Modeling of the process of retaining the concentration of aggressive gases during the operation of deaerators

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Abstract. In this article, in the process of deaeration of feed water in thermal deaerators in the saturation temperature range of 20-105 °C, a method is proposed for determining changes in partial pressure, absorption coefficient and concentration values of aggressive gases such as carbon dioxide, oxygen and nitrogen in the gas phase and dissolved in water is modeled according to Henry's law, and the results obtained are graphically depicted; conclusions are given on how the correspondence of the saturation temperature to an increase in pressure affects the change in the concentration of aggressive gases.

1 Introduction

Unsatisfactory performance of deaeration devices for thermal deaeration of supply water of steam boilers (the deaerator is designed to separate aggressive gases - oxygen and carbon dioxide from water) is one of the major problems in thermal energy, which is an intensive internal piping system of heat networks, boiler rooms and auxiliary equipment of thermal power plants. causes corrosion. As a result, the service life of pipelines is drastically reduced. The situation is especially unfavorable in heat systems with open water reservoirs, that is, in an open reservoir heat system, a large amount of water is required to fill the system, and water is transferred through one pipe for heating and hot water supply [1-3].

The task of determining the size of the deaeration zone, which ensures effective separation of gases dissolved in water, is the main issue in the calculation of deaerators. However, the calculation of these devices is carried out using semi-empirical models, which limits the possibility of modernization using new contact devices [4,5]. Therefore, it is considered appropriate to determine the optimal parameters using mathematical modeling [6].

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2 Materials and methods

In the deaerator equipment, the statics of the desorption process, which takes place according to the solubility of gases in water, is based on the laws of equilibrium between the liquid and gaseous phases. In the general case, subject to the law of interphase equilibrium, the simultaneous existence of different phases in the same environment is determined by the presence of dynamic equilibrium between them.

According to the given conditions, a certain "equilibrium" composition of the second phase at a certain pressure and temperature corresponds to a certain composition of one of the phases. If the amount (concentration) of any component in the gas phase is greater than the equilibrium value, this component will pass into the liquid phase or vice versa. A state of dynamic equilibrium between the phases is established when the phases are in contact with each other for a long time.

Oxygen, nitrogen and carbon dioxide have different solubility in water. The greater solubility of carbon dioxide in water (compared to O_2 and N_2) leads to the formation of carbonic acid in its chemical interaction with water.

$$H_2O + CO_2 = H_2CO_3. \qquad (1)$$

In deaeration devices, gas solutions can be considered infinite. In this case, the transition of one or another component from the liquid phase to the gas phase does not depend on the presence of other components in the solution and is determined only by the content of this component in it. For ideal mixtures with temperatures above the critical temperature of gases, equilibrium at relatively low partial pressures of gases is determined by Henry's law.

$$p = E \cdot x, \qquad (2)$$

where E is Henry's coefficient with pressure dimension; x is the molar fraction of the gas component in the liquid.

In equilibrium determined by Henry's law, the mass concentration or solubility of a component in water (mg/kg) is determined as follows.

$$c_g = \alpha^a \cdot \frac{\gamma_g}{\gamma_c} \cdot \frac{p_g}{p_0} \cdot 10^6 \qquad (3)$$

where a^a – When the partial pressure of gases is 760 mm above sea level, the absorption coefficient of water at a specified temperature (at a temperature of 0 °C, the pressure is 760 mm above sea level), m^3/m^3; γ_g – specific gravity of gas under normal conditions, kgk/m^3; γ_c – specific gravity of water, kg/m^3; p_0 – physical atmospheric pressure, kgk/m^2; p_g – partial pressure of gas above water, kgk/m^2.

At temperatures up to 120 °C, the Henry's coefficient for solutions of gases in water increases with increasing temperature, which leads to a decrease in the solubility of the component. At temperatures above 120 °C, the Henry coefficient decreases, leading to an increase in solubility.

The dependence of the absorption coefficient for oxygen, carbon dioxide and nitrogen on water temperature is presented in Figures 1-2.

If as many molecules fly out of the surface of the liquid and change to the gas state, and the same number of molecules condense and return to the liquid state, such a phenomenon is considered a state of saturation, that is, the parameters of steam and water in the same medium are balanced. Vapor in dynamic equilibrium with liquid is called saturated vapor. The vapor that saturates the space above the free surface of the liquid is called wet vapor. Saturated moist steam contains small water droplets. If additional heat is transferred to the generated wet steam, the very small water droplets contained in it will turn into steam and saturated dry steam will be formed [3, 7-13]. Therefore, it can be considered that even after transitioning to the vapor state, liquids separate into wet and dry saturated vapor phases.

If additional heat is transferred to saturated dry steam at constant pressure, its temperature rises and it becomes superheated steam.

Superheated steam approaches gases in its physical properties [3].

Superheated steam and especially saturated steam have very different properties from ideal gases. The equations of state of steam are extremely complicated and almost impossible to use in practice.

The amount of heat transferred to or removed from a body is represented by the area under the process curve in the TS-diagram. Therefore, in order to determine the amount of heat supplied or removed, it is necessary to calculate these quantities each time by calculating their respective surfaces, which makes it difficult to calculate quickly and accurately in practice. If enthalpy values h are placed instead of temperature on the ordinate axis of the TS-diagram, then the work when s=const and the amount of heat when p=const are depicted in this diagram not by surfaces, but by line sections.

The first hs-diagram for water vapor at pressure up to 20 atmospheres was proposed by Mole in 1904. The emergence of the hs-diagram greatly simplified the methods of thermodynamic investigation and calculation of steam processes and cycles.

Currently, MEI Professor M.P. Water vapor tables and diagrams developed under the guidance of Vukalovich are used. These tables are compiled with high accuracy for superheated and saturated steam up to 1000 °C temperature and 980 bar pressure [4].

Saturated steam tables show saturation temperature, pressure, specific volume, enthalpy and entropy of liquid and dry steam, heat of steam formation. In the superheated steam tables, the values of the basic parameters: specific volume, enthalpy and entropy are presented for different pressures and temperatures [4].

3 Results and discussions

Mathematical solutions of the change in the absorption coefficient of oxygen, nitrogen and carbon dioxide gases into the water content with the increase of the saturation temperature from 20 °C to 105 °C in deaerator devices with atmospheric pressure were obtained (Figures 1-2).

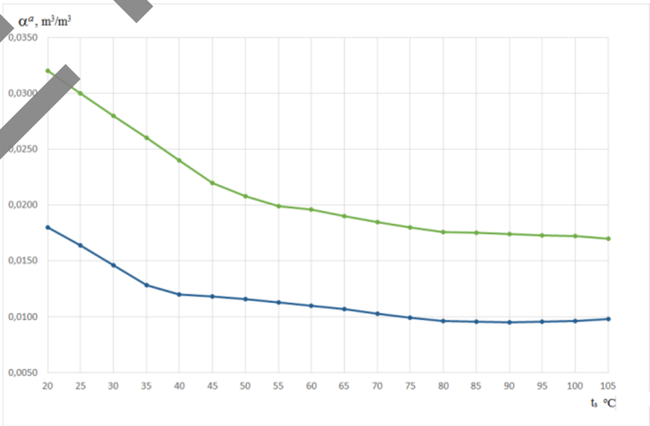

Fig. 1. Dependence of oxygen and nitrogen gas absorption (m^3/m^3) on water saturation temperature (°C).

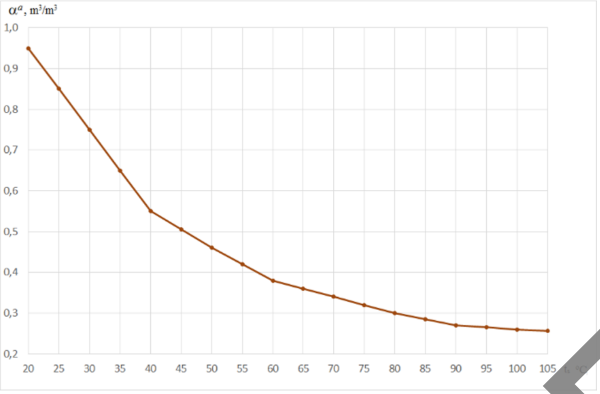

Fig. 2. Dependence of carbon dioxide absorption (m^3/m^3) on water saturation temperature (°C).

Given that the pressure in deaerators operating at atmospheric pressure is 1.2 atm, we calculate the partial pressures of air, oxygen and nitrogen using the following formulas:

$$p_a = \left(p_a + \frac{p_a}{5}\right) - \left(\frac{p_a^t * 1000}{p_a^{Rt}}\right); mmHg\ art. \tag{4}$$

$$p_{O_2} = \left(p_a + \frac{p_a}{5}\right) - O_2 \cdot \left(\frac{p_a^t * 1000}{p_a^{Rt}}\right); mmHg\ art.(O_2) \tag{5}$$

$$p_{N_2} = \left(p_a + \frac{p_a}{5}\right) - N_2 \cdot \left(\frac{p_a^t * 1000}{p_a^{Rt}}\right); mmHg\ art.(N_2) \tag{6}$$

In the calculation results, when the temperature change limit changes from 20 °C to 105 °C for saturation conditions, the graph of the change of the partial pressure of oxygen, nitrogen and carbon dioxide gases over the deaerated water mass is presented in Fig. 3. In this case, it is understood that as the temperature of water rises, the partial pressure of water vapor in the void space increases, and the partial pressure of other gases decreases by itself. Calculations allow us to obtain accurate values and help to model the dynamic state of the process.

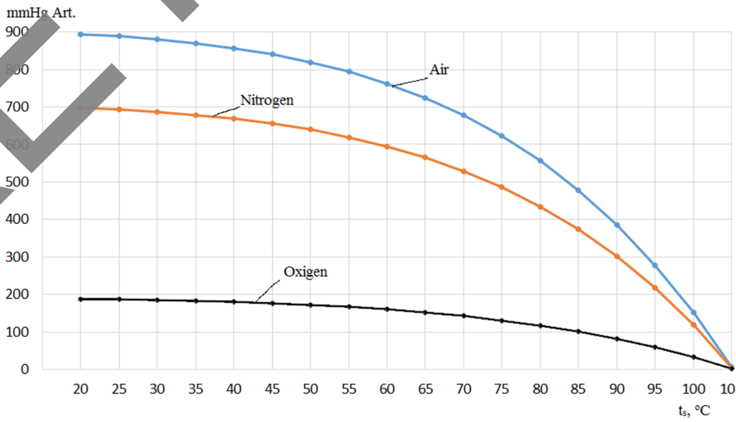

Fig. 3. Graph of dependence of partial pressure of air, nitrogen and oxygen gases on saturation temperature.

In heating networks, thermal power centers and stations, the preparation of cycle filling water is carried out in atmospheric pressure deaerators. Coordination of thermal processes for this type of devices, work aimed at calculating concentrations of oxygen, nitrogen and carbon dioxide dissolved in water vapor will be launched.

The conversion of the pressure measurement from Pascal to mm wire is calculated on the basis of the theory of dimensions and using the expressions of dependence in the available literature (Fig. 4). Also, calculated values of changes in concentrations of various aggressive gases at pressure values corresponding to saturation temperature are determined (Figures 5-7). Focusing on the main results in the determined values, it can be seen that in all cases, increasing pressure decreases the concentration of dissolved gases, corresponding to increasing temperature.

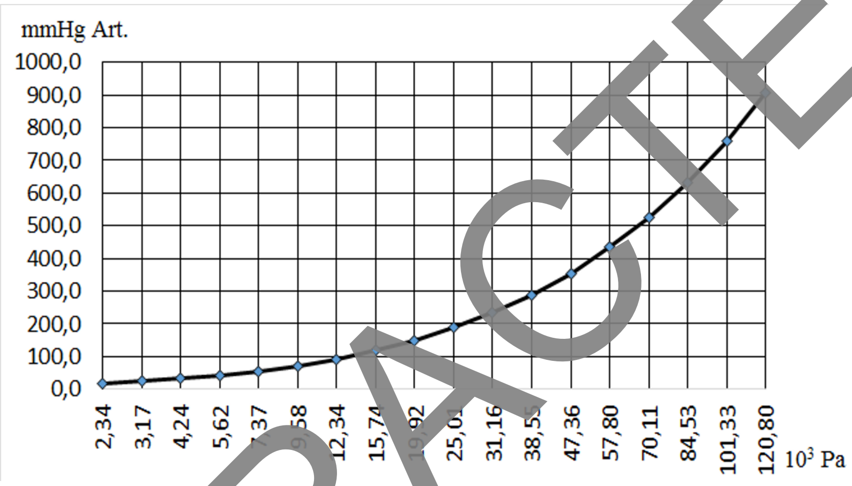

Fig. 4. Based on the obtained data, the pressure measurement is transferred from Pa to mm.

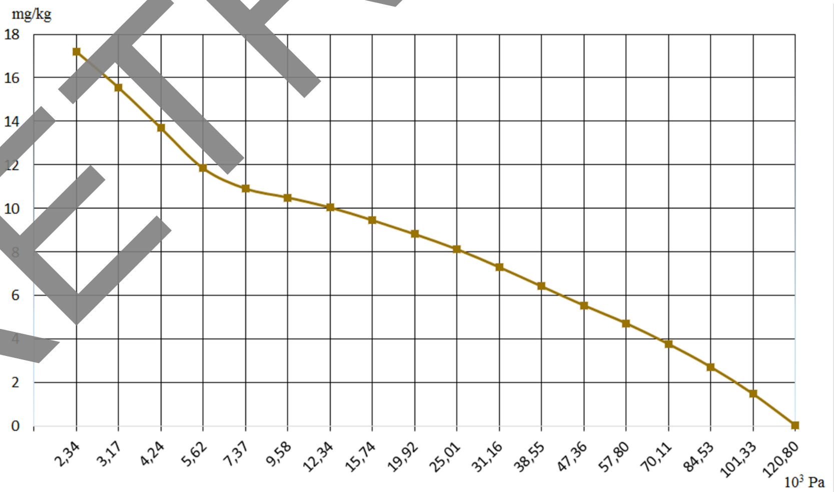

Fig. 5. A graph of the change in the concentration of dissolved nitrogen gas in water with increasing pressure corresponding to the saturation temperature.

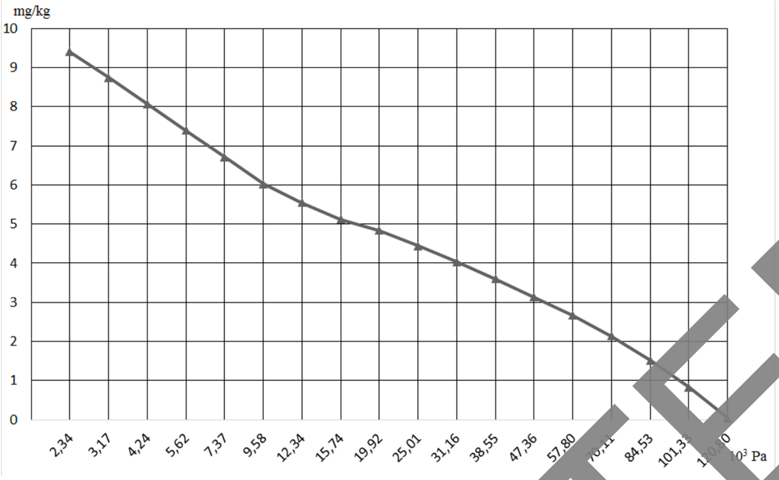

Fig. 6. A graph of changes in the concentration of dissolved oxygen gas in water with increasing pressure corresponding to the saturation temperature.

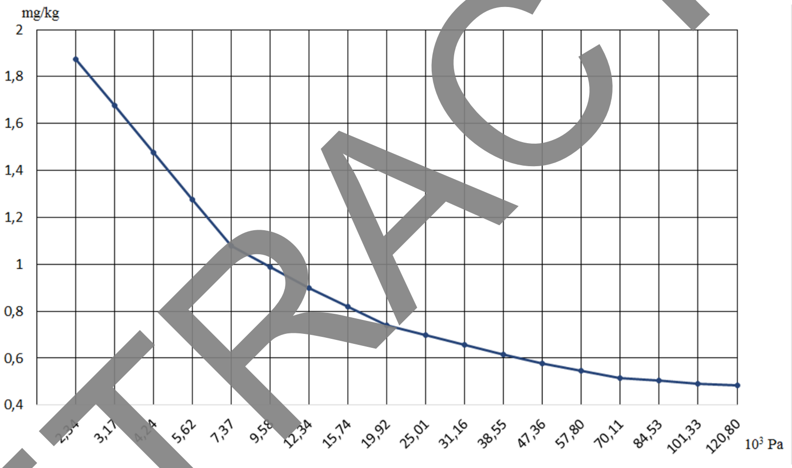

Fig. 7. A graph of changes in the concentration of dissolved carbon dioxide gas in water with increasing pressure corresponding to the saturation temperature.

According to the results obtained in Figures 5 and 6, it can be seen that the concentration of dissolved nitrogen and oxygen gases in water with initial parameters is around 10-20 mg/kg, but with the increase of saturation temperature and pressure, it can be seen that it decreases sharply and approaches 0 value. As a result of processes like expression (1) from the chemically purified and deaerated water content, the concentration of carbon dioxide gases decreases to a certain limit with the increase of saturation temperature and pressure, according to the presence of carbonate residues, but it can be observed that this concentration increases again with the increase of parameters (Fig. 7).

4 Conclusions

Based on the obtained results, it can be noted that reducing the concentration of aggressive gases when studying the operating parameters and temperature regimes of deaerator devices with atmospheric pressure guarantees an increase in the reliability of the device. To do this, it is necessary to prevent the molar mass fraction of aggressive components in the working fluid according to Henry's law. Long-term use of the deaerator device can be achieved if the amount of aggressive gases and air particles is not allowed to develop naturally due to various absorption or carbonate compounds.

Finally, reducing the concentration of gas solutions improves the quality of the deaerated water, and there is no need to introduce various compounds into the water for purification purposes.

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