Development of water deaeration technologies with boiler exhaust gases

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Abstract. The calculation of the heat and mass transfer efficiency of the proposed technology for deaeration of water by the exhaust gases of a gas-proof boiler in deaerators of serial design has been performed. The conditions and criterial values of the media consumption in the apparatus have been studied. It is shown that the technology can be successfully applied in operating thermal power plants.

1. Introduction
Thermal deaeration of the make-up water of the heating system and the make-up of boiler water at thermal power plants is a traditional method of anticorrosive water treatment and is widely used in the Russian Federation and on the territory of the post-Soviet space. Over the decades of using this method, the modes of operation of deaerators have been studied, various designs have been proposed, measures have been developed to improve their effective operation, however, the use of unconventional media as a desorbing has recently been proposed.

Thermal deaeration is the most energy-consuming process of water preparation in thermal power plants. Foreign scientists dealt with the problems of optimizing this process. A. E. Kittredge and A. W. Kingsbury developed deaerator designs in the middle of the 20th century to improve their efficiency. R. E. Athey the 90s published the results of his study and tests [1]. The purpose of the study is to develop new effective methods for water degassing and substantiate the possibility of their application in modern energy systems.

2. Boiler exhaust gases degassing technology
The method of thermal deaeration of water with steam at thermal power plants has a number of disadvantages, such as the need for additional steam consumption for the deaeration process itself, unwanted heat losses with steam, as well as losses of steam and condensate during the preparation of the make-up water of the heating network in atmospheric deaerators. The owners of boiler houses operating on steam boilers in many medium and small cities of Russia face similar problems. In the case of transferring the boiler house to hot water mode in order to reduce fuel consumption and reduce heat losses, thermal deaeration becomes difficult to implement [2]. At the same time, most of the boiler houses do not have steam generators in the installed equipment, and the problem of thermal deaeration is quite acute and the anti-corrosion treatment of water should somehow be carried out in the absence of steam.
In the research laboratory "Heat power systems and installations" of the Ulyanovsk State Technical University, the researchers proposed the use of a gas-proof boiler in the deaerator as a desorbing agent of flue gases, operating under pressurization and burning natural gas [3].

The developed technology is aimed not only at increasing the efficiency of the water degassing process, but also at the beneficial use of the heat of the boiler exhaust gases in the deaeration process. The possibility of organizing deaeration of the heating network make-up water on hot water boilers without steam sources is the main advantage of the proposed solution [4]. The authors believe that the highest efficiency can be achieved with non-stoichiometric combustion of fuel - natural gas [5], as well as in the operation of the boiler under pressure, which avoids an increase in the oxygen content in the exhaust gases due to possible air leaks into the furnace and gas ducts.

3. Mass transfer efficiency of flue gas deaeration

The determination of the mass transfer efficiency is presented in the form of a calculation based on the solution of the balance equations for the processes of mass transfer and heat transfer.

The area of application of the developed technology is proposed to be determined after calculating the residual flow rate of the desorbing agent for the reaction. The operating parameters of the boiler and atmospheric deaerator with the required capacity of 25 t/h are taken.

The heat balance equation to determine the flue gas flow rate sufficient to ensure the deaeration process with the boiler flue gases:

\[ Q_{sw} + Q_{exgas} = Q_{dw} + Q_{vent}. \]

Also, the equation for the heat balance of deaeration can be expanded as

\[ G_{sw} h_{sw} + D_{exgas} h_{exgas} = G_{dw} h_{dw} + D_{vent} h_{vent}, \]

where \( G_{sw} \) and \( G_{dw} \) - the quantity of source and water, that was deaerated, kg/h; \( D_{exgas} \) - rate of the desorbing agent, kg/h; \( D_{vent} \) - vapor consumption, that consist of mixture of corrosive gases released from water, kg / h; \( h_{sw} \) - the enthalpy of water at the entrance to the deaerator, kj; \( h_{dw} \) - the enthalpy of water at the exit from deaerator, kj; \( h_{exgas} \) - the enthalpy of flue gases at the entrance to the deaerator, kj; \( h_{vent} \) - the enthalpy of flue gases at the exit from the deaerator, kj.

The required consumption of flue gases for the process will be determined as

\[ D_{exgas} = \frac{G_{dw} h_{dw} + D_{vent} h_{vent} - G_{sw} h_{sw}}{h_{exgas}}. \]

The calculations carried out showed that the required flue gas flow rate will be 71.5 m³/h to ensure the deaeration process of 25 t/h of water at a standard value of the vapor consumption of 50 kg/h.

The equation of material balance for deaeration with exhaust boiler gases for determining the oxygen concentration can be written as

\[ G_{sw} X_{sw}^{O_2} + D_{exgas} Y_{exgas}^{O_2} = G_{dw} X_{dw}^{O_2} + D_{vent} Y_{vent}^{O_2}, \]

where \( G_{sw} \) and \( G_{dw} \) - the amount of source and deaerated water, kg / h; \( D_{exgas} \) - consumption of flue gases supplied to the deaerator, kg / h; \( D_{vent} \) - deaerator vapor consumption (mixture of corrosive gases and flue gases released from water), kg / h; \( X_{sw}^{O_2} \), \( X_{dw}^{O_2} \) - oxygen concentration in water at the inlet to the deaerator and at the outlet from it, mg/dm³; \( Y_{exgas}^{O_2} \), \( Y_{vent}^{O_2} \) are the oxygen content in flue gases at the inlet to the deaerator and in the vapor at the outlet from the deaerator.

The oxygen content in the flue gas at the water inlet and in the steam can be expressed in terms of the gas concentration in the water. The total pressure of a gas or vapor-gas mixture is equal to the sum
of the partial pressures of gases and vapors that make up the mixture (Dalton’s law). At the same time, the concentration of a gas dissolved in water is proportional to the partial pressure of this gas above the water surface.

At the inlet of the deaerator, the concentration of oxygen in the flue gases will be:

$$Y_{ex,\text{gas}}^{O_2} = K_{H}^{O_2} X_{dw}^{O_2} / p,$$

where $K_{H}^{O_2}$ is Henry’s coefficient (constant of phase equilibrium for oxygen [6]), Pa; $p$ - pressure in the deaerator, Pa.

With countercurrent flow of water and gases in the deaerator, the oxygen concentration in the steam-gas mixture is

$$Y_{vent}^{O_2} = K_{H}^{O_2} X_{sw}^{O_2} / p,$$

where $K_{H}^{O_2}$ is Henry’s coefficient (constant of phase equilibrium for oxygen), Pa; $p$ - pressure in the deaerator, Pa.

With certain assumptions, the material balance equation can be written in the form:

$$G_{sw} X_{sw}^{O_2} + D_{ex,\text{gas}} K_{H}^{O_2} X_{dw}^{O_2} / p = G_{dw} X_{dw}^{O_2} + D_{vent} K_{H}^{O_2} X_{sw}^{O_2} / p.$$

We find the oxygen concentration in deaerated water, for which we take the values of the initial parameters $X_{sw}^{O_2} = 8000$ mg/dm$^3$, $D_{vent} = 50$ kg/h, $K_{H}^{O_2} = 7104 \cdot 10^6$ Pa, $K_{H}^{O_2} = 6372 \cdot 10^6$ Pa, $p = 1.2 \cdot 10^6$ Pa, $G_{sw} = G_{dw} = 25 \cdot 10^3$ kg/h:

$$X_{dw}^{O_2} = \frac{X_{sw}^{O_2} \left( D_{vent} K_{H}^{O_2} / p - G_{sw} \right)} {D_{ex,\text{gas}} K_{H}^{O_2} / p - G_{dw}} = 48.5$ mg/dm$^3$.

For makeup water, the permissible oxygen content is up to 50 mg/dm$^3$ [7]. The proposed technical solution with the use of boiler flue gases as a desorbing agent in atmospheric deaerators makes it possible to provide the standard oxygen content. According to the above calculations, the theoretically required specific gas consumption for deaeration will be 2.86 m$^3$ per 1 ton of deaerated water.

The results of calculating the deaeration process performed according to formulas (3) and (8) at a concentration of dissolved oxygen in water at the inlet to the atmospheric deaerator of 8 mg/dm$^3$ are shown in figure 1. Thus, the calculations performed not only show the possibility of using the technology of deaeration of water by the flue gases of the boiler, but also prove its effectiveness in the case of use with deaerators of a common design.

Due to the high content of carbon monoxide in flue gases, the question of neutralizing carbon dioxide to the minimum standard values for the implementation of the possibility of using this method for deaeration of feed water without damage to boiler equipment arises. The authors propose to dose an alkaline agent into the feed water pipeline after the deaerator. This can be sodium sulfite or hydrazine.
Figure 1. Consumption of flue gases for degassing dissolved oxygen in a countercurrent flow of water and flue gases in the deaerator.

4. Conclusions
A new technology for deaeration of water has been developed due to the use of a gas-proof boiler as a desorber of flue gases. The estimation of the residual oxygen concentration in the deaerated water was made, as well as the theoretically required flow rate of the boiler flue gases for the realization of the make-up water deaeration process was calculated.

The suitability of the new technology for deaeration of make-up water using boiler flue gases as a desorbing agent has been proven by calculation calculations based on the equations of heat and material balance.

References
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