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Recirculation of Backwash Water in the Water Treatment Plant for the Needs of the Combined Heat and Power Plant

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ABSTRACT

The power industry is one of the most water-consuming industries, therefore water management in this sector of the economy is a very important element of sustainable development. The analysis of the management of water streams at the surface water treatment plant (WTP) with decarbonization and ion exchange for water softening and demineralization was done. The main emphasis was placed on the effect of recycling of water used for the WTP's own purposes on the quantity of water taken from the river and the quality of treated water. The article shows that water savings should also be sought at WTP in combined heat and power plants. Accurate distribution of used technological water streams and determination of their quality allows for the appropriate indication of the points of their return to the main technological line without additional treatment or only with the use of basic technological processes, e.g. sedimentation. In the analysed WTP, the quality of the backwash water returned after treatment was in terms of parameters, i.e. conductivity, hardness, alkalinity, COD_{KMnO4} and iron concentration, better than the quality of raw surface water. The reduction in the amount of water abstracted due to recycling of water treatment plant technological waters was about 8.3% (approximately 130 000 m^3/year).

Keywords: backwash water, reuse, recirculation, water savings, industrial water treatment plant, sustainability.

INTRODUCTION

The global water needs of the energy sector are large and will increase in the future. Conventional power generation uses water mainly for two purposes: water is the working medium in hydropower plants and the standard cooling medium in thermal power plants such as coal or nuclear power plants [Roehrkasten et al. 2015]. Also, in Poland, the energy industry has the highest annual demand for water, in 2020 it was approx. 87% of industrial water consumption (approx. 71% of intake water was used for industrial purposes, i.e. 5,929 hm^3) [SP 2021].

As a member of the European Union, Poland is bound by the requirements of Directive 2000/60/EC of the European Parliament and of the Council (the so-called EU Water Framework Directive, [WFD 2000]), to which Polish legislation has been adapted. The WFD defines a common water management policy in a sustainable manner, the aim of which is to improve the quality of surface and groundwater, meet the demand for quality drinking and technological water, and protect and sustainably use water resources. The introduction of the WFD along with the amendment to the Water Law Act [WLA 2001] in Poland contributed to the intensification of measures taken to economically use water resources and improve their condition. However, the percentage of water recycled in industrial plants in Poland is still small and amounts to approx. 6% [SP 2021].

Water treatment plants (WTP) are also treated as industrial plants where the product is treated water. While the water production process is accompanied by the formation of significant amounts of wastes in the form of spent backwashings and sediments. The quality of the backwashings depends on the type of raw water, the type and doses of the reagents used as well as the technological system of the WTP and the course of the filtration and backwashing processes [Komorowska-Kaufman and Lasocka-Gomuła 2018, Wiercik and Domańska 2011].

Underground water treatment plants generate backwashings of a relatively unchanged composition, characterized by a significant content of iron and manganese compounds [Shafiquzzaman et al. 2021] and the presence of bacteria which influences the catalytic removal of manganese, iron and ammonia. The composition of the backwashings produced at the surface water treatment plants is strongly correlated with the quality of the abstracted water, which changes throughout the year. These backwashings contain large amounts of post-coagulation suspension, as well as organic and mineral compounds, microorganisms, protozoa and heavy metals [Petris et al. 2019, Mahdavi et al. 2018, Leszczyńska and Sozański 2009]. The backwashings quality is also influenced by the degree of their dilution related to the filter backwashing frequency and parameters [Komorowska-Kaufman and Lasocka-Gomuła 2018]. In order to be able to return the backwashings to the water treatment line, it is often necessary to prepare them in advance. It usually involves the removal of contaminants by sedimentation [Kučera and Hanušová, 2018], which can be accelerated by dosing lime and polyelectrolytes [Petris et al. 2019, Arendze and Sibiya 2014, Kuś and Koźmiński 1993]. Increasingly, ultra and microfiltration is also used to purify the recycled filter backwashings, it is an expensive solution, so it is recommended to use other equally effective but low-cost alternatives [Shafiquzzaman et al. 2021]. Depending on the processes used for purifying backwash water, the main indicators of their quality could even meet the requirements of drinking water [Shafiquzzaman et al. 2021, Skolubovich et al. 2017].

Currently, the reuse of spent backwash water by returning it to the water treatment line is a popular solution in the world, but the rules for its implementation and operation are not regulated by legal provisions. There are recommendations issued by the United States Environmental Protection Agency (US EPA) for the reuse of backwashings from drinking water treatment plants. The Filter Backwash Recycling Rule (FBRR) [EPA 2001] concerns water treatment plants treating surface water by processes of coagulation, flocculation and filtration (possibly also sedimentation) and recycling used technological waters (backwashings, supernatant liquids or drainage effluents). The requirements contained in the FBRR indicate that the presence of microorganisms and the location of the point where the recycled water is introduced has a huge impact on the course of the treatment process and, consequently, the quality of the obtained treated water. The problem of microbiological water quality concerns especially the cooling cycle, because direct contact with the environment causes the presence of microorganisms in the cooling water responsible for the biofouling process. The water in the cooling circuit undergoes periodic thermal disinfection (while removing heat from the cooled devices and media), but it should be constantly monitored, also in terms of microbiology. Regarding the location of the point of turning on of the recycled water, the economic factor is also important - the choice of the place of returning water affects the dose of used reagents, e.g. backwashings containing a certain amount of coagulated suspended solids can support the coagulation process.

Due to the high-water consumption of the energy industry, it is necessary to introduce solutions limiting the consumption of water from primary sources. This could be achieved by acting on many levels, both at the stage of energy production, as well as in the field of water and sewage management of the plant. The primary way to reduce the amount of primary water used is to close the water circuits in the power plant. It is carried out through the reuse of technological media and wastewater generated in individual stages of energy generation [Bartkiewicz and Umiejewska 2010]. Additionally, alternative water sources are sought, such as treated municipal wastewater [Li et al. 2011, Sąkol-Sikora 2010] or mine waters [Feeley 2008], also changes in the operation of the cooling system are introduced, e.g. increasing its efficiency or reducing of the frequency of desalination of the system [Feeley 2008].

The aim of this article is to point out that the use of simple backwash water purification processes and the correct point of incorporation into the water treatment line allows for a significant reduction in the amount of river water intake without affecting the quality of the treated water.

MATERIAL AND METHODS

Water treatment plant configuration

The analysis covers the management of water streams at the water treatment plant for the needs of the combined heat and power plant (Poland), especially the effect of recycling of water used for the station's own purposes on the quantity of intake water and the quality of treated water. The analyzed water treatment plant is fed with surface water taken from the river bank's water intake. The treatment processes are carried out in three technological systems (Fig. 1):

- decarbonization system – its task is to purify additional water for cooling, condensing and operating circuits as well as preliminary treatment of water for boiler and heating circuits. The treatment of raw water consists in decarbonization with lime and coagulation with ferric sulphate in an accelerator and filtering on quartz sand pressure filters. The parameters of the treated water are as follows: carbonate hardness < 1 mval/L, COD_{KMnO4} < 20 mg O_2/L and total suspended solids < 5 mg/L;
- softening system – water treatment for replenishing water losses in the heating cycle. The source is water from the decarbonization system. Water purification consists of softening in the following system in parallel: a) sequence I: weakly acid cation exchanger (H^+) – CO_2 desorber – strongly acid cation exchanger (Na^+), b) sequence II: strongly acid cation exchanger (Na^+),
- demineralization system – treatment of additional water for high-pressure steam boilers. The source is water pre-treated in the decarbonization system. Water is fully demineralized in the system of weakly acid cation exchanger (H^+) – strongly acid cation exchanger (H^+) – sorption filter (OH^-) – weakly basic anion exchanger (OH^-) – CO_2 desorber – strongly basic anion exchanger (OH^-) – double ion exchanger (H^+/OH^-). The parameters of the treated water are as follows: conductivity < 0.5 µS/cm, silica < 0.03 mg Si/L, pH approx. 7, COD_{KMnO4} < 5 mg O_2/L.

In addition, there is a ground water intake in the area of the plant, from which the water purified in the aeration and filtration system is intended for living purposes of workers of the plant. The operation of an industrial water treatment plant carries a significant burden on the natural environment in the form of spent technological water (wastewater) emissions. Properly conducted water management should always aim at reducing amount of raw water from the source and spent wastewater discharge. It is possible thanks to the reuse of a part of the water used for technological purposes. The generated wastewater streams should be separated at the source, their quality, treatment methods and potential for reuse should be determined. This may enable some of the spent water to be recycled directly, without any treatment, at a specific point in the manufacturing process or recycled back into the overall industrial water supply (Tng at al. 2020). In the presented WTP, a part of the water used for technological purposes is subject to neutralization and treatment in an industrial wastewater treatment plant, while part after preliminary treatment is returned

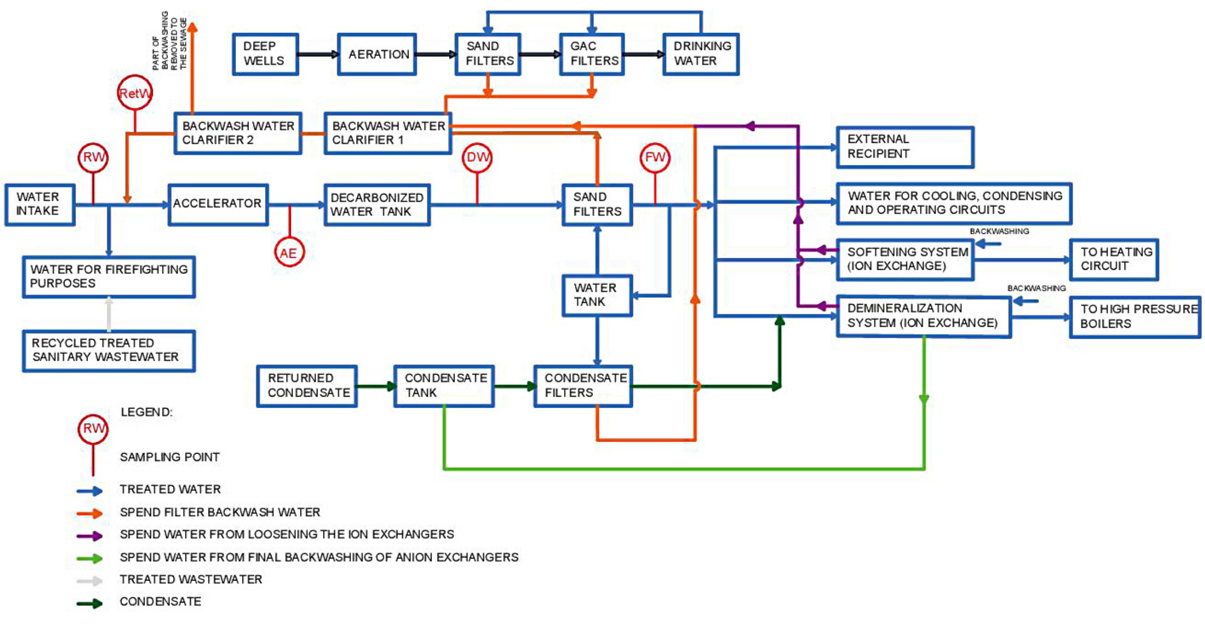

Fig. 1. Scheme of the WTP with recycled water streams and water sampling points

to the water treatment line. Spent water reused in the plant comes from following processes:

- backwashing of quartz filters treating water after decarbonization;
- primary backwashing (loosening) of ion exchangers;
- rapid backwashing of anion ion exchangers;
- backwashing filters for groundwater treatment.

The plant also recycles steam condensate and water from water samplers. The point of inclusion of the recycled water in the water treatment line depends on its quality (Fig. 1), the water is used without treatment (water from sampling points), or it is subjected to simple treatment processes. The most contaminated spent water produced in the filter backwashing process are subjected to sedimentation and clarification processes, and then are directed to the beginning of the water treatment system.

The backwashings are cleaned in two adapted concrete tanks (clarifiers), which were designed as tanks for the sediment discharged from the accelerator. Each clarifier consists of two chambers with a total active volume of 110 m^3. Currently, the clarifier-clarifier system receives spent backwash water from quartz sand filters treating decarbonized water, condensate sand filters, underground water filters and backwashing from loosening ion exchangers. The clarified backwashings from the second clarifier are pumped to the accelerator inlet with the pumping system as necessary, i.e. when the clarifier is full (to empty it before the next filter backwashing). The average hydraulic retention time in the clarification system is approx. 48 hours. All water streams are metered, which makes it possible to determine the amount of recycle water.

Methodology of sampling and water quality testing

The quality of water in the water treatment line and returned backwashings were tested over a period of three months. The water sampling points were selected in a way that allows to examine the changes in physical and chemical parameters of the treated water and backwashings after various treatment processes (Table 1, Fig. 1). Backwash water intake from the pipeline downstream of the clarifier (Sed2) was performed while pumping water from the clarifier to the accelerator in order to empty the tank before backwashing another filter from which the backwashings sample (BW) was taken. This means that the iron concentrations on the inflow and outflow from the clarifier used for calculations did not come from washing the same filter. However, the quality of the backwashings produced within a few days is similar, therefore it does not affect the results.

Samples (7 series) were taken at selected points, in which, according to the Standard Methods for the Examination of Water and Wastewater [APHA 2017], selected parameters of water quality were analyzed: specific conductivity, pH, turbidity, total alkalinity, total hardness, total iron concentration. Chemical oxygen demand (COD_{KMnO4}) was determined with acidic permanganate method according to Polish Standard PN-C-04578-02:1985.

RESULTS AND DISCUSSION

Quality of water and recycled backwashings

The changes in water and backwashings quality parameters presented in Figure 2 show that

Table 1. Summary of tested water streams and sampling points

No.	Symbol	Water stream	Sampling point
1	RW	Raw water	The pipeline suppling the raw water to the accelerator
2	AE	Decarbonized water	The accelerator effluent – collective trough
3	DW	Decarbonized water	The pipeline supplying decarbonized water to sand filters
4	FW	Filtered water	The pipeline discharging filtrate from sand filters
5	BW	Backwash water	The backwashings discharge pipe outlet from the washed filter – first phase of backwashing
6	Sed1	Backwash water during the first sedimentation phase	The second chamber of the first clarifier
7	Sed2	Backwash water during the second sedimentation phase	The first chamber of the second clarifier
8	RetW	Recycled backwashing	The pipeline discharging treated backwashings from the second clarifier

water obtained in the decarbonization and filtration processes had required quality: alkalinity 0.82 mval/L, iron concentration 0.1 mg Fe/L, turbidity 1 NTU, and only the COD_{KMnO4} is slightly exceeded and fluctuates around 22 mg O_2/L. In the backwashings collected directly from the filter outlet (BW) analyzed contaminants amounts were found to be several times higher than in raw water: the concentration of iron about 21 times, turbidity about 28 times and COD_{KMnO4} about 4.5 times. However, even a simple cleaning of backwash water in the sedimentation process allows to reduce the amount of these contaminants so that the quality of the returned backwash water (RetW) is better than that of raw water. As the filters are backwash with decarbonized water, the hardness, alkalinity and conductivity of the backwashing are lower than those of raw water.

Returning to the accelerator backwashings containing some of suspended iron and calcium hydroxides may also have a positive effect on the water treatment process carried out in this device [Wołowiec et al. 2019]. In the long-term operation of the softening system, no negative impact of the implementation of backwash recycling on the quality of decarbonized water was noted. The quality of decarbonized water is more influenced by the hydraulic underload of the accelerator and the correct control of the reagent doses. The obtained results show the high efficiency of the backwashings clarification tanks without any reagents dosing. The iron removal efficiency is 96%, and the turbidity is 97%.

In the case of higher concentrations of iron and suspended solids in the treated backwashings, higher treatment efficiencies were obtained. Higher concentrations of these pollutants promote autocoagulation and improve the sedimentation effect [Komorowska-Kaufman et al. 2018, Komorowska-Kaufman and Lasocka-Gomuła 2018]. In addition, it should be remembered that the spend water from loosening the ion exchangers is of good

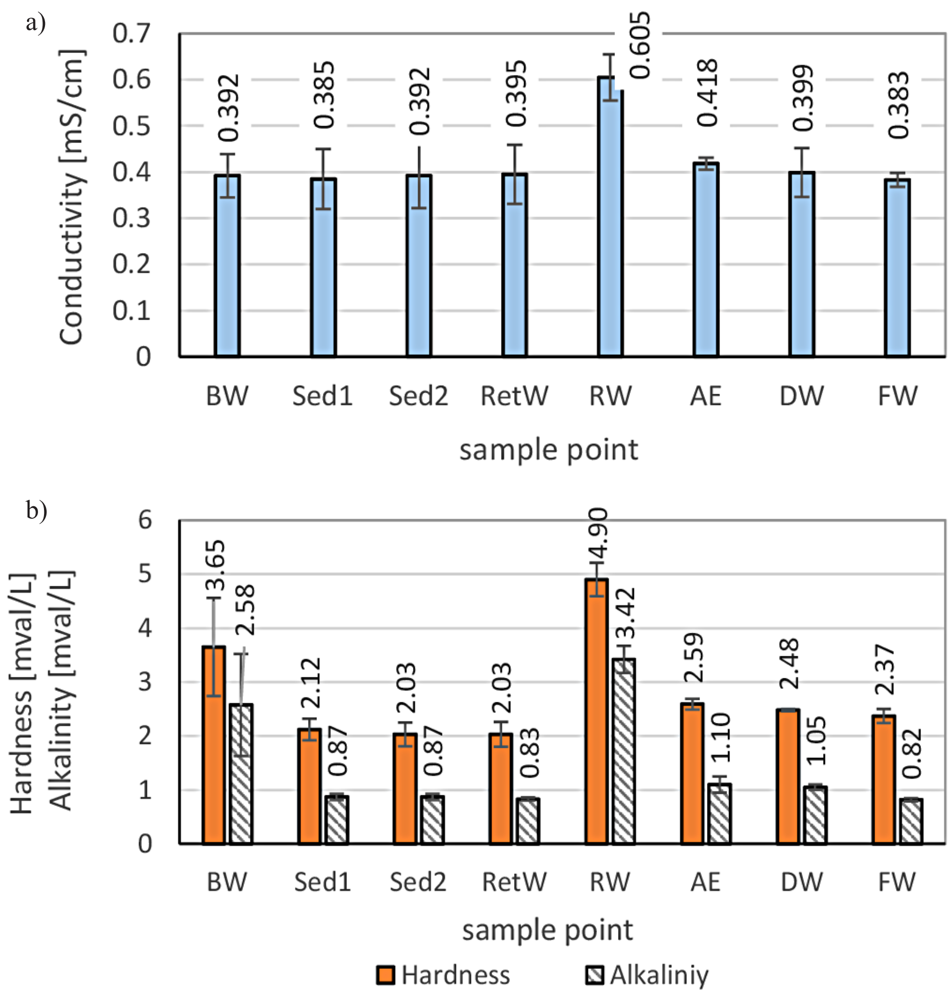

Fig. 2. Changes in the quality of water and recycled backwashings during treatment a) conductivity; b) hardness and alkalinity; c) pH and iron concentration; d) COD and turbidity

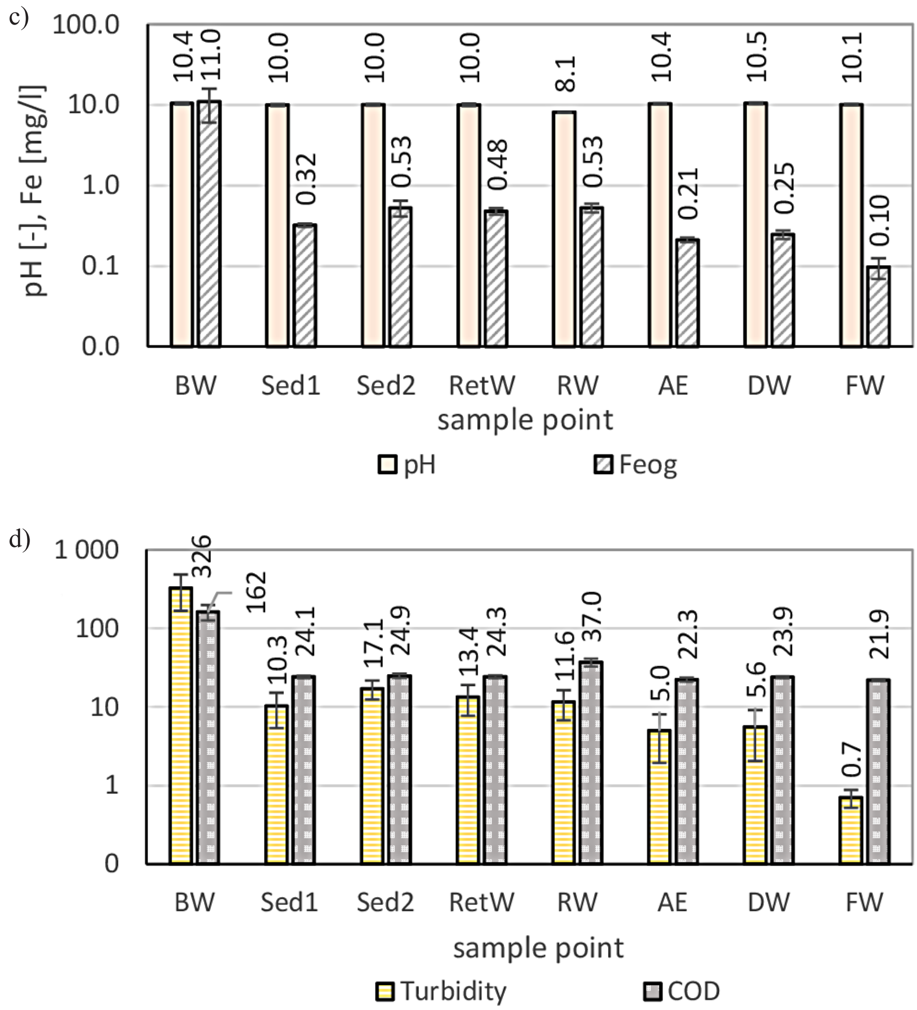

Fig. 2. Cont. Changes in the quality of water and recycled backwashings during treatment a) conductivity; b) hardness and alkalinity; c) pH and iron concentration; d) COD and turbidity

quality, practically free of iron, therefore their presence dilutes the backwashings from the gravel filters in the clarification tank, and thus increases the iron removal efficiency in this device. During the tests, it was not possible to determine the share of loosening wastewater in the returned water.

The treated backwash water returned to the treatment line after the sedimentation process, in terms of the analyzed parameters, is of better than the quality of raw river water introduced into it, except for turbidity, which is only 2 NTU higher.

Water treatment plant water balance

Using the metering of individual streams of water taken and produced at WTP, the annual water balance of the plant was made, which is shown in Table 2. The obtained data show that plant returned a year an average of 103,700 m^3 of backwash water from gravel filters of decarbonized water and 25,900 m^3 of primary washings of ion exchangers. In total 129,577 m^3 of backwashings were reused at the treatment plant during the year, which constitutes 8.3% of the total amount of water taken from the river. In addition, the plant recycles 275,600 m^3 of steam condensate and 16,670 m^3 of treated sanitary wastewater. Approximately 27.1% of the abstracted water circulates in a closed circuit.

The recycled sanitary wastewater is directed to the fire water tank. Water from the final washing of the softening system exchangers and water from the softened water samplers are used to top up the cooling circuit with fresh decarbonized water. The backwashings from gravel filters of decarbonized water along with the backwashings from ion exchanger loosening after treatment are directed to the beginning of the treatment system, to the accelerator inflow. About 11% is discharged to the sewage system or utilized as a water treatment sludge.

Table 2. The total annual amount of water for individual streams of the water treatment plant [m^3]

Water stream		Water amount [m^3]	
Raw water – intake		1 556 660	
Recycled sanitary wastewater		16 670	
Water for firefighting purposes		165 330	
The inflow to the accelerator		1 408 000	
Decarbonized water		1 582 240	
Return condensate		275 600	
Cooling circuit	Fresh	533 920	559 790
	Returned	25 870	
Softened water		238 960	
Demineralized water		699 180	
Flue gas desulphurization installation		137 172	
External recipient		16 597	
Backwash water	Fresh	11 523	115 230
	Returned	103 700	
Other WTP own purposes		20 378	

CONCLUSIONS

Closing water circuits reduces the amount of water taken from primary sources and discharged wastewater, thus generate financial savings and reduce the negative impact on the quality of the environment, which is in line with the requirements of the EU Water Framework Directive.

The obtained results indicate the correct operation of the discussed backwashings return system. A simple sedimentation system allows for effective removal of post-coagulation suspension washed out of the filter without the need to add reagents to support this process. A 96% reduction in iron concentration and a 97% reduction in turbidity were achieved. The treated backwash water returned to the treatment line after the sedimentation process, in terms of the analyzed parameters, is of better than the quality of raw river water introduced into it, only turbidity is about 2 NTU higher.

Thanks to the analysis of the water quality of individual water streams used in the water treatment plant for technological purposes and their return to the appropriate places in the water purification line, the plant returned a year an average of 103700 m^3 of backwash water from gravel filters of decarbonized water, 25900 m^3 of primary washings of ion exchangers and water from samplers, which constitutes about 8.3% of the total amount of water taken from the river. Considering the entire plant, also thanks to the re-use of some of the treated domestic wastewater and the recycling of steam condensate, approx. 27% of the water collected is reused in a closed circuit. In the industrial plant in question, it is possible to look for further water savings, e.g. by optimizing the backwashing process and the conditions for the treatment of ion exchanger washings and post-regeneration leachate.

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