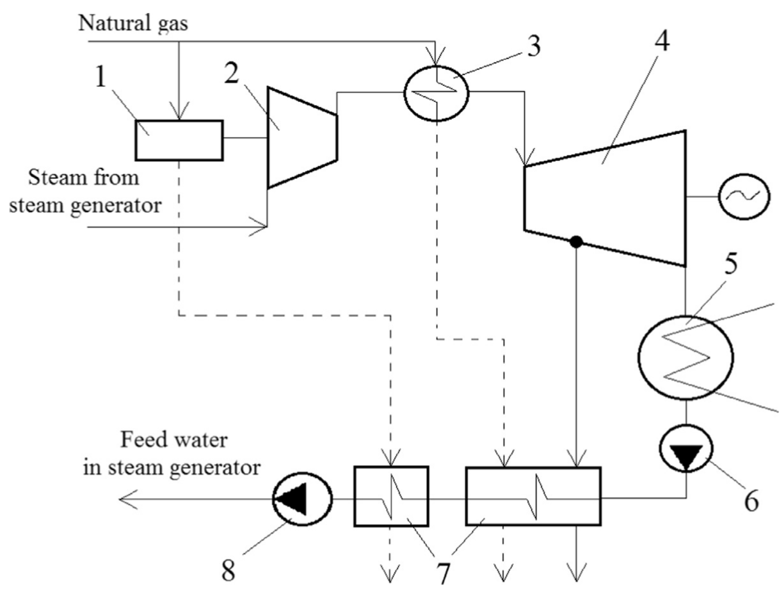

Fig. 2. General layout of the combined nuclear-thermal NPP: 1 – gas turbine engine; 2 – steam compressor; 3 – steam superheater; 4 – steam turbine operated on superheated steam; 5 – steam turbine condenser; 6 – condensate pump; 7 – regeneration system; 8 – feed pump.

Thermodynamic features of contemporary nuclear power generation

Technological cycles of NPPs equipped with water—cooled thermal reactors (LWR) possess the following distinguishing features:

- Value of pressure in the primary cooling loop of high-power LWR reactors (15.7 MPa) selected at the present moment is associated with restrictions on the temperature equal to 350 °C for fuel cladding made of zirconium alloys. It follows from the above that limiting temperature of steam in the secondary cooling loop cannot exceed 315 °C in case of steam overheating. Therefore, selection of zirconium alloy as fuel cladding material and increase of per unit capacity of reactors practically predetermied the following thermodynamic parameters of NPPs equipped with LWRs: pressure in the primary cooling loop equal to about 16 MPa, coolant temperature at the reactor outlet equal to 320 °C–330 °C; pressure and temperature of steam in the secondary cooling loop equal to 6.3 MPa – 7.2 MPa and 279 °C–285 °C, respectively [3].
- High capacity of turbine plants is achieved by elevated gas flow rates which influences losses of thermal energy in the condenser of the steam turbine. Increased non-recoverable heat losses in the low-temperature receiver reduce financial performance of operation of such power units and, therefore, gross thermal efficiency of contemporary nuclear power plants does not exceed, as a rule, 32–35% [3].

Liquid metals allowing removing heat at significant levels of specific heat release are used as a coolant in fast reactors (FR). At present liquid sodium with temperature at the outlet from the reactor core amounting to about 550 °C (boiling point of sodium is equal to 878 °C) is used by practically all power FRs. This allows producing in steam generators superheated steam with elevated parameters ($p = 13$ MPa, $t = 505$ °C), enhances thermodynamic efficiency of the NPP