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ISSUES OF WATER USE IN THERMAL POWER PLANTS. PROBLEMS AND SOLUTIONS

ЖЫЛУ ЭЛЕКТР СТАНЦИЯЛАРЫНДА СУДЫ ПАЙДАЛАЛАНУ МӘСЕЛЕЛЕРІ. ПРОБЛЕМАЛАРЫ МЕН ШЕШІМДЕРІ

ВОПРОСЫ ВОДОПОЛЬЗОВАНИЯ В ТЕПЛОВЫХ ЭЛЕКТРОСТАНЦИЯХ. ПРОБЛЕМЫ И РЕШЕНИЯ

Abstract.*The article considers the most effective methods of water treatment for thermal power plants. Water treatment is one of the most important processes in the operation of thermal power plants (TPP). The quality of water treatment for use in boiler units of thermal power plants is of fundamental importance to ensure the efficiency and durability of process equipment. This article reviews the main aspects of water treatment in TPP plants, including treatment methods, water quality characteristics and standards, and the impact of water treatment on the overall energy efficiency and safety of power generation in TPP plants.*
Keywords: *water treatment, combined heat and power plant, thermal power plant, boiler, turbine, sorption material, metal ions.*

Аңдатпа. *Мақалада жылу станцияларындағы суды тазартудың ең тиімді әдістері қарастырылған. Су дайындау жылу электр станцияларының (ЖЭО) жұмысындағы маңызды процестердің бірі болып табылады. ЖЭО қазандық қондырғыларында қолданылатын суды дайындау сапасы технологиялық жабдықтың тиімділігі мен беріктігін қамтамасыз етуге тікелей қатысты. Осы мақалада ЖЭО-да су дайындаудың негізгі аспектілері, оның ішінде тазарту әдістері, су сапасының сипаттамалары мен стандарттары, сондай-ақ су дайындаудың ЖЭО-да электр энергиясын өндіруде жалпы энергия тиімділігі мен қауіпсіздігіне әсері қарастырылған.*
Түйін сөздер:*су дайындау, жылу электр орталығы, электр орталығы, жылу станциясы, қазандық, турбина, сорбциялық материал, металл иондары.*

Аннотация. *В статье рассмотрены наиболее эффективные методы водоподготовки для тепловых станций. Водоподготовка является одним из важнейших процессов в функционировании тепловых электростанций (ТЭЦ). Качество подготовки воды для использования в котельных установках ТЭЦ имеет принципиальное значение для обеспечения эффективности и долговечности технологического оборудования. В настоящей статье рассмотрены основные аспекты водоаодготовки в ТЭЦ, включая методы очистки, характеристики и стандарты качества воды, а также влияние водоподготовки на общую энергоэффективность и безопасность производства электроэнергии в ТЭЦ.*

Ключевые слова:*водоподготовка, теплоэлектроцентраль, тепловая станция, котел, турбина, сорбционный материал, ионы металлов.*

Introduction. Water use by thermal power plants (TPPs) is of great importance, as a huge amount of water is required to cool the power equipment. Therefore, water use of thermal power plants has become a serious problem in many countries, including Kazakhstan. Efficient management and conservation of water resources in thermal power plants is critical for energy security and sustainable development. In this context, there is a need to study current trends and problems related to water use in thermal power plants, as well as to find options for optimising water use processes in order to minimise the negative impact on the environment.

Irrational use of water resources directed to the operation of thermal power plants for technological processes carried out in this kind of enterprises leads, often, to violation of the ecological balance. The paper [1] shows the results of the activity of thermal power plants in the Republic for the last 5 years.

The main part of water (more than 90 %) is consumed in cooling systems of various apparatuses: turbine condensers, oil and air coolers, moving mechanisms, etc. Wastewater is any flow of water discharged from the power plant cycle. In addition to cooling system water, wastewater or discharge water includes: discharge water of ash removal systems (HRS), spent solutions after chemical washing of heat and power equipment or its conservation: regeneration and sludge water from water treatment plants: oil-contaminated wastewater, solutions and suspensions arising from washing of external heating surfaces, mainly air heaters and water economisers of boilers burning sulphuric fuel oil.

One of the factors of interaction between thermal power plants and the water environment is water consumption by technical water supply systems, including irretrievable water consumption. The main part of water consumption in these systems is used for cooling of steam turbine condensers. Other technical water consumers (ash and slag removal systems, chemical water treatment, equipment cooling and washing) consume about 7 % of the total water consumption. At the same time they are the main sources of impurity pollution. For example, during washing of heating surfaces of boilers and units of serial thermal power plants units with capacity of 300 MW up to 10000 m3 of diluted solutions of hydrochloric acid, caustic soda, ammonia, ammonium salts are generated.

In addition, thermal power plants wastewater contains vanadium, nickel, fluorine, phenols and oil products. At large power plants, the consumption of water contaminated with oil products (oil and fuel oil) reaches 10-15 m3/h with an average oil product content of 1-30 mg/kg (after treatment). When discharged into water bodies, they have a detrimental effect on water quality and aquatic organisms. So-called thermal pollution of water bodies is also dangerous, causing various disturbances of their condition. Thermal power plants produce energy by means of turbines driven by heated steam, and the exhaust steam is cooled by water. Therefore, from power plants, water flows into water bodies with a temperature 8-12ºC higher than the temperature of water in the water body.

Large thermal power plants discharge up to 90 m3/s of heated water. The heating of water anywhere in the river should not exceed by more than 3ºC the maximum temperature of the river water, which is assumed to be 28ºC. Thermal pollution can lead to unfortunate consequences.

Based on forecasts, changes in the characteristics of the environment (increase in air temperature and change in the level of the world ocean) in the next 100-200 years may cause a qualitative restructuring of the environment (melting of glaciers, rise in the level of the world ocean by 65 metres and flooding of vast areas of land). The problem of utilisation of wash water is urgent for large water treatment plants in Russia. In the process of water treatment at filtering stations a large amount of wash water from filters and contact clarifiers (15 - 30 % of the treated water volume) is generated. The wash water discharged from the stations is characterised by high concentrations of aluminium, iron, suspended solids, and acidity, which negatively affects the condition of water bodies receiving this type of wastewater.

According to [2] Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, the statistical bulletin provides information on technical and economic performance of thermal power plants and boiler houses producing and supplying heat energy. All heat released from thermal power plants minus heat returned to the thermal power plant with condensate of production steam, return mains water, "crumpled steam" exhausted at external consumers, as well as cold water heat, which compensates for non-return of condensate and losses of mains water, is the heat supply by thermal power plants and boiler houses. Also this indicator - "heat supply by direction" - takes into account the amount of heat supplied to the population, for household and industrial needs of enterprises, organisations, as well as to other enterprises (resellers).

In 2021, the gross output of heat supply sources totalled 95.6 million Gcal, of which 55.9 million Gcal was generated by thermal power plants and 32.6 million Gcal by boiler houses. In 2021, the enterprises of the Republic supplied 68.5 million Gcal of heat energy. In 2021, the number of heat supply sources in the Republic totalled 2,801 units, autonomous heat sources - 425 units. Table 1 shows in thousand Gcal the total production and transmission of steam and hot water (heat energy) by power plants and boiler stations [3].

Table 1. Total production and transmission of steam and hot water (heat energy) heat supply sources by power plants and boiler houses

	Total production of heat and supply sources, total, thousand GCal	From		
		thermal power plants, thousand GCal	boilers, thousand GCal	other, thousand GCal
Republic of Kazakhstan	95 587,9	55 918,7	32 592,4	7 076,8

The Agency's statistical data make it possible to show the entire consumed water resource and the load on the very operation of water use systems of CHPPs and boiler stations.

Methods and materials. Thermal power plants need to create closed water cycles, which significantly reduce discharges of pollutants into water bodies and reduce water treatment costs due to minimisation of the environmental impact of production. The main environmental pollution occurs due to discharge of oil products, heavy metal ions, suspended solids and other pollutants into water bodies, which are formed after blowing and washing of equipment, pickling of parts and electroplating operations, and during operation of ash removal systems of thermal power plants.

The creation of closed water cycles requires the use of new effective materials for water treatment. Creation of such materials, obtained from available natural raw materials, simultaneously combining ion-exchange, sorption and filtration properties, is an important task that allows to improve methods of water and wastewater treatment, to improve environmental performance in thermal power plants.

Water treatment is an important step in industrial production and is mandatory for the efficient operation of thermal power plants (TPPs). As part of the operation of thermal power plants designed to provide hot water to consumers, ensuring suitable water quality becomes an integral part of the process. However, as in many other industries, water use is becoming a major challenge requiring careful management and optimisation of water use processes. This current area of research is becoming critical for energy security and sustainable development, emphasising the need to study current trends and challenges related to water use in thermal power plants.

Boilers and turbines play a key role in the process. Boilers heat the water while turbines generate it. Both processes require a significant amount of clean water. Raw, hard and untreated water with impurities and microorganisms is not suitable for use in boilers and turbines. There are a number of regulatory requirements for the quality of water used in thermal power plants.

The quality of the water used to feed the boiler plant and to supply the boilers is important to ensure stable and efficient operation of the system. A negative aspect of the water treatment process is the formation of insoluble sludge, which is formed when the water is heated [4].

*Results.*Water treatment involves an array of processes. Before starting water treatment, the chemical composition of the water should be carefully analysed. Water hardness is an important parameter that must be determined. Many problems of water condition are related to its hardness and the presence of iron deposits, salts, silicon, as well as the presence of potassium and magnesium salts in water.

In [5, 6] a description of the basic technological scheme (Fig. 1) and economic indicators (Tab. 2) of purification using different sorption materials in the extraction of metal ions from water with a plant capacity of 28 m3/h is given.

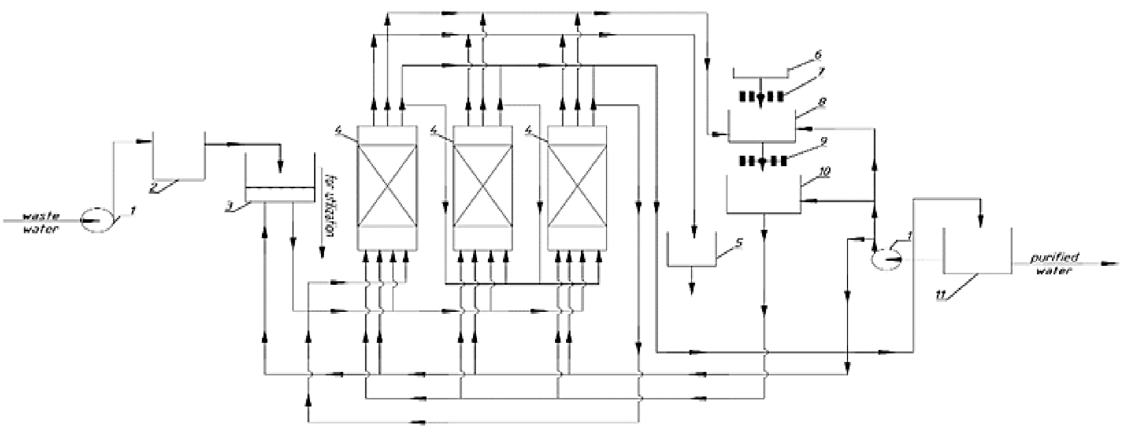

Figure 1. Scheme of water treatment from heavy metal ions: 1 – centrifugal pump; 2 – collector's digest; 3 – sand filter; 4 – ion exchange column; 5 – the regenerate tank; 6 – hopper of dry Na2CO3 and NaCl; 7 – weight dispenser; 8 – collection of concentrated Na2CO3 and NaCl solution; 9 – liquid dispenser; 10 – collection of the regeneration solution; 11 – purified water collection

The use of such technological schemes makes it possible to reduce the use of fresh water and to carry out the treatment process at a relatively low cost.

Table 2. Capital and operating costs of the plant with different types of sorbents

Sorbent	Cost and expenses for maintenance of installations per month, tenge		
	Capital expenditure	Electricity	Expenses for reagents
BIRM Green Sand (Germany)	2553600	11015	15600
MTM, USFilter (USA)	3103710	9200	8950
КУ-2-8, АН-2В (domestic)	1903750	10200	14000
The sorbent being considered	961215	8220	6250

When using sorbent for treatment of industrial storm water of thermal power plants from emulsified oil products it is possible to provide high efficiency of treatment (87-97 %), creating closed water recycling cycles.

Resource saving and improvement of environmental safety of water treatment equipment by developing and introducing promising schemes, technologies and equipment of desalting water treatment plants of additional water of power units of thermal power plants are considered in [7, 8]. The scheme is proposed (Fig. 2), according to which, ionic filters are equipped with a bypass line bypassing the collector, which allows to carry out washing in a closed circuit. The water for layer clamping is supplied from the treated water collector bypassing the resin traps. This solution allows to get rid of "unnecessary" pipelines and reduce water consumption for own needs. Schematic solutions with recirculation of a part of treated water provide expansion of the operating range of capacity and stable operation of the desalting plant based on countercurrent ionic filters.

This scheme is characterised by high reliability, because even in case of possible malfunctions of the reverse osmosis system, the aftertreatment unit will ensure the specified water quality. At the same time, there is still a need to use acid and alkali, so this technology, although to a much lesser extent, has the same disadvantages as the traditional one.

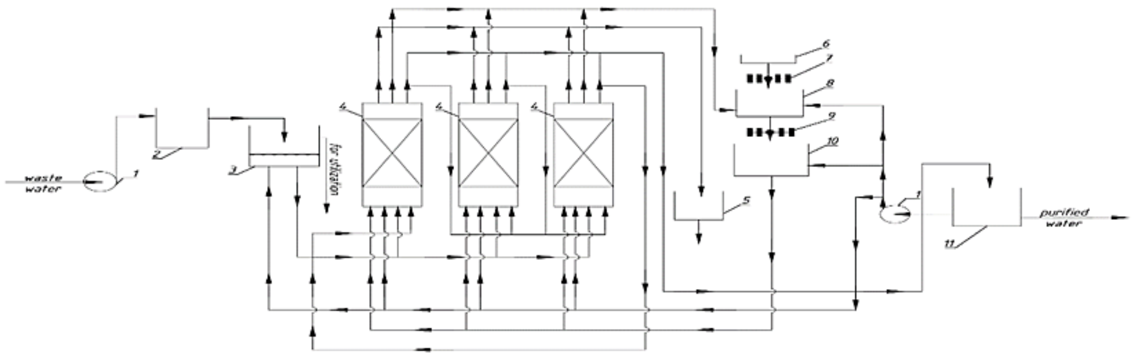

Figure 2. Schematic diagram of a combined plant for treatment of deeply desalinated water using ion-exchange aftertreatment: ASU – air separator; BC – jet burst capacity; SMF – self-flushing mechanical filters; BT – buffer tanks; UFU –ultrafiltration unit; D – decarboniser; PDWT – partially desalinated water tank

Efficient, accident-free operation of electrodeionisation plants is only ensured if the water supplied to them is of high quality. To assess the water quality, it is necessary to take into account not only the actually measured electrical conductivity, but also the concentrations of weak acids such as silicic and carbonic acids. To assess the quality of the desalinated water obtained, in the presented scheme, instead of electrical conductivity, the concept of specific conductivity is used, which can be calculated by the following formula:

$$\chi = \chi_{изм} + 2,66C_{CO2} + 1,94C_{SiO2} \quad (1)$$

where $\chi_{изм}$ – actually measured specific conductivity; CCO2 – concentration of free carbon dioxide; C_{CO2} – бос көмірқышқыл газының концентрациясы, мг/дм^3; C_{SiO2} – concentration of silicic acid, mg/dm^3.

Application of this scheme showed the necessity of deep pre-treatment of natural water with increased content of organo-iron compounds, including coagulation clarification of natural water in combination with addition of flocculant.

Considering the experience of thermal power plants in countries with advanced production indicators, we can conclude that the issues of water treatment are solved in a complex way, i.e. it is not enough to bring the composition of make-up and circulation water to the appropriate quality, it is necessary to pay attention to the material used in the system. For example, in [9] the company "HYDRO-X A/S" (Denmark) after system renewal categorically refused to use aluminium in the system, because this metal causes corrosion at pH values>8,7. The requirements for softened/desalinated water were also developed:

Feed water	Softened / deaerated water	Desalinated / deaerated water
Conductivity, μS/cm	as for raw water	< 10
Rigidity, dH°	< 0,1	---
Oxygen content, mg/l	< 0,02	0,02
Unbound carbon dioxide, mg/litre	---	< 10

Circulating water	Softened / deaerated water	Desalinated / deaerated water
Conductivity, μS/cm	as for raw water	< 25
Rigidity, dH°	< 0,5	0
pH value	9,5 – 10,0	9,5 – 10,0
Presence of sludge	clear water without sediment	clear water without sediment
Oil content	oil missing	oil missing
Oxygen content, mg/l	oxygen is absent	oxygen is absent

In a number of countries, ion-exchange technologies have been applied in the water treatment cycle, allowing to consistently ensure minimum concentrations of dissolved impurities in the filtrate. However, the use of ion-exchange resins leads to a significant environmental load on the receiving water bodies of wastewater due to the imperfection of regeneration processes that require the use of aggressive reagents and, accordingly, the formation of significant volumes of spent regeneration solutions and wash water [10] Therefore, at present, both abroad and in our country, baromembrane technologies characterised by high environmental performance are increasingly used in water treatment processes at thermal power plants. Depending on the quality of source water and requirements to the degree of desalination of the added water, depending on the characteristics of the main equipment, the technological schemes of water treatment plants, including baromembrane units, have distinctive features [11].

Conclusion. Nowadays, make-up water correction treatment is becoming more and more widespread. Various reagents are used for correction treatment, depending on the temperature of the water in the heating system [12]. These reagents, such as sodium hexametaphosphate, can either form soluble complexes with calcium or stabilise already formed solid particles, i.e. antiscaling agents.

The antiscaling agents include phosphonates, such as 1-oxyethylenediphosphonic acid (OEDP) and its salt OEDP-Zn, sodium salt of aminomethylene phosphonic acid (IOMS), which are effective in preventing the formation of calcium carbonate and phosphate [13]. In addition, phosphonates are corrosion inhibitors of structural materials used in heat exchangers, i.e. steel and brass. The use of antiscaling agents eliminates the need for water treatment in ionic filters such as Na-cationic filters. The choice of the reagent and its concentration are determined by the quality of the source water and the temperature of the water in the heating system. The use of IOMS is quite effective at water temperatures up to 100°C. At higher temperature it is preferable to use OEDP or OEDP-Zn.

The obtained results on the dynamics of the formation of an insoluble precipitate agree well with the known theory of the dependence of the diffusion permeability of membranes on concentration [14] - since impurities can diffuse in the membrane not only through the pore space, filled with solution, but also through the amorphous swelling regions of the membrane, the presence of insoluble impurities in solution initiates gel polarisation, leading not only to a decrease in the permeability of the cell, but also to the accumulation of insoluble precipitate on the membranes.

The volume of ultrafiltration plant wash water directly determines the efficiency of its operation as well as the degree of environmental friendliness. The degree of water clarification at the pre-treatment stage is decisive in assessing the overall economics and environmental friendliness of the entire technological scheme including baromembrane technology.

For water treatment, nowadays, the ion exchange stage to obtain deeply desalinated water is more and more often proposed [15]. Deeply desalinated (deionised) water with specific electrical resistance up to 18 Mohm-cm is widely used for make-up of steam boilers, turbines and HRSGs operating under pressure up to 140 atm. at thermal power plants. To obtain deionised water, ion exchange, reverse osmosis and electrodialysis methods are used in industry. However, for obtaining deeply desalinated water with specific electrical resistance up to 18 Mohm-cm each of these desalination methods can be used only as a preliminary method before subsequent additional deep desalination.

In ion exchange technology, water after the pre-desalination stage is first fed to an H-cationic filter, then to a decarboniser to remove free carbon dioxide, and then to an OH-anionic filter. However, feeding water first to the H-cationisation stage leads to a significant decrease in the pH of the water. In this connection to the available free carbon dioxide is added additional, which is formed at a lower pH value from hydrocarbonate ions HCO3- and carbonate ions CO32-. Therefore, the "OH-H" scheme is proposed. The positive moment at the organisation of ion exchange according to the scheme "OH-H" is the increase of pH values in the zone of anion exchange that it promotes dissociation of weak carbonic and silicic acids and their transfer to ionised state (carbonic acid - in ions HCO3-, CO32-, silicic acid - in ions HSiO3-), therefore they can participate in reactions of ion exchange at use of strongly basic anionites. It is also necessary to note that the result of ionisation according to the scheme "OH-H" is the complete removal at the stage of OH-anionisation of the residual anions of strong acids, which contribute to the slippage of cations and increase the residual hardness after the H-cationic filter. Since at the scheme of ion exchange "OH-H" all residual anions are completely detained at the OH-anion filter with strong-base anionite, at the subsequent water passing through the H-cationic filter with strong acid cationite all cations are completely detained [15].

Water treatment in thermal power plants (TPPs) plays a key role in ensuring reliable and efficient operation of equipment. Efficient water treatment systems prevent corrosion, deposits and other negative processes, helping to extend equipment life andimprove energy efficiency. The need to continuously monitor water quality and treatment emphasises the importance of maintaining high standards in water treatment, which in turn contributes to ensuring sustainable and safe operation of thermal power plants.

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