

Implementation of emergency measures to improve the efficiency of nickel removal from water at the existing water treatment plant

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Abstract

In this paper, based on the data of the Ribnica accumulation (Serbia), and the required quality of raw and treated water, an optimal solution for improving and optimization of the technology of water purification to drinking quality at a water treatment plant (WTP) in Zlatibor, Serbia, was proposed to ensure maximum efficiency and flexibility in system operation. Analysis of water quality has shown that after the treatment at the plant, all parameters were within the respective maximum available concentrations (MAC) stipulated by the Rulebook on the hygienic suitability of potable water of the Republic of Serbia, except for the nickel content. The paper presents the results of the nickel removal using multiple laboratory tests as well as at the WTP to achieve the best procedure for water treatment. In accordance with the results obtained the water quality problem in terms of the nickel removal was solved and the required effects are obtained (nickel content below the MAC, *i.e.* $<0.02 \text{ mg dm}^{-3}$)

Keywords: Jar test; aluminium-sulphate; polyaluminium chloride; flocculation.

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1. INTRODUCTION

Zlatibor is a mountain that covers an area of about 1000 km^2 , largely located in the municipality of Čajetina, Serbia. Thanks to the specific climate and characteristic air currents, Zlatibor has developed into a prominent summer and winter tourist centre with the longest tourist tradition among the mountains in Serbia. The entire area of the municipality of Čajetina is provided with potable water by the public utility company (PUC) "Waterworks Zlatibor", which uses water from the river Crni Rzav, accumulated in the water supply reservoir Ribnica, with a volume of 3.5 million m^3 . Water flows by gravity from the water intake to the water treatment plant (WTP) located directly below the dam. The WTP was built in 1972 with a capacity of $25 \text{ dm}^3 \text{ s}^{-1}$.

Since the number of houses for rent, hotels and other accommodations was growing very quickly along with the number of visitors, the municipality gradually expanded the capacity of the plant in order to ensure the sufficient amount of drinking water, so that the capacity first was increased to 50 L s^{-1} , then to 80 L s^{-1} , to finally reach the current capacity of 150 L s^{-1} , by adding individual technological units.

The task considered in this paper estimates the possibility to reduce the concentration of nickel in the treated water below the maximum available concentration (MAC) of 0.02 mg dm^{-3} [1], by applying the currently present technologies at the WTP. Since nickel had not been identified in raw water at the time of WTP implementation, the existing technology is not suited for nickel removal.

Nickel, a metal pollutant, is widely used by various modern industries like electroplating, tanning, textiles, etc. resulting in discharge and accumulation in large quantities into the environment. Nickel exists in the environment in the form of a divalent cation, which is very toxic. Adsorption is one of the leading techniques to remove nickel from wastewater in which pH has a significant effect on the process [2]. For metals such as nickel and lead, adsorption increases as pH rises, with the highest adsorption observed just before precipitation begins. However, for other metals,

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like chromium VI, adsorption is not directly related to precipitation [3]. Adsorption techniques for nickel removal primarily rely on the use of solid adsorbents that interact with metal ions, either through electrostatic forces, ion exchange, or chelation. A variety of adsorbents have been studied, including activated carbon [4], natural materials like chitosan [5], and synthetic adsorbents such as mesoporous silica [6]. Another promising class of adsorbents for nickel removal is metal-organic frameworks (MOFs), which are highly porous materials with tunable structures and functional groups that facilitate selective ion adsorption [7]. MOFs have shown remarkable efficiency in removing nickel from aqueous solutions due to their high surface area, chemical stability, and the possibility of functionalizing their surfaces for enhanced adsorption performance [8]. Various processes for nickel removal from water solutions were investigated along with parameters affecting the removal rate and efficiency and various adsorbents such as Jordanian natural zeolite [9]. Powdered activated carbon has been also used to enhance nickel removal from soil, in the case of ground water, as well as effective removal of nickel has been achieved using chelating ion exchange resins [10]. Other experiences have shown that nickel ions could be significantly adsorbed on cationic exchange resins where the removal from aqueous solutions depends on the solution pH, adsorbent dose, contact time and initial nickel concentration [11]. Removal of nickel ions from aqueous solutions was also achieved by using ferric chloride (FeCl_3) coagulant and the precipitate formation during the coagulation process at pH levels 7 and 8 was accurately represented by classical adsorption isotherms [12]. Based on the available data on the water accumulation and the quality of raw and treated water, an initial proposal for solving water quality in terms of nickel content in water is given in this paper

The water quality at Ribnica accumulation (Zlatibor) was assessed by the City Institute for Public Health from Belgrade, Serbia, and the Institute for Public Health "Batut" from Belgrade, Serbia, with the focus on content of metals. The monitoring also included other components required by Rulebook on the hygienic suitability of drinking water [1].

2. MATERIALS AND METHODS

2. 1. Existing conditions of the water treatment plant

Although the water treatment plant in Čajetina, Serbia, with the original settling tank and filters has been in operation since 1972 (50 years), it is still in relatively good condition in terms of construction so that it functionally maintains the quality of the treated water regardless of the equipment, continuously exploited over the long period of time. The current capacity of the plant is $150 \text{ dm}^3 \text{ s}^{-1}$ and the process line includes clarification (coagulation and flocculation), sedimentation, filtration on sand filters and disinfection with chlorine [13].

The chemicals used in the clarification process are aluminium-sulphate ($\text{Al}_2(\text{SO}_4)_3$) and polyelectrolyte. Clarification takes place in a lamellar clarifier (which was the last one built for a capacity of 80 to $90 \text{ dm}^3 \text{ s}^{-1}$ and two circular clarifiers, after which the clarified water is taken to gravity sand filters (8 in total), and from there into a treated water reservoir where it is disinfected. After the treatment, water is distributed through the water supply network to consumers.

Specific details on water treatment are as follows. Raw water is collected from the accumulation Ribnica and through a distribution chamber it is introduced into the coagulation chamber, where aluminium-sulphate is dosed at concentrations of 50 to 80 mg dm^{-3} , after which water is distributed to the first stage (Stage I) of flocculation, where polyelectrolyte is dosed at concentrations of 0.2 to 0.5 mg dm^{-3} . The water with the prepared flocs is distributed into the lamellar clarifier, which is sized to optimally work at 80 to $90 \text{ dm}^3 \text{ s}^{-1}$, while part of it is diverted to two circular clarifiers (one was transformed into a lamellar one with a capacity of approximately $40 \text{ dm}^3 \text{ s}^{-1}$ by installing lamellas), while the other receives only a small amount of water from the second stage (Stage II) of flocculation.

After sedimentation, water is distributed to eight gravity sand filters with a constant level during filtration. Clean, non-chlorinated water is used for washing filters at the plant. The filters are washed with air and water at the required intervals and lengths depending on the quality of the raw water. After filtration, the water is distributed to the treated water tank, where final disinfection is performed by chlorination.

Building for preparation of the chemicals is equipped with tubs with mixers for preparation of aluminium-sulphate solutions, as well as a modern compact unit for preparation and dosing of polyelectrolytes.

At a WTP internal laboratory chemical analyses of water are performed every 3 h, comprising analyses of raw water, water from all sedimentation tanks, after each filter, and treated water. Analyses include temperature measurement, determination of pH value, turbidity, residual chlorine, nitrite, nitrate, sulphate, organic matter, and electrical conductivity. In addition, regular controls are carried out by the Institute for Public Health from Užice, Serbia, in accordance with the Rulebook on the hygiene of drinking water of the Republic of Serbia. Bearing in mind that the water taken from the reservoir has an elevated nickel content, the laboratory was equipped with adequate equipment for measuring the Ni concentration in water.

2. 2. Water quality

Reservoir "Ribnica" is one of the smaller reservoirs and is quite protected, considering that it is in the rural part of Zlatibor, far from settlements and human impact. It is very important to maintain and use the reservoir "Ribnica" primarily for water supply purposes, considering that the tourist center is constantly developing and the need for healthy drinking water is the basis of the system functioning. The consumption of KMnO_4 (up to 40 mg dm^{-3}) and turbidity (up to 10 mg dm^{-3}) exceeded the MAC values in raw water. However, following the treatment process, these parameters were within the MAC range.

The consumption of KMnO_4 in the raw water in the reservoir was elevated to approximately 20 mg dm^{-3} , (MAC = 8 mg dm^{-3}), while the ammonia concentration was approx. 0.2 mg dm^{-3} (MAC = 0.1 mg dm^{-3}). In addition, the nickel concentration was increased to about 0.04 mg dm^{-3} (MAC = 0.02 mg dm^{-3}). Turbidity of the raw water is slightly elevated, at around 2 NTU in the measurement period (December 2015.). Quality of the water is presented in Table 1 for several sampling points, for the measurements performed in 2016 [14].

Table 1. Quality of raw and treated water in the Ribnica accumulation

| | Raw water | Treated water | Settling tank I | Settling tank II | Settling tank III |
|---|-------------|---------------|-----------------|------------------|-------------------|
| pH | 6.73 | 6.28* | | | |
| Electric conductivity, mS cm^{-1} | 128 | 170 | | | |
| Colour, $^{\circ}\text{Pt-Co}$ | 55 | 1 | | | |
| Turbidity, NTU | 3.35 | 0.68 | | | |
| Ammonium ion content, mg N dm^{-3} | 0.17 | < 0.02 | | | |
| Total organic carbon, mgC dm^{-3} | 5.64 | 1.53 | | | |
| Content of iron, mg dm^{-3} | 0.41 | 0.02 | 0.05 | 0.04 | 0.07 |
| Content of nickel, $\mu\text{g dm}^{-3}$ | 46.4 | 25.2 | 26.6 | 26.1 | 27.9 |

*Values above MAC are bolded

The pH value, colour, ammonium ion, organic matter, iron, and nickel are among the physicochemical characteristics that are different from MAC in raw water. Except for nickel, which was still elevated at the concentration of about 0.025 mg dm^{-3} , all parameters after the treatment were within the MAC limits outlined by the Rulebook. Thus, an intervention was made to address the treated water quality according to this parameter using technology that is now available but not designed to remove nickel.

2. 3. Experimental section

In the Laboratory Jaroslav Černi at Water Institute Jaroslav Černi (JCWI) and the laboratory at the WTP "Zlatibor", during 2016 numerous tests and analyses were performed to achieve the required effects in terms of reducing nickel in water in the shortest possible time. Based on tests and analyses at laboratory conditions, guidelines were obtained in which directions for the structuring of the process treatment were outlined to overcome the problem with the increased nickel concentration in water. Accordingly, activated carbon powder and lime were dosed into the system to raise the pH to create a suitable environment for nickel removal. Many tests and dosing combinations were performed in the laboratory as well as at the WTP itself, from which numerous samples were taken to compare the obtained results, all with the aim of system reliability. The performed tests included dosing of only aluminium-sulphate, then dosing of lime and activated carbon before aluminium-sulphate, as well as dosing of ferric-chloride (FeCl_3), with and without the dosing of lime, etc.

Given the specificity of the water quality, and addition of innovation into the current system without the need for plant reconstruction, each modification represented a unique task for the participants in this effort. This paper presents two selected series of performed tests to optimize water treatment in terms of nickel removal.

Jar testing is a method that simulates a segment of the water treatment process, offering system operators a reliable understanding of how a treatment chemical will interact with a specific type of raw water. Since it mimics full-scale operation, system operators can use jar testing to help determine which treatment chemical will work best with their system's raw water. Jar testing entails adjusting the number of treatment chemicals and the sequence in which they are added to samples of raw water held in jars or beakers. The sample is then stirred so that the formation, development, and settlement of flocs can be observed just as it would be in the full-scale treatment plant (floc forms when the treatment chemicals react with material in the raw water and clump together).

To identify the ideal floc size for a certain plant, the operator then conducts several tests to examine the effects of varying concentrations of flocculation agents at various pH levels [15].

In addition to the jar tests, the experiments included a filter column through which selected samples were passed to complete the treatment process. Fixed-bed column experiments were conducted using columns of 2.54 cm internal diameter and 36 cm length. The columns were packed with anthracite - sand media.

After the preparation of the samples, the required two sets of jar testing and analysis were performed, one in the laboratory of the JCWI and the other in the laboratory of the PUC "Waterworks". Measurement of Ni content was done on ICP-OES apparatus which is a highly sensitive and accurate method for detecting heavy metals in a sample. ICP-OES stands for Inductively Coupled Plasma Optical Emission Spectroscopy.

2. 3. 1. Series 1 jar tests - JAR 1

Water was passed through a column of filler (sand/anthracite) as an addition to jar testing, and this type of mini treatment simulated the treatment at the plant. Jar tests and analysis have been performed for the first series of samples (A to F) termed JAR 1 with applied chemicals and doses, given in Table 2.

Table 2. Applied chemicals during experiments in the laboratory of JCWI for series JAR 1

| | Dose concentration, mg dm ⁻³ | | | | | |
|----------------------------------|---|----------|----------|----------|----------|----------|
| | Sample A | Sample B | Sample C | Sample D | Sample E | Sample F |
| Lime | 20 | 30 | 40 | 15 | 15 | 15 |
| Aluminium-sulphate (8 wt.%) | 55 | 55 | 55 | 45 | | |
| Polyaluminium chloride (10 wt.%) | | | | | 15* | 15** |
| Polyelectrolyte (0.1 wt.%) | 0.5 | 0.5 | 0.5 | 0.3 | 0.3 | 0.3 |

*Producer AluStar, Italy [13], **Producer Donau, Germany [13]

The general procedure for jar testing and filtration was:

- filling the appropriate number of 1000 ml transparent jars with well-mixed raw water
- placing the filled jars on a stirrer, with the paddles positioned identically in each beaker
- adding the chemicals as per the sample number for each of the series
- continuing mixing at a speed of 120 to 50 rpm for 3 min after the last chemical dosing
- continuing mixing the samples at a speed of 90 rpm for 5 min
- continuing mixing the samples at a speed of 45 to 60 rpm for 10 min
- allowing the samples to settle for 40 to 60 min
- decanting the clarified water into another beaker without disturbing the settled sludge at the bottom
- filtering the decanted water of the selected samples through a column with a filtering medium,
- analyzing the filtrate samples for the required parameters.

All experiments were conducted more than 30 times.

2. 3. 2. Series 2 jar tests - JAR 2

Jar tests and analyses have been performed for the second series of samples (1 to 9) termed JAR 2, applied chemicals and doses used are shown in Table 3. Water again was passed through a column with anthracite/sand media as an

addition to jar testing. Additional test chemicals were used in this series comprising powdered granulated activated carbon (GAC), polyaluminium chloride (PAC), and ferric chloride (FeCl_3).

Table 3. Applied chemicals during experiments in the laboratory of PUC for series 2

| | Dose concentration, mg dm^{-3} | | | | | | | | |
|-----------------------------|---|----------|----------|----------|----------|----------|----------|----------|----------|
| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Sample 7 | Sample 8 | Sample 9 |
| Lime | 20 | 20 | 20 | 20 | 20 | 25 | 20 | 20 | 20 |
| GAC (0.75 %) | 7.5 | 0 | 0 | 7.5 | 7.5 | 0 | | | |
| Aluminium-sulphate (8 wt.%) | 55 | 55 | 55 | 55 | 55 | 55 | | | |
| PAC (10.0 wt.%)* | | | | | | | | 10 | 15 |
| FeCl_3 (2.0 wt.%) | | | | | | | 40 | | |
| PE (0.1 wt.%) | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.3 | 0.3 | |

*Producer AluStar, Italy [13]

The general procedure for jar testing and filtration through the column of anthracite and sand media was the same as in the previous testing.

Based on the obtained results of the laboratory tests, the improvement of treatment was started by the direct application of measures in the process line at the WTP.

3. RESULTS AND DISCUSSION

3.1. JAR 1 test

The results of the JAR 1 test are shown in Table 4.

Table 4. Results of the JAR 1 test

| Parameter | pH | Turbidity, NTU | Concentration, mg dm^{-3} | | Removal, % |
|--------------------------------------|-------------|----------------|------------------------------------|--------------|------------|
| | | | KMnO_4 | Ni | |
| Raw water | 7.64 | 3.5 | 23.50 | 0.040 | |
| A set | 8.9 | 0.8 | 8.91 | 0.023 | 43 |
| B set | 9.09 | 0.7 | 15.91 | 0.027 | 33 |
| C set | 9.28 | 0.5 | 19.73 | 0.028 | 30 |
| A anthracite / sand - through column | 6.74 | 0.3 | 8.90 | 0.022 | 45 |
| B anthracite / sand - through column | 6.69 | 0.26 | 8.91 | 0.024 | 40 |
| C anthracite/sand - through column | 7.53 | 0.42 | 13.05 | 0.018 | 55 |
| D set | 8.69 | 0.35 | 10.82 | 0.024 | 40 |
| E set | 8.76 | 0.25 | 13.05 | 0.022 | 45 |
| F set | 8.61 | 0.35 | 7.00 | 0.024 | 40 |
| D sand - through column | 7.46 | 0.19 | 11.46 | 0.023 | 43 |
| E sand - through column | 7.44 | 0.18 | 11.46 | 0.022 | 45 |

*Values above MAC are bolded

The results of the tests conducted show a significant reduction in the nickel content, but again the obtained values are above the MAC. The samples in which aluminium-sulphate was dosed as a coagulant performed better compared to those in which PAC was dosed. The sample termed C anthracite/sand showed the best results, where all parameters were below MAC including nickel (0.018 mg dm^{-3}) with the removal of 55 % compared to the content in raw water. The sample termed C involved dosing of 40 mg dm^{-3} of lime to raise the water pH to 9.28, followed by dosing of 55 mg dm^{-3} of aluminium-sulphate (8 wt.% solution) and 0.5 mg dm^{-3} of polyelectrolyte (0.1 wt.% solution). The pH of water after filtration was 7.53, which is significantly lower than the value recorded after lime dosing, indicating good consumption and reaction of the added chemicals.

3.2. JAR 2 test

Results of the performed analysis in the JAR 2 test are shown the Table 5.

The results of the tests conducted in JAR 2 series show a significant reduction in the nickel content. The samples in which ferric chloride was added were unsuccessful in terms of nickel removal, and the water quality decreased in terms

of the other monitored parameters as well. Also, the addition of activated carbon in some samples did not significantly contribute to the improvement in terms of nickel removal.

Table 5. Results of the JAR 2 test

| Parameter | pH | Turbidity, NTU | KMnO ₄ | Ni | Removal, % |
|---------------------|-------------|----------------|------------------------------------|--------------|------------|
| | | | Concentration, mg dm ⁻³ | | |
| Raw water | 7.56 | 2.3 | 22.9 | 0.037 | |
| Sample 1 | 7.58 | 0.70 | 15.0 | 0.023 | 38 |
| Sample 2 | 7.56 | 0.73 | 8.9 | 0.025 | 33 |
| Sample 3 | 8.86 | 0.28 | 8.0 | 0.021 | 43 |
| F1 - through column | 7.50 | 0.55 | 14.3 | 0.018 | 51 |
| F2 - through column | 7.65 | 0.38 | 8.9 | 0.014 | 62 |
| F3 - through column | 7.65 | 0.23 | 9.2 | 0.015 | 60 |
| Sample 4 | 7.67 | 1.25 | 8.3 | 0,026 | |
| Sample 5 | 7.56 | - | - | - | |
| Sample 6 | 8.78 | - | - | - | |
| F4 - through column | 7.30 | 2.1 | 15.7 | - | |
| F5 - through column | 7.59 | 0.88 | 12.3 | 0.027 | 27 |
| F6 - through column | 7.38 | 0.38 | 8.0 | 0.014 | 62 |
| Sample 7 | 8.9 | 4.0 | 21.2 | 0.039 | |
| Sample 8 | 8.79 | 0.47 | 14.9 | 0.025 | 32 |
| Sample 9 | 8.81 | - | - | - | |
| F7 - through column | 7.4 | 4.0 | 19.0 | - | |
| F8 - through column | 7,53 | 0.45 | 16.4 | 0.022 | 40 |
| F9 - through column | - | - | - | - | |

*Values above MAC are bolded

The samples termed F2 and F6 gave the best results, as all the parameters were below MAC, especially the nickel content ranging from 0.014 to 0.018 mg dm⁻³, with the removal up to 60 % compared to the content in raw water. The sample termed Sample 2 involved the dosing of 20 mg dm⁻³ of lime to raise the water pH, followed by dosing of 55 mg dm⁻³ of aluminium sulphate (8 wt.% solution) and 0.5 mg dm⁻³ of polyelectrolyte (0.1 wt.% solution). The water pH after filtration was 7.65, indicating again good consumption and reaction of the added chemicals. The sample termed Sample 6 involved dosing of 25 mg dm⁻³ of lime and same dosages of aluminium-sulphate and polyelectrolyte solutions. The water pH after filtration in this case was 7.38 similarly as in the previous case.

Since samples Sample 5, Sample 6 and Sample 9 did not precipitate, the analyses were not continued. The sample F7 still contained a significant amount of organic matter, which is the reason the concentration of nickel was not measured.

Based on the results of the experiments, emergency measures were implemented at the WTP by applying certain chemicals directly to process line. The experimental results indicated that the water pH and its precise adjustment, as well as the use of aluminium-sulphate as a coagulant, play a significant role in nickel removal. The high nickel removal was achieved because of the formation of Al(OH)₃ due to the reaction between the aluminum plates and water which has a large surface area to adsorb organic and inorganic materials and able to capture colloidal particles. In addition, the high removal efficiency could be achieved due to the hydroxide precipitation reaction mechanism as a result of basic condition (pH 8.5) which increased the precipitation of Nickel.

Biosorption capacities for heavy metals are highly dependent on pH, with adsorption increasing as the solution pH rises. At lower pH values, the total surface charge of the cells becomes positive, and the presence of H⁺ ions reduces the access of metal ions to the surface functional groups due to repulsive interactions, thereby decreasing the metal removal efficiency. Below pH 3, nickel adsorption decreases, likely due to competitive interactions with hydronium ions (H₃O⁺). Furthermore, at elevated pH levels, the formation of insoluble hydroxyl species leads to nickel precipitation. Consequently, cationic metal biosorption is reduced at pH 7, most likely due to chemical precipitation. Sorption studies above pH 7 were not meaningful due to the formation of insoluble products, which aligns with the solubility products of metal hydroxides [16]. pH also influences processes such as hydrolysis, complexation with organic or inorganic

ligands, precipitation, and the availability of toxic metals for biosorption. Additionally, pH affects the ionization and activity of functional groups in the biomass, particularly carboxylic groups [17].

The results of the application of selected chemicals in the WTP are given in Table 6 where the results show the water pH values and nickel concentrations after each of the 8 sand filters at the WTP.

Table 6. Results after application of the improvement measures at the maximum flow rates at the plant .

| Parameter | pH in 12 h | pH in 14 h | pH in 18 h | Ni concentration, mg/dm ³ | Ni removal, % |
|-----------|------------|------------|------------|--------------------------------------|---------------|
| Raw water | 7.1 | 7.1 | 7.2 | 0.045 | |
| F1 | 7.24 | 7.21 | 7.85 | 0.020 | 55 |
| F2 | 7.25 | 7.16 | 7.78 | 0.013 | 71 |
| F3 | 7.28 | 7.30 | 7.98 | 0.010 | 78 |
| F4 | 7.34 | 7.23 | 8.06 | 0.020 | 55 |
| F5 | 7.40 | 7.29 | 8.08 | 0.015 | 67 |
| F6 | 7.35 | 7.34 | 8.14 | 0.018 | 60 |
| F7 | 7.34 | 7.38 | 8.05 | 0.019 | 58 |
| F8 | 7.35 | 7.43 | 8.06 | 0.010 | 78 |

The obtained results show high degrees of nickel removal from raw water, which range up to 78 %, which is an excellent achievement. The problem during the application of emergency measures with lime dosing and fine pH adjustment is the high concentration of lime, since this solution creates problems in water, primarily in the filters, where they become clogged and require more frequent washing. The increase in the water pH after filtration over time is caused by the untimely reduction of lime dosage before the filters to correct the pH in relation to the reduction in nickel concentration.

In the treated water reservoir, an excellent result was recorded in terms of nickel concentration 0.016 mg dm⁻³, which achieved the goal in terms of all parameters by the regulations in the Republic of Serbia.

In a relatively short period of time, results were obtained that gave effects in the removal of nickel, which means that the experiments were well conceived and performed, quickly leading to practical applications in the water treatment process. In this way, an improvement was achieved in the degree of removal of heavy metals from water, which represents a major problem in the treatment of potable water. The path has been opened in terms of nickel removal so that it is possible to obtain satisfactory purification effects by upgrading the system with new process units, such as activated carbon filters and very precise pH adjustment. For such a system to be sustainable, it is necessary to perform further laboratory testing to find an optimal way of correcting the pH value in such a way that the filters are not clogged.

The introduction of an improved technology that gave an effect and which has been applied since April 2016 is the dosing of a 0.1 % solution of granulated activated carbon powder into the raw water (the pH of the activated carbon must be greater than 8) before the dosing of aluminium-sulphate and polyelectrolyte, namely in doses of 10 to 15 g m⁻³ and adding of lime in doses of 25 to 30 g m⁻³ after clarification in a lamellar precipitator and in front of the filter with strict pH control that should range from 8.0 -8.5 in order to lower the nickel concentration below MAC (< 0.02 mg dm⁻³) after the filter. The pH value was appropriate in the treated water tank, which made it possible for the level of organic matter to be below the MAC.

When the stability of the system was established, the nickel concentration dropped to 0.015 mg dm⁻³ in the clean water reservoir. The analysis results were admirable, the nickel concentration values in water were below the MAC in all samples both at the plant and in the network.

At the beginning of July 2016, the water processing flow at the plant was increased due to the increased water consumption, resulting in a slight increase in the nickel content in the stages of the treatment process and therefore in the output water. Thus, the recommendation was to apply temporary measures to reduce the nickel content, which have already been tested from April to July 2016 leading to a successful reduction of nickel concentrations below the MAC value in the treated water, at a plant capacity of 80 to 90 dm³ s⁻¹.

Numerous adjustments were made on the spot, during the emergency tests at the plant itself in July 2016, together with the Waterworks expert team, and the Ni content was kept within the MAC limits, even though the plant was working beyond its optimal capacity. This primarily referred to the clarification process, which is one of the key steps in lowering the Ni content in water with the existing technology. It should be mentioned that the applied methodology of chemical precipitation is an effective and by far the most widely used process for removing heavy metals [18]. Due to the large consumption of water and therefore the significant consumption of powdered carbon, the dosing of powdered carbon into the raw water was temporarily turned off and the dosing of lime before the filter was maintained to maintain the pH of the water around 8.5 [19]. Since dosing of lime causes a heavy load on the filters, causing frequent filter washing and thus a reduction in their service life, it is recommended to use sodium hydroxide instead of lime, although it is affordable and effective. Addition of sodium hydroxide, on the other hand, does not produce sediments and easily increases pH, and was successfully tested on site at laboratory conditions.

4. CONCLUSIONS

This work addressed a problem in a water treatment plant in the municipality Čajetina, Serbia. The water quality after the treatment in the plant did not meet the quality standards, so it was necessary to perform experiments to find an appropriate solution to primarily decrease the nickel content. Thus, two experimental series tests were conducted in two laboratories to determine methods of intervention to improve the water treatment process. The best results were obtained at the dosing of a 0.1 wt.% solution of granulated activated carbon powder into the raw water before the dosing of aluminium-sulphate and polyelectrolyte, namely at the doses of 10 to 15 g m⁻³ and dosing of lime at 25 to 30 g m⁻³ after clarification in a lamellar precipitator and in front of the filter, with strict pH control that should range from 8.0 to 8.5 in order to lower the nickel concentration below MAC (< 0.02 mg dm⁻³) after the filter. The chosen dose of the 8 wt.% aluminium sulfate solution is 55 mg·dm⁻³, while the dose of the 0.1 wt.% polyelectrolyte solution is 0.5 mg·dm⁻³. The pH of the water after filtration is 7.38 which indicates consumption and reaction of the added chemicals. After applying this combination of chemicals, the nickel concentration decreased to 0.015 mg dm⁻³, with a satisfactory pH value in the treated water.

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Sprovođenje hitnih mera za poboljšanje efikasnosti uklanjanja nikla iz vode na postojećem postrojenju za prečišćavanje vode

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(Naučni rad)

Izvod

Projektovanje postrojenja za prečišćavanje vode (PPV) podrazumeva kompleksnu analizu i primenu kriterijuma projektovanja zajedno sa praktičnim iskustvom. Osnovni kriterijumi standardnog projektovanja obuhvataju kapacitet, kvalitet sirove i prečišćene vode, lokaciju postrojenja za prečišćavanje vode i skup prihvatljivih, proverenih tehnologija. Kombinovanjem kriterijuma pouzdanosti sistema sa tehnokonomskim pokazateljima moglo bi se dobiti optimalno procesno rešenje za nova postrojenja, kao i za unapređenje procesa u postojećim postrojenjima. U ovom radu, na osnovu podataka iz akumulacije Ribnica, Srbija, i zahtevanog kvaliteta sirove i prečišćene vode, predloženo je optimalno rešenje za unapređenje i optimizaciju tehnologije prečišćavanja vode do kvaliteta za piće na PPV na Zlatiboru, Srbija, kako bi se osigurala maksimalna efikasnost i fleksibilnost u radu sistema. Analiza kvaliteta vode pokazala je da su nakon tretmana u postrojenju svi parametri bili u granicama odgovarajućih maksimalno dozvoljenih koncentracija propisanih Pravilnikom o higijenskoj ispravnosti vode za piće Republike Srbije, osim sadržaja nikla. U radu su prikazani rezultati uklanjanja nikla primenom višestrukih ispitivanja u laboratoriji i na PPV radi uspostavljanja najbolje procedure za tretman vode. Prema dobijenim rezultatima, rešen je problem kvaliteta vode u pogledu uklanjanja nikla i ispunjeni su zahtevani uslovi (sadržaj nikla ispod maksimalne dozvoljene koncentracije < 0.02 mg dm⁻³).

Ključne reči: Jar test; aluminijum-sulfat; polialuminijum hlorid; flokulacija



