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Slovak Journal of Civil Engineering

Vol. 30, 2022, No. 4, 17 – 22
DOI: 10.2478/sjce-2022-0024

THE EFFECTIVENESS OF THE IMPLEMENTATION OF RESEARCH RESULTS IN A TECHNOLOGICAL SCHEME OF WATER PURIFICATION

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Abstract

The paper proposes technical solutions for the use of the reagent method of water preparation at coke plants in order to bring it to a quality suitable for use in the circulating water supply system of the PJSC Kharkiv Coke Plan. It is proposed to dilute phenolic water in a biochemical installation in a mixer before purification and to purify water with a flocculant. The paper recommends dosing the flocculant solution automatically using a preparation station. Additional purification of the clarified water is carried out using a filtration unit with a filter media from a layer of quartz sand. The economic effect from the implementation of the technical measures is achieved not only due to the reduction in fresh water consumption by 60 540 m3/year and the cessation of the discharge of phenolic water into the city sewer network, but also the replacement of the reagent with a more efficient one and a decrease in its consumption. It has been found that the introduction of the technical solutions for the circulating water supply system is economically and environmentally justifiable.

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Key words

- Purification,
- Coke plants,
- Effectiveness,
- Flocculant,
- Phenolic water.

1 INTRODUCTION

In today's environmental conditions, industrial waste water purification regulations are becoming more restrictive. Therefore, there is a need to develop new technological solutions that will ensure the high efficiency of technological water purification of industrial enterprises, including coke plants. It is recommended to use technology for the utilization of phenolic waste water from coke plants, which allows minimizing and, in some cases, preventing the discharge of phenolic waste water into a city sewerage system (Bargieł, P., Zabochnicka-Świątek, M., 2018; Pal, P., Kumar, R., 2014; Lei, G. et al., 2004; Chenglong, Y., et al., 2000; Kwarciak-Kozłowska, A., et al., 2011; Shatnyi, S., Kunytskyi, S., Volkov, V., Shatna, A., 2021).

Depending on the nature and concentration of contaminants contained in waste water from coke plants, as well as on the directions for the use of this water, it can require different preparations (Lei, G. et al., 2004).

A peculiarity of coke-chemical production technology is determining a significant amount of waste water in the process of coking coal charge, capturing and processing the chemical products. Waste water is formed in chemical plants (phenolic waste water) in the process of quenching coke during the cooling of coke oven gas. The largest source of water pollution is the excess ammonia water formed from the pyrogenetic moisture of the charge. An analysis of the quality of the waste water from coke-chemical production showed the following characteristic contaminants: suspended solids, resins and oils, phenols, ammonia, cyanides, rhodanides, organic matter, BOD5, etc. (Bargieł, P., Zabochnicka-Świątek, M., 2018; Pal, P., Kumar, R., 2014; Lei, G. et al., 2004; Chenglong, Y., et al., 2000).

The complex qualitative composition of phenolic waste water and a large amount of chemical pollution creates a number of difficulties in its purification and implementation into the technology of a plant and therefore requires several stages of purification.

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Filtration and coagulation are used to remove resins and oils in water. More often, water filtration is carried out on gravel filters, the efficiency of which is 85 %. The advantage of this method of purification is the relatively low cost of the process, while a disadvantage is the lack of the degradation of pollutants (Bargieł, P., Zabochnicka-Świątek, M., 2018; Chenglong, Y., et al., 2000; Lee, C. S., Robinson, J., Chong, M. F., 2014).

Phenolic waste water purification technologies involve the use of a complex of physicochemical and biological methods, including nitrification, denitrification, etc. (Bargieł, P., Zabochnicka-Świątek, M., 2018; Pal, P., Kumar, R., 2014; Lei, G. et al., 2004; Chenglong, Y., et al., 2000). The complexity of the mechanism for the purification of phenolic water is explained by the fact that phenolic water is classified as hazardous water (among industrial waste waters) and as a source of environmental pollution.

As a result of the analysis performed, it has been determined that the purification of phenolic waste water from coke plants is ineffective and is caused by insufficient treatment at biochemical plants. This is due to insufficient purification at the previous stages, in particular at the physico-chemical stage of the purification of water from suspended solids, resins, oils, etc. Therefore, the improvement of reagent water treatment processes at coke plants is the main factor in the preparation of water for reuse in water supply systems.

Thus, the purpose of the work is to develop and apply effective technological and environmental solutions for the purification of phenolic waste water at coke plants with the industrial testing of the application of the solution. In the present work, we have developed methods using effective reagents and the method of dosing these reagents, together with the additional purification of water with filters.

2 MATERIALS AND METHODS

2.1 Analysis of the technological scheme of water purification at the PJSC Kharkiv Coke Plant

The research was carried out in laboratory and production conditions on the circulating water supply system of the PJSC Kharkiv Coke Plant. Waste water purification at the PJSC Kharkiv Coke Plant is carried out at a biochemical installation. On the territory of the site there is a mechanical purification unit building:

– 2 filters loaded with coke breeze;
– 1 primary heat exchanger;
– 2 secondary heat exchangers;
– 1 resin settling tank;
–1 collector of water from the ammonia column;
–2 pumps;
–2 averaging settlers;
–1 tank for the coagulant.

The biological purification block building contains:

– 1 aeration unit;
– 1 water clarification unit;
– 1 water and sludge injection unit;
– 1 air supply unit;
– 1 panel board;
– 1 operating control room.

According to the technological scheme (Fig. 1), sewage treatment has the following sequence: after the ammonia column, the wastewater is collected in the storage of the condensation compartment collector. Then, after passing through the spiral heat exchanger, it enters the waste water collector, from where it is pumped by a pump for cooling into the plate heat exchanger, after which the waste water with a temperature of 30-35 °C is fed into two concentrators, from which it flows by gravity to the oil separator for the purpose of the resin and oil removal. Next, the water is sent by gravity through the overflow tray to two aerotanks. Air consumption in the aeration tanks is at least 90 m^3 per 1 m^3 of waste water.

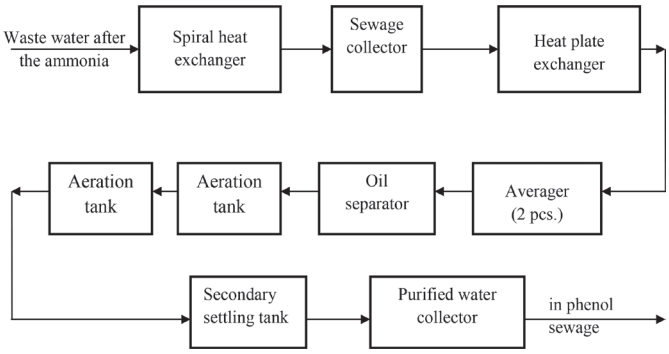


Fig. 1 *Technological scheme of the biochemical units at the PJSC Kharkiv Coke Plant*

After going through the second aeration tank, the purified waste water flows through the overflow tray into the secondary sump. The water separated from the activated sludge flows by gravity to the purified water collector, from where it is sent to the phenolic sewage system. The return of activated sludge to the aeration tanks from the bottom of the secondary sedimentation tank is carried out by a centrifugal pump.

The facilities of the biochemical installation (BCI) at the PJSC Kharkiv Coke Plant are used for:

– mechanical purification of waste water on filters with the loading of the coke breeze;
– physical and chemical purification with the use of a composite coagulant and settling in the averaging settler;
– biochemical purification in the aeration tanks.

2.2 Analysis of the quality of the purified waste water

The analysis of the quality of the purified waste water at the biochemical installation of the PJSC Kharkiv Coke Plant was carried out in accordance with standard methods.

The water quality control was carried out using a physico-chemical analysis of the samples according to standard methods of titration, complexometry, etc. (Baird, R. B., Eaton, A. D., Clesceri, L. S., 2012).

The water quality results showed an inconsistency with the requirements for the use of water in the circulating water supply cycle of the plant by several indicators (see Tab. 1). Thus, it is has been established that the concentrations of suspended solids, phenols and rhodanides in the purified water are higher and do not meet the requirements for the use of water in the reversible water supply cycle of the plant.

Tab. 1 *The results of the waste water quality analysis at the PJSC Kharkiv Coke Plant (Galkina, O., Blahodarna, H., 2019)*

Indicators	Indicator values, mg · dm-3		
	Before the biochemical unit	After the biochemical unit	For use in a reverse cycle established by the Kharkivkommunochist-vod trust
pH, ea	8.3	8.3	6.5-8.5
Suspended substances, mg · dm-3	300-500	60	40
Phenols, mg · dm-3	263	17	1-2
BOD full, mgO2 · dm-3	1800	150	150
Ester-soluble, mg · l -1	9	6	20
Sulfides, mg · l-1	1	1	1
Phosphates, mg · dm-3	3	3	5
SSAA, mg · dm-3	0,1	0,1	-
Total iron, mg · dm-3	5	3	4
Rodanides, mg · dm-3	955	47.2	5
Ammonium nitrogen, mg · dm-3	780	50	150
Petrochemicals, mg · dm-3	30	3	50
Cyanides, mg · dm-3	30	5.0	28
Salt content, mg · dm-3	1200	1200	2000

Note: Water quality results provided by the laboratories of the PJSC Kharkiv Coke Plant and "UkrVODGEO"

3 RESULTS AND DISCUSSION

3.1 Implementation of the research results into the water purification technological scheme

The results of the analysis of the existing state of the waste water purification of the plant, the water and sewage system, the study of various technical methods for the phenolic waste water purification, and the experience of other coke-chemical plants indicate the possibility of changing the existing water use scheme of the plant as follows:

– by mixing industrial and domestic waste water before purification;
– by preventing the discharge of phenolic effluents into the public sewer network;
– by increasing the efficiency of the biochemical purification installation.

Thus, in order to improve the waste water purification process at the plant and meet the requirements for its quality, a number of measures have been envisaged.

First, before the phenolic waste water is purified in a biochemical installation in order to dilute it, we propose to mix industrial waste water from the condensation department with domestic waste water in a mixer in a separate container with a volume of 100 m³. This will reduce the concentration of phe-

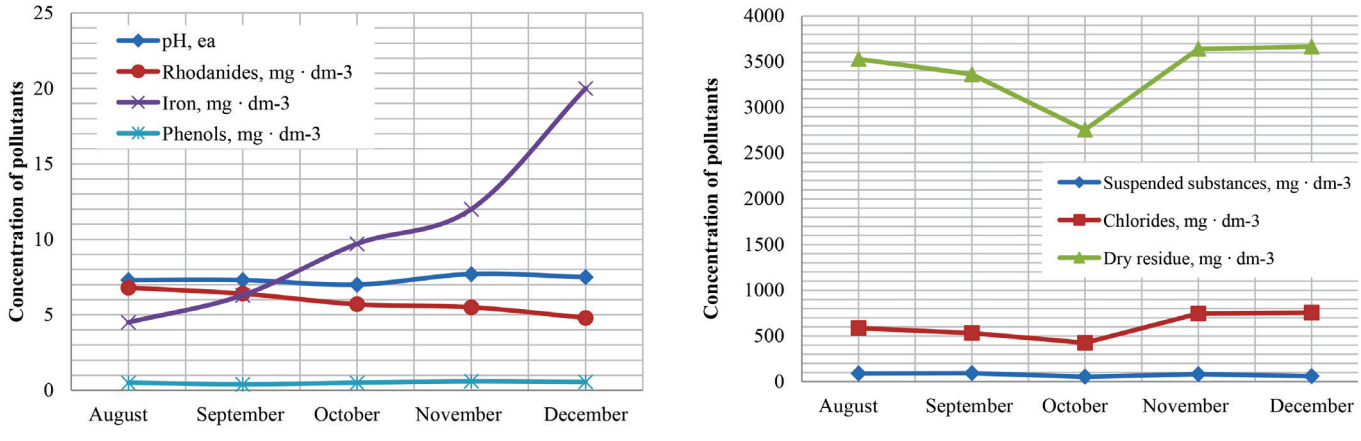


Fig. 2 *Effect of the Besfloc flocculants at a dosage of 4 mg · dm-3 on the quality of the circulating water (a, b) of the cycle of the primary gas coolers at the PJSC Kharkiv Coke Plant when using the Besfloc flocculant*

nols and thiocyanates in the purified water. Then the waste water can be filtered before entering the biochemical plant.

Secondly, it is possible to increase the efficiency of the biochemical purification installation by improving the biological purification and an additional deep purification of the water. For this purpose it is necessary:

– to intensify the process of the physico-chemical purification of phenolic water by using effective reagents (Besfloc or Extraflock flocculant with a recommended dose of 4 mg/dm^3);
– to dose the flocculant solution in the technological scheme of the phenolic water purification by means of the SPR 2100 BV reagent preparation station of the Ekoton Industrial Group (Ekoton Product Catalogue, 2018).
– to additionally purify the clarified waste water (after the secondary sedimentation tanks) with a filtration unit using a layer of quartz sand as a filtering load.

The effect of dosing a solution of Besfloc flocculant on the quality of circulating water was carried out in the circulating water supply system of the PJSC Kharkiv Coke Plant (Figs. 2 a, b).

The analysis of the water quality proves the effectiveness of its purification at a 0.1 % dosage of the flocculant solution. This reduces the content of the suspended solids from 500-600 mg · dm-3 to 50-100 mg · dm-3.

The efficiency of the flocculant application is explained by the proposed reagent supply technology (Galkina, O., Blahodarna, H., 2019):

– feeding the circulating water supply system with an effective quality of this water;
– using the method for dosing the flocculant solution;
– supplying water after the dosing reagents settle in a separate container.

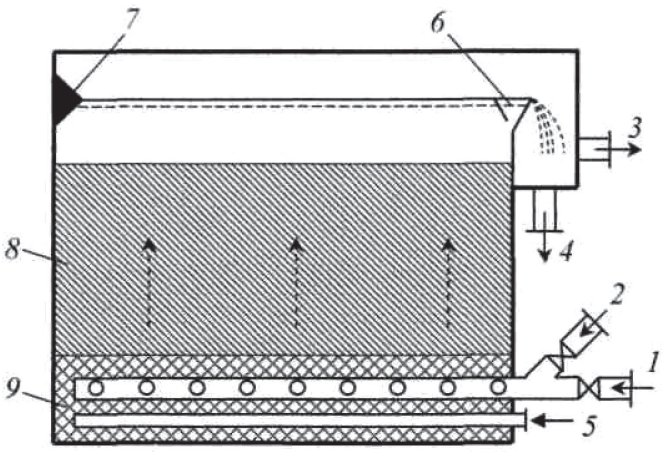
In the technological scheme of the phenolic water purification, the flocculant solution is recommended to be dosed using the SPR 2100 BV reagent preparation station of the Ekoton Industrial Group (Lee, C. S., Robinson, J., Chong, M. F., 2014; Ekoton Product Catalogue: Ekoton Industrial Group (Ekoton), 2018) with a capacity of 100 liter per hour, made of a structural material, i. e., polypropylene.

The equipment is a two-chamber unit for the cyclical preparation of a polymer solution from a dry starting product and continuous dosing of the finished solution.

The preparation process takes place periodically or continuously in the upper chamber (solution preparation chamber); then, the finished solution is poured into the lower chamber (dosing chamber), where the finished solution for dosing has been selected. Dosing of the reagent into the upper chamber is carried out using a screw dispenser. The dry reagent is poured into the receiving tank. The receiving tank is equipped with a reagent level sensor and a vibrating device to prevent agglomeration of the bulk materials.

The recommended quality of the water purification for use in the reversible cycle is achieved by deep water purification after the secondary settling tanks. It is necessary to install an additional filtration unit using a layer of quartz sand as a filtering load (Klimov, S., Pinchuk, O., Kunytskiy, S., Klimova, A., 2019), to accomplish this.

We designed filters with an ascending stream. Water filtration occurs from the bottom up, which significantly improves the operating conditions of the filter as a result of the implementation of the principle of decreasing grain size along the flow (Fig. 3).



1 – water supply; 2 – flush water supply;
3 – filtrate discharge; 4 – wash water drain; 5 – air supply;
6 – sand-catching gutter; 7 – jet-directing protrusion;
8 – downloads; 9 – supporting layer

Fig. 3 *Filter with ascending water flow (Karmanov, A., Polina, I., 2022)*

As a result of using this filter, the dirt holding capacity of the filter and the duration of the filter cycle increases, and also the silting of the fine-grained layers is excluded (Dushkin, S. S., Galkina, O. P., 2021). To remove such accumulations during the regeneration of the load before washing, it is necessary to blow the load with air for 10-15 minutes at an intensity of 18-20 l / s m^2. After blowing the load with air, it should be washed for 7 minutes with purified water. The filtrate is then discharged into a sludge compactor. Purified water flows by gravity into the purified water collector, from where the water is supplied by a network of pipelines to the circulating water supply cycle of the plant.

Waste water for additional purification is supplied to the filter from the clarified water collector after purification in the secondary settling tank. The unit consists of three filters with sand loading, as well as three piping systems (for each filter), which are designed to control and regulate the filtration process. The filter loading consists of a layer of quartz sand, under which there are several layers of gravel.

Tab. 2 *Designed quality of waste water purification on filters (Galkina, O., Blahodarna, H., 2019)*

Indicators	Average indicators	
	before filter , mg · dm-3	after filter, mg · dm-3
pH, ea	7-8.5	6.5-8.5
Suspended substances, mg · dm-3	60	20
Phenols, mg · dm-3	0.4	0.4
Rhodanides, mg · dm-3	5	5
Resins and oils, mg · dm-3	25	2
Cyanides, mg · dm-3	0.7	0.7

Thus, by reducing the amount of suspended solids to 20 mg · dm-3, the use of the proposed solution provides and allows for reusing the water in the circulating water supply system (Tab. 2).

Thus, the research results show that the implementation of the proposed measures makes it possible to achieve the required quality of the purified wastewater that will meet the requirements for the use of water for technical purposes of the circulating water supply cycle of the plant and ensure uninterrupted operation of the heat exchange equipment (Galkina, O., Blahodarna, H., 2019). Such purified waste water can be used for the technical purposes of the plant.

Provided that the above requirements are met, the quality of the purified waste water will meet the requirements for the use of water for the technical purposes of the circulating water supply cycle of the plant. The purified waste water can be used for technical purposes of the plant (Fig. 4).

It has been calculated that the introduction of a circulating water supply system at the plant (Fig. 4):

– will reduce the consumption of fresh water (artesian water from wells) from 241,200 m^3 in year to 180,660 m^3 in year;
– will reduce phenol emissions on the quenching tower by 10 times;
– will stop the discharge of phenolic effluents into the city sewer network.

Therefore, the introduction of this technical solution using phenolic effluent together with fresh water permits reducing the amount of reagents required for water purification, as well as significantly reducing the discharge of wastewater into the public sewer network and the withdrawal of fresh water from an artesian well. That is, through the introduction of these measures, a technical effect is achieved, as well as economic and environmental effects are achieved.

Reducing the discharge of water into the public sewer network and reducing the consumption of fresh water improves the state of the environment, i.e., the ecological situation at the plant and confirms the effectiveness of the proposed measures.

The economic effect of the introduction of water purification technology at the PJSC Kharkiv Coke Plant has been achieved by the introduction of a circulating water supply system, and the following technical solutions have been provided:

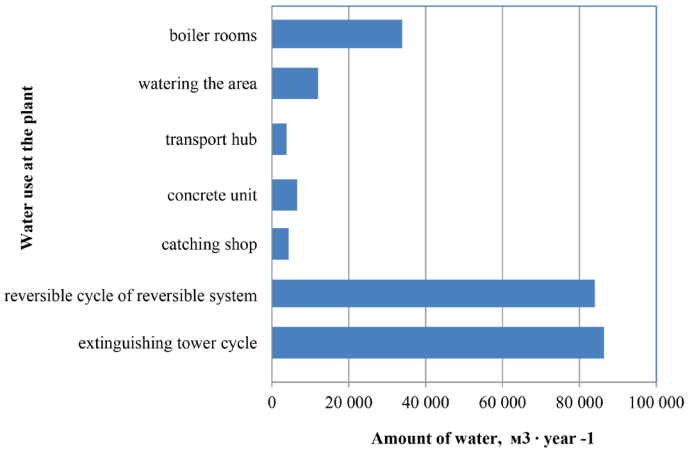


Fig. 4 *Use of purified water for technical purposes at the PJSC Kharkiv Coke Plant*

– the introduction of flocculant solutions using an automatic station for preparation of "Smart Mix" flocculant solutions;
– increasing the efficiency of the biochemical installation by adding additional purification of the filtration unit for clarification of waste water using a layer of quartz sand as a filter load;
– pipelines for the supply of technical purified water to the circulating water supply network of the plant.

The economic effect therefore consists of capital and operating costs, taking into account the effectiveness of the proposed measures (Goodstein, E. S., Polasky, S., 2017; Caputo, A. C., Pelagagge, P. M., Salini, P., 2008).

This technological solution involves the use of a solution of flocculant to intensify the process of water purification at the plant. To that end, there are additional costs associated with the use of reagents (replacement of the composite coagulant, i.e., a mixture of ferrous sulfate ($FeSO_4$) and aluminum chloride ($AlCl_3$) with Extraflock or Besfloc flocculant). In this case, cost savings are achieved by changing the reagent and reducing the dose.

So, the capital costs for the intensification of the water purification process at the coke plant include:

– the cost of the reagent preparation station;
– the cost of the filtration unit for water purification;
– the operating costs (installation of the equipment and the equipment maintenance costs).

The operating costs, in turn, take into account the following parameters:

– maintenance costs of the SPF 2100 reagent preparation station;
– maintenance costs of the filtration unit for waste water clarification using a layer of quartz sand as a filter load;
– maintenance costs for a mixer for the industrial and domestic waste water.

Thereby, the economic effect from the implementation of the results of the technical solutions (the use of an effective flocculant and additional water purification on the sand filters, taking into account the use of phenolic water as a supplying water) into the technological scheme of water purification at the plant in the first year of operation will be 49.5 US Dol / year.

4 CONCLUSIONS

It has been determined that the reuse of water in the circulating water supply system can be achieved by improving the quality of the purified water, i.e., the introduction of a number of measures in the technological scheme of the water purification at the coke plant. The results of the work were used during the development of technical solutions for the intensification of the water purification process at coke plants, particularly the PJSC Kharkiv Coke Plant.

It has been established that the introduction of technical solutions in the water purification process can be achieved by improving the biological purification units (using effective reagents) and by deep additional purification of the water after it

is in secondary sedimentation tanks (using a filtration unit with a layer of quartz sand as a filtering load).

The economic and environmental effects are achieved by reducing the consumption of artesian water from wells by 60,540 m^3 per year and preventing the discharge of phenolic wastewater into the municipal sewerage network, as well as by replacing the reagent with a more efficient one and reducing its consumption.

It has been determined that the implementation of the technical solutions of the circulating water supply system at the PJSC Kharkiv Coke Plant is economically feasible and proves the positive effect of the proposed technical solutions.

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