Technology of desorption of dissolved oxygen from water by boiler exhaust gases

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Abstract. A new technology of water degassing based on the use of boiler flue gases as a desorbing agent is described. In the process of burning gaseous fuel, almost all oxygen is consumed, which ensures its absence in the composition of exhaust gases. This makes it possible to use the flue gases of a gas-tight boiler as a desorbent in the process of water deaeration and to avoid using steam. The increasing concentration of carbon dioxide in deaerated water is proposed to be reduced by metering an alkaline agent. The article presents the results of evaluating the mass transfer efficiency of water degassing by the proposed method, as well as the results of calculating the theoretically required specific flow rate of exhaust gases for deaeration.

1. Water degassing technology with boiler exhaust gases

The process of thermal deaeration of the heating system make-up water and the additional boiler feed water is a complex synthesis of the simultaneous flow of two components - heat transfer and mass transfer. Heat transfer is the process of heating deaerated water to saturation temperature. Mass transfer is provided by the release of corrosive gases from the deaerated water into the vapor medium. At the same time, water vapor is considered a traditional type of desorbing agent and at the moment is the only widely used medium that provides the process of degassing the additional feed water of boilers and the make-up water of the heating system.

The need for additional steam costs for deaeration, additional heat losses with vapor, as well as steam and condensate losses during the preparation of the make-up water of the heating network in atmospheric deaerators are inevitable disadvantages of the thermal deaeration method due to steam. In addition, in many medium and small cities of Russia, from 30 to 100% of heat energy for heat supply is generated by boiler houses [1,2]. For boiler rooms with steam generators in the installed equipment, the problem of thermal deaeration is solved quite simply. However, most hot water boiler houses are forced to apply anti-corrosion treatment of water without thermal deaeration due to the lack of steam.

Thus, in order to ensure the required quality of the heating system make-up water, as well as to simplify the deaeration technology itself in order to use it in hot water boilers, it is reasonable to search for new energy efficient methods of water degassing [3].

In the research laboratory "Heat power systems and installations" of the Ulyanovsk State Technical University (Research Laboratory "TESU" UlSTU), various technical and technological solutions are being developed to improve the efficiency of the water deaeration process [4,5]. The use of
unconventional media as a desorbent in standard deaeration devices is one of the promising areas of development in this area.

The authors proposed the use of a gas-tight boiler operating under pressurization and burning natural gas as a desorbing agent of exhaust gases in a deaerator [6, 7].

The proposed technology makes it possible to increase the efficiency of the water degassing process by eliminating the consumption of steam for deaeration, as well as the beneficial use of the heat of the boiler exhaust gases during the deaeration process. The main advantage of the proposed solution is the possibility of organizing the deaeration of the make-up water of the heating network at hot water boilers without steam sources.

Note that the scope of the proposed technical solution is limited by the following conditions. The highest efficiency can be achieved with non-stoichiometric combustion of natural gas [8], as well as in the operation of a pressurized boiler, which avoids an increase in the oxygen content in flue gases due to suction into the furnace and gas ducts.

2. Determination of the required flue gas flow rate to implement the proposed solution

The calculation is carried out on the basis of solving the balance equations of the processes of mass transfer and heat transfer during thermal deaeration, provided that equilibrium between the phases is achieved at the outlet of the deaerator [9].

For the calculation, the operating parameters of a typical boiler of the DKVR series and an atmospheric deaerator of the DA-25 type are taken.

To assess the scope of application of the proposed solution, it is necessary to determine the values of the theoretically required flow rate of the desorbing agent (boiler exhaust gases). It is assumed that the maximum mass transfer and energy efficiency of the thermal deaerator is achieved at the lowest possible consumption of the desorbing agent and the vapor removed from the deaerator.

The design scheme of the deaerator is shown in Figure 1.

Let us determine the flow rate of flue gases to ensure the deaeration process with the flue gases of the boiler, for this we compose the heat balance equation:

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

Figure 1. Scheme of deaeration column of countercurrent type: 1 - supply of source water; 2 - supply of exhaust gas; 3 - drainage of deaerated water; 4 - deaerator outlet tap.

The heat balance equation for deaeration can be written as
\[ G_{sw} h_{sw} + D_{ex, gas} h_{ex, gas} = G_{dw} h_{dw} + D_{vent} h_{vent} \]  

(2)

where \( G_{sw} \) and \( G_{dw} \) - the amount of initial and deaerated water, kg/h; \( D_{ex, gas} \) - consumption of the desorbing agent supplied to the deaerator, kg/h; \( D_{vent} \) - deaerator vapor consumption (mixture of corrosive gases and flue gases released from water), kg/h; \( h_{sw} \), \( h_{dw} \) are the enthalpy of water at the entrance to the deaerator and at the exit from it; \( h_{ex, gas} \), \( h_{vent} \) are the enthalpy of flue gases at the entrance to the deaerator and the enthalpy of vapor at the exit from the deaerator.

The flue gas flow rate is determined by the expression

\[ D_{ex, gas} = \frac{G_{dw} h_{dw} + D_{vent} h_{vent} - G_{sw} h_{sw}}{h_{ex, gas}} \]  

(3)

The calculations show that to ensure the deaeration process of 25 t/h of water, the required flue gas flow rate will be 71.5 m³/h.

3. Determination of the residual oxygen content in deaerated water

The material balance equation for deaeration for determining the oxygen concentration can be written as

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

(4)

where \( G_{sw} \) and \( G_{dw} \) - the amount of initial and deaerated water, kg/h; \( D_{ex, gas} \) - 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; \( Y_{ex, gas} O_2 \), \( Y_{vent} O_2 \) are the oxygen content in flue gases at the inlet to the deaerator and in the vapor at the outlet from the deaerator.

Let us also express through the concentration of gas in water. According to Dalton's law, 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. It follows from Henry's law that the concentration of a gas dissolved in water is proportional to the partial pressure of this gas above the surface of the water.

The oxygen concentration in the flue gases at the inlet to the deaerator \( Y_{ex, gas} O_2 \) will be expressed:

\[ Y_{ex, gas} O_2 = K_{H, ex, gas} O_2 X_{sw} O_2 / p \]  

(5)

where \( K_{H, ex, gas} O_2 \) is Henry's coefficient (constant of phase equilibrium for oxygen [10]), Pa; \( p \) - pressure in the deaerator, Pa.

The oxygen concentration in the vapor leaving the deaerator depends on the flow pattern of water and steam in the apparatus. With countercurrent flow, the molar fraction of \( O_2 \) in the vapor-gas mixture \( Y_{vent} O_2 \) is

\[ Y_{vent} O_2 = K_{H, vent} O_2 X_{sw} O_2 / p \]  

(6)

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

The material balance equation will take the form:
\[ G_{sw}X_{sw}^{O_2} + D_{ex.gas}K_{H_1}^{O_2}X_{dw}^{O_2}/p = G_{dw}X_{dw}^{O_2} + D_{vent}K_{H_1}^{O_2}X_{sw}^{O_2}/p \]

Substituting the obtained values into the equation, we find the oxygen concentration in deaerated water

\[ X_{dw}^{O_2} = \frac{X_{sw}^{O_2}\left(D_{vent}K_{H_1}^{O_2}/p - G_{sw}\right)}{D_{ex.gas}K_{H_1}^{O_2}/p - G_{dw}} = 48.5\text{mg/dm}^3 \]  

In accordance with the PTE [11], the permissible oxygen content in the make-up water is 50 mg/dm³; therefore, the use of boiler flue gases as a desorbing agent in atmospheric deaerators makes it possible to ensure the standard value of oxygen.

If the boiler flue gases are used as a desorbing agent, according to the above calculations, the theoretically required gas consumption for deaeration will be 2.86 m³ per 1 ton of deaerated water.

The development of the proposed method for water degassing also includes solving the problem of excess carbon dioxide content in flue gases and its negative impact on the quality of deaerated water. To neutralize carbon dioxide in deaerated water, it is proposed to dose an alkaline reagent, for example, sodium hydroxide, into the feed water pipeline.

Binding of carbon dioxide contained in feed water by alkali occurs in the form of a reaction:

\[ \text{CO}_2 + \text{NaOH} = \text{NaHCO}_3 \]

Thus, the introduction of alkali into deaerated water eliminates the presence of carbon dioxide in the make-up water.

**Conclusions**

- A new technology of deaeration of the heating system make-up water using the boiler exhaust gases as a desorbing agent is proposed.
- The theoretically required flow rate of the boiler flue gases for deaeration of the make-up water was calculated, the residual oxygen concentration in the deaerated water was estimated.
- The performed calculations prove the applicability of the new technology for deaeration of the make-up water of the heating network using the boiler exhaust gases as a desorbing agent.

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