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PERFORMANCE OF THE NUCLEAR POWER PLANT CONDENSING UNIT

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Abstract. In the article the analysis of the modernization of the condensing unit. Thermal calculations and design of the condensing unit of the Kalininskaya nuclear power plant was conducted. Extension of service life of the operating NPP power units is one of the most important tendencies of the modern stage of nuclear power engineering development and the most efficient funds investment for preserving generating capacities. The data indicate when modernizing the condensing unit, its cooling area was increased for about 4,000 m^2 due to increasing number of tubes. In addition, tube geometrical dimensions were changed; the wall thickness was reduced from 1 and 2 mm to 0.7 and 1.25 mm respectively.

1 Introduction

Service life of first generations of the nuclear power plants (NPP) of the Soviet Union and Russia was determined by absence of actual operational data on the NPP equipment wear and tear, and economic aspects providing necessity of compensating expenses on construction and operation of NPPs [1, 2], obtaining normative amount of profit and forming financial resources for subsequent decommissioning of NPPs.

Further operation experience of the Russian and foreign nuclear power plants provided basis for justifying a technical possibility of revising the power unit service life periods previously set. Comparison of expenses for service life extension of the operating NPPs with investments in construction of new generating capacities demonstrated obvious economic efficiency and attractiveness of investments in service life extension. As a result, long-term growth plans of the nuclear industry of Russia [3, 4] included extension of the operating NPP service life as one of the most important tendencies of the modern stage of nuclear power engineering development.

Processes of carbonate scale deposition on condenser heat-exchange surfaces (CHS) from oversaturated solutions of recirculating water of the closed-circuit cooling system (CCS) can be theoretically divided into several stages, separation of which is found quite impossible [5-9]. Increase of deposit amount in local overheating areas causes corrosion damages of the heat-exchange surfaces and can result in necessity to perform expensive works on repair and even replacement of a steam generator.

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2 Numerical analysis

For providing reliability and increasing steam generator lifetime, and improving reliability and efficiency of the secondary system power units of NPP with a pressurized water reactor PWR-1000 was made of the design and the thermal design of the condenser of the steam turbine K-1000-60/1500 of unit 1 of Kalinin NPP, using the following basic equations (1-6):

The equation of heat balance:

$$Q = G \cdot \Delta h_s \cdot \eta = D \cdot \Delta h_w \tag{1}$$

G – consumption of steam, kg/s;
$\Delta h_s, \Delta h_w$ – enthalpy of steam, water, kj/kg;
η – efficiency factor.

Number of tubes in the one water course:

$$N = \frac{4 \cdot D \cdot v_w}{\pi \cdot d_{in}^2 \cdot w_w} \tag{2}$$

v_w – volume of water, m^3/kg;
d_{in} – inner diameter of the tubes, m;
w_w – velocity of the water, m/s.

Heat transfer coefficient:

$$K = \frac{1}{d_a \cdot \left(\frac{1}{\alpha_1 \cdot d_{ou}} + \frac{1}{2 \cdot \lambda} \cdot ln\left(\frac{d_{ou}}{d_{in}}\right) + \frac{1}{\alpha_2 \cdot d_{in}}\right) + R} \tag{3}$$

d_a – average diameter of the tubes, m;
d_{ou} – outer diameter of the tubes, m;
α_1 – heat transfer coefficient during condensation of steam, W/(m^{2}K);
α_2 – heat transfer coefficient from tubes to water, W/(m^{2}K);
λ – thermal conductivity, W/(m*K);
R – thermal resistance of a contaminated tube, (m^{2}K)/ W.

The surface area of the heat exchange:

$$F = \frac{Q}{K \cdot \Delta t_a} \tag{4}$$

Δt_a – average temperature difference, ^{o}C.

The length of the tubes:

$$L = \frac{F}{\pi \cdot d_a \cdot N} \tag{5}$$

The diameter of the tube bundle:

$$D_t = 1.05 \cdot d_{ou} \cdot b \sqrt{\frac{N}{\Psi}} \tag{6}$$

b – relative pitch;
Ψ – fill factor of the tube plate.

3 Practical implementation

After that JSC "Energospetsmontazh" performed works on replacement of the tube systems. These works were performed on the existing condenser of the steam turbine K-1000-60/1500 of power unit No. 1 of the Kalininsky NPP.

The works were performed during maintenance outage. The condensers with heat exchange tubes from copper-nickel alloy were replaced with condensers with corrosion-resistant steel tubes with weight 33 tons and over 8 m long each. In addition, metal structures for demounting condensers, trestle bridge for condenser replacement, and support assemblies with total weight 19 tons were mounted.

The developed tube systems and assemblies of the modular design condenser of turbine plant K-1000-60/1500 of power unit No. 1 of the Kalininsky NPP shall provide for:

- excluding copper-containing alloys from the NPP secondary system equipment;
- reliability, safety and performance of the condenser tube systems and assem-blies, with extended service life of the NPP equipment being taken into account;
- hydraulic closeness of the condenser tube systems due to fastening tubes in outer tube sheets by expanding and welding; elimination of thermal stresses in places of "cooling tube – tube sheet" attachment with relative motion of the shell and tubes;
- growth of the design vapor pressure in the condenser (of vacuum) with the respective gain of the turbine plant generator output on terminals of the generator with steam turbine K-1000-60/1500 manufactured by JSC "Turboatom", being confirmed by testing conducted by an independent specialized body.

The condenser modernization included replacement of the old tube systems (tubes from copper-nickel alloy grade MNZH5-1 and outer and intermediate sheets from carbon steel grade Steel 20) with new tube systems – of module No. 1…8 of every shell, with side walls and bottoms, with collected, expanded and welded tubes (tubes from corrosion-resistant stainless steel grade TP316L).

4 Comparative analyses

Among all the parameters determining the condensing steam turbine operation mode, vapor pressure at the end of expansion – spent vapor pressure in the condenser (vacuum level) – has the greatest influence on the turbine economical operation. Providing and maintaining the required vacuum in the condenser that ensures most economical operation of the turbine plant as a whole, is a very important task of the operating personnel. Therefore, increase of the vapor pressure in the condenser for 0.01 kg/cm^2 causes increase of a gross average heat rate of a unit for NPP turbine plant approximately for 1% for wet steam turbine plants - approximately for 2% of the steam turbine nominal capacity.

The main criteria of the condensing unit operation, characterizing the equipment performance under given conditions (rate of condensation per sq. m. of condenser surface, cooling water flow rate and temperature, etc.) are spent vapor pressure in the condenser and temperature drop at the condenser output δt (difference between spent vapor saturation temperature and cooling water temperature at the condenser output).

Table 1. Comparative analysis of condensers K-45600 and K-49210.

Characteristic	Unit of measurement	Condenser type	
		K-45610 before modernization	**K-49210 after modernization**
Type		Surface, single-pass, two-flow	Surface, single-pass, two-flow
Design cooling area in the condenser shells			
F1 F2 F3	m^2	12877 16366 16366	16403 16403 16403
Cooling tube length	mm	8970	8970
Cooling tube effective length	mm	8910	8910
Cooling tube type		"one-piece"	"welded"
Cooling tube assortment	mm	28x1.0x9000 28x2.0x9000	28x0.7x9000 28x1.25x9000
Number of cooling tubes in the condenser	pc.	57360/960, incl.:	61800/984, incl.:
Shell No. 1:			
28x1.0x9000/28x0.7x9000		16160	20600
28x2.0x9000/28x1.25x9000		304	328
Shell No. 2:			
28x1.0x9000/ 28x0.7x9000		20600	20600
28x2.0x9000/28x1.25x9000		328	328
Shell No. 3:			
28x1.0x9000/28x0.7x9000		20600	20600
28x2.0x9000/28x1.25x9000		328	328
Fastening of cooling tubes in the end (outer) sheets		expansion	expansion and welding
Number of passes / flows		1/2	1/2
Overall dimensions			Installation in the existing foundation
Number of outer sheets	pc.	2	2

4 Conclusion

Extension of service life of the operating NPP power units is one of the most important tendencies of the modern stage of nuclear power engineering development and the most efficient funds investment for preserving generating capacities.

The data given in table No. 1 allow making a conclusion that when modernizing the condensing unit, its cooling area was increased for about 4,000 m^2 due to increasing number of tubes in shell No. 1. In addition, tube geometrical dimensions were changed; the wall thickness was reduced from 1 and 2 mm to 0.7 and 1.25 mm respectively. It was necessary due to the lower thermal conductivity coefficient of stainless steel as compared to the copper-containing alloy previously used. Moreover, it should be noted that the condenser overall dimensions remained unchanged that is a very important parameter of modernization.

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