Primljen / Received: 6.3.2020.
Ispravljen / Corrected: 9.6.2020.
Prihvaćen / Accepted: 22.8.2020.
Dostupno online / Available online: 10.3.2021.

Analysis of Water Treatment Plant Operation in Ilijaš Municipality

Authors:

Prof. **Suvada Šuvalija**, PhD. CE
University of Sarajevu, B&H
Faculty of Civil Engineering
Department of Hydraulic Engineering and Environmental Engineering
suvadasuvalija69@gmail.com
Corresponding author

Nedžad Mekić, MCE
Ministry of Economy - Sarajevo Canton, B&H
nedzadmekic@gmail.com

Professional paper

Suvada Šuvalija, Nedžad Mekić

Analysis of Water Treatment Plant Operation in Ilijaš Municipality

The operation of the Karašnica Water Treatment Plant, forming part of the water system in Ilijaš Municipality, in Bosnia and Herzegovina, is analysed in the paper. Two distinct water treatment lines are described and analysed. The first line consists of an internal circular settling tank and rapid sand gravity filters, while the second line consists of an external circular settling tank and pressure filters. In order to evaluate operating efficiency, a tour of the system facilities was made, interviews with the employees were conducted, the existing documentation was examined, and additional physicochemical and bacteriological analyses of appropriate water samples were conducted. Following analysis of all available data, appropriate conclusions and significant recommendations were made toward more efficient operation of the water treatment plant.

Key words:
water supply system, water treatment, gravity filter, pressure filter, laboratory analyses

Stručni rad

Suvada Šuvalija, Nedžad Mekić

Analiza rada postrojenja za kondicioniranje vode u općini Ilijaš

U radu se analizira rad postrojenja za kondicioniranje vode "Karašnica", u sklopu vodoopskrbnog sustava općine Ilijaš u Bosni i Hercegovini. Opisane su i analizirane dvije različite linije kondicioniranja, i to prva linija koju čini unutrašnji kružni taložnik i brzi pješčani gravitacijski filtri te druga linija koju čini vanjski kružni taložnik i filtri pod tlakom. Kako bi se ispitala učinkovitost rada postrojenja, autori su obišli postrojenja, razgovorali sa zaposlenicima, istražili postojeću dokumentaciju i proveli dodatne fizikalno-kemijske i bakteriološke analize odgovarajućih uzoraka vode. Analizom svih raspoloživih podataka doneseni su odgovarajući zaključci i važne preporuke za učinkovitiji rad tog postrojenja.

Ključne riječi:
vodoopskrbni sustav, kondicioniranje vode, gravitacijski filtar, filtar pod tlakom, laboratorijske analize

Fachbericht

Suvada Šuvalija, Nedžad Mekić

Analyse des Betriebs der Wasseraufbereitungsanlage in der Gemeinde Ilijaš

Das Papier analysiert den Betrieb der Anlage „Karašnica" im Rahmen des Wasserversorgungssystems der Gemeinde Ilijaš in Bosnien und Herzegowina analysiert. Es werden zwei verschiedene Aufbereitungslinien beschrieben und analysiert: nämlich die erste Linie, die aus einem internen kreisförmigen Abscheider und schnellen Sandschwerkraftfiltern besteht, und die zweite Linie, die aus einem externen kreisförmigen Abscheider und Druckfiltern besteht. Um die Effizienz der Anlage zu untersuchen, haben die Autoren die Anlagen besichtigt, mit den Mitarbeitern gesprochen, die vorhandene Dokumentation eingesehen und zusätzliche physikalisch-chemische und bakteriologische Analysen geeigneter Wasserproben durchgeführt. Die Analyse aller verfügbaren Daten führte zu angemessenen Schlussfolgerungen und wichtigen Empfehlungen für einen effizienteren Betrieb der Anlage.

Schlüsselwörter:
Wasserversorgungssystem, Wasseraufbereitung, Schwerkraftfilter, Druckfilter, Laboranalyse

1. Introduction

Water that is extracted from nature for water supply purposes (the so called raw water) may have varied characteristics depending on its origin, place and method of extraction. Raw water at the water intake generally involves some physicochemical and microbiological parameters in concentrations exceeding maximum values specified in the *Byelaw on hygienic quality of drinking water* [1], and can not therefore be used for drinking without prior treatment [2]. The water supply system of the central part of the Ilijaš Municipality has been dependent in the long term on the water intake from the surface flow of the torrential Misoča River via a Tyrolean water intake. Torrential flow results in sudden increase in turbidity [3], especially after rainfalls, which decreases the quality of water at the intake and complicates preparation of drinking water, i.e. treatment of water at the plant site [4].

Traditional technology has been widely used for treatment of surface waters in water plants. This technology, if well planned, designed and realized, provides – with proper maintenance - satisfactory results, especially in the treatment of surface waters of torrential character, as is the case with the Misoča River. Efficient operation of the already realized plants also calls for continuous monitoring of new trends and technologies, in order to meet increasingly strict standards and more and more pronounced and diverse pollution of water at the source, which especially applies to surface waters. In order to gain a better insight into the current condition of the water supply system and water treatment plant in the Ilijaš Municipality, the system infrastructure was inspected, the available documentation (reports, analyses, design documents, etc.) was consulted, and employees were interviewed to learn from their experience about the operation of the plant [5, 6]. An overview of current condition of the Karašnica system and water plant is presented in Section 2. Furthermore, in order to additionally analyse the efficiency and functionality of the plant facilities, with particular emphasis on the settling tank and filter, additional samples of water were taken at a point before the water reaches the plant, as well as after each particular operation, i.e. after treatment operations at both lines of the water plant. Additional physicochemical and microbiological analyses of water samples were made at a reference laboratory (public institution), i.e. at the *Institute for the hygiene and safety of food* in Zenica. An overview of laboratory results following these additional analyses is presented in Section 3. The aim of the discussion of results (Section 4) was to determine current effects of the operation of the plant facilities, and to explore possibilities for further improvement of the overall performance of the plant. The experience gained with regard to the operation of this plant, some disadvantages that have been noted, and also some improvements that have been made, can assist other similar plants using traditional surface water treatment technology, to make use of the positive experience, and to avoid or mitigate negative effects [7]. The improvement primarily involves application of new trends and technologies, use of new chemicals, new facilities, equipment and devices [8, 9]. Based on the analyses and discussions (Sections 3 and 4), guidelines are given in conclusion for further improvement of the overall performance of the Karašnica Plant in Ilijaš. These guidelines can also be of assistance to other plants that use this or similar technology in similar operating conditions.

2. Water supply system and water treatment plant in Ilijaš Municipality

2.1. Basic data on the facilities and equipment used in the Ilijaš Municipality water supply system

The water supply in the central part of the Ilijaš Municipality is operated via the system managed by the public utility company Vodostan d.o.o. based in Ilijaš. The water supply system is composed of the following facilities and equipment (Figure 1):

- facilities built for the intake and preliminary treatment of water at the Misoča River,
- transport pipelines (gravity operated and pressurized),
- Karašnica Water Treatment Plant (two lines),
- water tank, and
- distribution network.

The following facilities were built next to the water intake:

Drainage – filtration channel was constructed immediately next to the right-side bank of the Misoča River, to the upstream of the barrier, in order to partly filter the Misoča River water before it is extracted and carried to the sand trap.

Barrier with small water-storage reservoir on the Misoča River is the first place where turbidity improvement starts, because an intake storage reservoir is formed by construction of a small concrete barrier on the Misoča River. The role of this facility is to increase depth at the water intake point, to calm down the water flow and reduce deposition of bedload material [3].

Tyrolean weir is composed of a rectangular concrete channel positioned perpendicular to the river flow, where water flows over the barrier, and a trash rack is placed in the channel as a means for removing leaves and bigger floating substances [4]. The water runs through the rectangular concrete channel and reaches the sand trap, which is situated immediately next to the water intake.

Sand trap is realized as a concrete structure and its role is to accept some of the water coming from the Tyrolean weir and drainage-filtration channel, and it is in this trap that the process of sedimentation of some of the suspended particles takes place. This sand trap enables an undisturbed connection to a DN 400 gravity pipeline.

DN 400 gravity pipeline is 4.3 km in total length and it conveys raw water from the water intake, i.e. from the sand trap, to the pumping station in the municipality of Misoča.

Pumping station receives water from the gravity pipeline and, using two water pumping generators, the water is carried via a pressure pipeline to the water treatment plant situated at the Karašnica hill. The role of the pumps is to fill the settling tanks (first and second lines) and keep the water level in these tanks constant, regardless of the filter operating velocity.

Karašnica Water Treatment Plant is the most complex element of the water supply system. It is also the most significant element from the aspect of ensuring good quality of water and hence protecting health of the users.

The plant's main building called central unit features the *command room* where the SCADA (Supervisory Control and Data Acquisition) system is used. The SCADA system automatically monitors quality and controls operation of the facilities and equipment in the entire water supply system and in the plant itself [5, 7]. More specifically, this system measures, supervises and controls operation, remotely controls the pumps, filtration, and water levels in water tanks, and other elements, thus checking all parameters that are considered significant for efficient operation of the system. Furthermore, the water supply system operator has introduced and implemented, in the water quality segment, the so called HACCP Codex Alimentarius Standard, as a standard ensuring respect of good manufacturing and hygienic practices, all this aimed at delivering hygienically safe water to consumers [5].

The *Processing Equipment System* is formed of the pumping station (for filtered water for higher areas in the municipality), transformer station, generator, equipment ensuring operation of the chemical proportioning system (for disinfection, coagulation, and flocculation), coagulant/flocculent mixers, and other equipment.

The *Water Tank System* ensures continuous and safe water supply (via distribution network) to local residents and industry operators in the Ilijaš municipality. To provide for a reliable operation of facilities in the scope of the water supply system, appropriate reserves of water have been secured by means of the following water tanks:

- "Brdo Karašnica I" water tank (V = 600 m^3),
- "Brdo Karašnica II" water tank (V = 3000 m^3 (2 x 1500 m^3))
- "Hamzin gaj III" water tank (V = 1000 m^3),
- Water tank for washing filters (V = 100 m^3).

The *distribution network* consists of distribution pipelines of various diameters, divided into two height zones, with a sufficient number of pumping stations for ensuring proper pressure within the network. However, the water supply system conceived in this way creates water losses in the distribution network which, according to the public operator's report, reach up to 40 % [10]. Such a system in which the pressure is realized via a system of pumps, is characterized by a considerable energy consumption and frequent breakdowns. In order to reduce network losses, a software was installed in 2015 to control consumption measurements, to check flow in individual zones, and to control pressure regulation. Based on the database created through measurements and processing of measurement results, localities with greater losses were identified and, hence, the sections in the distribution network requiring pipeline renovation and elimination of losses were determined. Such an approach to the reduction of network losses should serve as an example to other watery supply system operators, and it should encourage them to adopt such an efficient loss reduction and system monitoring methodology, in order to increase sustainability of the system [11].

2.2. Water treatment technology at Karašnica plant

The quality of raw water at the intake point in the Misoča River does not comply with some parameters prescribed by the Byelaw [1]. and so the public utility company Vodostan from Ilijaš, in its capacity as the operator of this plant, applies appropriate water treatment measures. The treatment begins already at the surface water intake at the Misoča River where, within the intake and next to it, appropriate facilities were built in order to ensure an efficient water intake and an appropriate pre-treatment, all aimed at relieving the pressure from the water plant itself. Water intake and pre-treatment facilities are described in Section 2.1. Water treatment continues at the Karašnica Plant, with the total capacity of 150 l/s. The block diagram of the water treatment technology next to the water intake and at the plant itself is presented in Figure 1.

The *Karašnica Water Treatment Plant* in Ilijaš municipality is formed of a number of built facilities in which a technology traditionally used for the preparation of drinking water is applied. This technology involves coagulation, flocculation, sedimentation, filtration, and disinfection [12]. A specific feature of this plant are two treatment lines operating in parallel, differing from one another mostly in the way in which the water is filtered. In fact, the second line was built subsequently to meet a higher water demand (Figure 1). Thus the treatment if water in this plant is operated as follows:

- First line (capacity: 50 l/s): the process involves coagulation/flocculation in the chamber situated next to the internal circular settling tank, which is followed by filtration via rapid sand gravity filters,
- Second line (capacity: 100 l/s): the process involves coagulation/flocculation in the chamber situated next to the external circular settling tank, which is followed by filtration via vertical cylindrical tanks under pressure.

The basic information about these operations, and about facilities forming the Karašnica plant.

The *coagulation and flocculation* are operations that

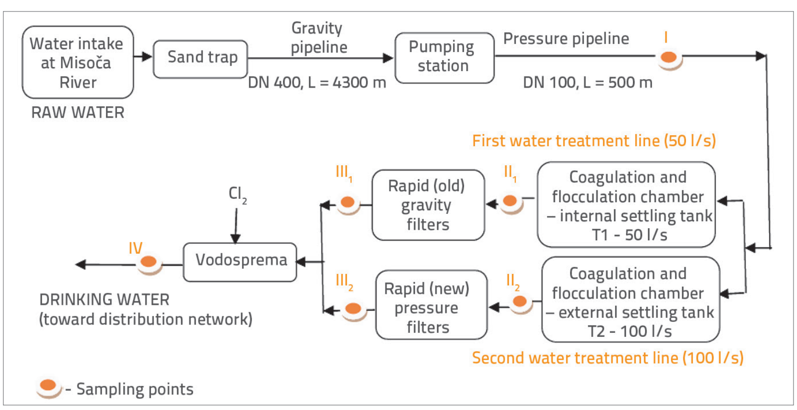


Figure 1. Block diagram of the water treatment technology at the water supply system in Ilijaš municipality

Figure 2. Circular settling tanks at Karašnica plant: (I) internal settling tank (T1) with a capacity of 50 l/s (II) external settling tank (T2) with a capacity of 100 l/s

take place in integrated coagulation and flocculation chambers that have been built next to circular settling tanks (Figure 1). The previously used aluminium sulphate and polyelectrolyte – polyacrylamide (PAA) have been replaced by a new coagulant/flocculent, i.e. by polyaluminium chloride (PAC). According to plant employees, PAC has proven to be highly efficient [13]. In effect, as a polyvalent non-organic polymer of high zeta potential, PAC presents numerous advantages as compared to ALUM and PAA: it acts both as coagulant and flocculent, it regulates the pH value, it is simpler to use, its mass consumption is lower, and so the quantity of deposit/sludge is much lower and, finally, it is more efficient and rapid in eliminating turbidity. In addition, the use of PAA presents a potential hazard as, in greater concentrations, it acts as a cumulative neurotoxin and complicates washing of filters.

Sedimentation. Two circular settling tanks with vertical flow of water, 150 l/s in capacity (Figure 2) are used, during preparation of drinking water, for separating from water the floccules created by coagulation and flocculation. The internal settling tank (T1) in the first line of treatment exhibits a capacity of 50 l/s and is situated in the central facility, while the second external open settling tank (T2), belonging to the second line of treatment, has a capacity of 100 l/s. After the clarification process, the water is supplied via a pump system to the filtration unit.

The *filtration of water* at the Karašnica plant is operated via two filtration systems. These filtration systems are presented in Figure 3, while the basic properties of these filters are given in Table 1. At the first treatment line (Figure 1) the filtration system is based on rapid gravity filters, 50 l/s in total capacity. These filters are situated in the enclosed central facility, and the water is carried to the filters from the internal settling tank (T1). Gravity filters are filled with quartz sand, measuring 0.5-1.2 mm in grain size, and 100 cm in layer thickness. There are three filtration fields, each measuring 20 square meters in area, and so the total area of gravity fields is 60 square meters. The filtration of water under pressure is a newly introduced filtration process at the Karašnica plant. After settlement, the water is carried from the external settling tank T2 (Figure 1 (second line)) to six vertical filtration vessels – modules, each with the operatic capacity ranging from 7 l/s to 20 l/s, which is regulated with a gate that can be operated either manually or automatically. During the filtration vessel washing, the gate closes itself so as to avoid contamination of water in the water tank [14]. Filters are made of special steel destined for vessels under pressure, and they have an appropriate two-sided corrosion protection [5]. The filter fill material, formed of quartz sand and garnet, is 120 cm in total thickness. The garnet between the support fill and filtering fill eliminates the problem of gravel overturning and disturbance of fill material when filters are washed under pressure.

Water disinfection system. Water disinfection is operated using gaseous elemental chlorine, and the system is composed of a

Table 1. Characteristics of gravity and pressure filters of the plant "Karašnica"

Filter characteristics	Unit	Filters under pressure	Gravity filters
Filter capacity	l/s	100	50
Real velocity of filtration	m/h	12.22	9.0
Consumption of filter-washing water	m^3/god	10.950	9.700
Filter-washing frequency	mjesečno	6	8
Height of quartz sand fill	cm	120	100
Area occupied by one filter	m^2	4.91	20
Total filter area	m^2	(6 x 4.91) = 29.46	3 x 20=60

igure 3. Filters situated in Karašnica plant: a) gravity filter b) filters under pressure and facility accommodating these filters

chlorine station with equipment, chlorine proportioning unit and chlorine bottles storage, which is situated in the central facility. The chlorine station is fully automatized. Water chlorination is operated via a system designed in such a way that the chlorination unit is under vacuum, so as to prevent release of chlorine and unwanted consequences of such release in the case of damage to the unit, deterioration of the device, loss of impermeability, or for any other reason. The injector is equipped with a non-return valve so as to prevent entry of water in the vacuum unit.

3. Laboratory testing of water samples

3.1. Quality of raw water at the surface intake of the Misoča River

Water quality monitoring at the source is an indispensable and obligatory procedure that is aimed at ensuring continuous supply of water complying with quality requirements specified in the Byelaw [1]. As already mentioned, the water intake at the Misoča River is often affected by high turbidity, resulting from torrential nature of this watercourse [3]. According to the data suppled by the operator, i.e. by the public utility company Vodostan d.o.o. from Ilijaš, the highest level of turbidity measured to this date is 8290°NTU [14]. In addition, turbidity durations and levels registered at the Misoča River in the period of catastrophic floods (precipitation) that affected Bosnia and Herzegovina in May 2014 are presented in Figure 3. The relationship between turbidity, flow rate and other water quality parameters is presented in Table 2. An overview of average values of some physicochemical parameters for source water (Misoča watercourse 2006-2016) over the rain and dry periods is given in Table 2 [5]. Higher turbidity in the rain period negatively affects the quality of water and its physicochemical composition (Table 2, columns (2) and (3)) while also complicating the water chlorination process. In effect, various admixtures (microorganisms, dissolved substances, etc.) that negatively affect physicochemical properties of water are retained on turbidity-causing particles (suspended and colloidal). The aim is to achieve at least 20 NTU through clarification so that proper operation of the filters can be ensured (Table 3, last row) [5, 6]. In this respect, the quantity of water reaching settling tanks is reduced by 20 to 40 % in the case of extreme turbidity values and this either by regulation using gates or by completely shutting off the flow of water.

The mentioned public utility company (JKP) Vodostan from Ilijaš does not have an accredited laboratory that could perform all

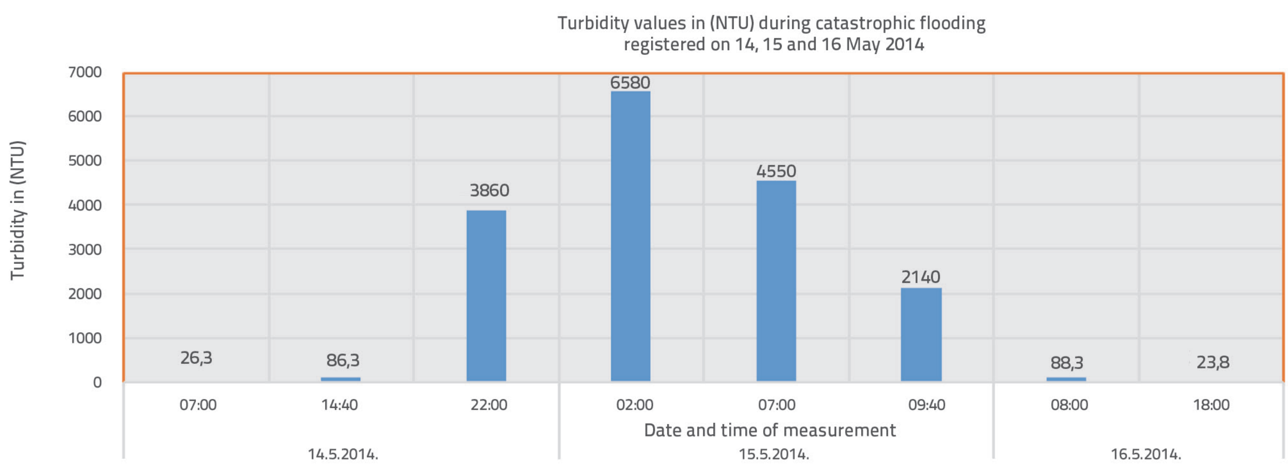


Figure 4. Diagram showing rise and fall in raw water turbidity at the measuring point in front of the Karašnica Plant

Table 2. Average values of basic water quality parameters for the Misoča River (2006-2016.) [5]

Physicochemical indicators (units of measurement)	Rain period	Dry period	Maximum allowable concentration (MAC) [1]	NOTE: hydrological conditions – water quality
(1)	(2)	(3)	(4)	(5)
Flow rate (l/s)	80 - 150	80 - 150	-	RAIN PERIOD: Mostly after intense precipitation and snow melting (high water level); DRY PERIOD: Mostly without precipitation over a longer period of time (low water level);
pH value (-)	7.5 - 8.0	8.0 - 8.24	6.5 - 9.5	
Electrical conductivity (μS/cm²)	250	305	2500	
Nitrates (mg/l)	4.4	2.3	50	
Ammonium (mg/l)	0.03	0.0	0.5	
KMnO4 consumption (mg/l)	2.0	1.1	5.0	
Sulphates (mg/l)	34	14	250	
Phosphates (mg/l)	0.05	0.03	0.3	
Iron (μg/l)	10	10	200	
Copper (μg/l)	0.04	0.03	2	
Turbidity (NTU)	100 - 500	5 - 10	1	
Turbidity after clarification (NTU)	7 - 40	0.5 - 10	(20)	Requirement for successful filtration

Table 3. Results obtained by physicochemical analysis of water samples [15, 16]

Test parameter	Unit	Reference value (Byelaw [1])	**Measuring points** (marked in Figure 1)					
			I	II_1	II_2	III_1	III_2	IV
			Entrance to the station	Behind internal settling tank	Behind external settling tank	Behind rapid gravity filters	Behind pressure filters	Water tank – drinking water
Colour	SkalaPt-Co	No	5⁰	5⁰	No	No	No	No
Odour	-	No	No	No	No	No	No	No
Turbidity	°NTU	1	18	5.2	4.40	0.32	1.0	0.25
pH value at 250C	pH	6.5-9.5	7.81	7.67	7.18	7.29	7.78	7.66
$KMnO_4$ consumption	mg/l O_2	5.0	3.80	2.0	2.0	1.52	1.76	1.60
Residual chlorine	mg/l	0.5	0	0	0	0	0	0.2
Chlorides	mgCl/l	250	5.50	5.50	9.0	5.0	10.0	4.00
Ammonia	mgNH_4/l	0.5	0.114	0.084	0.089	0.075	0.076	0.058
Nitrites	mgNO_2/l	0.5	0	0	0	0	0	0
Nitrates	mgNO_3/l	50	2.944	2.656	3.453	3.249	3.409	3.462
El. conductivity at 25⁰C	μS/cm	2500	314.2	299.80	310.50	331.10	295.5	307.40
Results of second testing conducted on 21/05/2019								
Colour	SkalaPt-Co	No	No	No	No	No	No	No
Odour	-	No	No	No	No	No	No	No
Turbidity	NTU	1	5.6	2.6	3.2	0.14	0.9	0.14
pH value at 250C	pH	6.5-9.5	8.13	8.03	8.01	8.04	8.08	8.01
$KMnO_4$ consumption	mg/l O_2	5.0	1.52	1.76	1.60	1.36	1.44	1.36
Residual chlorine	mg/l	0.5	0	0	0	0	0	0.2
Chlorides	mgCl/l	250	<5	<5	<5	<5	<5	<5
Ammonia	mgNH_4/l	0.5	0.112	0.057	0.084	0.079	0.064	0.050
Nitrites	mgNO_2/l	0.5	0	0	0	0	0	0
Nitrates	mgNO_3/l	50	1.244	1.355	1.687	1.483	1.394	1.572
El. conductivity at 25⁰C	μS/cm	2500	343.8	350.20	352.20	351.6	365.6	355.90

Table 4. Results of microbiological analyses of water samples [17]

Test parameter	Unit	Reference value [1]	Measuring points (marked in Figure 1)					
			I	II_1	II_2	III_1	III_2	IV
			Entrance to the station	Behind internal settling tank	Behind external settling tank	Behind rapid gravity filters	Behind pressure filters	Water tank – drinking water
Total number of coliform bacteria	Cfu/100 ml	No	80	30	30	0	8	0
Number of Escherichia coli	Cfu/100 ml	No	70	30	30	0	8	0
Total number of faecal streptococci (enterococci)	Cfu/100 ml	No	30	10	25	0	0	0
Total number of aerobic mesophilic bacteria	Cfu/ ml	100/ml	140	80	150	5	60	0
Total number of aerobic mesophilic bacteria	Cfu/ ml	20/ml	110	10	110	0	10	0

analyses required according to the Byelaw [1]. That is why the quality of water that is supplied to end users is checked in a certified laboratory formed at the public institution *Institute of Health and Food Safety – Zenica*. The JKP Vodostan Ilijaš has established a basic field laboratory performing only those checks that are essential for functioning of the plant, such as water turbidity checking.

3.2. Results of physicochemical and microbiological analysis of water samples

In order to analyse effectiveness of the plant and its facilities, monitoring must also be conducted within the plant itself, i.e. it should not be restricted to monitoring at the entry (source water – raw water) and exit (distribution water tank) only, which is unfortunately normal practice in this field. In this respect, additional sampling was conducted in the scope of this research, even after sedimentation and filtering in the first and second water treatment lines. Block diagram given in Figure 1 and Table 3 points to the places from which samples were taken for analysing efficiency of individual water treatment operations (I, II1, II2, III1, III2, IV). The samples were taken at two different time intervals, i.e. in winter period (February 2019) and in spring period (May 2019) and the comparison of results was made. Conclusions resulting from this comparison are presented in Section 4. The analysis results are presented in Table 3 [15, 16]. In order to determine water quality from the aspect of presence of microorganisms in water, microbiological testing was conducted, in addition to physicochemical analyses, in the second testing campaign on 21 May 2019 (Table 4) [17].
The discussion of results obtained by physicochemical and microbiological analysis of samples (Tables 3 and 4) is presented, mostly from the aspect of the plant's efficiency, in Section 4. In addition, an overview is given of measured characteristic quality parameters, significant for analysing the efficiency of sedimentation, filtration, and disinfection.

4. Discussion of results

4.1. Analysis of laboratory results

The results of laboratory analysis of water samples (Tables 3 and 4) taken at the point before entry to the plant, and at points following individual operations at both water treatment lines (Figure 1), are a good indicator of the level of efficiency of the water treatment system used at the Karašnica Plant. Based on the analysis results, it can be stated that the operation of the plant is satisfactory, as all quality parameters at the exit from the plant (at the clean water tank – measurement point IV, tables 3 and 4) are within reference values specified in the Byelaw [1]. The analysis of laboratory results for some parameters, which improve to a great extent during the treatment processes and are significant for monitoring efficiency of the plant's operation, is presented below.

Turbidity of water
After analysis of results obtained by turbidity measurements conducted by the operator JKP Vodostan Ilijaš [10, 14], it was established that the turbidity value increases and decreases more rapidly in the period of precipitation following longer dry periods. On the other hand, it should be noted that during a long-lasting rain period registered in May 2014, turbidity values actually increased and decreased more slowly, as can be seen in Figure 4. These are extreme turbidity values when the plant operation is stopped until the turbidity values return to acceptable levels and, according to the data provided by the operators, these values are: turbidity should be less than 40 °NTU at the entry to the plant, and less than 20 NTU and the entry to the filters (Table 2). An average raw water turbidity prior to entry to the Karašnica Plant is always above the maximum allowable concentration (MDK), which amounts to 1.0 °NTU. Thus, for instance, in 2017, an average measured turbidity of raw water prior to the entry to Karašnica plant amounted to 21.82 °NTU [10].

According to additional measurements conducted in 2019 [15, 16], the turbidity level at the entry to the plant was also above the MDK (Table 3), while the turbidity level obtained at the water tank was within the limits specified in the Byelaw [1]. More information about the way turbidity changes in the plant itself is given is Section 4.2 where the efficiency levels of the settling tank facilities and filters at both treatment lines are discussed.

Consumption of potassium permanganate

Consumption of potassium permanganate ($KMnO_4$) is partly an indicator of the content of organic substances in water as, if organic substances are found in raw water, then the latter will use up some $KMnO_4$ for their oxidation. The organic matter content is particularly unfavourable if disinfection of water destined for drinking is operated using gaseous elemental chlorine because of possible formation of carcinogenic by-products, such as trihalomethanes (THM) [4, 12]. According to the Byelaw [1], water is allowed to contain $KMnO_4$ for up to 5 mg/l O_2 (Table 3). Laboratory analyses of samples taken on 5 February and 21 May 2019 show that the consumption of $KMnO_4$ is below the maximum allowed concentrations. The highest consumption of $KMnO_4$ occurred after sedimentation (measurement points II1 and II2), and it amounted to T1=T2=2.0 (mg/l O_2), which is probably due to separation and deposition of organic matter.

Ammonia in surface water

Presence of ammonia in water points to bacterial activity, indicates that the water pollution is fresh, while also pointing to microbial decomposition of organic substances containing nitrogen. The analyses made show that concentrations of ammonia present in water samples are low and that the maximum measured value in raw water amounts to 0.114 mgNH_4/l, while in the water tank where the water is supplied after the treatment the ammonia value amounts to 0.058 mgNH_4/l. Measured ammonia concentrations are lower than maximum allowed concentrations (MDK) of 0.5 mgNH4/l specified in the Byelaw [1] (Table 3), which shows that ammonia concentrations registered at the time of measurement are very small.

Electrical conductivity

Electrical conductivity is the capacity of water samples to conduct electricity. Inorganic compound solutions are relatively good conductors, while molecules of organic compounds, which do not decompose in water solutions, are very poor conductors [12]. The data on electrical conductivity at 25 °C in front of the plant and within the plant are given in Table 3. The results obtained by laboratory analyses conducted after all water treatment operations at the plant show that electrical conductivity is by several times lower than the MDK value [1]. However, the concentration of 343,8 mS/cm measured at 25°C in raw water prior to the entry to the plant points to the presence of some ions concentrations formed by dissolution of inorganic compounds.

Results of microbiological analysis

Results obtained by microbiological analyses, shown in Table 4, indicate that the total number of coliform bacteria, the number of Escherichia coli, the number of faecal streptococci (enterococci), the number of aerobic mesophilic bacteria, and the number of aerobic mesophilic bacteria exceed concentrations specified in the Byelaw [1] when measured at the pressure pipeline situated at the very entrance to the plant, i.e. in raw water. However, after clarification, filtration and disinfection in the water tank for distribution, their number was found to be zero, which points to an efficient disinfection process, i.e. to a low microbiological risk.

4.2. Analysis of plant operation

Pre-treatment of surface water

It should be noted that good quality of water at the intake, and good pre-treatment next to the intake, is a precondition for good operation of the water treatment plant. As in this case the water at the intake is surface water of torrential character, the efficiency of the pre-treatment is of particular significance. Pre-treatment components of the water supply system are: drainage filtration channel, barrier, trash rack and sand trap in the scope of the water intake facility (briefly described in Section 2.2). These components have to be regularly maintained in order to preserve their capacity (so as to avoid clogging by suspended substances), and to facilitate operation of the downstream facilities at the plant itself, which guarantees more efficient realisation of downstream processes and a generally more economical operation of the system (lower consumption of chemicals, and lower consumption of water for washing the filters and for maintaining all plant facilities, etc.).
The effect of sedimentation and filtration in the plant was checked by additional measurements conducted within the plant [15-17]. The change in turbidity levels of the water passing through the plant is shown in Figure 5, and discussion about operation of the plant is presented below.

Operation of settling tank.

The preparation of water for sedimentation starts by PAC proportioning in the mixing chamber situated next to the settling tank. This is followed by sedimentation of water at two parallel lines. At the first line (line I) the sedimentation is operated via the internal settling tank T1. By sedimentation of water at the internal settling tank T1 (measurement point II1 (Figure 1); first line (Figure 5)), the initial turbidity of the sample taken on 5 February 2019 was reduced from initial 18 °NTU to 5.2 °NTU, and so 12.8 °NTU is removed at the settling tank T1. The turbidity of the sample taken on 21 May 2019 was reduced from initial 5.6 °NTU to 2.6 °NTU, and so 3.0 °NTU was removed by the settling tank T1 in this case. It can be noticed that the efficiency of the settling tank T1 varies depending on the initial turbidity, as in the first case 12.8 °NTU was removed, while only 3.0 °NTU was removed in the second case. Of course, this is the result of the quantity of PAC added to the water, which is added depending on the turbidity of the influent [13]. In effect, greater initial turbidity calls for greater quantity of chemicals, and hence the turbidity lowering was more pronounced during the measurement conducted on 5 February 2019, when the initial turbidity amounted to 18 °NTU.

At the second line, the sedimentation was operated via the external settling tank T2. By sedimentation of water at the external settling tank T2, the initial turbidity of the sample taken on 5 February 2019 was reduced from initial 18 °NTU to 4.4 °NTU, and so 13.6 °NTU was removed at the settling tank T2 (Figure 5). The turbidity of the sample taken on 21 May 2019 was reduced from initial 5.6 °NTU to 3.2 °NTU, and so 2.4 °NTU was removed by the settling tank T2 in this case. Just like in the case of the settling tank T1, greater efficiency of the settling tank T2 in the case of the first sample (turbidity: 18 °NTU) is due to greater quantity of chemicals (PAC) added.
An average decrease in turbidity at the internal settling tank T1 (12.8 and 3.0 °NTU) is 7.9 °NTU, while it amounts to 8.0 °NTU (13.6 and 2.4 °NTU) for the external settling tank T2. It can therefore be concluded that the turbidity abatement efficiency of the two settling tanks is almost the same.

Operation of filters

The use of traditional technology implies application of rapid filters after the end of sedimentation. Filter efficiency is dependent of the efficiency of settling tanks, and so the clarified water should have the turbidity level of less than 20 NTU (Table 2). At the first line, the filtration is operated via gravity filters. For the sample taken on 5 February 2019 at the measurement point III1 (Figure 1), the turbidity was reduced from 5.2 to 0.32 °NTU (Figure 5). The total reduction in turbidity amounted to 4.88 °NTU. For the sample taken on 21 May 2019, the turbidity was reduced from 2.6 to 0.14 °NTU and so the total reduction in turbidity amounted to 2.46 °NTU.
At the second line, the filtration is operated via six filters under pressure. For the sample taken on 5 February 2019 at the measurement point III2 (Figure 1), the turbidity was reduced from 4.4 to 1.0 °NTU (Figure 5). The total reduction in turbidity amounted to 3.4 °NTU. For the sample taken on 21 May 2019, the turbidity was reduced from 3.2 to 0.09 °NTU and so the total reduction in turbidity amounted to 3.11 °NTU.
It was established by comparing turbidity abatement levels using gravity filters and pressure filters that gravity filters are somewhat more efficient in turbidity abatement. Average turbidity abatement values for gravity filters and pressure filters amount to 3.67 °NTU and 3.26 °NTU, respectively. After analysis of operation of these new filters it was concluded that they should be more efficient. In this respect, a recommendation was given to check design criteria for these filters, with a particular emphasis on the regulation of operation and fill properties (grading and height of fill material). The following conclusions on the use of gravity filters and pressure filters can be made based on analysis conducted for filters (Table 1) [2, 12], and according to relevant experience gained on this and other similar plants: Rapid gravity filters present the following advantages over pressure filters:
- better quality of filtered water,
- cheaper maintenance,
- longer service life,
- experience in their use is satisfactory
- good control of operation and cleaning of filters.

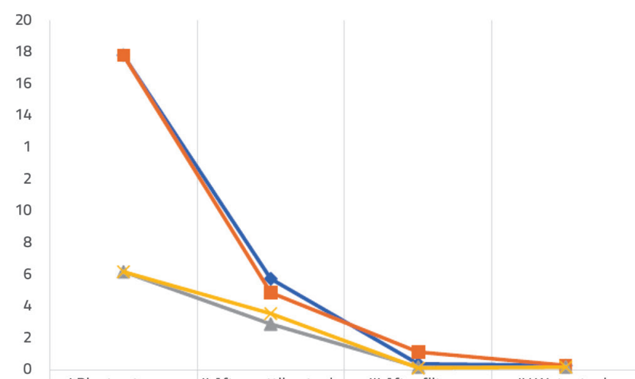
Deficiencies of gravity filters are:
- they take up more space,
- more frequent regeneration of fill material
- greater hydraulic losses in the filter
- more complex and longer rinsing of filters (water and water+air).

Pressure filters present the following advantages over rapid gravity filters:
- greater filtering speed and hence greater quantity of treated water,
- they take up less space and are therefore more favourable in case of space constraints,
- lower consumption of water for filter washing,
- the process is partly automated,
- lower quantity of filter fill material, making replacement of fill less expensive,
- installation is less expensive,
- easier adjustment to various pipe networks.

Deficiencies of pressure filters are:
- the filtration process is difficult to control as vessels are closed,
- during washing, fill layers are disturbed in case excessive water pressure is applied,
- it is difficult control filter cleaning,
- these filters are not efficient for filtation of highly polluted (turbid) raw water.

Consumption of water for plant operation

According to the report submitted in 2017 by JKP Vodostan doo Ilijaš [10],



	I Plant entrance	II After settling tank	III After filters	IV Water tank
5.2.2019. First line 1	18	5,2	0,32	0,24
5.2.2019. Second line 2	18	4,4	1	0,24
21.5.2019. First line 1	5,6	2,64	0,14	0,14
21.5.2019. Second line 2	5,6	3,2	0,09	0,14

Figure 5. Change in turbidity at Karašnica Plant – results of additional measurements conducted in 2019

1,899,808.0 m3 of water were taken from the river to meet the needs of the central part of the Ilijaš Community (7,347 residents and 474 companies). Out of this quantity, 1,542,411 m3 were distributed to the water supply network, while 357,397 m3 of the water were used for the maintenance and operation of the plant (for washing filters, settling tanks, vessels for chemicals, etc.), which is 18,81 % and constitutes a significant quantity. This is the so called consumption of water for plant operation, and it usually ranges from 5 to 10 % of the total plant capacity [12].

Disinfection is automatized and involves the use of elemental gaseous chlorine, which is added at the entry to the water tank, respecting at that all safety measures and appropriate regulations [6]. Here, it should be noted that the use of gaseous chlorine implies possible formation of harmful by-products, due to reaction between the chlorine and organic substances. Although gaseous chlorine is a highly efficient and economical disinfection agent, possible presence of organic matter in the water that is being disinfected not only reduces its reliability, but also impairs the safety of its use from the aspect of formation of harmful carcinogenic compounds, such as trihalomethanes (THM) [4]. The THM formation risk can be alleviated by applying new trends, i.e. by using other disinfection methods (chlorine dioxide, hypochlorite, ozone, UV-radiation). In this respect, the use of chlorine dioxide or hypochlorite instead of elemental chlorine is recommended for this plant. The use of such recommended chemicals reduces to minimum the hazard of formation of harmful by-products and, in addition, it does not require expensive equipment, and ensures residual in the distribution network (unlike ozone and UV-radiation).

Sludge water from the plant

As related to sludge treatment, i.e. treatment of sludge water from the plant, a device for the treatment of sludge water generated at this plant is planned, and is soon to be installed. For the time being, sludge water is directed toward the municipal sewer. Increasingly stringent requirements for the protection of our environment call for mechanical treatment procedures resulting in filtrates of high quality, which are returned to the treatment process, and the dried sludge is deposited at waste disposal sites or is used as raw material in other industries. Lagoons are an economical way of sludge thickening and dewatering, and for temporary storage of sludge. They require, however, a lot of isolated space and are sensitive to climatic conditions.

Water treatment technology

At an already built plant based on traditional technology, such as the Karašnica Plant, it is technically justified and cost-effective to make some corrections or to replace old and degraded facilities and equipment, automatize the operation, improve management procedures, proceed to more frequent maintenance, and apply other chemicals, all in order to improve the water treatment efficiency and cost-effectiveness of the system. A lot has already been done in this respect. For instance, a new and more efficient chemical for coagulation and flocculation is used (PAC); significant efforts have been invested to automatize and control the plant operation (use of SCADA system, implementation of the HACCP Codex of good hygienic and manufacturing practice); old and degraded automatic self-rinsing filters have been replaced with rapid pressure filters; control and maintenance improvements are carried out, and construction of the device for the treatment of sludge water generated by the plant is planned.

Modern technologies imply, for instance, introduction of membranes for filtering and also for disinfection, or the use of ozone and UV radiation. A precondition for an efficient use of membrane technologies and disinfection is a low level of turbidity. In the case of treatment of surface torrential waters, these technologies could be used as a supplementary procedure, coming after the traditional treatment by which the high level of turbidity is efficiently reduced. In addition, it should be noted that membrane technologies are also quite expensive.

5. Conclusions

Plants already in operation require continuous modernisation and monitoring of new trends, so that the plant operation can meet increasingly stringent standards and prove efficient in the face of growing pollution, the goal being to maintain proper levels of functionality and sustainability [11]. Modernisation and new trends imply introduction of automation, comprehensive monitoring, use of new highly efficient chemicals, application of new filtering fill materials, use of advanced equipment for mixing and proportioning of chemicals, implementation of new and more reliable disinfection methods aimed at preventing formation of harmful by-products, etc. Continued efficiency of the Karašnica water treatment plant is a key factor that will provide for continuous and safe water supply to the Ilijaš Community. That is why a description of the plant's operation is presented in this paper, with a particular emphasis on the comparison of two water treatment lines.

Results obtained during this research undoubtedly show that the quality of drinking water prepared at the plant depends, on the one side, on the quality of raw water that is subjected to treatment and carried to the plant after pre-treatment and, on the other side, on the efficiency of individual operations carried out in the plant itself. The level of efficiency is also affected by the selected technology and equipment, by the type and quantity of chemicals used in the water treatment process, and by human factor, i.e. by appropriate control and management of the plant's operation.

The analysis of efficiency of individual water treatment operations, and review of the overall operation of the Karašnica Plant, have shown that the current level of efficiency has to be increased. In order to increase efficiency of the plant and its water treatment operations, the following measures are recommended to the operator:

- identify factors that cause turbidity in the Misoča River drainage area, and define short term and long term measures for reducing turbidity at the water intake;

- perform detailed analysis of the operation and maintenance of Tyrolean water intake and sand trap, and the clogging level of the drainage system carrying water to the sand trap, in order to reduce turbidity at the water intake itself, so that water with a lower level of turbidity would be carried to the plant;
- consider infill properties (thickness of layers, grain diameter, coefficient of uniformity) and a method for regulating operation of filters under pressure;
- automatize plant shut-off in the event of critical turbidity levels at the entry to the plant;
- harmonise capacity of the settling tank and filter with the quantity of raw water that is supplied from the pumping station as this is currently not the case, i.e. currently, the surplus water is evacuated via overflow channels of the settling tanks in cases when filters are unable to accept the water, and so water losses are generated;
- reduce consumption of water used for maintenance of the Karašnica Plant;
- build clean water tank of appropriate capacity so that sufficient quantities of water can be supplied to consumers in cases when the plant is out of operation;
- continue with the practice of frequent sampling and laboratory analysis of samples in the plant itself, in order to obtain the greatest possible number of data, as this will enable making better and more reliable conclusions and taking actions for improving operation of the Karašnica Plant;
- consider replacing the gaseous chlorine disinfection with disinfection by sodium hypochlorite or chlorine dioxide, so as to reduce formation of harmful by-products;
- perform appropriate treatment of sludge water generated at the plant.

REFERENCES

[1] Pravilnik o zdravstvenoj ispravosti vode za piće, ''Službeni glasnik BiH'', broj: 40/10, 43/10, 30/12

[2] Gulić, I.: Kondicioniranje vode, Hrvatski savez građevinskih inženjera (HSGI), Zagreb, 264.

[3] Jahić, M.: Uređivanje bujica, Univerzitet u Sarajevu, Sarajevo, 2005.

[4] Margeta, J.: Vodoopskrba naselja: planiranje, projektiranje, upravljanje, obrada vode, prvo izdanje, Sveučilište u Splitu-Građevinsko-arhitektonski fakultet, 2010.

[5] Idejni projekat-tehnološki dio-rekonstrukcija filtarskog postrojenja Karašnica, IBIS d.o.o. Zavidovići, 2016.

[6] Priručnik tehnološki proces prečišćavanja vode rijeke Misoče – filtarsko postrojenje Karašnica, JKP Vodostan doo Ilijaš, decembar 2011.

[7] Bekić, D., Halkijević, I., Gilja, G., Lončar, G., Potočki, K., Carević, D.: Examples of trends in water management systems under influence of modern technologies, GRAĐEVINAR, 71 (2019) 10, pp. 833-842, https://doi.org/10.14256/JCE.2728.2019

[8] Skejović, S.: Klor dioksid kao sredstvo za dezinfekciju na postrojenju za prečišćavanje pitke vode za potrebe Goražda i Vitkovića. Časopis JP za Vodno područje slivova rijeke Save Sarajevo, 35 (2003), pp. 15-23.

[9] Avdić, N.: Tretman mulja iz procesa proizvodnje pitke vode, 7. Naučno-stručni skup sa međunarodnim učešćem - KVALITET 2011, Neum, BiH, 1.-4. June 2011.

[10] Izvještaj o radu filtar postrojenja i laboratorije za 2017. godinu, JKP Vodostan d.o.o Ilijaš,

[11] Halkijević, I., Vuković, Ž.: Orientation toward sustainable water supply, GRAĐEVINAR, 64 (2012) 5, https://doi.org/10.14256/JCE.655.2011

[12] Stanojević, M.: Tretman pijaće vode, Građevinska knjiga d.o.o. Beograd, 492, 2009.

[13] Jusić, S., Ademović M.: Coagulation and Flocculation in Technology of Potable Water Treatment, Časopis za hemiju i tehnologiju Tehnološkog fakulteta u Tuzli, TECHNOLOGICA ACTA, Tuzla, 5 (2012) 1, pp. 45-5

[14] Izvještaj kontrole kvaliteta vode za grad Ilijaš broj: 2316/18 od 05.11.2018. godine, Laboratorija JKP Vodostan d.o.o Ilijaš,

[15] Izvještaji o fizikalno-hemijskoj analizi vode koje je izvršila JU Instituta za zdravlje i sigurnost hrane Zenica, Izvještaji broj: 16.01.08: -15116/19,HM-147/19, 15075/19, HM-115/19, -15072/19,HM-112/19, -15022/19, HM-116/19, - 15073/19, HM-113/19, -15078/19,HM-117/19, -15074/19,HM-114/19, za uzorke uzete 05.02.2019.

[16] Izvještaji o fizikalno-hemijskoj analizi vode koje je izvršila JU Instituta za zdravlje i sigurnost hrane Zenica, Izvještaji broj: 16.01.08: -15799/19,HM-809/19, - 15800/19,HM-10/19, -15801/19, HM-811/19, -15802/19,HM-812/19, -15803/19,HM-813/19, -15804/19,HM-814/19 za uzorke uzete 21.05.2019.

[17] Izvještaj o mikrobiološkoj analizi vode, koju je izvršila JU Instituta za zdravlje i sigurnost hrane Zenica, broj: 14.01.05.-32689/19,MV-1052/19 za uzorke uzete 21.05.2019.