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EVALUATION OF EXPERIENCES OVER THE EIGHT-YEAR-LONG OPERATION OF THE ULTRAFILTER SETUP CONSTRUCTED FOR THE PROTECTION OF DRINKING WATER IN MISKOLC

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As a result of careful, persistent work over several years, since the successful technical handover in September 2015, the new water treatment plant is one of the most powerful ultrafiltration drinking water purifiers in Central Europe and continuously ensures high-quality drinking water for the population. Not only was the construction of the water treatment plant essential for the safe supply of drinking water to the city, it is also capable of solving regional water supply problems in the event of a disaster, as the last eight years of its operation have demonstrated. Our present study is intended to summarize the most important operating experiences since the technical handover in September 2015.

Keywords: ultrafiltration, drinking water, karst water

1. Introduction

The waterworks on average meets more than half of the water demand required by the city of Miskolc and has been continuously operating since 1913. Over the second half of the last century, anthropogenic pollution has become significant. In the event of water pollution caused by raw sewage above the acceptable limit (in the absence of water purification technology), the operator often had to stop producing water.

The main cause of the emerging problems is the increase in turbidity and microbiological contamination of karst springs on the surface of the land after periods of rainfall. Since the technology of ultrafiltration provides a suitable and safe solution to the problems that arise, in 2013, after the conclusion of the construction tender, the winning MI-DU-HI Consortium (Duna Aszfalt Ltd., Hidrofilt Ltd.) was able to start constructing a new water purification plant, which was successfully handed over in September 2015.

Karst aquifers are an important supply of freshwater for about 25% of the world's population. The preservation of chemically safe karst water should be of paramount importance to protect human health. Because of the peculiar geographical and hydrogeological circumstances of karst regions, this water is vulnerable to pollution from human activities and the effects of climate change, e.g. steadily decreasing average annual precipitation and global warming [1]-[5]. Water infiltrating the aquifer may originate from precipitation (rain and/or snow) in the karst region itself (diffuse infiltration; autogenic recharge) or accumulate in adjacent regions before flowing into the karst as sinking streams (concentrated, point infiltration; allogenic recharge). Underground, it flows fast through large openings, for instance, caves or conduits (turbulent flow). Alternatively, it can also move slowly through small and narrow openings in low-permeability zones (laminar flow) [6]-[7].

Filtration processes through membranes are increasingly used as alternatives for treating freshwater and wastewater in the anticipation of more stringent quality standards [8]-[11]. However, meeting the quality standards of drinking water using conventional water treatment processes has become increasingly challenging because of the discharge of various organic chemicals and heavy metals into water bodies. The problem is induced by rapid industrialization, urbanization and population growth, which gradually deteriorate surface water quality, affect drinking water security and increase the treatment costs of drinking water [12]. In developing countries, drinking water production is potentially a very large market for ultrafiltration (UF) membranes. Given that one of the most critical problems is the lack of drinking water, people in these regions are supplied with surface water which contains a significant number of

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Table 1: The most important technical parameters of the ultrafiltration equipment

Characteristics of the UF equipment	Values
Quantity of modules	8 units; 40 modules/unit, i.e. a total of 320 modules
Total membrane surface	19 200 m^2
Module type	Inge dizzer XL 0.9 MB 60 T-Rack
Pore size	0.02 µm
Membrane material	PESM
Membrane surface/module	60 m^2

microorganisms that can cause several diseases. Globally, the application of UF technology is increasing with regard to drinking water treatment, with an estimated market value projected to reach $2.14 billion in 2023 [13]. Filtration processes in the treatment of surface water are the fastest developing application of membrane technology [14]-[17].

UF uses low-pressure membranes with pore sizes of between 0.001 and 0.1 µm [18] as well as pore diameters from 1,000 to 100,000 Da [19]-[20]. UF membranes are physical barriers which are able to efficiently remove suspended particles, bacteria, colloids, algae, parasites and viruses as well as prevent turbidity for purification and disinfection purposes. UF technology has many advantages such as the superior quality of treated water, its compact system, easy operation and maintenance, lack of chemicals as well as the minimal production of sludge [11],[12],[14],[21]. Although UF is a promising technology for water and wastewater treatment, it has many significant disadvantages, e.g. membrane fouling and the insufficient removal of soluble contaminants [20]. Membrane fouling refers to the accumulation of particulates and colloids, dissolved organic and inorganic matter as well as microorganisms on the membrane surface and within the membrane pores, resulting in the reduction in its permeability. Consequently, membranes must be cleaned periodically to reduce membrane fouling [19],[22]-[25].

The objectives of this study were to evaluate UF performance in terms of permeability and the quality of treated water as well as present the most important operating experiences.

2. Brief introduction to the water treatment system

By modernizing the existing waterworks, an ultrafiltration capacity of 1,500 m^3/h was realized with two 500 m^3 outdoor filtered water storage tanks. The role of ultrafiltration technology during water treatment is to reduce the content of suspended matter and microbiological pollutants in the water, i.e. to remove colloids, bacteria, viruses and protozoa as well as macromolecules with a molecular weight greater than 100 kDa. During the operation, the dissolved salts and water molecules flow over the surface of the UF membrane before the purified water, after being disinfected, is sent to the surface tanks then into the network. The technical parameters of the equipment are shown in *Table 1*.

2.1. Feedwater

The feedwater for the UF membrane is karst water from caves. The raw water is first sent to the pre-filter unit to ensure its safe. Here, impurities larger than 300 µm are filtered out.

2.2. Ultrafiltration process

During water production by ultrafiltration, the well pumps provide the pressure and flow rate necessary for the treatment process during which the resulting filtrate is sent to the clean water storage tank with a nominal flow rate of 198 m^3/h per unit. In order to optimize the degree of stress on the membrane, all processes involving liquid flow (backwashing, rinsing, water production, etc.) are carried out alternately from below and above. The UF modules are cleaned immediately based on a timed program or when the TMP (Trans Membrane Pressure) of the filtrate increases (during backwashing). The backwashed water is supplied per device at a flow rate of 600 m^3/h as well as at a pressure of 2.5 bars. The typical operating parameters of the equipment are shown in *Tables 2* and *3*.

Table 2: Main operating parameters (during normal operation)

Characteristics of the UF equipment	Values
Gross flux, $l/m^2/h$	82.5
Net flux, $l/m^2/h$	78.1
Yield, %	96.5
Filtering time, min	80
Backwash duration, s	50
Forward flush duration, s	0
Acid CEB frequency, h	168
Base CED frequency, h	168
NaOCl CED frequency, h	168

Table 3: Main forms of chemical cleaning

	Base	Acid	NaClO solution
Backwashing, s	50	50	50
Chemical injection, s	60	60	60
Soaking, min	15	15	0
Chemical leaching, s	60	60	60

Table 4: Annual data regarding the measured parameters between 2016 and 2023

Year	Annual precipitation (q) (mm)	Average turbidity of raw water (z) (NTU)	Average permeability (p) (L/m^2/h/bar)	Average load (w) (kg/day)	Average water production (m^3/day)	Annual water production (m^3/year)
2016	874	1.35	304	22.28	16 482	5 557 067
2017	773	1.42	239	26.70	18 795	6 860 189
2018	608	2.52	191	49.24	19 527	7 107 900
2019	687	0.79	267	17.27	21 963	7 533 300
2020	703	1.18	327	22.22	18 898	6 916 680
2021	663	1.35	327	28.03	20 838	7 606 020
2022	588	1.66	304	42.87	25 880	9 446 240
2023	699	2.71	291	54.16	20 023	5 286 010

2.3. Data Querying/Service

The variable parameters (temperature, flow rate, pressure, turbidity) were measured in real time by a data transmission device. Each variable was queried with millisecond precision. When multiple values were measured within a millisecond, the highest value was recorded. These values were then converted into daily datasets for each variable. Only values greater or equal to 10 were considered during this conversion process which were averaged to determine the daily values.

The permeability values were determined individually for the 8 UF units on a daily basis. For easier handling, they were converted into average annual permeability values. The operational values over the past 8 years were analyzed.

3. Results and analysis

3.1. Measurements

Between 2016 and 2023, the following parameters were determined on a daily basis (i = 1, 2, ..., 365 denotes the day number): turbidity (z_i) from which the daily load (w_i) was calculated, daily precipitation (q_i), average daily permeability (p_i) over 8 measurements, average daily water production and total annual water production.

The summarized annual results are presented in *Table 4*. It should be noted that between 2016 and 2018, no significant maintenance was performed. In 2019, the system was optimized and has been regularly maintained ever since.

Linear regression analysis using Excel was employed to determine the correlation between the measured values and their corresponding functions:

$$y = \alpha \cdot x + \beta \qquad (1).$$

In addition to determining the parameters, the regression coefficient r^2 was calculated. r^2=1 indicates a perfect correlation, while r^2=0 suggests no correlation. The actual values typically fell between 0 and 1 with values closer to 1 indicating a stronger correlation. Deciding when data are considered to be correlated is a matter of definition (typically a significant correlation is when r^2>0.8).

3.2. Changes in average annual permeability

The average annual permeability was calculated using the following relation:

$$\bar{p} = p_0 + \frac{1}{365}\sum_{i=1}^{365} p_i \qquad (2),$$

where i refers to the day number of the year for the nth year $\bar{p} = \overline{p_n}$.

When the sample sizes are small, the correlation depends not only on r^2 but also on the degrees of freedom (f), which is determined by the sample size (n), e.g. when n=2, r^2=1. This relationship can be expressed as follows:

$$t_f \equiv \sqrt{f}\,\frac{r}{\sqrt{1-r^2}} \qquad (3).$$

In the case of linear regression, $f = n - 2$, following a Student's t-distribution. From this t-Table, the critical value t_{95} corresponding to the given probability level and degrees of freedom was determined. If $t_f > t_{95}$, then the function can be approximated by a straight line when the confidence level is equal to 95%.

The change in the average annual permeability between 2016 and 2023 is shown in *Figure 1*. For the correlation line fitted over the entire range, r^2=0.1902, indicating no significant correlation between permeability and time in years.

In 2019, the system was optimized, resulting in an increase in permeability. If the operational periods are divided into two intervals, namely 2016–2018 and

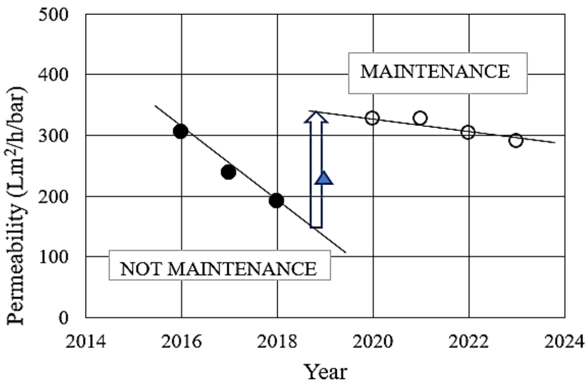

Figure 1: The change in average annual permeability between 2016 and 2023

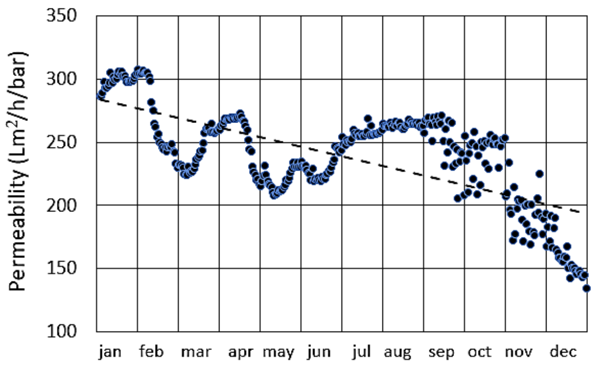

Figure 2: Average daily permeability as a function of time in the year 2017 (The dots represent the measured values and the dashed line denotes the fitted regression line.)

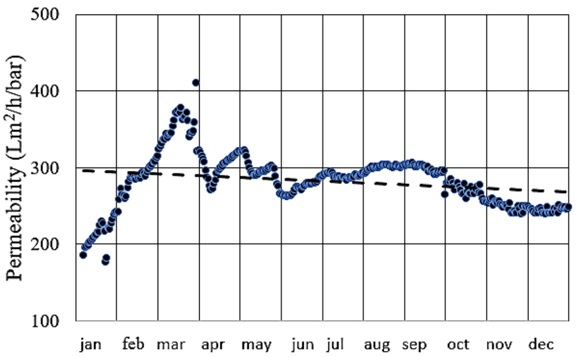

Figure 3: Average daily permeability as a function of time in the year 2023 (The dots represent the measured values and the dashed line denotes the fitted regression line.)

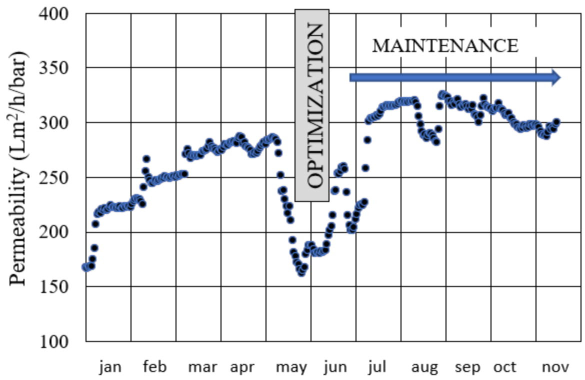

Figure 4: Average daily permeability as a function of time in the year 2019 with the optimization period marked

2020–2023 representing periods during which maintenance was not (*before* period) and was carried out (*after* period), respectively, and separate lines are fitted to the data series for each interval, we obtain the followings:

$$\overline{p_{before}} \equiv 310 - 57.0 \cdot t \quad (4),$$

$$\overline{p_{after}} \equiv 330 - 13.1 \cdot (t - 4) \quad (5),$$

where p represents the permeability and t denotes the number of years since 2016.

In this case, segment-wise correlations show strong results:

- before maintenance, r^2=0.9916 and according to *Equation 3*, t_f=10.8 > t_{95}=6.31,
- after maintenance, r^2=0.9683 and t_f=7.81> t_{95}=2.92.

Therefore, both relationships can be considered linear at a confidence level of 95%, as shown in *Figure 1*.

In both cases, permeability decreases, however, the rate of decrease before renovation is more than four times that after renovation. Due to regular maintenance and backwashing following renovation, permeability increased, resulting in a slower rate of decrease compared to the period during which maintenance was not carried out. The annual decreases are consistent with the similar annual results obtained, although the ratio is slightly higher in the latter but not significantly.

From the two periods (poorly maintained and well maintained), one year was selected for each to examine the daily permeability. Permeability was measured simultaneously through the 8 units and the averages of these measurements are shown in *Figures 2* and *3*.

In 2017, the decrease in average daily permeability was 32%.

In 2023, the decrease in average daily permeability was 6%.

3.3. Optimization in 2019

Up until 2019, the UF units only underwent warranty repairs. In this year, permeability decreased, prompting maintenance to be carried out. The trends in permeability in 2019 are shown in *Figure 4*. Maintenance revealed that the system was improperly optimized. Changes to the control program, CEB (chemical enhanced backwash) frequency and the chemical settings were required. The CIP (cleaning in place) of the 8 UF units was completed. During the integrity test, 20 damaged UF modules were replaced. The period during which the optimization took place is marked in *Figure 4*.

4. Conclusions

It can be concluded that if the system had not been optimized in 2019, the permeability would have dropped to almost zero by 2021, indicating that the maintenance of systems during the warranty period is crucial. Every system is different, moreover, their optimization and regular professional supervision are very important to help prevent membranes from failing as well as ensure the long-term operational functioning of the system without clogging and flux reduction.

In order to correlate the available data, it was important to separate it. Further ongoing analyses of the available data need to be performed to clarify the relationships.

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