ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.4. Application of air condensers in power industry

6.4.5. Cost-effectiveness analysis of air condensers application

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Cost-effectiveness of new equipment introduction is determined by comparing of new and base alternatives. For the base alternative (1) we will take surface condenser (with wet water cooling tower) of turbine T-250/300-240, and for the new one (2) – air condenser (AC) under development is taken.

Surface condenser

The initial parameters of the base alternative with a surface condenser are as follows:

Condenser thermal capacity
Q, MW 369,83
Steam consumption G_s, kg/s 165
Condenser heat-exchange surface, $F_{s.c}$, m^2 14 000
Cooling water temperature at the condenser inlet,
t_{w1}, ... 20
Steam pressure in the condenser, p_c, kPa .. 5,3
Cooling water consumption,
$G_{circ.\ water}$, m^3/h 28 000
Cooling ratio, m 28,6

Cost-effectiveness analysis of the alternatives under consideration will be conducted under reduced costs. We define a difference between the reduced costs:

$$\Delta C = C_1 - C_2.$$

Reduced costs in the base and new alternatives:

$$C_1 = K_1 E_p + S_1 + S_e Э_1;$$

$$C_2 = K_2 E_p + S_2 + S_e(Э_{vent} + Э_1).$$

We define capital expenditures in the base alternative:

$$K_1 = (K_{s.c} F_{s.c} + K_t F_t)(1 + \alpha_{pl})(1 + \alpha_i),$$

where $K_{s.c}$ = 370 rub/m^2 — specific capital expenditures in the surface condenser; $K_t F_t$ = 83,65·10^6 rub — water cooling tower cost; α_{pl} = 1,27 — coefficient, considering plant facilities; α_i = 0,18 — coefficient, considering installation costs.

$$K_1 = (370 \cdot 14\,000 + 83{,}65 \cdot 10^6)(1 + 1{,}27)(1 + 0{,}18) =$$

$$= 237{,}94 \cdot 10^6 \text{ rub}.$$

Cost value of the base alternative:

$$S = S_{am1} + S_{pi1} + S_{pl1} + S_{ind.\ w}$$

We accept amortization charges H_{am} in the value of 3,3%, than costs for amortization are the following:

$$S_{am1} = H_{am} K_1 = 0{,}033 \cdot 237{,}94 \cdot 10^6 =$$

$$= 7{,}852 \cdot 10^6 \text{ rub/year}.$$

Costs for the pipe installations:

$$S_{pi} = 0{,}2 S_{am1} = 0{,}2 \cdot 7{,}852 \cdot 10^6 =$$

$$= 1{,}5704 \cdot 10^6 \text{ rub/year}.$$

Salary S_s and fuel costs S_f are not considered, as in the base and estimated alternatives they are considered to be the same.

We define costs of industrial water acquisition. Water consumption:

a) for evaporation

$$G_{ev} = 1\,794\,656 \text{ m}^3\text{/year};$$

b) for droplet entrainment

$$G_{dr.\ ent} = 121\,837 \text{ m}^3\text{/year};$$

c) for blowing-down

$$G_{bd} = 3\,401\,486 \text{ m}^3\text{/year}.$$

Industrial water price P_w = 1,22 rub/m^3, price of blow-down water discharge $P_{bd.w}$ = 1,09 rub/m^3.

Industrial water consumption

$$G_{ind.\ w} = G_{ev} + G_{dr.\ ent} + G_{bd} =$$

$$= 5\,317\,979 \text{ rub/m}^3.$$

Costs for acquisition of industrial water

$$S_{ind.\ w} = 5\,317\,979 \cdot 1{,}22 = 6{,}488 \cdot 10^6 \text{ rub/year}.$$

Costs for blow-down water discharge

$$S_{dis.bd} = 3\,401\,486 \cdot 1{,}09 = 3{,}708 \cdot 10^6 \text{ rub/year}.$$

Costs for industrial water:

$$S_{ind.\ w} = 6{,}488 \cdot 10^6 + 3{,}708 \cdot 10^6 =$$

$$= 10{,}196 \cdot 10^6 \text{ rub/year}.$$

Plant costs

$$S_{pl1} = 0{,}2(S_{ind.\ w} + S_{am1} + S_{pi1});$$

$$S_{pl1} = 0{,}2(10{,}196 \cdot 10^6 + 7{,}852 \cdot 10^6 + 1{,}5704 \cdot 10^6) =$$

$$= 3{,}924 \cdot 10^6 \text{ rub/year}.$$

Total costs in the base alternative

$$S_1 = S_{ind.\ w} + S_{am1} + S_{pi1} + S_{pl1};$$

$$S_1 = (10{,}196 + 7{,}852 + 1{,}5704 + 3{,}924)10^6 =$$

$$= 23{,}5424 \cdot 10^6 \text{ rub/year}.$$

Annual energy consumption for circulating pumps

$$E_{a.c.p} = N_{c.p}\, n_{c.p}\, \tau,$$

where $N_{c.p}$ — electric motor power of one circulating pump; $n_{c.p}$ — amount of circulating pumps for the power unit; τ — total operating hours in a year, h;

$$Э_{a.c.p} = 780 \cdot 2 \cdot 7500 = 11{,}7 \cdot 10^3 \text{ MW·h/year}.$$

Reduced costs in the base alternative

$$C_1 = K_1 E_н + S_1 + S_e Э_{a.c.p};$$

$$C_1 = 237{,}94 \cdot 10^6 \cdot 0{,}1 + 23{,}5424 \cdot 10^6 +$$

$$+ 0{,}1 \cdot 11{,}7 \cdot 10^6 = 48{,}506 \cdot 10^6 \text{ rub/year}.$$

Air condenser

The initial parameters:

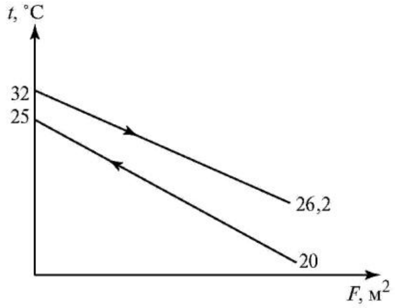
Condenser thermal capacity
Q, MW 369,83
Steam consumption, G_{s2}, kg/sec 165
Temperature of the cooling atmosphere air
t_{a1}, °C 20
Steam pressure in the condenser p_c, kPa ... 5,3
Temperature of steam saturation t_s, °C 34
Cooling ratio m 100

Temperature of power water in the mixing condenser is below the saturation temperature by 0,5……2 °C, i.e. we assume $t_1' = t_s - 2 = 34 - 2 = 32$°C. We define water heating in the ejector-condenser

$$\delta t_1 = \frac{r}{c_p m} = \frac{2420 \cdot 10^3}{4170 \cdot 100} = 5{,}8\ ^\circ\text{C},$$

where r — latent heat of evaporation; c_p — water heating capacity.

The analytic model is taken:



We define an efficiency of air heating

$$\varepsilon = \frac{t_2'' - t_2'}{t_1'' - t_1'} = \frac{25-20}{32-20} = \frac{5}{12} = 0{,}42.$$

Air consumption

$$G_2 = \frac{Q}{c_p \delta t_2} = \frac{369{,}83 \cdot 10^6}{1005 \cdot 5} = 74\ 000\ \text{кг/с}.$$

According to the model [11] at $\varepsilon = 0{,}42$ we define a number of heat transfer units of NTU = 0,75.

We estimate Gc_p:

$$G_1 c_{p1} = G_c m \cdot 4174 = 165 \cdot 100 \cdot 4174 = 68{,}87 \cdot 10^6;$$

$$G_2 c_{p2} = G_w \cdot 1005 = 74\ 000 \cdot 1005 = 74{,}00 \cdot 10^6.$$

We estimate the ratio of water equivalents of heat transfer agent:

$$\frac{W_1}{W_2} = \frac{68{,}87}{74{,}00} = 0{,}92.$$

We calculate the heat exchange surface:

$$F_2 = \text{NTU}\ \frac{W_{\min}}{k} = 0{,}75 \cdot \frac{68{,}87 \cdot 10^6}{40} = 1\ 291\ 313\ \text{м}^2$$

— the finned surface from the cooling air side. A factor of finned surface of bundle tubes is assumed to be 20, than the heat exchange surface from the cooling water side will be as follows:

$$F_2' = F_2 / 20 = 64\ 566\ \text{м}^2.$$

Electrical power of the fan drive at air pumping by the ventilation installation will be defined as follows. Productivity of one fan is G_2 = 260 kg/s, therefore, an amount of ventilation installations will be equal to N_{total}=74 000/260 = 285. Since power of one engine makes 75 kW, then the total power is E_{vent} = 285 75 = 21 375 kW.

Reduced costs in the new alternative:

$$C_2 = K_2 E_p + S_2 + S_e (E_{vent} + Э_{circ.p}).$$

Capital expenditures in the new alternative

$$K_2 = KF(1 + \alpha_{pl})(1 + \alpha_i) =$$

$$= KF_2(1 + 1{,}27)(1 + 0{,}18) = KF'_2 \bullet 2{,}68,$$

where K — price of the finned surface, rub/m^3.

Cost price of the new alternative

$$S_2 = S_{am2} + S_{pi2} + S_{pl2}$$

Amortization costs

$$S_{am} = 0{,}033 K$$

Costs for pipe installations

$$S_{pi2} = 0{,}2_{am2} = 0{,}2 \cdot 0{,}033K = 0{,}0066K.$$

Plant costs

$$S_{pl2} = 0{,}2(S_{am2} + S_{pi2}) = 0{,}2(0{,}033 K + 0{,}0066 K) =$$

$$= 0{,}2 \cdot 0{,}0396K = 0{,}00792 K.$$

Total costs in the new alternative

$$S_2 = 0{,}033 K + 0{,}0066 K + 0{,}00792 K = 0{,}04752K.$$

Electricity consumption of circulating pumps is taken 3,5 times higher, as the cooling ratio in the new alternative is m = 100 (in the base m = 28.6).

$$E_{circ\cdot p} = 3{,}5(780 \cdot 2) = 5460\ \text{kW};$$

$$E_{circ\cdot p} = S_e \cdot \tau \cdot E_{circ\cdot p} = 0{,}1\ 7500\ \ 5460 =$$

$$= 4{,}095 \cdot 10^6\ \text{rub/year}.$$

Electricity consumption by the fan drives

$$S_{vent} = S_e\ E_{vent} = 0{,}1\ 21375\ 7500 =$$

$$= 16{,}03 \cdot 10^6\ \text{rub/year}.$$

Reduced costs

$$C_2 = 2{,}68(KF)0{,}1 + 0{,}04752 K + S_{circ\cdot p} + S_{vent};$$

$$C_2 = K(0{,}268F + 0{,}04752) +$$

$$+ (4{,}095 \cdot 10^6 + 16{,}03 \cdot 10^6);$$

$$C_2 = K\text{-}\ 17304 + 20{,}125 \cdot 10^6.$$

If the price of the finned surface is K = 1000 rub/m^2, than

$$C_2 = 1000 \cdot 17304 + 20{,}125 \cdot 10^6 =$$

$$= (17{,}304 + 20{,}125) \cdot 10^6 = 37{,}429 \cdot 10^6\ \text{rub/m}^2.$$

At the prices up to K = 1500 rub/m^2, alternative of AC application is more beneficial than application of traditional cooling scheme. The difference of the reduced costs is:

$$\Delta C = C_1 - C_2 = 48{,}506 \cdot 10^6 - 37{,}429 \cdot 10^6 =$$

$$= 11{,}077 \cdot 10^6\ \text{rub/year}.$$

The gained result testifies about economic benefits of air condensing installation application compared to traditional system of the surface condenser (with "wet water cooling tower").