Degassing of water with exhaust gases of the boiler

V I Sharapov1 and R I Kamalova1

1Ulyanovsk State Technical University, st. Severny Venets, 32, Ulyanovsk, Russia

vlad-sharapov2008@yandex.ru kamalovari@oblkomhoz.ru

Abstract. A method for degassing the make-up water is described, the feature of which is the use of the exhaust gases of the boiler after the smoke exhauster as a desorbing agent. In the exhaust gases of the boiler, there is a small portion of corrosive oxygen, due to the fact that all oxygen is consumed in the combustion process in the furnace. The problem of the possible saturation of the deaerated water with carbon dioxide due to its increased content in the boiler waste gases is solved by dispensing the alkaline agent into the make-up water. The mass exchange efficiency of the make-up water degassing by the proposed method is estimated, the required specific consumption of the exhaust gases for deaeration is theoretically calculated. It is shown that the consumption of the desorbing agent, which is the exhaust gas, is sufficient for degassing practically any quantities of nutrient and make-up water.

Technology of degassing of water with waste gases of the boiler

The process of removing dissolved corrosive gases from the make-up water - deaeration - is the final stage of the technological treatment of water. Currently, the most common method of thermal deaeration, which consists in the desorption of dissolved gas when it is heated to the saturation temperature by using steam.

Water vapor is traditionally used as the desorbing agent in deaeration plants. In this case, the process of thermal deaeration is inevitably associated with the need for additional steam wastages for deaeration, as well as undesirable losses of heat with the discharge of the deaerator. Deaeration technologies significantly affect the efficiency of heat power plants [1]. In order to increase the energy efficiency of electricity generation, the process of deaeration should be carried out at the lowest possible temperature of the heat transfer medias, which provides heating of the streams of initial and deaerated water [1]. The necessity for additional steam costs for deaeration in the cycle of operation of heat power plants (HPPs), additional heat losses with deaerator dehumidifications are inevitable disadvantages of the thermal deaeration method.

In research laboratory of Heat power systems and Plants of Ulyanovsk State Technical University developed various solutions directed to increase energy efficiency and optimize the process of deaeration of the make-up water. One of the promising elaborations of development in this area is to increase the thermal efficiency of the deaeration process using non-traditional low-temperature medias as a desorbing agents [2,3].

One such solution is the use of the exhaust gases of the boiler - methane combustion products - as a desorbing agent in the deaerator [4]. The outgoing gases of the boiler practically do not contain oxygen, and the excess air values in the gas path can be assumed to be minimal provided to the organization of non-stoichiometric combustion of fuel [5]. The scheme for implementing this technology is shown in figure 1.
Figure 1. The scheme for degassing the make-up water with the boiler exhaust gases: 1 - steam boiler, 2 - flue gas duct, 3 - deaerator, 4 - source water pipeline, 5 - feed water pipeline, 6 - dosing system for alkaline agent.

A distinctive feature of the proposed scheme of water degassing is that the deaerator is switched on by desorbing medium into the flue gas outlet of the boiler. The outgoing gases of the boiler 1 from the flue gas duct 2 are fed to the lower part of the deaerator column 3. As they rise up inside the deaerator construction, the flue gases cross the water jets, heating the source water to the saturation temperature, and securing the release of corrosive gases and mixing them with the desorbing agent. The mixture of exhaust gases and discharged gases from the source water is removed from the top of the deaerator column through the flue gas duct to the chimney. The water thus deaerated is discharged from the deaerator by the feed pump, passes the dispenser of the alkaline agent (sodium hydroxide) 6, removal of corrosive carbon dioxide from the water. Then, the deaerated water is supplied to the economizer of the boiler 1.

The proposed technology makes it possible to increase the economics of the process of water degassing due to elimination of steam costs for degassing at HPPs and utilizing the heat of the boiler exhaust gases by lowering their temperature in the deaerator before being released to the atmosphere. Anticorrosion treatment of the feed and make-up water by the outgoing gases of the boiler can also be arranged in heat-generating installation in the absence of steam sources, for example in hot water boilers.

Estimation of the energy efficiency of degassing by the exhaust gases of the boiler

To estimate the mass-exchange and energy efficiency of this solution, the values of the theoretically required consumption of the desorbing agent should be determined.

Determination of the theoretically necessary specific consumption of the desorbing agent for removal of dissolved oxygen from the water \( d_{\text{min}} \), kg/t, is performed on the basis of the solution of the balance equations of the processes of mass transfer and heat transfer during thermal degassing, provided that the equilibrium between the phases is reached at the exit from the deaerator [6]. It is assumed that the maximum mass-transfer and energy efficiency of the thermal deaerator is achieved with the minimum possible costs of the desorbing agent and the vapor produced by the deaerator.

The design scheme of the deaerator is shown in figure 2.

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

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

(1)
where $G_{sw}$ and $G_{dw}$ is the consumption of the influent and deaerated waters, kg/h; $D_{gas}$ is the consumption of exhaust gases supplied in the deaerator, kg/h; $D_{vent}$ is the discharge of the deaerator vent steam (mixture of corrosive gases liberated from water and desorbing agent), kg/h; $X_{sw}$ and $X_{dw}$ 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 exhaust gases at the deaerator inlet and in the vented steam at the deaerator outlet [6].

![Figure 2](image_url)

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

Oxygen concentration $Y_{gas}$ in gas at the deaerator input is practically zero, since the outgoing gases of the boiler do not contain oxygen because of its full consumption of the combustion process of fuel (natural gas) in the boiler furnace.

$$CH_4 + 2CO_2 = CO_2 + 2H_2O$$

(2)

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.

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 oxygen in the gas–steam mixture is

$$Y_{vent} = K_{sw} X_{sw} / p$$

(3)
where $K^O_H$ is the Henry coefficient (phase equilibrium constant for oxygen [7]), Pa; and $p$ is the pressure in the deaerator, Pa.

At the countercurrent flow of water and exhaust gases in the deaerator, the minimum consumption of exhaust gases is

$$D_{\text{gas}}^{\text{min}} = G_{\text{sw}} \frac{p}{K^O_H} \frac{X_{\text{sw}} - X_{\text{de}}}{X_{\text{sw}}},$$

(4)

and its specific value is

$$d_{\text{gas}}^{\text{min}} = \frac{D_{\text{gas}}^{\text{min}}}{G_{\text{sw}}}$$

(5)

The results of calculation of the deaeration process, performed according to formulas (4) and (5) for different values of the oxygen concentration in water at the inlet to the atmospheric deaerator and the values of dissolved oxygen content in deaerated water given in GOST [8] when using as exhaust gas desorbing gases of the boiler, are shown in figure 3.

Figure 3. Theoretically required desorbent (exhaust gases) consumption at the countercurrent of water and gas as a function of the deaerator load. Quantities of $X_{\text{s.w.}}$, mg/dm$^3$: (1) 8, (2) 10, and (3) 12.

In this case, the theoretical flow $d_{\text{gas}}^{\text{min}}$ corresponds to a deaerator with an infinitely large contact surface of the liquid and gas phases, which explains the relatively small amount of flue gases needed for deaeration. In practice, in deaerators mass transfer takes place at a limited contact surface of phases and for a limited time, so the equilibrium between water and steam adopted in the calculation can not be achieved.

In case of using as a stripping agent the boiler exhaust gases according to the above calculations, theoretically the required gas flow rate for deaeration will be 5-8 m$^3$ per 1 ton of deaerated water. As follows from the obtained dependence, the required specific consumption of the desorbing agent for
deaeration with the exhaust gases of the boiler exceeds the theoretically required water vapor flow rate when used as a desorbing agent.

The problem of excess carbon dioxide in the flue gases (2) and its negative effect on the quality of the de-aerated water is solved by dosing the alkaline agent (sodium hydroxide) into the pipeline of deaerated water.

Neutralization of carbon dioxide contained in feed water, alkali occurs as a reaction:

\[ \text{CO}_2 + \text{NaOH} = \text{NaHCO}_3 \]  \hspace{1cm} (6)

To maintain the pH value of the feed water is added to it an aqueous solution of ammonia, which also reacts with the free carbon dioxide by the following reaction equations [5]:

\[ \text{NH}_3 + \text{CO}_2 = \text{NH}_4\text{HCO}_3 \]  \hspace{1cm} (7)

\[ \text{NH}_4\text{HCO}_3 + \text{NH}_3 = (\text{NH}_4)_2\text{CO}_3 + \text{H}_2\text{O} \]  \hspace{1cm} (8)

It is advisable to introduce ammonia into chemically purified desalinated water, since this allows to protect from the carbon dioxide corrosion and the path of purified or desalted water.

To neutralize free carbon dioxide and increase the pH of feed water, organic amines are often introduced, including cyclohexylamine \(\text{C}_6\text{H}_{11}\text{NH}_2\), morpholine \(\text{C}_4\text{H}_8\text{N}\text{O}\) and piperidine \(\text{C}_5\text{H}_{11}\text{N}\). With alkaline properties and volatility, these corrosion inhibitors create protective oxide films on the surfaces of the feed water tract.

**Conclusions**

- a non-traditional technology for low-temperature deaeration of feed water with the use of boiler exhaust gases as a desorption agent is proposed;
- the efficiency of mass transfer of the water deaeration process for a new technical solution was estimated, the theoretically calculated required desorption agent consumption for deaeration was calculated;
- various methods for removing excess of carbon dioxide from deaerated water are considered.

**References**

[1] Sharapov V I 1994 *Current Problems in the Use of vacuum deaetators for Open Heat-Supply systems* (Therm. Eng. vol 41) pp 635-639

[2] Sharapov V I, Pazushkina O V and Kudryavtseva E V 2016 *Energy-Effective Method for Low-Temperature Deaeration of Make-up Water on the Heating Supply System of Heat Power Plants* (Therm. Eng. vol 63) pp 687-690

[3] Sharapov V I and Kudryavtseva E V 2016 *Energy Efficiency of Low-Temperature Deaeration of Makeup Water for a District Heating System* (Power Tech. and Eng. vol 50) issue 2 pp 204-207

[4] Sharapov V I, Kamalova R I, Kudryavtseva E V and Rogachev S S 2017 *Boiler installation* RF Patent 2629321 IPC F 22 B 33/18 (Byul. Izobr. vol 5)

[5] Roslyakov P V and Zakirov I A 2001 *Non-stoichiometric combustion of natural gas and fuel oil in heat power plants* (Moscow: MEU)

[6] Sharapov V I and Malinina (Pazushkina) O V 2004 *Determining the Theoretically Required Vapor-Venting Rate for Thermal Deaerators* (Therm. Eng. vol 51) pp 321-324

[7] Pavlov K F, Romankov P G and Noskov A A *Examples and tasks on the course of processes and devices of chemical technology. Textbook for high schools* (Leningrad: Chemistry)

[8] GOST (State Standart) 16860-88* 1989 *Thermal deaerators. Types, basic parameters, acceptance, control methods* (Moscow: Izd. Stanartov)