Microbiological safety and quality of water intended for human consumption.

Rakocz K.[1*], Rosińska A.[1]

[1]The Faculty of Infrastructure and Environmental, Czestochowa University of Technology, Dąbrowskiego St. 69, 42-201 Częstochowa

*corresponding author:

e-mail: klaudiarakocz@o2.pl

Abstract

The following article's objective is to analyze the microbiological safety and quality of water for consumption, illustrated with an example of water for Częstochowa city located in Silesia region, Poland.

Underground water is collected and treated for the needs of the residents of the city.

Sanitary safety is a major priority in water treatment process, whose main aim is assuring water biostability. Biological stability of water is confirmed by the content of BDOC (biodegradable dissolved organic carbon) and AOC (assimilable organic carbon).

The research results show that BDOC and AOC content in water was 42 - 56 µm/L and 4 - 9 µm/L, respectively. Therefore all examined waters met requirements for biostability in terms of BDOC and AOC content.

In terms of microbiological properties, it was determined that bacteriological quality of all examined waters met applicable national standards. The value of colony forming units ranged from 10 CFU/ml to 34 CFU/ml.

In terms of quality properties, the values of the physicochemical markers of the quality of water which was introduced into water system, were in consonance with requirements set for water intended for human consumption.

Keywords: water quality, BDOC, AOC, treatment of water, microbiological safety

1. Introduction

The quality of tap water depends on its composition at the intake, treatment and storage methods and the condition of the network, connections and water distribution system (Świderska–Bróż and Wolska 2011).

The quality of water introduced into the system co-determines the phenomena which occur in it as well as processes whose products are most often the cause of secondary pollution of water supplied to consumers. To minimize adverse changes in the physico-chemical and bacteriological composition of water, it is necessary to ensure its biostability (Świderska 2003).

In terms of chemical and microbiological parameters, water quality is regulated by Polish law (The Ministry of Health Regulation 2015).

One of the main threats to water quality is the growth and development of microorganisms in water supply network. Research conducted by Bonalam *et al*. and Chandy & Angels has shown that it is organic carbon that has the greatest impact on the development of biofouling forming in water supply network (Bonalam *et al*. 2002 and Chandy, Angels 2001). Organic carbon, which occurs in water, can be divided into biodegradable fraction, i.e. BDOC, and refractive fraction, which does not affect the growth and development of biofouling in the network.

The assimiliable fraction of organic carbon (AOC) constitutes a part of the BDOC fraction.

Whereas the content of total organic carbon (TOC) in water is standardized (the permissible value is 5 mg/L), its individual fractions responsible for the growth and development of biofouling in network (BDOC, AOC) are not (The Ministry of Health Regulation 2015). However, their maximum values have been determined, which might lead to secondary water contamination in network, if they are exceeded. According to literature sources, the condition of water biostability is: 150-200 mg C/m^3. On the other hand, Volk *et al*. (1994) determined a biodegradable organic matter content changes (BDOC) value of 0.15 mg/L at 20°C and 0.30 mg/L at 15°C for biostability. The permissible content of AOC and BDOC in non-chlorinated water is 3-10 µg/L and 160 µg/L, respectively (Van Der Kooji *et al*. 1999 and Volk *et al*. 2002). The permissible concentration of AOC in chlorinated water is 50-100 µg/L (M. LeChevallier *et al*. 1996).

This water is delivered to consumers by water company, whose duties involve drawing water from natural sources and preparing it in such a way so that it is harmless to consumers. The selection of water treatment technological processes is mainly determined by raw water quality.

Water is delivered to consumers from 4 treatment plants. All of the plants draw water from underground intakes. In two stations the water is ozonated, whereas in the other two it is treated with sodium hypochlorite.

The selected water supply pipeline covers an area of approximately 1000 km^2 and supplies water to approximately 328.5 thousand residents.

The main water network is composed of iron tubes of the diameter larger than Ø 250 mm, whereas distribution network is made of gray iron - 41%, PVC - 37.1%, steel - 5.8%, asbestos cement - 3.3%, PE - 12.5%, spherical iron - 0.3%. Connections are made of steel and PE tubes. The total water consumption is 14328.2 thousand m^3/year, whereas the average water consumption is 121.3 L/person/day.

2. Analytical procedure

The samples were collected in accordance with the standards set by the Polish Committee for Standardization (Polish Standards and Polish Standardization Documents).

Water samples were collected for examination in the morning, around 8 (after the night stagnation, at a time of high water consumption). The samples underwent a physico-chemical analysis. The following physico-chemical indicators were determined: turbidity, colour, odour, pH, ammonium ion, nitrite, nitrate, permanganate index, chlorides, total iron, total hardness, alkalinity, non-carbonate hardness, free carbon dioxide, dissolved oxygen, electrical conductivity, ozone residue, total organic carbon (TOC), manganese, sulphates, calcium, magnesium, fluoride, phenols (phenol index), free chlorine, phosphates.

In order to examine water quality, selected physico-chemical water quality indicators were used, identified in accordance with the applicable standards of the Polish Committee for Standardization.

BDOC was examined using Joret method, while AOC was examined according to Standards Methods. In order to obtain DOC fraction, water samples were filtered through a Ø 25 mm membrane filter with a Ø 0.45µm sieve mesh. General number of microorganism was determined by heterotrophic plate counts method (HPC). Coliform count was determined by fermentation test.

Water from the intake stations marked A and B symbols was ozonated; however, water from the intake stations C and D was treated using sodium hypochlorite.

3. Results and discussion

The analysis of the selected quality parameters of water [Table 1] showed that the chemical state of water intended to consumption is good, and it was shown that the water does not exceed threshold concentration for good state of water, specified in the Minister of Health Regulation 2015.

The analysis of the selected physical quality parameters of water [Table 1] showed the following results.

The odour in all water samples was acceptable. It had a very weak plant smell.

In water from intakes A, B and D, turbidity was 0.34-0.69 NTU, and general iron content totaled up to 40 µg/dm^3 in B and D, in C water is 76 µg/dm^3 while in the case of water C intake turbidity was 1.5 NTU, and general iron content totaled 160 µg/dm^3. According to literature sources, turbidity is correlated with iron content in water, which is proven by the above-mentioned results. The higher the content of this element, the higher the turbidity (Świderska – Bróż M., Wolska M. 2005)

The color of D water was 5 Pt/dm^3, whereas in other samples this indicator did not reach the limit of quantification.

pH value – one of the analyzed chemical indicators of quality of examined water–totaled 7.7-7.9. The range of pH value characteristic for water is 6.5-8.5. The value of pH indicates physicochemical conditions of migration of substances in underground water, including toxins. Therefore, the assessment of pH value may be made not only in terms of its value but also in terms of the possibility of toxic contamination of underground water (Witczak S., *et al.* 2013).

Another analyzed indicator of the examined water was nitrogen in three forms: ammonium nitrogen, nitrate nitrogen and nitrite nitrogen. Nitrogen mostly occurs in water as nitrate (Świderska–Bróż, M. Wolska M., 2011). The content of ammonium ion and nitrites did not reach the limit of quantification. According to Kowal *et al.*, the occurrence of only nitrates proves that water was contaminated a long time ago (Świderska–Bróż, M. Wolska M., 2011, Kowal A., Świderska–Bróż M. 2000). The presence of nitrate in water is mostly caused by human impact, such as the use of mineral nitrogen fertilizers and liquid manure and the transfer of municipal liquid waste to underground water in rural areas with no sewerage system (Marszewski W., 2012). Nitrates content in examined water ranged from 0.64 to 43.2 mg/L.

The content of chloride ions in the examined waters was from 11.8 to 30.7 mg/dm^3. The content of chloride ions is directly proportional to the degree of mineralization of water (Marszewski W., 2012).

B and C intakes yielded medium-hard waters, while the water from A and D intakes was soft according to the water hardness scale (Lipkowska-Grabowska K., Faron-Lewandowska E., 1998).

Alkalinity amounted to 2.08-3.10 mval/L. Non-carbonate hardness amounted to 0.6–2.12 mval/L.

Free carbon dioxide content ranged from 6.6 to 7.7 mg/L in the analyzed samples. Kowal *et al.* (2000) reported that as water carbonate hardness increases, so does the amount of carbon dioxide (Świderska–Bróż, M. Wolska M., 2011 and Kowal A., Świderska–Bróż M. 2000). This dependency was noticed in the examined waters. Carbon dioxide plays a key role for the chemical composition of water. On the one hand, it enhances dissolution of many minerals by water, and on the other it is the source of HCO^{3-} ions as it dissolves in water itself (Świderska–Bróż, M. Wolska M., 2011 and Kowal A., Świderska–Bróż M. 2000).

Dissolved oxygen content ranged from 4.85 mg/L for water D to 9.55 mg/L for A water. According to Kowal *et al.* (2000), dissolved oxygen is one of the main ingredients which shape the content of water because its amount determines the conditions for oxidation and reduction and influences a lot of the chemical and physical processes (Świderska–Bróż, M. Wolska M., 2011 and Kowal A., Świderska–Bróż M. 2000).

Total organic carbon content (TOC) is a general parameter, which provides information on the presence of organic substances in underground water. In the examined samples the content of TOC was 0.86–1.28 mg/L. These values are low and indicate a very good state of these waters.

The next parameter is conductivity. It indicates the amount of free ions in the examined solution and was 418–476 μS/cm.

In terms of microbiological properties, it was determined that bacteriological quality of all examined waters met applicable national standards. The value of colony forming units is shown in Table 1. According to Biłozor *et al.* (2000), underground water is virtually free of pathogenic microbes and even if such contamination takes place, it is mostly caused by secondary contamination. Secondary contamination of water with microorganisms is mainly caused by the development and growth of bacteria in water network, whose condition, the material it is made of, its length, the rate and mode of water flow, the content of chemical substances such as organic carbon, phosphor etc. all influence the microbiological condition of water. Research conducted by Bonalam *et al.* and Chandy & Angels has shown that it is organic carbon that has the greatest impact on the development of biofouling forming in water supply network (Bonalam *et al*. 2002 and Chandy, Angels 2001).

The largest number of microorganisms in 22 °C was detected in C water (34 CFU/mL), which might have been caused by the fact that the network carrying water from intake C is the oldest in the city.

However, the number of those microorganisms in A, B and D water was 10-21 CFU/mL. No coliforms were detected in any samples. After determining the number of coliforms, which is a key sanitary indicator of water, the examination of Enterococcus faecalis was not conducted, because it was considered that the lack of coliforms and a low content of the general number of microorganisms are sufficient to determine the microbiological state of tested waters. Threat of development of a higher number of microorganisms and of the growth and development of biofouling in water supply network is illustrated by such parameters as BDOC and AOC. The values in the table below [Table 1] are presented in comparison to the water biostability requirement specified in the literature (150-200 mg C/m³ (Volk *et al*., 1994). On the other hand, Volk *et al*. (1994) determined a biodegradable organic matter content changes (BDOC) value of 0.15 mg/L at 20°C and 0.30 mg/L at 15°C for biostability. The permissible concentration of AOC in chlorinated water is 50-100 μg/L (M. LeChevallier *et al*. 1996). The permissible content of AOC in non-chlorinated water is 3-10 μg/L (Van Der Kooji *et al*. 1999 and Volk *et al*. 2002).

Taking the values into account, all examined waters met the abovementioned requirement in terms of BDOC and AOC content. The values of these parameters ranged from 0.42 to 0.56 and from 0.04 to 0.08 mg/L. When considering the content of each organic carbon fraction detected in examined waters, it can be stated that the fraction having the largest share in TOC was DOC (TOC=DOC+NDOC), while in DOC the greatest fraction was BDOC (DOC=BDOC+NBDOC).

Comparing ozonated water with chlorinated water, it can be observed that the biodegradable fraction was far greater in case of the former than in case of the latter. In the first and second water sample, the biodegradable fraction was 61.8% and 57% of DOC, respectively, whereas in the case of chlorinated water, the same values were 38.9% and 43.7%.

However, it’s necessary to monitor these indicators because when permissible values of BDOC and AOC are exceeded, the threat of secondary contamination is highly probable, as according to Volk & LeChevallier, microorganisms can grow in water containing only trace amounts of nutrient substrates (Volk C., Lechevallier M., 2002).

Table 1. Physico-chemical and microbiological indicators of examined water

Indicator	Unit	Consumer A	Consumer B	Consumer C	Consumer D
Turbidity	NTU	0.69	0.34	1.5	0.38
Colour	Pt/L	<5	<5	<5	5
Scent		z1R	z1R	z1R	z1R
pH		7.7	7.7	7.9	7.8
Ammonium ion	mg/L	<0.05	<0.05	<0.05	<0.05
Nitrites	mg/L	<0.018	<0.018	<0.018	<0.018
Nitrates	mg/L	29.6	42.7	43.2	0.64
Permanganate index	mg/L	<0.50	<0.50	<0.50	<0.50
Chlorides	mg/L	24.0	30.7	21.3	11.8
General iron	μg/L	76	<40	106	<40
General hardness	mval/L	3.78	4.20	4.34	3.70
Alkalinity	mval/L	2.32	2.08	2.58	3.10
Non-carbonate hardness	mval/L	1.46	2.12	1.76	0.60
Free carbon dioxide	mg/L	7.7	6.6	7.0	6.6
Dissolved oxygen	mg/L	9.55	8.94	7.37	4.85

Electrical conductivity in 25°C	µS/cm	435	476	459	418
Residual ozone	mg/L	<0.007	<0.007	-	-
Free chlorine	mg/L	-	-	<0.02	<0.02
TOC	mg/L	0.89	0.86	1.08	1.28
DOC	mg/L	0.69	0.72	0.98	1.06
NDOC	mg/L	0.2	0.14	0.1	0.22
NBDOC	mg/L	0.14	0.23	0.56	0.5
BDOC	mg/L	0.55	0.49	0.42	0.56
AOC	mg/L	0.08	0.09	0.05	0.04
General number of microorganism in temp. 22 ±2°C after 68 ± 4h	CFU/mL	10	13	34	21
General number of microorganism in temp. 36 ±2°C after 44 ± 4h	CFU/mL	1	0	4	2
Coliform count (NPL)	CFU/100mL	0	0	0	0

4. Summary and conclusions

Water for human consumption in the city of Częstochowa is drawn from underground reservoirs.

As a result, water delivered to consumers has physicochemical composition which is advantageous for health.

The conducted research showed that:

- examined water does not contain excessive amounts of minerals (low-chlorides water);

- all of the examined waters could be classified as drinkable - water is chemically and bacteriologically stable;

- examined water doesn’t contain coliform microorganisms;

- natural organic matter, regardless of its quantity and origin, has a potential for formation of BDOC;

- all examined waters meet the requirement for biological stability in terms of BDOC and AOC content;

- comparing ozonated water with chlorinated water, it can be observed that the biodegradable fraction was far greater in case of the former than in case of the latter

- organoleptic tests show that produced water is clear, transparent, colorless and very tasty in its natural state.

Despite the high quality of drawn underground water, it is essential to monitor the parameters of the water delivered to consumer, because there is a risk of its secondary contamination during its distribution process.

Obtaining biostability of water in water treatment processes is a condition for maintaining stability of the water composition in the water supply network and at the consumer. The water quality legislation does not determine the permissible concentration of individual fractions of carbon. The changes in BDOC in water supply network should be routinely analyzed, since they are indicative of the likelihood of bacterial growth in the network. A detailed analysis of water supply network is also recommended, possibly supplemented with a model to facilitate its exploitation.

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