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RESEARCH OF PROCESS WATER OF A THERMAL POWER PLANT

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The article is devoted to the study of technical water used in thermal power plants. One of the devices of thermoelectric plant are heat exchangers, heat exchangers consist of pipes of different diameters. Heat exchangers used in production plants are made of carbon steel, suitable for high temperatures (up to 565 °C). At the same time inside the heat exchangers used for a certain period of time, a scale is formed in the form of a solid sediment, which reduces the thermal efficiency of heat carriers. Therefore, in this paper, the object of research are the heat transfer fluids of industrial heat exchangers, namely feed and process water. In order to obtain feed water at industrial thermal power plants, special water treatment processes are carried out. That is, its main purpose is to prevent the formation of solid deposits in heat exchangers. The studied water samples were taken directly from the thermal power plant from different stages of water treatment, i. e. raw water entering the chemical shop, treated water entering the deaerator, feed water entering the boiler. As a result of the study, water samples related to the formation of scale on the surfaces of heat exchangers, i. e. dosed amounts, elemental composition and particles were studied. During the study, hourly, daily and monthly dosages of reagents were determined. In addition, the elemental compositions of raw water, pure water and feed water of the thermal power plant were investigated. The results of this study allow to explore ways of economical and effective descaling formed in heat exchangers

Keywords: thermal power plant, flow rate, pressure, temperature, scale, reagents, coagulants, elements, filtration, cleaning, washing

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1. Introduction

The study of suitability for operation and improving the heat dissipation efficiency of industrial heat exchangers is one of the current tasks today, in this article deals with heat exchangers in combined heat and power centers and the feed water used in them, reducing their thermal efficiency.

The thermal power plant, where the research was conducted, provides electricity to 80 % of the city of Karaganda, located in the center of the Republic of Kazakhstan. This plant is one of the five largest thermal power plants in the Republic of Kazakhstan, i.e. one thermal power plant that operates without shutting down during the year. At present, the installed capacity of the combined heat and power plant is 690 MW, and the heat capacity is 1,069.1 Gcal/hour. Reliable and long-term operation of the combined heat and power plant is determined by 100 % availability of the units. 70 % of units at the plant consist of heat exchangers, i.e. depend on heat output of heat exchangers.

The thermal power plant uses technical water as a coolant, so under the influence of high-temperature coolants solid deposits (scale) are formed on the walls of heat exchangers, which reduce the heat exchange properties of heat exchangers.

There are several methods of descaling formed on the surfaces of heat exchangers, that is, mechanical, electrical and much more. The study of chemical structures of industrial water to study optimal approaches to descaling is an urgent problem today. The thermal power plants were created 40–50 years ago, but in connection with the development plan they are undergoing modernization with the construction of additional power units. However, new installations cannot produce the necessary electricity, so all old devices are restored after reconstruction. When using new filters for water purification at industrial enterprises, the dosage in them is carried out according to normal standards. Therefore, it is necessary to conduct additional studies in order to improve the composition of the industrial water content.

The results of these studies allow to study the correct and effective methods of descaling in heat exchangers. Therefore, the research that is devoted to descaling in heat exchangers is of scientific importance.

2. Literature review and problem statement

The enormous but still growing demand for electricity in China has led to the thermal power industry becoming one of the largest consumers of water. Consequently, the structure and performance of water consumption in this industry is directly related to the degree of water use in China. The water consumption of thermal power plants can be divided into two parts, which are production water consumption and non-production water consumption. Production water consumption in thermal power plants accounts for about 95 % of the total. The main uses of production water at a thermal power plant include the use of circulating cooling water, the use of water for ash removal (bottom ash), the use of boiler make-up water and the use of water for independent chemical use, etc. Non-productive water consumption includes domestic water consumption, firefighting water consumption, use of clean water and use of water for landscaping. In the article [1] presents on water conservation at thermoelectric power plants in the People's Republic of China, with water conservation reducing the amount of power produced. In the article [2] presents in detail the physical-chemical treatment system used for industrial water production at the Romanian thermal power plant (Veolia Energy Iasi Co.), with a description of its installations, the characteristics achieved as well as the quality characteristics of the treated industrial water and some of the resulting sludge (i. e. primary and desulphurization). Industrial water treatment efficiency is very good (85–100 %) in terms of suspended solids, turbidity, organic compounds (expressed as chemical oxygen demand), fixed residues, heavy metals, total hardness and microbiological inhibitors. The primary sludge had high water content and total iron content, and the desulfurization sludge had low water content and moderate calcium content. Information on the treatment and valorization methods used for the primary sludge and sludge is recommended, as it all depends on the operating and maintenance costs of the conditioning and dewatering units used. The end result could be a new by-product with added value, which could be used as raw material or auxiliary material (homogeneous compact plates) and minimize the amount of sludge produced, combined with environmental protection and control of environmental pollution due to the operation of industrial water treatment plant [2]. In the article [2], the general principles of cleaning of thermoelectric power plants have been considered, and their elemental compositions have not been studied.

According to the source [3], a study was made by placing a side flow filter in the cooling tower to observe water retention in the system. The water parameter was measured using various flow rates, pressures, and other factors. The maximum make-up water and outflow were reduced by 14 % and 48 %, respectively. Water savings were minimal due to silica deposits on the membranes. The selected membranes are capable of lower total dissolved system rejection (TDS) than 88 % of the total membranes required in the primary study, which may help save water. The increased energy used in membrane treatment was offset by lower water consumption. To prevent scaling, an anti-scaling reagent with a reagent dosing system was installed along with the membrane system.

In the scientific source [4], pH is an important parameter in desulfurization and scale formation units in boiler tubes at thermal power plants. As an indicator of the concentration of hydrogen ions in the aqueous solution, it plays an important role in controlling clean water treatment and wastewater quality. The most important problem with pH is the difficulty of making a pH-electrode. The pH measurement does not match any other ion analysis in terms of sensitivity or range of measurement. Consequently, the pH-electrode should be considered more realistically than any other pH-electrode.

Many manufacturing companies are looking for ways to replace environmentally problematic surface cleaning methods with more environmentally friendly ones. B [5] article describes one possible solution. One way is to reduce or replace the use of chemicals, such as for cleaning. Industrial cleaning processes, often solvent-based and often central to the production process, are often considered environmentally problematic because they involve various forms of more or less hazardous solvents and detergents. The main problems are related to: the production and transportation of these solvents and detergents; the energy consumption in their use, since high temperatures are often required in the cleaning process; the potential risk of emissions to air, soil and water; and the resulting problematic hazardous waste, which must be handled with extreme caution. Therefore, it is important to reduce the consumption of chemicals used in cleaning processes.

Raw water in combined heat and power plants is taken from natural or artificial reservoirs, purified in three stages by special installations and fed to steam boilers as feed water [6].

Currently, the sources of water supply for boiler feed are ponds, rivers, lakes, as well as ground and artesian water are used, in our case the main source as a source or raw water is water from the river. In the composition of natural waters are mechanical impurities of mineral or organic origin, so without pre-treatment and preparation of natural waters are not suitable for boiler feed. An important role in combating the formation of deposits and corrosion of metal pipes is played by a system of treatment of feed and makeup water, designed according to the characteristics of water quality in the water supply source. Currently, new methods of water purification are used at thermal power plants, for example, the method proposed presented in source [7].

The water treatment plant (WTP) is designed to produce demineralized water to feed the heating system and pretreat water for further desalination.

Technical water from Irtysh-Karaganda channel is an external water supply source for chemical water treatment. Physical parameters of feed water at the inlet of the chemical water treatment plant: flow rate – 1200÷1230 m^3/h; pressure – 0.3÷0.4 MPa; temperature – 20÷25 °C. Maximum capacity of the water treatment plant is at maximum load: pre-treatment process unit – 300 m^3/h; desalting process unit – 800 m^3/h.

Raw water used in thermal power plant, according to its technical specifications, contains dry residue – 420÷667 mg/l, suspended solids – 4÷35 mg/l, sulfates – 62÷102 mg/l, chlorides – 84÷116 mg/l, nitrites – 3÷19 mkg/l, nitrates – 205÷805 μg/l, stiffness – 2.5÷5.5 mg-eq/l, alkalinity – 1.7÷2.7 mg-eq/l, oxidizability – 2.5÷3.5 mgO_2/l, iron – 105÷355 μg/l, silicic acid – 1÷3.7 mg/l, carbonic acid – 1.9 mg/l, pH – 7.8÷8.4, natrium – 50÷93 mg/l, copper – 3÷17 μg/l [8].

Water treatment at thermal power plants with physico-chemical treatment ensures that there is no formation of solid scale deposits in heat exchangers that have been in operation for a long time. Such processes occur not only at thermal power plants, but also at nuclear power plants. In the process of water treatment at the Rivne NPP in Ukraine, mineral acid is not dosed, mineral acid is subjected to chemical control in a water-chemical regime with the content of feed water and acrylic. As a result, the values of empirical stability indicators and their changes over time may not be used to estimate the amount and rate of $CaCO_3$ precipitation from a solution and even the precipitation rate on heat exchange surfaces often used in practice [9].

Despite numerous scientific papers studied on scale formation and corrosion inhibitors in heat exchangers, this issue has not lost its relevance at present. Therefore, various methods are used to solve this problem. For example, sodium di methylene sulfonate phosphinate (DMSFN) was used in water treatment. According to the author's research, DMSFN is an inhibitor that leads to the formation of scale in tap water. Therefore, DMSFN has shown that it is an effective inhibitor for protecting heat exchangers made of steel St3, copper M2 and brass L2 from corrosion [10].

All this suggests the expediency of conducting a study devoted to an in-depth study of the prevention of scale formation when using purified feed water by thermal power plants.

3. The aim and objectives of the study

The aim of the study is to determine the amount of reagents used in industrial water purification, and to study the chemical elements of industrial water to study effective methods of descaling. This allows heat transfer fluids to be treated at production facilities in accordance with normalized standards.

To achieve this aim, the following objectives are accomplished:

– determine the hourly, daily and monthly consumption of reagents $Al_2(OH)_nCl_{6-n}$ and H_2SO_4 required for technical water purification;

– determine the hourly, daily and monthly costs of the reagents sodium hypochlorite (NaClO), sulfuric acid (H_2SO_4) and sodium hydrochloride (NaOH) used in chemical washing of industrial water;

– investigate the chemical elements of industrial water;

– investigate insoluble impurities in water samples;

– investigate the scale structures.

4. Materials and methods

The object of research is thermal power center No. 3 of the city of Karaganda.

Scale formation in heat exchangers used in production can be caused by improper purification of industrial waters, therefore, let's study the processes of formation of solid deposits with the study of dosages of industrial waters and their chemical elements.

The scale formed in the heat exchangers may be caused by incorrect supply of the amount of reagent added during chemical flushing of process water, or their improper dissolution. Therefore, the amounts of doses of reagents, their dissolving particles and chemical elements were investigated.

In the course of the study, all reagents are completely dissolved in process water, the quantitative ratios of their chemical elements are investigated.

The process technology of the water treatment plant of Karaganda city combined the thermal power plant is based on the use of modern and traditional methods of water treatment: filtration, ultrafiltration and softening on Na-cationic-exchanger. This will reduce to a minimum the amount of hazardous chemicals used (sulfuric acid, sodium alkali) compared with traditional technologies.

In the process of water treatment, the turbidity, suspended solids, iron content in the source water, organic compounds, softening of process water are reduced. Source water in WTP, preheated to a temperature of 25÷35 °C is fed to the water treatment plant through a pipeline of source water. As the amount of treated water is rather high (>1200 m^3/h), to ensure stable operation of the water treatment unit the flow is divided into four parallel flows between the pressure filtration units F-01; F-02; F-03; F-04, with 4 filtration columns each. The filters are loaded with anthracite.

The complete water-treatment unit includes the following main equipment and units: pressure filtration units F-01; F-02; F-03; F-04; filter loading air unit A-05; NG P-06 for backwashing filter loading with water; TW-40/1 and TW-40/2 filtered water storage tanks to wash filters of mechanical filtration unit; coagulant dosing units MX-07/1.2 and MX-08/1.2; dosing units of sulfuric acid MX-07/3 and MX-08/3 for pH correction; UF-09, UF-10, UF-11, UF-12 ultrafiltration units; accumulation tanks of filtered water after ultrafiltration TW-50/1, TW-50/2; NG P-13, P-14 for washing ultrafiltration membranes; dosing units of chemical reagents MX-15, MX-16, MX-12; UF-12 for dosing of filtered water, MX-7/3 for dosing of filtered water. MX-15; MX-16 for washing of ultrafiltration membranes; NG P-17 for water supply after ultrafiltration installation for softening units, softening units S-18; S-19; storage tanks for softened water TW-60/1; TW-60/2; brine filters F-20 for regeneration of softening units loading, tanks for filtered brine T-21; NG P-22 for softened water supply for washing and regeneration of softening units, washing tanks for mechanical filters and ultrafiltration units TW-30/1, TW-30/2, TW-30/3, TW-30/4, NG P-23 for water supply from the tanks for mixing with produced water, NG P-24 for brine supply for regeneration of softening units preparation and dosing unit for flocculant MX-25; softened water supply to deaerator P-26; membrane chemical washing unit CIP-27; dosing unit for caustic soda into softened water pipeline MX-28 for pH correction; NG P-31 for water supply after ultrafiltration to desalination unit; waste water neutralization unit N-32; sodium bisulfite dosing unit for waste water neutralization unit MX-33; antiscale dosing unit for softened water MX-34; sulfuric acid and caustic soda dosing unit for waste water neutralization unit MX-35; waste water tanks for neutralization TW-32/1; TW-32/2 [11].

Since the operation of irrigation facilities at thermal power plants depends on the composition of raw water, the elemental composition of technical water used in production was studied.

To study the elemental composition of technical water from the thermoelectric center, water samples of 3 types were taken. The first sample is raw water before feeding the chemical shop, the second sample is pure water that came out of the chemical shop. The third sample – feed water coming from the deaerator to the water economizer.

The elemental composition of water samples was carried out in the "Laboratory of Analytical Research" of "Center-geoanalit" LLP, Karaganda. Researches were carried out on atomic-absorption spectrometer AANALYST-400 manufactured by USA company Perkin Elmer (Fig. 1).

Fig. 1. Atomic-absorption spectrometer AANALYST-400

Atomic absorption spectrometry methods detect up to 5 % such elements as Pb, Zn, Cu, CD, Ag, Au, Hg, Mn, Ni, Co, Ca, Mg.

This research is based on the use of fluorescence of the detected substance, excited by the energy of ultraviolet radiation and the visible spectrum. Using this method, elements such as indium (In), selenium (Se) are determined. Perken Elmer "LS 45" fluorescence spectrometers are used for this research.

Research work was carried out by evaporation, so each water sample was taken in an amount of 6 liters. That is, water samples were boiled, evaporated, translated into dry form and the composition of the sample determined 40 elements.

After studying the elemental composition of raw water used in thermal power plants, solids in heat exchangers can be caused by salts not dissolved in water. Therefore, research work was carried out in connection with the determination of solids in the feed water used in production. Determination of particles of reagents added during treatment of raw water was carried out in the Collective National Scientific Laboratory of East Kazakhstan University named after Amanzholov in Ust-Kamenogorsk. Instrument used for research: Intelligent laser particle size analyzer "Winner-2005". The analyzer "Winner-2005" is specially designed for industrial use. The principle of operation is based on the theory of light scattering. The device implements the patented calculation method, reliable calibration method (certified standard D50) and patented original technology of orthogonal beam of two lasers, which allows obtaining accurate and reproducible results with high resolution. It is currently one of the most widely used devices for particle sizing. It works according to a special program, the samples are used mixed with purified (distilled) water (Fig. 2).

a *b*

Fig. 2. Instrument working cell and program interface: *a* – cell in which water samples are poured; *b* – window in which water sample concentrates are determined

After the study of technical waters, it is necessary to conduct structural studies of scale formation, because the structure of scale formation is important when carrying out work on cleaning heat exchangers. In order to study the system of scale formation, a peak blower was obtained and used at the production site.

The peak broiler is one of the units operating continuously with high-temperature steam-water coolant. Its image is shown in Fig. 3 [12].

Scale studies were conducted in the interdepartmental research laboratory "Electron Microscopy" of Karagandy university.

The solid sediments were used as a powder in a spectral electron microscope. The model was viewed at an accelerating voltage of 7 kV, although it continued to heat up to 5 kV due to strong charging. The sample was prepared by applying a small amount to the carbon tape on both sides. A second electron detector (SE detector) and back reflection electron detectors (BSE detector) were used for the study. The Se detector shows topographic contrasts and the BSE detector shows composite contrasts.

a *b*

Fig. 3. Peak heat exchanger: *a* — photo of the scale formed inside the peak boiler; *b* – images of the peak boiler

In order to avoid the formation of solid deposits in any combined heat and power plant, process water is pre-treated, i.e. the feed water is treated in several stages before it enters the boiler. The most important step in the treatment of service water is called coagulation or chemical flushing. With this method, the composition of the service water is changed by adding various reagents and the water becomes softer. The main purpose of water treatment processes is to prevent solid deposits from forming in heat exchangers. For example, at the Romanian thermal power plant (Veolia Energy Iasi Co.) the scale formed from the process water has a higher iron (Fe) content, a lower sulfur (S) content and a more moderate calcium (Ca) content [2]. When studying the composition of industrial water used in thermal power plants in Central Kazakhstan, the above elements of iron, sulfur and calcium are absent.

For example, in [5], methods of purification of industrial waters using Qlean Water and environmental conditions are considered. Improvements in technical characteristics and water quality during treatment using the proposed method are given. Nevertheless, the method of water purification at the production facility that we are considering has been used for many years, that is, it considers methods of natural precipitation, chemical washing and filtration. At thermal power plants, water is used not only as a heat carrier, but also for its own needs and cooling processes, i. e. industrial water is consumed in large quantities. Therefore, methods that require large amounts of money to clean them are not used.

In [7], work on improving water purification technologies for thermal power plants in Japan is considered, that is, several measures to prevent corrosion and solid waste generation are identified. In their research, they touched upon the problems of water quality, which means that Japanese scientists have proposed a new and more effective method of water purification.

The main difficulties in obtaining results are that it is impossible to control the formation of scale in technological equipment (boilers, condensers, etc.) during the heating season. This process continues around the clock and continuously. Also, during the operation of the technological line, due to the uncontrolled supply of feed water, scale and solid deposits are formed unevenly.

Some heat exchangers after seasonal operation form scale, which are easily amenable to cleaning work when applying chemical cleaning. However, some scale is difficult to clean, even mechanically.

5. Results study of process water at industrial thermal power plants

5. 1. Determination of hourly, daily and monthly costs of reagents $Al_2(OH)_nCl_{6-n}$ and H_2SO_4 required for filtration of process water

Doses of adding reagents at the combined heat and power plant were calculated using special formulas according to the standard norm and their results are shown in Fig. 4 [12].

As shown in Fig. 4, 24,464 l/hour of coagulant $Al_2(OH)_nCl_{6-n}$ is fed to the raw water, and 3.8 l/hour of coagulant H_2SO_4.

The pH value in raw water is measured by a special test tube, the value of which is ~7,3.

Daily and monthly dosing costs for hourly consumption of reagents are calculated. The results of calculations of daily and monthly consumption (taking into account two dispensers) at maximum load is shown in Fig. 5.

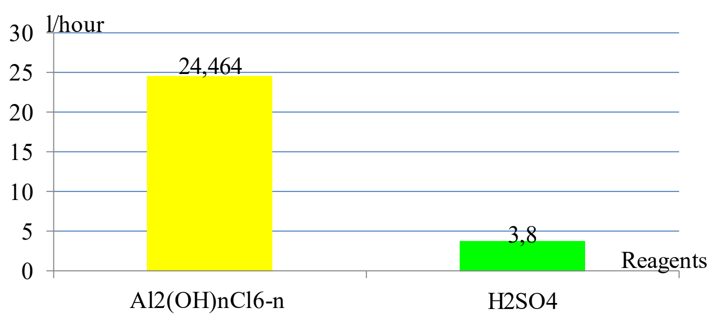

Fig. 4. Reagent calculation diagram

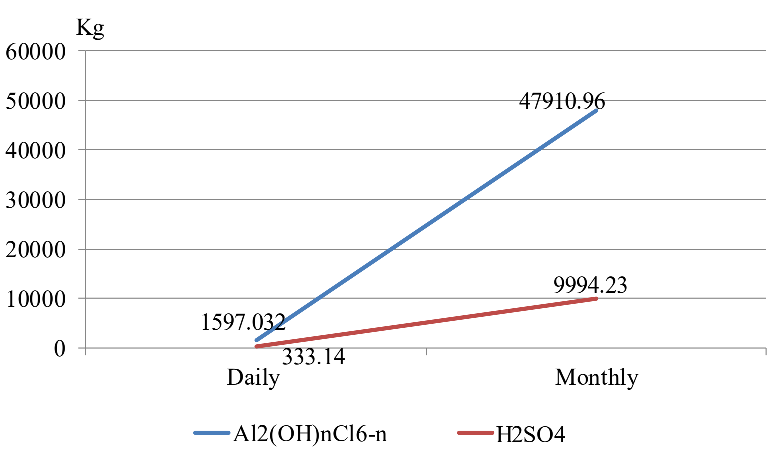

Fig. 5. Results of calculations of daily and monthly consumption

Fig. 5 shows that the daily consumption of reagents $Al_2(OH)_nCl_{6-n}$ is 1597.032 kg, and the monthly consumption is 47910.96 kg. The daily consumption of reagent H_2SO_4 is 333.14 kg and the monthly consumption of 9994.23 kg. On the basis of these calculations let's build a cyclogram.

Reagent is dosed directly into the flow of water fed to the backwash. Fig. 6 shows the cyclogram of ultrafiltration unit (UFU).

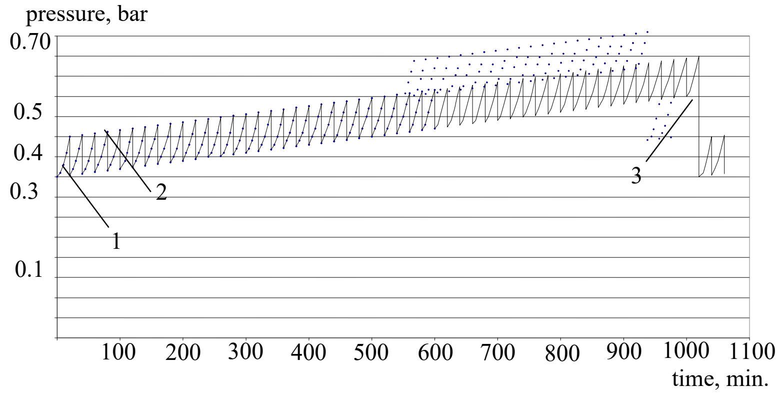

Fig. 6. Cyclogram of the ultrafiltration unit (UFU) operation: 1 – filtration process; 2 – physical washing process; 3 – chemical washing process

The first peak is the filtration process. During the filtration cycle, sludge accumulates on the membranes and the pressure drop increases. In this example, for 20 minutes, the pressure drop varies from 0.35 to 0.45.

The second peak is the physical washing process. In order to avoid the formation of a dense sludge layer and to restore the membrane to serviceability, a water rinse is performed after each filtration cycle. During the physical washing process, the membrane is not completely flushed and the initial pressure drop increases all the time. This is due to the accumulation of organic and inorganic salts on the membrane surface.

The third peak is the chemical washing process. During chemical washing, the membrane is washed of organic and inorganic salts. After chemical washing, the original pressure parameters are restored.

An important point in the operation of ultrafiltration systems is to determine the timing of membrane washing. This parameter directly depends on the water quality and is calculated based on the ratio of the capacity of the ultrafiltration system to the water consumption by the user.

5. 2. Determine the hourly, daily and monthly dosage of reagents used for chemical washing

The chemical flushing process in the third peak begins first with disinfection.

Sodium hypochlorite 12 % (NaClO) is periodically fed into the unit to prevent microbial growth and pore clogging. Dosing a sodium hypochlorite solution into the water for disinfection, the concentration of active chlorine in the water to be prepared should be between 100–120 mg/l Cl_2, but no more than 200 mg/l.

NaOH 42 % is used to remove organics and colloids. Washing is carried out automatically every 5–15 cycles of physical backwashing – the mode is selected individually during commissioning. Dosing a sodium alkali solution into the water for backwashing, the hydrogen index in the prepared water must be within 12.

H_2SO_4 92.5 % is used to remove deposits of mineral salts. Washing is carried out automatically every 10–15 cycles of physical backwashing – the mode is selected individually during commissioning. When dosing sulfuric acid into the water for backwashing, the hydrogen index in the prepared water must be within 2.

Percentage ratio of chemical reagents used in backwashing is shown in Fig. 7.

As can be seen from Fig. 7, sulfuric acid (H_2SO_4) is used in the treatment of service water in the amount of 80 % more than sodium hypochlorite (NaClO), as this solution has a better effect on the removal of mineral salts deposits.

Costs for dosing quantities of chemical reagents used for flushing of raw water in TPP were calculated according to special typical methods. The first calculated flow rate is the hourly flow rate, the results of which are shown in Fig. 8.

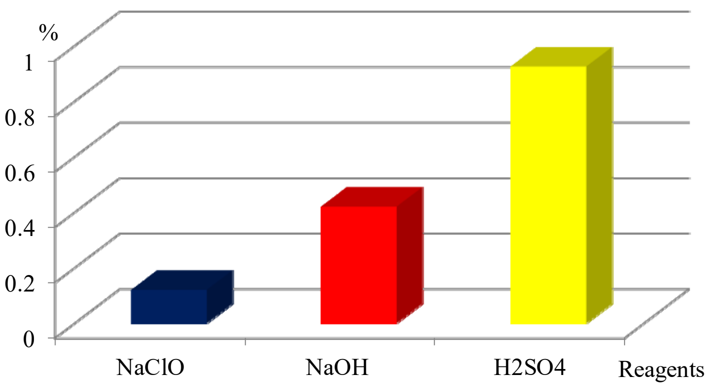

Fig. 7. Percentage of reagents used in raw water treatment

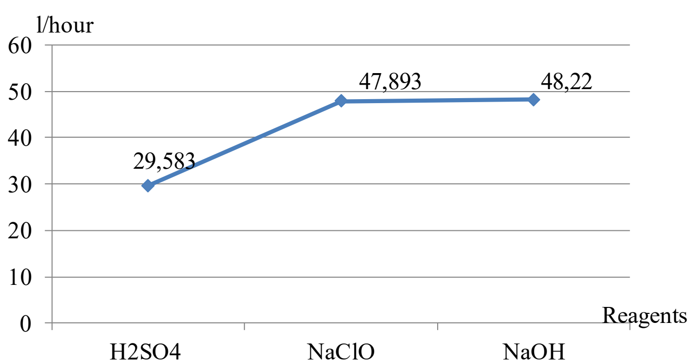

Fig. 8. Results of calculation of hourly consumption of chemical reagents for water flushing

As shown in Fig. 8, despite the percentage of sulfuric acid added, the hourly consumption of H_2SO_4 reagent is less than the consumption of the two reagents, that is, it is 29.583 liters per hour. Sodium hypochlorite and sodium hydroxide have the same hourly flow rate, that is, their average flow rate is 48 liters per hour. When adding sodium hydroxide reagent to water 42 %, its hourly consumption is 47.893 liters, that is, let's note an increase in consumption by 5 %. And the addition of sodium hypochlorite reagent to water is 12 %, and their hourly consumption is 48.22 liters, that is, let's find that the reagent consumption has increased by 36 %.

Daily and monthly expenditures of chemicals were calculated based on hourly expenditures, the results of which are shown in Fig. 9.

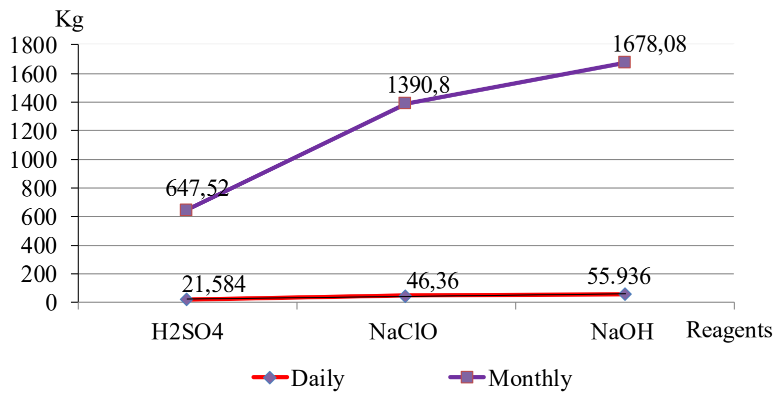

Fig. 9. Results of calculations of daily and monthly expenditures of chemical reagents

As can be seen from Fig. 10, sodium hydroxide is the most widely used reagent in terms of daily and monthly consumption of cleaning chemicals, that is, its daily consumption is 55.936 kg, and monthly consumption is 1678.08 kg. Daily and monthly consumption of sulfuric acid with a percentage of 92 % is less than other reagents, for example, the daily consumption of H_2SO_4 is 21.584 kg and the monthly consumption is 647.52 kg.

5. 3. Investigation of the elemental composition of raw water, pure water and feed water of thermal power plants by the method of semi-spectral analysis

According to the results of investigations, 33 species out of 43 elements were found in water samples in varying amounts, and the remaining elements Au, Hf, Hg, In, Pt, Ta, Te, Th, Tl, U were not detected. According to the results of studies based on purification, filtration and chemical washing processes, the minimum amount of the element ytterbium (Yb) in the feed water is 1 mg, and the most abundant element is titanium (Ti), i. e. its value reaches 2500 mg.

According to research data 6 elements in the nutrient water before and after treatment did not change: Phosphorus (P – 300 mg), Arsenic (As – 100 mg), Tungsten (W – 5 mg), GSermanium (Ge – 1.5 mg), Cadmium (Cd – 5 mg), Boron (B – 300 mg).

The analysis of elemental composition of nutrient water was carried out by dividing it into 3 stages. The first stage collected elements up to 10 mg, their results are shown in Fig. 10.

Under number 1, shown in Fig. 10, shows the amount of element in raw water, i. e. samples before the chemical shop; 2 – the amount of element of treated water, i. e. samples before the deaerator; 3 – shows the amount of elements in feed water, i. e. in samples before boiling.

It can be seen from the graph that the number of elements increases due to the purified water content.

In the second stage, the set of elements up to 100 mg is considered, the results of which are shown in Fig. 11.

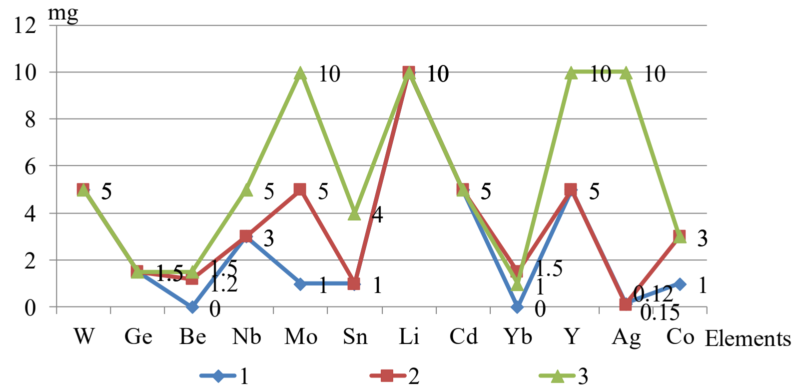

Fig. 10. Number of elements up to 10 mg: 1 – 1st sample; 2 — 2nd sample; 3 — 3rd sample

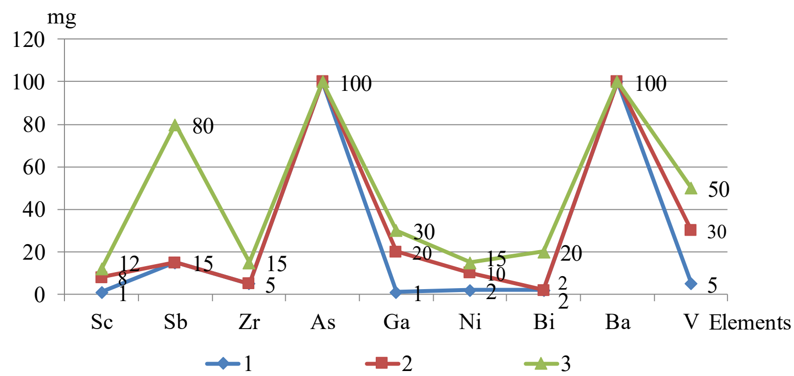

Fig. 11. Number of elements up to 100 mg: 1 – 1st sample; 2 — 2nd sample; 3 — 3rd sample

The third step considers a set of elements up to 1000 mg, the results of which are shown in Fig. 12.

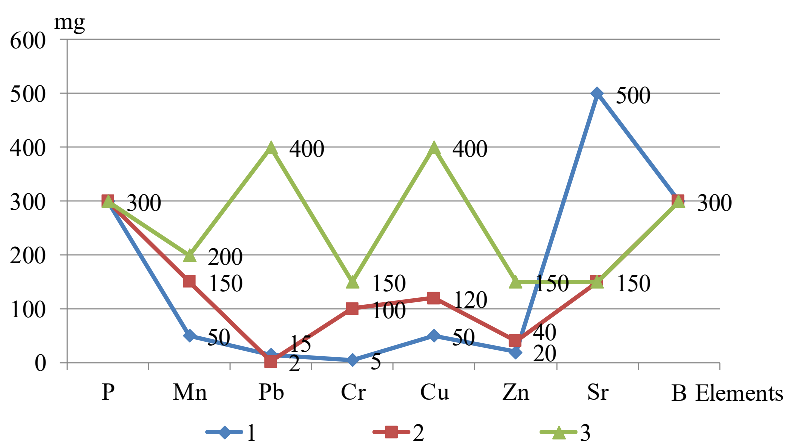

Fig. 12. Number of elements up to 1000 mg: 1 – 1st sample; 2 — 2nd sample; 3 — 3rd sample

As shown in Fig. 12, the element strontium (Sr) decreases from 500 mg/kg to 150 mg/kg. The most common elements are lead (Pb) and copper (Cu). The element titanium (Ti) is contained, the content of which can be increased up to 2500 mg/kg.

5. 4. Investigation of the content of dissolved impurities in water samples

When the concentration of the added sample reaches 10 %, the particle sizes begin to be determined. The concentrations of the raw water samples in which the research work was conducted did not reach 10 %, but only increased to 0.2–0.35 % (Fig. 13).

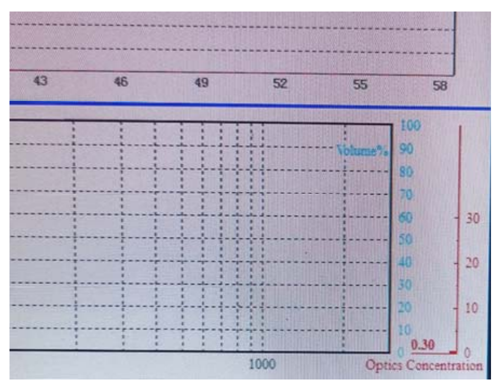

Fig. 13. Concentrate addition samples

According to the results of the study, undissolved particles of reagents were not found in the 3 samples examined, that is, the amount of concentrates did not reach even 0.5 %. This means that all reagents added during the treatment of raw water used in production facilities are completely dissolved and do not remain in the form of insoluble particles.

As a result of using reagents to treat the raw water used in the thermal power plant, the water does not contain insoluble particles, i. e. all added caogulants are dissolved. Nevertheless, even with sufficient water treatment, solid deposits form in the heat exchangers of the thermal power plant in the form of scale. Scaling is caused by boiling water in boilers or by high temperatures in the water mixture. The emergence of large amounts of scale reduces the heat output of heat exchangers, so ways of cleaning heat exchangers from scaling are considered. Before let's consider methods of cleaning, it is necessary to conduct a structural study of the scaling.

5. 5. Investigation of the structure of solid deposits

The result of the spectral study is shown in Fig. 14.

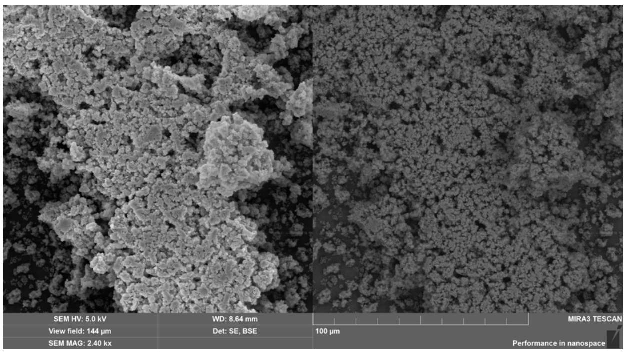

Fig. 14. Results of spectral study

As can be seen from the figure, the field of view here is enlarged at a scale of 144 and 2.40. The composition of the solid deposits resembles a soft foamy appearance, adheres not tightly. Scale accumulation is uneven, i.e. formation is different. The structure resembles a crushed pellet.

6. Discussion of the results of calculating the use of metered amounts of reagents for softening feed water

The study of technical water consisted of 3 stages. First, the dosages of reagents and chemical coagulants added to the water treatment facilities were calculated and analyzed. After filtration of process water, hourly, daily and monthly doses of aluminum polyoxychloride reagent ($Al_2(OH)nCl_{6-n}$) were calculated. Aluminum polyoxychloride is a highly efficient inorganic coagulant that forms stable compounds with inorganic and organic substances. The reagent is used in water treatment processes of boilers of thermal power plants. It is mainly used in cold weather. Aluminum oxychloride increases the rate of coagulation of colloidal particles of organic and inorganic pollutants in water without alkali, and provides quality water treatment without sediment and with a minimum aluminum content in water.

Fig. 4, 5 show the results of calculations of hourly, daily and monthly consumption of reagents $Al_2(OH)_nCl_{6-n}$ and H_2SO_4, required for filtration of technical water. That is, the reagent $Al_2(OH)_nCl_{6-n}$ was added up to 25 % per hour, and the sulfuric acid reagent (H_2SO_4) was added up to 4 % per hour, thus determining the daily and monthly consumption of reagents. The consumption of aluminum polyoxychloride is 1263.892 kg per day, and the monthly consumption is 37916.73 kg more than the consumption of sulfuric acid, because it helps to prevent the formation of solid deposits in the pipes. However, when studying the elemental composition of water, the element Aluminum (Al) was not detected at all.

Fig. 7 shows the results of the percentage of reagents. Regarding the percentage of compounds, the reagent added in the largest amount is sulfuric acid (H_2SO_4, 92.5 %), and the reagent added in the smallest amount is sodium hypochlorite (NaClO, 12 %). Calculated hourly, daily and monthly costs of sodium hypochlorite (NaClO), sulfuric acid (H_2SO_4) and sodium hydrochloride (NaOH) used in the chemical treatment are shown in Fig. 8, 9. In terms of dosing costs the largest reagent was sodium hydroxide (NaOH), in percentage average – 42 %, its hourly consumption is 48.22 liters, daily consumption – 55.936 kg, monthly consumption – 1678.08 kg.

The elemental composition of the thermal power plant water samples was studied, that is, the types of 43 elements in the water were determined and their composition was shown.

The elemental composition was followed by the determination of particles in water samples in the water treatment process.

Fig. 10–12 show the milligrams of elements in the water samples. According to the results of studies based on purification, filtration and chemical washing processes, the minimum amount of the element ytterbium (Yb) in the feed water is 1 mg, and the most abundant element is titanium (Ti), i. e. its value reaches 2500 mg.

Fig. 13 shows the amount of concentrate of water samples, that is, the concentrate of water samples taken from the thermal power plant did not reach 0,5 %, which means that the amount of reagents in the technical water is not found in the form of particles, but completely dissolved.

This means that all the reagents contained in the process water are completely dissolved, and the formation of scale in the heat exchangers can occur under the influence of water vapor when the water boils at a high temperature (the temperature of the heated steam is 565 °C).

Technical water used in production does not contain insoluble particles, while scaling is formed in heat exchangers. Their structures were examined using electron microscopy to determine scale formation. The results of the research work are shown in Fig. 14. i.e., the structures of scaling in peak boilers were examined as an example, the structure of scaling in the form of sawdust, soft.

As shown in the research results, the formation of carbonate phases is influenced by temperature, the content of magnesium sulfates in the source water and pH. Therefore, calcium in water is formed in the form of $CaCO_3$ in the ratio Ca_{2+}:Mg_{2+}=20:1 and pH 7.0–7.2.

It is possible to see, a large number of elements are contained in the process water used in our heat and power center, which is why scale formation in heat exchangers is possible.

7. Conclusion

1. The hourly, daily, and monthly dosages of the reagents $Al_2(OH)_nCl_{6-n}$ and H_2SO_4, which are added to treat raw water in a thermal power plant, were determined. As a result, the hourly consumption of $Al_2(OH)_nCl_{6-n}$ increased by 20.664 liters, the daily consumption by 1263.892 kilograms, and the monthly consumption by 37916.73 kilograms.

2. Calculated and determined the dosage of sodium hypochlorite (NaClO), sulfuric acid (H_2SO_4) and sodium hydrochloride (NaOH) for chemical washing of technical water. As a result, according to percentages sulfuric acid (H_2SO_4 – 92 %) is used more reagent, but according to calculation results NaOH reagent consumption is more than

other joined reagents, i. e. hourly consumption is 48.22 liters, daily consumption is 55.936 kilograms, monthly consumption is 1678.08 kilograms. And the cost of dosing sulfuric acid, which is added in very large quantities, costs less than other costs.

3. Chemical elements of water samples from the production site were determined. As a result, 33 elements were identified from the composition of water samples, the size of the elements varied according to the stages of technical water treatment. Of the 33 elements: the element content of phosphorus (P), arsenic (As), tungsten (W), Germany (Ge), cadmium (Cd), Boron (B) was not changed; the element content of Pb, Ti, Cr, Cu increased by stage of water treatment; the element Sr was reduced (initially 500 mg/kg, finally, 150 mg/kg).

4. The composition of insoluble particles was determined in the technical water samples. Since the value of concentrates during the studies did not reach 0.5 %, it is found the absence of insoluble particles of reagents in the water samples.

5. The structure of scale in the peak boiler is investigated, their structural picture is given. The field of view was investigated in 144 µm scale and SEM MAG 2.40 kx. Scale composition resembles a soft foamy appearance, not tightly fitting. Scale accumulation is uneven, i. e. formation is different. The structure resembles a crushed pellet.

Conflict of interest

The authors declare that there is no conflict of interest regarding this research, including financial, personal, authorship or other nature that could affect the research and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

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