

Ozone water treatment in small water purification plants in Poland – Mszana Dolna case study

Jan Pawelek^{1,*}, and Tomasz Bergel¹

¹University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying, Department of Sanitary Engineering and Water Management, Al. Mickiewicza 21, 31-120 Krakow, Poland

Abstract. The study analyzed possibilities of using ozone for water treatment in supply stations that provide water to small water supply systems. We analyzed a containerized water treatment plant (CWTP) in Mszana Dolna, located in Małopolska region, with a nominal production of $15 \text{ m}^3 \cdot \text{h}^{-1}$. The plant uses a two step pressure filtration system with indirect water ozonation prior to active carbon filters. The treated water meets all the requirements set for drinking water. A cost analysis was also carried out to find out whether using this type of technology in small water supply stations in Poland is economically justified. The calculations were based on water production and its costs in 2017. The unit cost of water amounted to 0.59 and 0.77 EUR·m³ for the variant taking into account a nominal water production and a hydraulic load of the station in 2017 that reached 58.7% of a nominal load.

1 Introduction

Ozone discovered in 1840 by Schoenbein is now widely used for water treatment. In the beginning, it was applied mainly for disinfection, i.e. the final step of the treatment. Since 1970s it has also been implemented as an oxidizing agent either in the beginning of the process or between its individual stages. Switzerland has been a global leader in ozone treatment, and a long-term director of Zurich water supply system, Martin Schalekamp, PhD, published numerous papers on improving ozone production, introducing it into water, managing residual ozone as well as equipment construction and operation costs [1, 2]. In his publications, he advocated positive effects of ozone on water treatment based on ozone-activated carbon filter.

Increasing popularity of ozone is due to its activity towards a wide spectrum of substances present in water [3, 4]. Interest in ozone use for water purification has been growing in Poland since the 1990s. The technology was first implemented mainly in large facilities, e.g. Central water supply system for Warsaw, Kraków - Dobczyce, Wrocław - Mokry Dwór and Na Grobli, Katowice – Dzieńkowice, etc. Technical progress in improving the construction of equipment for ozone production and injection into water, managing residual ozone or the process automation markedly reduced the costs of ozone treatment and requirements for people operating the equipment. Considering a gap between the quality of withdrawn water and requirements for drinking water, ozone treatment is often necessary. This is confirmed by a growing number of facilities using this remarkably effective method to achieve the highest possible water quality. At the same time, due to the great

care for health safety of water for consumption, more and more attention is paid to by-products, toxic to living organisms, ozonation products [5, 6].

For these reasons, ozone treatment becomes increasingly popular even in small water purification plants. In Switzerland, ozone has been used in small water supply facilities for over 30 years [7]. Poland has only entered this path. A good example is Mszana Dolna, where a small containerized water treatment plant (CWTP) employing ozone-based technology has been constructed. This paper analyzes the operation of this facility.

Our aim was to assess performance of a small water treatment facility using ozone, and particularly to evaluate costs of this technology in a small facility to answer the question on economic justification of ozone treatment in small water purification plants in Poland.

2 Description of the study object

Mszana Dolna is a small town with a population of about 8 000 inhabitants, located in southern Poland by the river Raba, Małopolska region, ca. 60 km south from Kraków.

Drinking water is provided by two water purification plants. One of them is a CWTP constructed in 2016 with a nominal capacity of $15 \text{ m}^3 \cdot \text{h}^{-1}$ and operational range of 10 to $20 \text{ m}^3 \cdot \text{h}^{-1}$. The water intake of total capacity $13.5 \text{ m}^3 \cdot \text{h}^{-1}$ consists of three shaft wells with respective capacities of 2.5, 4.0 and $7.0 \text{ m}^3 \cdot \text{h}^{-1}$. The wells with a diameter of 2.0 m are shallow ones (4.5, 3.5, 5.3 m), and collect ground water and water infiltrated from the Raba. Water from the intake is pumped into the CWTP. The water treatment process [8] includes two stages of filtration separated by indirect oxidation with ozone

* Corresponding author: rmpawele@cyf-kr.edu.pl

produced from oxygen (Fig. 1). The first step is an aerator, in which residual ozone is removed from the ozonation columns. The water that leaves the aerator is first filtered through a pressure sand filter 1.6 m in diameter. If the raw water turbidity is high, a coagulant

is added, and surface coagulation occurs in the filter. Filtrated water is ozonized on multi-step contact columns. The time of water-ozone contact is determined so as to limit the formation

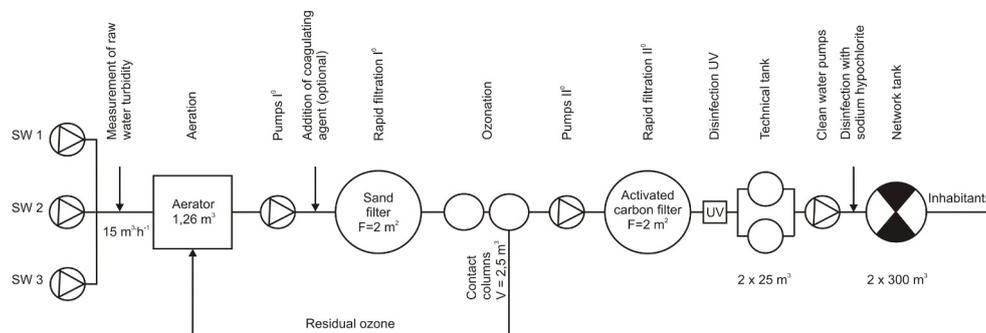


Fig. 1. Technological diagram of the containerized water treatment plant in Mszana Dolna

of bromates that negatively impact consumer's health [9]. Total capacity of the columns is 2.5 m³. Water leaving the contact columns is pumped through another filter 1.6 in diameter filled with Sorbotech activated carbon of the granule size 0.60 – 2.36 mm. Filtrated water is then disinfected with UV and transferred to two storage tanks for clean water with a capacity of 25 m³ each. From them it is pumped into a two-chamber network compensating tank with a capacity of 2 x 300 m³. To protect the water against possible secondary contamination, sodium hypochlorite may be added to water pumped into the network tank.

The basic technological line is completed with devices intended for water ozonation that include four TOPAZ oxygen generators, two ozone generators with a capacity of 80 gO₃·h⁻¹, a measuring device for online

sampling of residual ozone in water, a system for implementing ozone into water (circulating pump, injector, ozone separator, pneumatic shut-off valves, static mixer). The plant is fully automated and equipped with a touch panel visual monitoring.

Technological line of water purification in CWTP in Mszana Dolna is a standard system based on ozonation. Variable parameters of the process include ozone dose, contact time or management of residual ozone [10]. Currently, experts in the field suggest preceding the sand filters with activated carbon filters to protect water against coal dust containing microorganisms resistant to disinfection [11]. This type of slow filtration used as the third stage of filtration was already used in the 1980s at the water supply system in Zurich - ZUW Moss [2].

3 Technological performance of the facility

Table 1. Quality parameters of raw water supplied to CWTP in Mszana Dolna [12]

No.	Indicator	Unit	St-1	St-2	St-3	Permissible value [11]
1	Coliform bacteria	cfu/100 ml	60	90	10	0
2	Escherichia coli	cfu/100 ml	0	40	0	0
3	Color	mg/l Pt	6	5	4	15
4	Turbidity	NTU	2.0	5.6	2.2	1
5	Odor	-	acceptable	acceptable	acceptable	acceptable
6	pH	-	7.2	7.1	7.1	6.5 - 9.5
7	Specific conductance at 25°C	µS/cm	754	748	714	2500
8	Soap hardness	mg/l CaCO ₃	318	321	289	60 - 500
9	Permanganate index (oxidizability)	mg/l	<0.7	<0.7	<0.7	5
10	Total iron	mg/l	0.036	0.074	0.058	0.200
11	Manganese	mg/l	<0.015	<0.012	<0.015	0.050
12	Ammonia	mg/l NH ₄	<0.015	<0.015	<0.015	0.5
13	Chlorides	mg/l	45	46	41	250
14	Nitrates	mg/l	<0.01	<0.01	<0.01	0.5
15	Nitrites	mg/l	21	20	12	50

Table 1 presents selected quality parameters for water withdrawn via shaft wells at the stage of designing the technology of water purification. Table 2 shows microbiological quality and selected physical and chemical properties of water purified in 2017.

Apart from water quality indicators listed in Table 2 we also run laboratory tests for the presence of 46 different substances and compounds, such as iron, total organic carbon, oxygen consumption, cyanides, fluorides, sulfates, ΣWWA, benzo(a)pyrene, manganese, copper, sodium, ΣTHM, Σtrichloroethene and tetrachloroethene, tetrachloromethane (carbon tetrachloride), 1-2 dichloroethene, Σpesticides, aluminum, mercury, cadmium, nickel, chromium, boron, arsenic, selenium, antimony, free chlorine. Laboratory test results showed

that the water quality met the requirements set out in the Regulation of the Minister of Health [16].

Water quality assessment performed by a sanitary epidemiological service [17] in 2017 for Mszana Dolna included also the water supplied by the CWTP. The assessment concluded that “...water from the water supply system can be used for human consumption. No contaminations or exceedance of permissible levels of quality parameters were detected.” The assessment was based on nine water samples, including six collected at the CWTP outlet and three from the water supply network. Their complete analysis was run to cover all parameters set out in the Regulation of the Minister of Health.

Table 2. Results of microbiological, physical and chemical tests of the water treated in the CWTP in Mszana Dolna [14, 15]

No.	Parameter	Unit	Permissible value [16]	Date of water sample collection						
				04.01.2017	18.01.2017	28.02.2017	30.05.2017	04.09.2017	27.11.2017	18.12.2017
1	Coliform bacteria	cfu/100 ml	0	0	0	0	0	0	0	0
2	Escherichia coli	cfu/100 ml	0	0	0	0	0	0	0	0
3	Enterococci (fecal streptococci)	cfu/100 ml	0	0	0	-	0	0	0	0
4	Clostridium perfringens	cfu/100 ml	0	-	-	0	0	0	0	0
5	Turbidity	NTU	1	-	-	0.13	0.24	0.32	0.35	0.32
6	Color	mg/l Pt	up to 15	-	-	5	5	5	5	5
7	pH	-	6.5 - 9.5	-	-	7.8	7.5	7.6	7.7	7.6
8	Electrical conductivity	μS/cm	2,500	-	-	711	728	762	760	744
9	Odor	-	accept.	-	-	accep.	accep.	accep.	accep.	accep.
10	Taste	-	accept.	-	-	accep.	accep.	accep.	accep.	accep.
11	Ammonium ion	mg NH ₄ /l	0.50	-	-	<0.001	<0.05	<0.05	<0.05	<0.05
12	Nitrates	mg NO ₂ /l	0.50	-	-	0.188	-	-	-	0.055
13	Nitrites	mg NO ₃ /l	50	-	-	-	-	-	-	18.1
14	Soap hardness	mg CaCO ₃ /l	60 - 500	-	-	322.9	-	-	-	312.0

4 Water purification costs

Costs of introducing new water treatment technologies belong to key factors determining the possibility of their implementation. The price of water as a product should be socially acceptable and water fees need to be approved by a specific authority. Ozone water treatment has been for many years deemed expensive and thus mainly used in large water production facilities. CWTP in Mszana Dolna is a small station with a nominal daily production of 15 m³·h⁻¹, hence the matter of costs of water treatment with ozone is highly relevant. This information allows for assessing the possibility of using this technology in small WTPs. Table 3 presents the costs of construction and operation of the CWTP with regards to the volume of purified water and per one cubic meter [18]. The calculations were based on water production and its costs in 2017. As in 2017 the

hydraulic load of the facility was 58.7%, Table 3 shows also the production costs for nominal and target production volume. Unit cost reached 0.77, 0.59 and 0.53 EUR·m⁻³, respectively. Electricity costs included in unit costs covered also the costs of pumping the treated water into the network compensating tank. The calculated treatment costs seem acceptable.

The presented analysis of technological performance and calculated costs of water treatment allow us to recommend water ozonation in small facilities. The prevalent opinion that using ozone in small WTPs is too expensive is no longer valid. Current equipment for ozone treatment is cheaper than it used to be and thus the costs of this technology are also lower. Taking into account the benefits that include high water quality and high reliability of the technology, water ozonation should be recommended for small water treatment facilities, as shown on the example of CWTP in Mszana Dolna.

Table 3. Costs of water treatment in CWTP in Mszana Dolna (investment cost 301 870 EUR)

Element	Water purification costs			Water unit cost [EUR·m ⁻³]		
	In 2017	Nominal production	Target production	In 2017	Nominal production	Target production
Water production [m ³ ·y ⁻¹]	77 140*	131 400	175 200	-	-	-
Costs [EUR]						
Including :	59 658	80 386	92 949	0.77	0.59	0.53
10% depreciation	30 187	30 187	30 187	0.38	0.22	0.17
Electricity**	22 916	39 036	52 048	0.30	0.30	0.30
Other costs	6 554	8 859***	10 715***	0.09	0.07	0.06

*production minus the consumption of CWTP, ** electricity costs include also pumping water into the network tank; *** cost increase was assumed to be half of the production increase

5 Conclusions

The current requirements for drinking water often make ozone treatment necessary. Advances in development of devices used for ozone generation and dosage and the costs of ozone treatment in automated facilities considerably improve the possibilities of water ozonation also in small, rural water supply stations. This was confirmed in our analysis of the containerized water treatment plant in Mszana Dolna based on indirect ozone treatment. The process was highly efficient and water production costs were acceptable. Good quality of treated water and high reliability of the technology allow us to recommend the ozonation in small treatment stations.

Acknowledgement

Publication supported by the Polish Ministry of Science and Higher Education as a part of the program of activities disseminating science from the project „Organization of the First International Science Conference – Ecological and Environmental Engineering”, 26-29 June 2018, Kraków.

References

1. M. Schalekamp. Ozonung bei der Wasserversorgung Zürich GWA **9** (1988)
2. J. Pawelek. Gaz Woda i Technika Sanitarna **6**, 172-175, (1994)
3. J. Pawelek, T. Bergel. Czasopismo Techniczne **54-57**, 16-22 (2000)
4. Zimoch, J. Natonek. Instal **5**, 34-38 (2017)
5. U. Olsińska. Ochrona Środowiska **2**, 17-26 (2017)
6. M. O. Buffle, S. Galli, U. von Gunten. Environmental Science and Technology **19**, 5187-5195 (2004)
7. J. Pawelek. Gaz Woda i Technika Sanitarna **8**, 187-195 (1992)
8. J. Król. Operating instructions CWTP in Mszana Dolna. WOFIL Robert Muszański, (2016)
9. A. Łyko. Variability of bromate (V) ion concentrations in the process of ozone water treatment and methodological aspects of their determination. Dissertation of The Silesian Technical University, Gliwice (2014)
10. R. Muszański. Instal **5**, 39-44 (2017)
11. W. Dąbrowski. Instal **12**, 49-53 (2017)
12. MPWiK S.A. w Krakowie Central Laboratory. Research report nr 3036/2013
13. Regulation of the Minister of Health of 29 March 2007 (J. of Laws No. 61, item 417) on the quality of water intended for human consumption (as amended of 20 April 2010, J. of Laws No. 27, item 466)
14. MZGKiM Sp. z o.o. Water and Sewage Laboratory in Limanowa. Research report nr 913, 1553, 2170, 2329 (2017)
15. MZWik Sp. z o.o. Laboratory Myślenice. Research report (2017)
16. Regulation of the Minister of Health of November 13, 2015, on the quality of water intended for human consumption (Journal of Laws, 2015, item 1989)
17. National District Sanitary Inspector in Limanowa. Area water assessment in the city of Mszana Dolna for 2017
18. R. Miłaszewski. Instal **7/8**, 74-76 (2015)