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Energy, mass-exchange and hydrodynamic efficiency of degassers at low-temperature deaeration of water for thermal power plants

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Abstract. A new technology for low-temperature degassing of the make-up water was developed using natural gas as a desorbing agent. The calculation of the energy efficiency of the developed technology for a typical power unit of the heat power plants (HPPs) is performed. Theoretically necessary and actual specific costs of natural gas are estimated to ensure the normative quality of the deaeration. The calculation of the hydrodynamic characteristics of the atmospheric deaerator at work on natural gas is presented.

A new technology for low-temperature deaeration of make-up water in a heating network

The main means of removing corrosive gases (O_2 и CO_2) from water at thermal power plants is thermal deaeration. One of the most important ways to increase the energy efficiency of deaeration at CHP is the use of heating mediums with low potential [1].

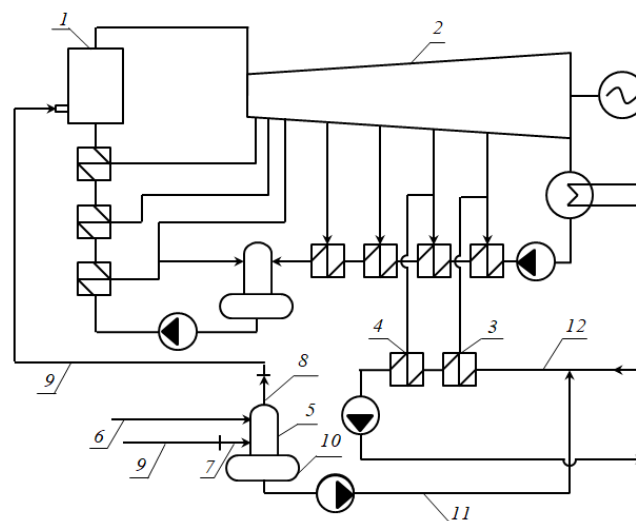


Fig. 1. Flow diagram of degasation of make up water of the heating supply system by natural gas. (1) steam boiler, (2) turbine, (3, 4) lower and upper network heaters, (5) deaerator, (6) pipeline of influent water, (7, 8) inlet and outlet branch for desorbent, (9) gas pipeline, (10) accumulator tank, (11) pipeline for make up water of the heating supply system, and (12) return network pipeline



Consider a new technology of low-temperature deaeration of make-up water of the heating network using natural gas as a desorbing agent, supplied to the boilers of the power plant. Natural gas does not contain oxygen and carbon dioxide in its composition. (Fig. 1) [2].

Natural gas after the reducing facilities has a very low, often negative temperature. Due to this, deaeration is carried out at relatively low temperatures (10-30°C). Mixing of cold deaerated make-up water with reverse network water leads to a significant decrease in the temperature of the return network water before the lower network heater, an increase in the generation of electricity by thermal consumption and, consequently, to an increase in the economics of operation of the thermal power plant.

Energy efficiency of the HPP during low-temperature deaeration of the makeup water of the heat network with natural gas

The indicators of the energy efficiency of the operation of thermal power plants are calculated by the method of the specific generation of electricity for heat consumption due to the selection of steam for heating the heat carriers in the thermal scheme of water treatment[3].

Power N_{ch}^{lnh} , kW, developed by the turbine on thermal consumption due to the selection of steam from the turbine to the heating of water in the lower network heater:

$$N_{ch}^{lnh} = \frac{G_{n.w}(h_o - h_{lnh})(\tau_1 - \tau_2)c}{h_{lnh} - h_{c_{lnh}}} \eta_e \eta_m, \quad (1)$$

where $G_{n.w}$ – consumption of network water through network heaters, t/h; τ_1 – temperature of network water supplied to the consumer after heating in network heaters, °C; τ_2 – return water temperature after mixing with cold deaerated make-up water, °C; c – specific heat capacity of water, kJ/(kg·°C); h_o – enthalpy of fresh steam, kJ/kg; h_{lnh} – enthalpy of the steam of the lower selection of the turbine, kJ/kg; $h_{c_{lnh}}$ – enthalpy of the condensate of the lower network heater, kJ/kg; $\eta_e \eta_m$ – electric and mechanical efficiency of the turbogenerator.

The power produced by the steam of the turbine selections, which is spent for the regenerative heating of steam condensate, used for heating the streams of network water in the lower network heater:

$$N_{reg}^{lnh} = \frac{G_{n.w}(\tau_1 - \tau_2)(h_{f.w} - h_{c_{lnh}})(h_o - h_{reg}^{lnh})c}{(h_{lnh} - h_{c_{lnh}})(h_{reg}^{lnh} - h_{f.w})} \eta_e \eta_m, \quad (2)$$

where $h_{reg}^{lnh} = 0,5(h_o + h_{lnh})$ – enthalpy of conditional equivalent regenerative selection, kJ/kg.

The calculation for the upper network heater is similar.

The increase in fuel consumption for additional steam generation in the boiler with increasing steam flow to the lower and upper network heaters and lowering the enthalpy of this steam is calculated by the form:

$$\Delta B_{add} = \frac{\Delta D(h_o - h_{f.w})}{Q_{c.f} \eta_b}, \quad (3)$$

where ΔD – increase in steam consumption when the temperature of the network water changes, t/h; $Q_{c.f}$ – combustion heat of conventional fuel, kJ/kg; η_b is the boiler efficiency.

The annual savings of the conventional fuel at the HPP using the new technology is:

$$\Delta B = \left((\Delta N_{ch} + \Delta N_{reg}) (b_e^c - b_e^h) 10^{-3} - \Delta B_{add} \right) n_h, \quad (4)$$

where b_e^c, b_e^h are specific consumptions of the equivalent fuel for power output in the condensation and heat extraction modes, respectively, kg/(kW·h); n_h – number of hours of use of the turbine.

The calculation showed that on an installation with a turbine T-100-130, a boiler with a steam capacity of 500 t/h and a feed water consumption of a heat network of 800 t/h, an annual savings of about 4587 t of fuel is achieved.

Mass exchange efficiency at low-temperature deaeration of the make-up water of the heating network

To investigate the possibility of using the technology of low-temperature deaeration of water, it is necessary to estimate the mass-exchange efficiency of the deaerator operation when using natural gas as the desorbing medium.

The basis of the method for determining the theoretically necessary specific consumption of natural gas to remove dissolved oxygen from the water $d_{\text{gas}}^{\text{min}}$, kg/t, is the solution of the balance equations for the processes of mass transfer and heat transfer during deaeration, provided that an equilibrium between the phases is reached at the exit from the deaerator [4]. With certain assumptions, it can be assumed that the largest mass-transfer efficiency of the deaerator is achieved by ensuring the standard quality of the deaeration with the minimum possible costs of the desorbing agent and the evaporation leaving the deaerator.

The equation for the material balance of the deaeration can be written in the form:

$$G_{i,w}X_{i,w} + D_{\text{gas}}Y_{\text{gas}} = G_{d,w}X_{d,w} + D_{\text{vent}}Y_{\text{vent}}, \quad (5)$$

where $G_{i,w}$ and $G_{d,w}$ is the consumption of the initial and deaerated waters, kg/h; D_{gas} is the consumption of natural gas supplied in the deaerator, kg/h; D_{vent} is the discharge of the deaerator vent steam (mixture of corrosive gases liberated from water and natural gas), kg/h; $X_{i,w}$ and $X_{d,w}$ are oxygen concentrations in the water at the inlet and outlet of the deaerator; and Y_{gas} and Y_{vent} are the oxygen contents in the natural gas at the deaerator inlet and in the vented steam at the deaerator outlet.

According to the Dalton law, the total pressure of the gas and gas–steam mixtures is equal to the sum of partial pressures of gases and steams composing the mixture. From the Henry law, it follows that the concentration of the gas dissolved in water is proportional to the partial pressure of this gas over the water surface.

Oxygen concentration Y_{gas} in gas at the deaerator input is practically zero. The oxygen concentration in the vented steam leaving the deaerator depends on the flow chart of the water and steam motion in the apparatus. At the countercurrent, mole fraction Y_{vent} of O_2 in the gas–steam mixture is

$$Y_{\text{vent}} = K_H^{O_2} X_{i,w} / p, \quad (6)$$

where $K_H^{O_2}$ is the Henry coefficient (phase equilibrium constant for oxygen), Pa; and p is the pressure in the deaerator, Pa.

At the countercurrent of water and natural gas in the deaerator, the minimum consumption of natural gas is

$$D_{\text{gas}}^{\text{min}} = G_{i,w} \frac{p}{K_H^{O_2}} \frac{X_{i,w} - X_{d,w}}{X_{i,w}}, \quad (7)$$

and its specific value is

$$d_{\text{gas}}^{\text{min}} = \frac{D_{\text{gas}}^{\text{min}}}{G_{i,w}}. \quad (8)$$

The calculation of the theoretically necessary specific consumption of natural gas in the low-temperature degassing of water at the HPP showed that about 1 m³ of natural gas is required per 1 ton of water. In the actual operating conditions of the deaerator, the required specific gas consumption for deaerating should be taken as 3-5 times as much as theoretically necessary (by analogy with thermal deaerators operating on a steam). Ensuring the necessary consumption of natural gas for deaeration of water in thermal power plants does not present any difficulties. With deaeration of 800 t/h of make up water, the required gas flow will be 2400-4000 m³/h, while a steam boiler with a steam capacity of 500 t/h requires about 40000 m³/h of gas, i.e. deaeration will require no more than one tenth of the gas flow to the boiler [5].

Hydrodynamic efficiency of degassers working on natural gas

Calculation of the hydrodynamic characteristics of low-temperature deaeration of water using natural gas as a stripping medium is made for a jet-bubbling atmospheric deaerator DA-25 with an un-submerged perforated bubble-plate installed in the lower part of the deaeration column.

Hydrodynamic operating conditions of the deaerator for effective deaeration [6]:

1. Maintaining the desired gas velocities in the holes of the bubble-plate.
2. The presence of a gas cushion under the bubbling sheet, due to which the sheet is not immersed in water.
3. Absence of entrainment of droplets from the deaerator column.

The use of an un-submerged principle of bubbling, according to which water on a perforated sheet is continuously and repeatedly treated with gas supplied under the sheet and passing through the holes in it, is most effective when operating bubbling deaerators.

Under the sheet a gas layer ("cushion") is formed, which prevents dropping of liquid through the holes of the sheet. The hydrodynamic stability of un-submerged bubble sheet is determined by the rate of gas flow through the holes.

The minimum required speed may be determined by the empirical form [7-9].

$$w_{\min} = \frac{20,6}{\sqrt{\rho_{\text{gas}}}}, \quad (9)$$

where ρ_{gas} – the gas density under the sheet, kg/m³.

The height of the gas cushion under the sheet is

$$h = 2 \cdot \sqrt[3]{\frac{\sigma^2}{(g\rho_w - g\rho_{\text{gas}})^2 d} + \frac{\zeta w^2 \rho_{\text{gas}}}{2g(\rho_w - \rho_{\text{gas}})}}. \quad (10)$$

where σ – coefficient of surface tension of water-gas system, kg/m; ρ_w – the density of water, kg/m³; d – the diameter of the holes in the perforated sheet, m; w – the rate of passage through the holes of the sheet, m/s; $\zeta = 1,9 \dots 2,0$ – the coefficient of hydraulic resistance of the perforated sheet.

To assess the presence or absence of entrainment of drops from the deaerator is necessary to determine the gas velocity in the column deaerator [9, 10]. Sustainable mode downward flow exists at gas velocities of about 15-30 m/s, above which the entrainment of droplets [11].

In traditional thermal deaerators, used as the working medium is water steam, which condenses in the process of deaeration, flow rate of steam in the jet of the column is small and the danger of entrainment of droplets is practically absent. In deaerator using natural gas as a stripping agent the gas velocity and the risk of entrainment of drops from the column of deaeration to the gas pipeline before boiler is slightly higher, since natural gas by deaeration is not condenses.

The gas velocity in the column deaerator is

$$w_{\text{col}} = \frac{G_{\text{gas}}}{S}, \quad (11)$$

where G_{gas} – gas consumption, m^3/h ; S – section area, m^2 .

As a result of calculation according to formulas (9) - (11) with a specific gas consumption of 3-5 m^3 / t , ie 3-5 times more than theoretically necessary, the following hydrodynamic characteristics of the deaerator DA-25 were determined:

1. The estimated gas velocity in the holes of the bubble sheet $w_{\text{min}}=57,58 \text{ m/s}$.
2. The height of the gas cushion under the bubble sheet $h=0,025 \text{ m}$.
3. The gas velocity in the column of deaerator $w_{\text{col}}=0,13 \text{ m/s}$. Consequently, the entrainment of droplets is impossible, as in deaerator using steam as the stripping agent.

Thus, the operation of the deaerator jet-bubbling atmospheric deaerator on natural gas provided the required hydrodynamic conditions of operation of jet and bubbling steps of deaerating column.

Conclusions

1. A new technology for low-temperature deaeration of the make-up water of the heat network of thermal power plants using natural gas as a desorbing medium was developed.
2. The calculation of the energy efficiency of the new technology has been performed, showing that only one installation with a T-100-130 turbine and a 500 t/h steam generating boiler achieves an annual savings of about 4587 tons of conditional fuel.
3. Normative mass-exchange efficiency of deaerators using natural gas as stripping medium supplied to the burners of boilers of thermal power plants is ensured with a relatively low gas consumption for deaeration. Theoretically necessary and actual specific consumption of natural gas for low-temperature deaeration of water are estimated.
4. When operating a jet-bubbling deaerator with the use of natural gas as a working medium, all the necessary hydrodynamic conditions for the operation of the jet and bubbling deaeration stages are performed.

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