

Development of an algorithm for analyzing the causes of increased oxygen content of condensate

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Abstract. To increase the efficiency of condensers, one of the most important methods is to constantly maintain a high hydraulic density, since malfunctions of the condensing unit lead to a significant reduction in electricity generation. The increased air content in the wet vapor in the condenser and the air suction into the turbine, lead to exceeding the standard values of the condensate oxygen content and therefore have a significant impact on the uninterrupted operation of the TPP, causing the pipeline to corrode from the condensation unit to the deaerating unit. In addition, the increased oxygen content makes heat transfer difficult, since an insulating layer is formed between the condensate film on the heated surface and the steam. Currently, there are a number of methods for thermal calculation of a condensation unit. In this work, the most accurate Iglin-Shepelev technique was used. Using the developed algorithm, the work of the Kirov CHPP-4 and Bezymyanskaya CHPP was analyzed. The experimental data with the calculated characteristics plotted on them are also clearly shown at various temperatures of cooling water with an average flow rate of circulating water, and the reasons for the increased oxygen content of the condensing units of the stations under consideration are identified. Based on the calculation results, measures were proposed to eliminate the increased oxygen content.

1. Introduction

The condensation device of the steam turbine installation (STP) has a significant impact on the efficiency, continuity and reliability of the thermal power plant (TPP). The efficiency of the condenser is affected by: the contaminants presence on the heat exchange surfaces; the presence air suction in the condensation system of the turbine; vacuum depth in the condensation unit (including the efficiency of the ejectors), etc.

Any negative changes in the operation of the condenser lead to a decrease in the depth of vacuum, a decrease in the ejector efficiency, a decrease in the thermal power plant efficiency, and, as a result, an increase in fuel consumption.

According to studies [1, 2], a change in the pressure in the condenser by 1 kPa (1% vacuum) leads to a change in the power of the TPP turbine with an initial superheated steam pressure of 13-24 MPa by about 0.8-0.9% of the nominal power, data for various the turbines are shown in Figure 1. The deepening of the vacuum directly depends on the air extraction devices operation (ejectors).

In addition, the increased air content in wet steam in the condensing unit and the air suction into the turbine, lead to exceeding the standard values for the oxygen content of the condensate (20 $\mu\text{g}/\text{kg}$) and, as a result, have a significant impact on the uninterrupted operation of the TPP, causing the pipeline to corrode [3, 4] from the condensing unit before deaerating installation [5, 6].



Air and other non-condensable gases entering the vapor significantly impede heat transfer, since they form an insulating layer between the condensate membrane on the heated surface with steam (Figure 2). The presence of oxygen or air has a negative effect not only in condensers [7].

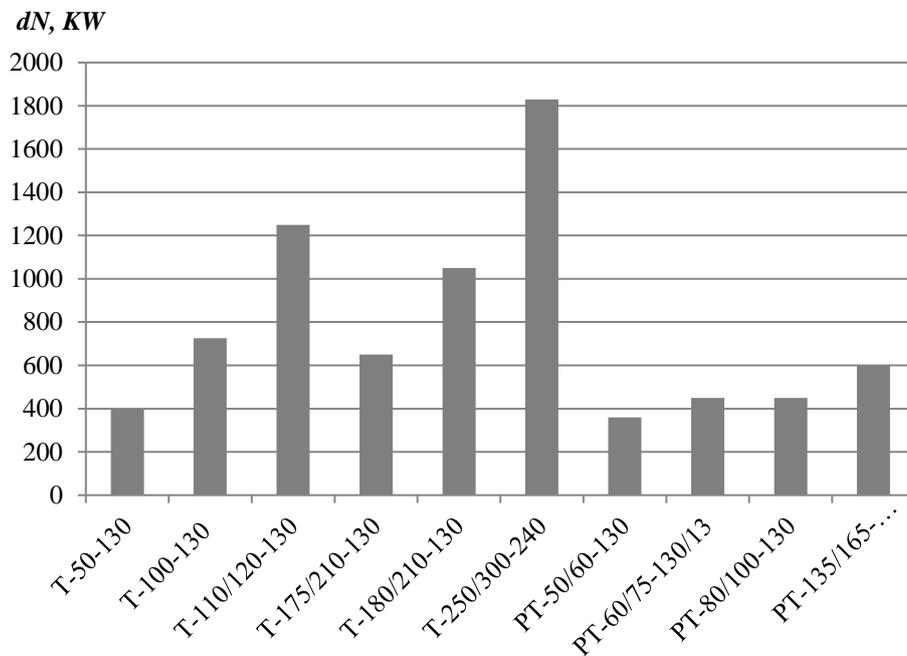


Figure 1. Change in turbine power with a pressure change in heating turbines condensers 1 kPa, operating in condensation mode.

With a decrease in the vapor load of the condenser, especially in the modes with increased air suction, the intensity of the heat and mass transfer process changes, the zone of intense vapor condensation decreases, the average heat transfer coefficient decreases, and the condensate supercooling increases.

In [8], it was shown that brass tubes corrosion in a condenser can also be caused by ammonia intense concentration in the apparatus zones. For example, the tests at one of the units of the Severnaya CHPP (St. Petersburg) showed that the ammonia concentration in the local damage zones of network heaters exceeds the standard value (1000 $\mu\text{g/l}$) by 50-60 times.

Thus, for the efficient operation of condenser, one of the most important methods is the high hydraulic density constant maintenance, since malfunctions of the condensing unit lead to a significant reduction in electricity generation. However, in order to develop these measures, it is necessary to create an effective condenser diagnostic system [9], which would make it possible to identify the cause of the condenser malfunction (decrease in the quality of its operation). Such a system should have a module for recording and storing all condenser operation parameters: steam flow rate, flow rate and temperature of the main condensate, recirculation condensate flow rate, flow rate and temperature of cooling water. Particular attention must be paid to the automatic fixation of the oxygen content of the main condensate. Most stations measure oxygen twice a shift, this is not enough to quickly eliminate problems and accidents in the event of their occurrence, the consequences of such accidents can lead to corrosion of equipment, and therefore to high costs. In addition, the diagnostic system must have an information analysis module, and this requires mathematical models [10-12] of all the processes occurring in the condenser, which will become the basis for the software.

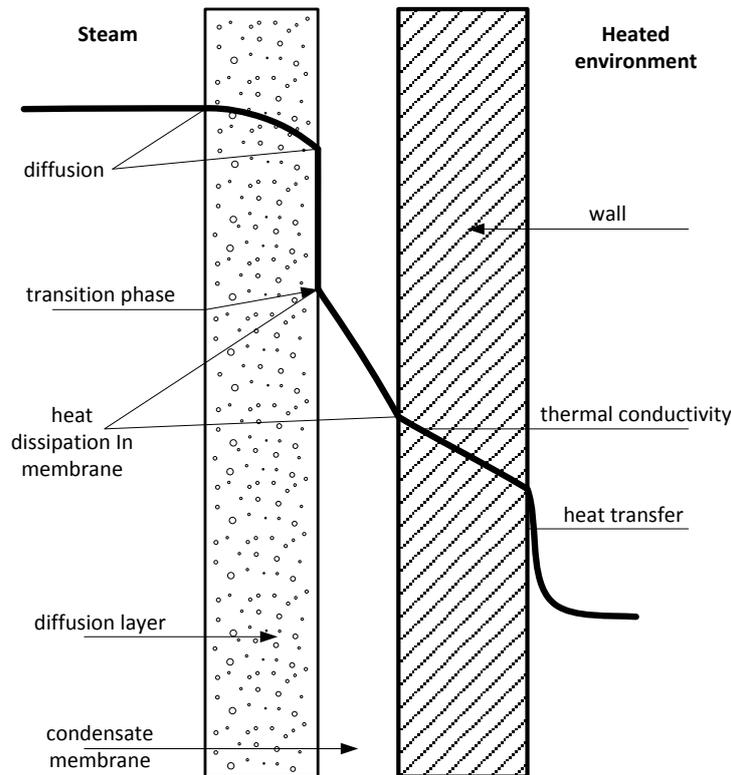


Figure 2. The effect of the air gap and the condensate membrane on the temperature regime.

It is necessary to develop an algorithm for analyzing the condenser reliability, which could be used to assess the reasons for the increase in oxygen content in the main condensate based on the available operational parameters.

2. Materials and Methods

To create an algorithm for the condenser reliability, it is necessary to choose its mathematical model as a basis. The difficulty in creating an accurate condenser calculation system is to find the heat transfer coefficient k . Currently, there are a number of different methods for calculating the heat transfer coefficient of a condensing unit [13, 14].

The US Institute of Heat Transfer [15] does not take air suction into the condenser and the dependence of the heat transfer coefficient on the steam load of the installation. In addition, it is still being finalized.

Also, there is a Russian method for calculating the heat transfer coefficient of a condenser. It belongs to the Kaluga Turbine Plant (KTP technique). In it, in addition to the speed of the coolant, the initial temperature and the contamination of the condenser tubes, air suction is also taken into account. However, during the condensation unit operation, the measurement of the pollution layer thermal conductivity coefficient λ in the condenser tubes is an almost impossible task. The KTP technique also does not take into account the nature of the condenser and ejector joint operation.

P V Iglin, A G Shempelev [16] proposed a different methodology for calculating the heat transfer coefficient in the condenser, which is in good agreement with experimental and regulatory data.

A comparison of the methods described above is shown in Figure 3.

As shown in Figure 3, when the condenser loads are less than half of the nominal, a large discrepancy in the results of the calculated and standard values of the heat transfer coefficient begins, associated with the influence of the ejector on the operation of the condenser and air suction.

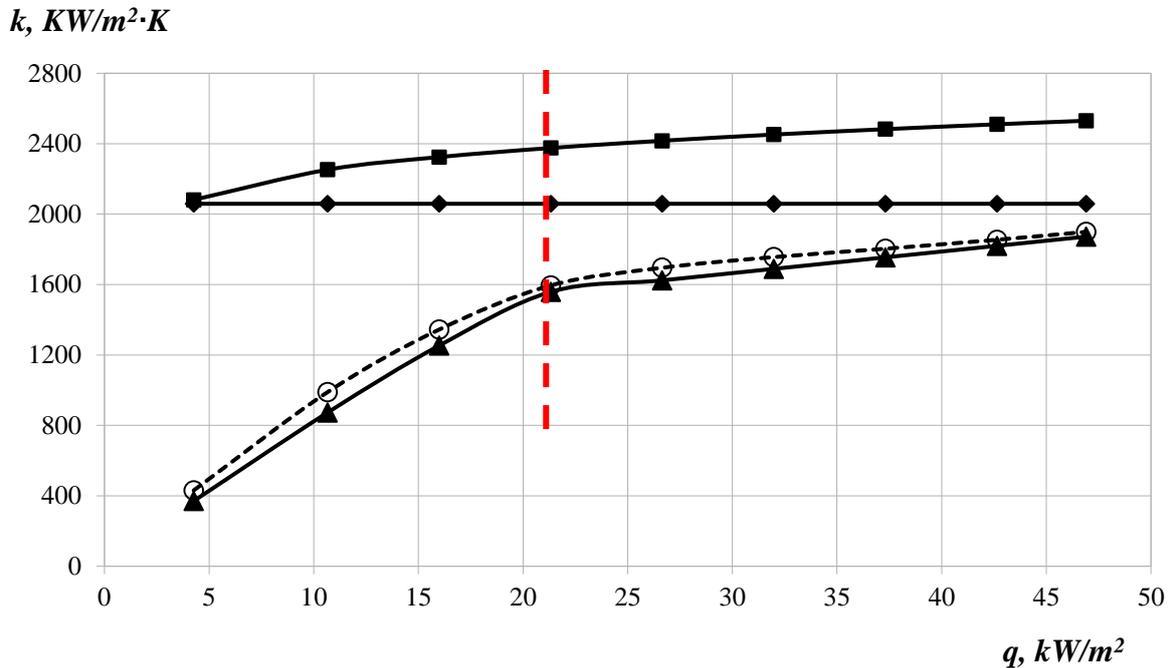


Figure 3. Comparison of the heat transfer coefficient using the example of a 100 MW turbine unit condenser and heat transfer area 3000 m²: ▲ – calculation according to the Iglin-Shempelev technique, ■ – KTP calculation, ◆ – calculation according to the ITO method, ○ – normative characteristic.

In the work, methods of numerical calculations using the mathematical model of the Iglin-Shempelev condenser were used, as well as regression analysis as applied to the experimental data for the Kirov CHPP-4 and Bezmyanskaya CHPP (Samara).

3. Results

The following algorithm was proposed to analyze the increased oxygen content causes in the main condensate after the condenser:

1) The necessary parameters of the condenser operation are fixed: the steam flow into the condenser neck D_c , the pressure in the condenser p_c , the temperature of the main condensate at the outlet of their condenser t_c , the flow rate of cooling water W , the temperature of cooling water at the inlet t_{1w} and at the outlet t_{2w} , air suction in the condenser (or turbo) G_{air} , the actual oxygen content in the main C_{O_2} real condensate. To do this, it is necessary to equip the condenser with measuring instruments at various points in the installation, which should record and take measurements and transfer them to a computer for storage and processing.

2) The measured parameters are transferred to the mathematical model of the condenser, in which the KTP methods are used to determine the characteristics of the condenser during condensation of pure steam, and the Iglin-Shepelev method is used to determine the characteristics of the condenser during steam-air mixture condensation in it. Under the characteristic of the capacitor is understood the dependence of the saturation temperature (pressure) in the capacitor on its specific heat load. For quick calculations, the algorithm can be written in Python.

3) The oxygen content of the main condensate is determined on the basis of Henry's law with air suction into the condenser corresponding to the measured (actual) $C_{O_2 \text{ fact}}$ and standard $C_{O_2 \text{ norm}}$.

4) The calculated values are compared with the actual $C_{O_2 \text{ real}}$ and the maximum allowable (20 $\mu\text{g}/\text{kg}$):

- $C_{O_2 \text{ real}} \leq 20 \mu\text{g}/\text{kg}$ - the oxygen content in the main condensate is normal, no control actions are required;

• $C_{O_2, real} > 20 \mu\text{g/kg}$, to determine the cause of the increase, it is necessary to compare the value of the actual G_{air} air suction with the standard value determined by the formula $G_{air, norm} = 8 + 0.065 \cdot N$ (where N is the nominal turbine power, MW). If $G_{air} > G_{air, norm}$, then the excess of oxygen content is caused by large suction of air into the turbine. In this case, it is necessary to increase the hydraulic density of vocational schools. If $G_{air} \leq G_{air, norm}$, then the increased oxygen content is associated with the supply of flows to the condenser, in addition to the steam stream from the turbine with high oxygen content, for example, recirculation condensates, condensates of regenerative heaters, ejector coolers, etc. In this case, the following measures can be taken to reduce the oxygen content: installing a deaerating device in the condensate collector (if it is absent), excluding the supply of drains under the level of condensate in the condensate collector.

For clarity, in Figure 5 shows a block diagram of the algorithm.

Using the algorithm above, the work of the Kirov CHPP-4 and Bezymyanskaya CHPP (Samara) was analyzed.

At Kirov CHPP-4, a turbine No. 2 with a condenser of 60 MW was considered during its operation for one calendar year.

During this period, the temperature of the cooling water changed from 9°C to 32°C, and the flow rate of cooling water from 500 t/h to 4000 t/h. Using the above algorithms, it was found that this installation works with air suction from standard (12 kg/h) to high (60 kg/h). Supercritical oxygen values above 400 $\mu\text{g/mg}$ were also observed. Such an excess is explained by the discharge into the condensate collector of the drainage contaminated with the oxygen flow, while the maximum value was 10,000 $\mu\text{g/mg}$. In addition, it is worth noting that oxygen is measured at the Kirov Thermal Power Plant-4 by the dissolved oxygen analyzer MARK-302T. This device has a low threshold of an acceptable measured value - 40 $\mu\text{g/mg}$, therefore, for large values, the indigo carmine method is used. In the indigo carmine method, the oxygen content in water is determined by comparing the colored test sample with the scale. This method is very subjective, as it depends on the person color perception.

Figure 4 shows the experimental data with the calculated characteristics plotted on them, at various temperatures of cooling water with a flow rate of circulating water $W = 2000 \text{ t/h}$. The calculated data revealed the reasons for the increased oxygen content of the installation.

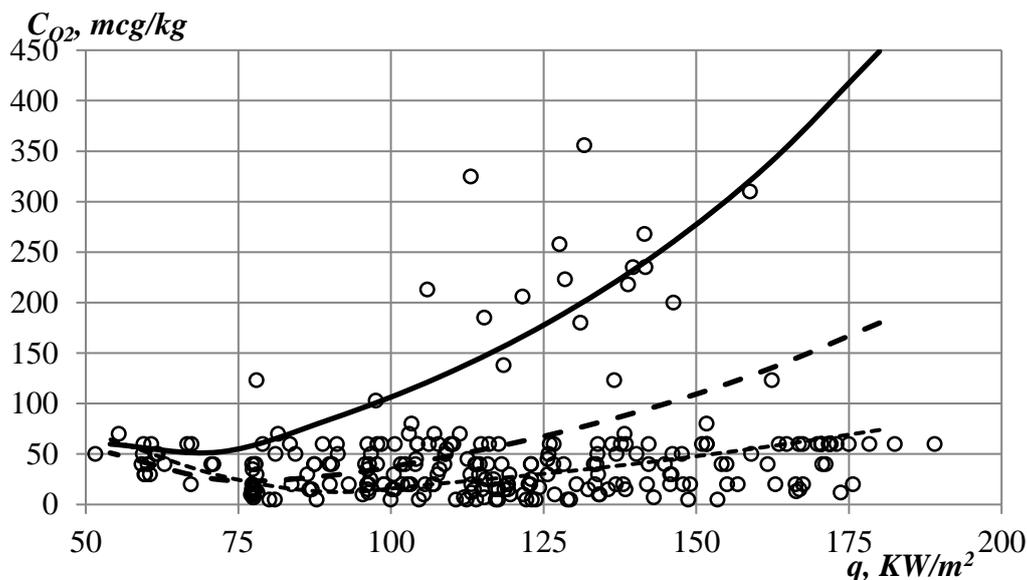


Figure 4. The dependence of the oxygen content on the specific heat load of the installation: ———— $t_{lw} = 30^\circ\text{C}$; - - - - - $t_{lw} = 20^\circ\text{C}$; - · - · - $t_{lw} = 10^\circ\text{C}$.

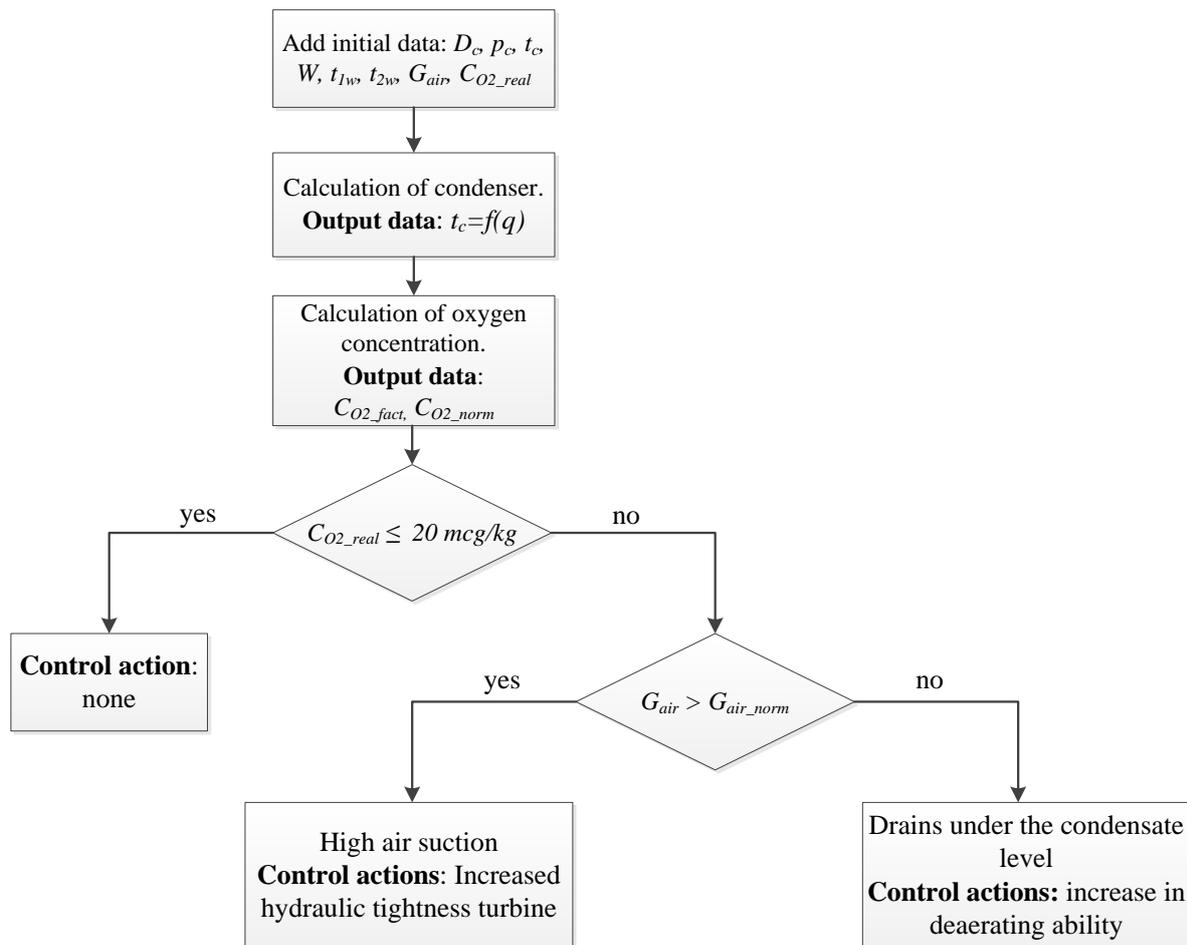


Figure 5. The flowchart of the analysis of the causes of the increased oxygen content in the main condensate after the condenser.

Further, an analysis of data on Bezymyanskaya CHPP in Samara was carried out. According to Bezymyanskaya CHPP, calculations were carried out according to the experimental data of a turbine unit No.6 with a capacity of 50 MW, with a week work period.

For the considered period of time, the specific load of the condenser q was in the range of 10–25 kW/m², the pressure of the condenser p_k varied from 3.101 kPa to 4.335 kPa. Using the Iglin-Shempelev technique, the average temperature of cooling water was determined, which was 14°C and the air suction into the turbine was 44 kg/h. According to experimental data, the oxygen content of the condenser was 12–40 µg/kg. As a result of the calculations, the following characteristics were obtained (Figure 6, 7).

Figure 4 shows that the experimental points lie in the calculated design characteristics area. In connection with increased air suction, an excess of experimental values is also observed over the calculated characteristic built with standard suction.

Figure 6 illustrates the oxygen content in the main condensate at the outlet of the condenser, depending on the heat load. Thus, we can conclude that there is a slight excess of oxygen content, which is caused by a 5-fold increase in air suction into the turbine unit.

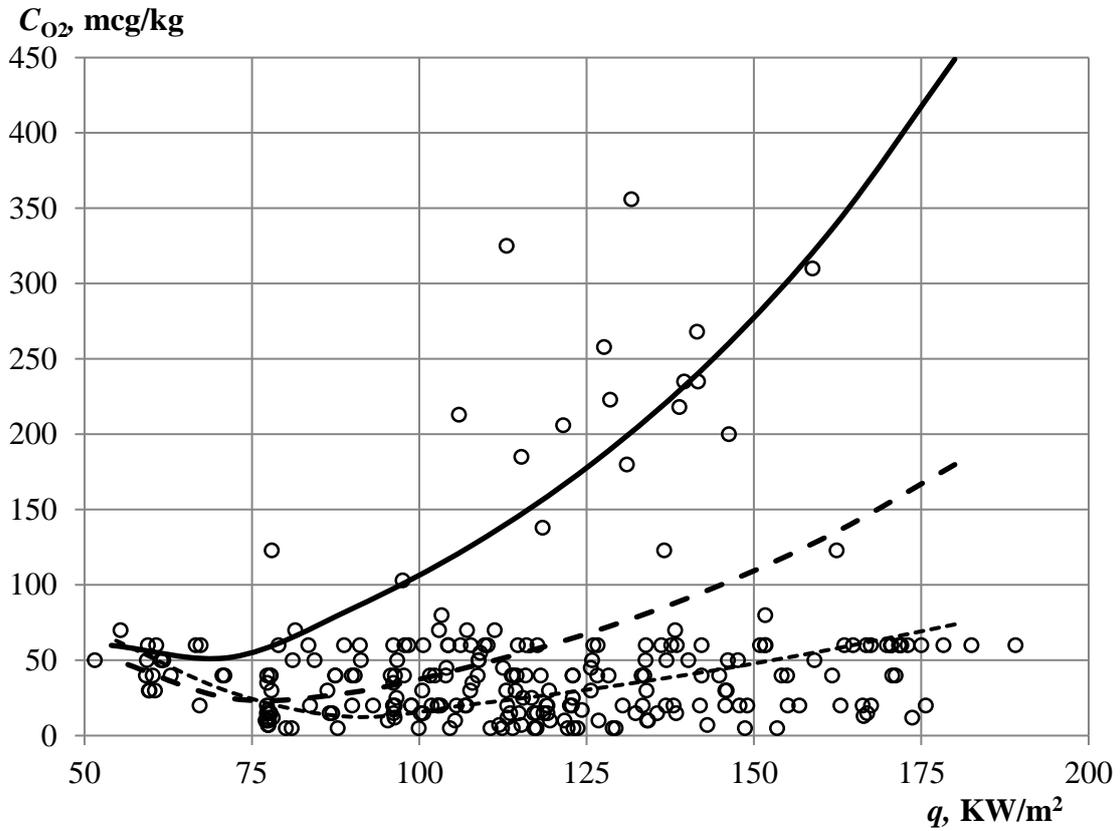


Figure 6. Characteristics of the condenser: — at $G_{air} = 11.2 \text{ kg/h}$; - - - - at $G_{air} = 44 \text{ kg/h}$.

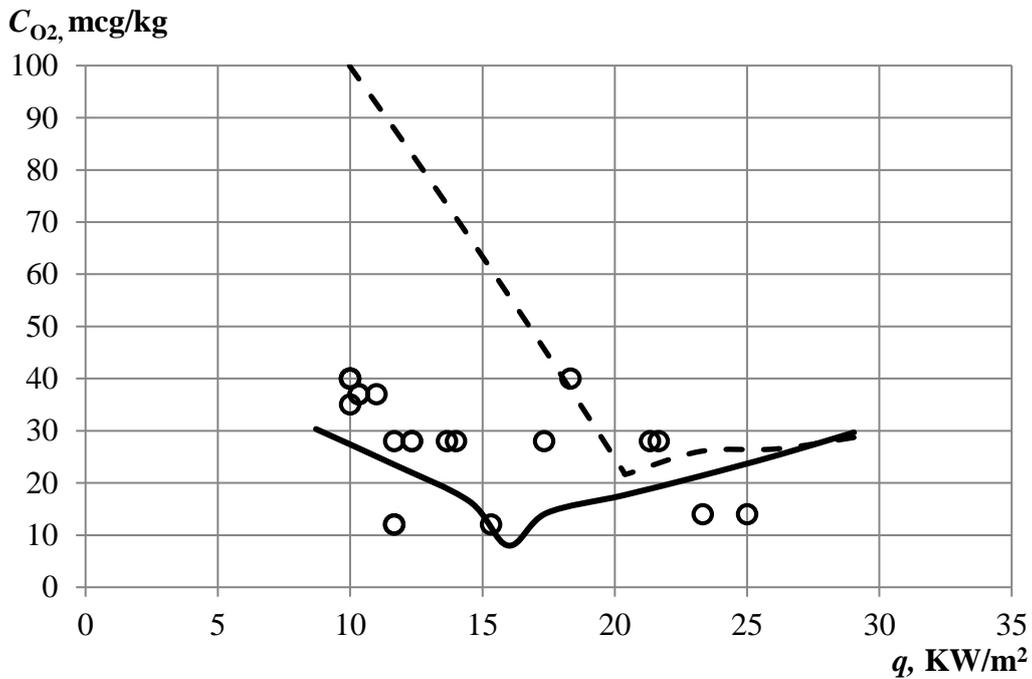


Figure 7. Oxygen content of the condenser: — at $G_{air} = 11.2 \text{ kg/h}$; - - - - at $G_{air} = 44 \text{ kg/h}$.

4. Discussion

Based on the analysis of the oxygen content of the condensers of the Kirov CHPP-4 and Bezymyanskaya CHPP, it can be judged that the employees do not provide the necessary care for the equipment, since the oxygen content at both stations is higher than the standard ones, and at the Kirov CHPP-4 the standard values are exceeded even hundreds of times.

According to the calculated and experimental data, Bezymyanskaya CHPP works more reliably and efficiently than Kirov CHPP-4. The maximum oxygen content at Bezymyanskaya CHPP is 40 µg/kg, at Kirov CHPP-4 this value reaches 10,000 µg/kg, thus there is a difference in exceeding the standards 250 times. The indicators that were obtained as a result of the analysis of the Kirov CHPP-4 are unacceptable for the uninterrupted operation of the equipment.

5. Conclusion

Due to the experimental data, the calculation of indicators according to the Iglin-Shempelev method and the constructed visual characteristics, it was possible not only to detect the oxygen content and air suction excess in the turbine unit over the standard ones, but also to put forward the closest assumption of the reasons for the excess values. The method of establishing the reasons for the excess is clearly described in the flowchart of Figure 5.

For the Kirov CHPP-4, the reason for exceeding the excess values by more than 500 times is the discharge into the condensate collector of drains that are contaminated with oxygen.

For Bezymyanskaya CHPP, as the algorithm passed result, the reason for the excess was air suction in the turbine low-pressure cylinder.

However, a more accurate determination of the reasons for the oxygen content and air suction excess requires a more detailed and deep instrumental examination of each condenser at the stations.

Acknowledgments

The study was carried out with the financial support of the RF President Council on grants as part of the research project MK-2614.2019.8.

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