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Assessing the feasibility of using ultrafiltration to recirculate backwash water in a surface water treatment plant

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Abstract: The necessity of rational water resource management and reduction of water consumption demands that water utilities address water losses during water treatment. Therefore, the backwash water generated during the filtration process is often the focus of research aimed at its reuse within the water treatment system. The studies outlined here were conducted in a large water treatment plant (100,000 m^3), focusing on the backwash water produced from sand bed filter flushing. Prior to its reintroduction into the treatment train, the backwash water underwent pre-treatment using ultrafiltration (UF) process with two different modules: a spiral module with a PVFD (200kDa) membrane and a capillary module with a PES (80kDa) membrane. The effectiveness of the process was evaluated based on the degree of retention of organic substances and microorganisms, which pose health risks in backwash water recirculation. The capillary membrane exhibited greater effectiveness in retaining these contaminants, thereby ensuring the complete elimination of pathogenic microorganisms. The study findings indicate that pre-treating backwash water using UF membranes and reintroducing it into the water treatment system before the ozonation process can lead to a reduction of environmental fees. However, this process results in a 1.5% increase in water treatment costs.

Introduction

The challenge of water deficit has an increasing effect on water utilities worldwide, prompting efforts to reduce water losses through the implementation of circular economy principles and sustainable water resource management (Zielina and Dąbrowski 2021). Leaks, including failures in distribution system, and sewage generated during water treatment are identified as the two primary sources of losses (Radzymińska-Lenarcik et al. 2019). Filtration systems are utilized in 95% of water treatment plants worldwide, (EPA 2011) resulting in the generation of backwash waters equivalent to 2 - 10% of the plant's capacity. Consequently, the treatment of this sewage stream is frequently studied for potential reuse. Currently, pre-treated backwash water is most frequently used for irrigation, a practice permitted and widely used in the European Union (Guidelines 2020). However, the scarcity of surface and groundwater resources has prompted research into the feasibility of reintroducing treated backwash water into the water treatment system (Alhussaini et al. 2023, de Souza et al. 2021). The choice of pre-treatment methods for backwash water depends on its composition and quantity.

The composition of backwash water is influenced by various factors, including the parameters of the filtration process, the characteristics of the treated water, and the type and granularity of the filter beds (Turan 2023). When generated during the treatment of surface water, backwash water contains a significant number of microorganisms and organic substances, presenting a barrier to its reintroduction into the water treatment process (Wang et al. 2023). Additionally, the quantity and composition of backwash water vary considerably throughout the year, closely mirroring changes in the input surface water composition. This variability complicates its pre-treatment and re-use efforts. The presence of microorganisms, including pathogens such as *Escherichia Coli* and *Salmonella*, poses a significant risk when considering the reintroduction of backwash water into the treatment system (Li et al. 2018). Therefore, the pre-treatment process aimed at facilitating the reuse of backwash water must prioritize the achievements of biostability and the removal of organic matter, which serves as a substrate for microbial regrowth.

Gottfried et al. (Gottfried et al. 2008) showed that the recirculation of backwash water, constituting 2-5% of treated water, into the main treatment system enhances the effectiveness of the coagulation process in removing dissolved organic substances and reducing UV absorbance. Recent studies have further underscored the utility of low-pressure membrane processes, such as microfiltration and ultrafiltration, for treating wastewater, including filter backwash water, to remove contaminants or recover water (Lin et al. 2017, Shafiquzzaman et al. 2021, Ahmed et al. 2021). Zhou et al (Zhoe et al. 2015) found that the efficiency of backwash treatment primarily depends on the raw water composition, with coagulation demonstrating the most effective removal of compounds with low molecular weight. Additionally, a comparison of PAFCl and $FeCl_3$ coagulants in the pre-treatment of sand bed backwash revealed that PAFCl exhibited greater colloid destabilization effects at lower doses, along with higher effectiveness in limiting membrane fouling when used as a second stage of pre-treatment (Ebrahimi et al. 2023).

Numerous studies worldwide emphasize the need to remove not only bacteria but also protozoa and rotaviruses from water sources (Collivignarelli et al.2017). Consequently, disinfection, particularly using chlorine compounds and UV light, is an essential process for backwash water recycling (Mosati 2011). However, due to the contamination levels of backwash water, disinfection can lead to the formation of significant amounts of disinfection by-products, especially trihalomethanes (THMs), whose concentration depends on the characteristics of the organic matter present in backwash water (Qian et al. 2023).

Low-pressure membrane separation processes play a vital role in treating wastewater, including backwash water. Microfiltration effectively removes suspended fraction and some microorganisms but falls short in separating colloidal and dissolved fractions (Lee et al. 2004). In contrast, ultrafiltration membranes offer the potential to produce water that can serve an alternative source of fresh water, suitable for use across various sectors of the economy after further purification (Ćurko et al. 2013, Mahdavi et al. 2017). Ultrafiltration has emerged as one of the most prevalent methods for the pre-treatment of backwash water intended for reuse due to its high effectiveness in removing organic substances and microorganisms present in treated liquids, such as biologically purified sewage (Mohamad Mazuki et al. 2020). However, a significant limitation of UF process usage is membrane fouling, resulting in a decrease in hydraulic performance. The selection of membrane type influences the quality of the permeate, a critical consideration when determining where in the water treatment train the where the recovered water from backwash water will blend with fresh water (Petersen et al. 2021).

The usefulness of the ultrafiltration process in wastewater treatment, as evidenced by numerous applications, justifies conducting studies on the effectiveness of pre-treating backwash water from a surface water treatment plant. These studies aim to select a membrane that guarantees the treated backwash water's composition is comparable to the quality of the intake water. Additionally, they assess the technical feasibility and associated costs of implementing such a solution, along with evaluating any potential increase in water purification costs.

To date, research findings have not provided clear and sufficient information regarding the variability of backwash water quantity and composition throughout the year. Furthermore, there are no established guidelines regarding the required pre-treatment level for the reintroduction of backwash water into the water treatment process. Additionally, there is a lack of information on the feasibility of using individual unit processes for pre-treating this wastewater stream. Moreover, considering microbiological threats, it is imperative that each process or system ensures biological stabilization.

The presented research investigated the feasibility of using ultrafiltration for pre-treating backwash water generated during surface water treatment, as well as ensuring the biological stability of the pre-treated stream. The objectives of the study were to assess the effectiveness of backwash water pre-treatment, determine the conditions of recirculation into the water treatment system, in particular, the optimal location of introduction, and ascertain the costs associated with backwash water pre-treatment.

The quality of the pre-treated backwash water was the basis for determining the location of backwash reintroduction.

The aim of the research was:

- to assess the effectiveness of backwash water pre-treatment using ultrafiltration membranes,
- to compare the effectiveness and operational stability of two types of membranes under flow conditions,
- to determine the optimal location for reintroducing pre-treated backwash water into the water treatment system,
- to evaluate the costs of backwash water pre-treatment and identify strategies for reducing environmental costs including water intake and sewage discharge.

The most novel aspects of the research include evaluating the effectiveness of ultrafiltration filtration under flow conditions, pretreating backwash water, and calculating the costs associated with recirculation.

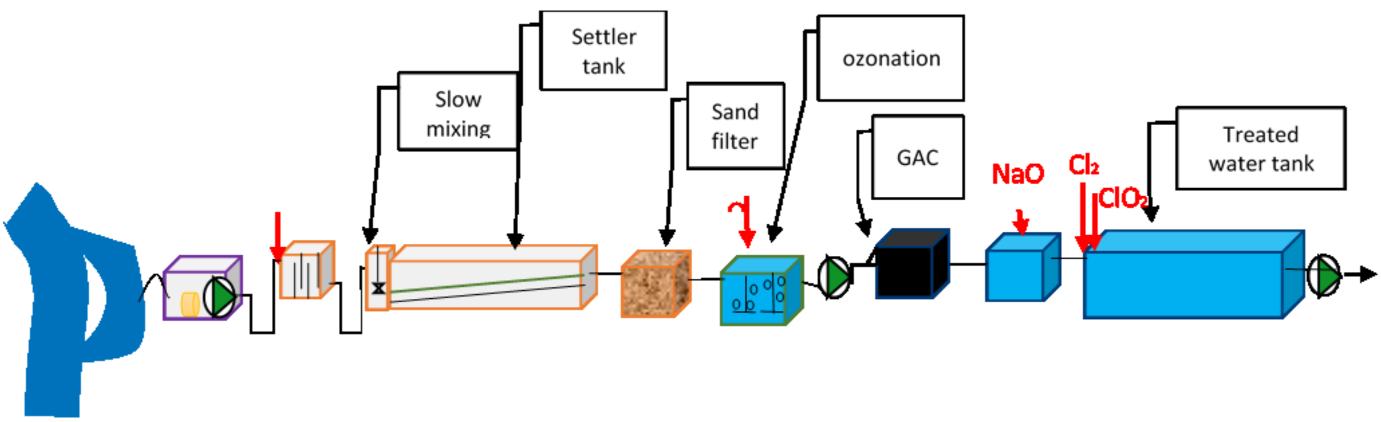

Figure 1. Scheme of the surface water treatment technology.

Table 1. Parameters of the sand filter backwashing

Parameter	Unit	
Air backwahs time	min	10-20
Air backwash intensity	$dm^3/s{\cdot}m^2$	14.6
Water backwash time	min	10-20
Water backwash intensity	$dm^3/s{\cdot}m^2$	8.29

Research methods

The research was conducted at a surface water treatment plant with a throughout of up to 100,000 m^3/d. The water underwent purification through several processes, including coagulation using aluminum sulphate or polyaluminium chloride, sedimentation, rapid sand filtration, ozonation, adsorption, and disinfection using chlorine and chlorine dioxide. A schematic diagram of the water treatment system is provided in Fig. 1.

The sand bed filters were flushed by water and air, with the flushing parameters presented in Table 1.

The study was conducted under flow conditions using a pilot ultrafiltration installation. (Fig. 2). The installation was supplied with backwash water from the surface water treatment plant. Subsequently, the water was collected in a settling tank, allowing for approximately 8 h of sedimentation.

The installation was equipped with a system to control the flow inflow and permeate, as well as pressure in each of its elements. Additionally, it featured online temperature measurement capabilities. The pre-treatment system included bag filters before the membrane modules, with filters having a pore size of 10 µm used in this study.

The installation enabled the installation of two membrane modules connected in parallel with different configurations. For the study, two modules were utilized: a spiral module featuring an M1 membrane and a capillary module equipped with an M2 membrane. The characteristics of these membranes are detailed in Table 2.

The effectiveness tests of the ultrafiltration were conducted in 7-day cycles, during which the filtration modules received

Table 2. Characteristics of the ultrafiltration membranes (Producer information)

Membrane	M1	M2
Membrane material	Polyvinylidene fluoride PVDF	Polyethersulfone PES
Producer	PolymemTech	
Membrane cut-off (kDa)	200	80
Maximum operating temperature (°C)	45	45
Maximum operating pressure (bar)	10 (recommended 0.7–5)	4
Membrane surface (m^2)	1.8	2

feedwater from settling tanks located at the water treatment plant. The stability of the backwash water flow was maintained by a buffer tank, serving as the initial component of the research installation.

The tests were repeated three times at various ambient temperatures in order to evaluate the impact of seasonal variability on both intake water quality and produced backwash water. Following each test, the membranes were chemically cleaned with 2% citric acid and 15% sodium hypochlorite solutions. Notably, membrane flushing is less frequent under technical conditions; therefore, the cost evaluation of backwash water pre-treatment does not include membrane cleaning costs.

The analysis of the composition of the backwash water before and after the ultrafiltration process included the measurement of several parameters, including pH, color, turbidity, UV_{254} absorbance, dissolved organic carbon concentration, and counts of psychrophilic and coliform bacteria (including *Escherichia coli, Enterococci, Clostridium perfringens*). Additionally, the molecular weight distribution of organic particles was evaluated using size exclusion chromatography (SEC).

The pH measurement was performed with the use of a Hach HQ440D multi-parameter meter. Turbidity was measured

Figure 2. Ultrafiltration installation.

Table 3. Ranges of the quality parameter values of the surface water and backwash water before and after ultrafiltration.

Parameter	Unit	Surface water	Raw backwash water	Membrane	
				M1 (200 kDa)	M2 (80 kDa)
pH		7.5-8.1	7.6-7.8	7.6-7.8	7.5-7.8
Colour	gPt/m^3	7.0-19.0	7.0-21.0	4.0-13.0	4.0-7.0
Turbidity	NTU	2.6-14.0	9.3-245.0	0.4-0.8	0.4
DOC	gC/m^3	3.07-7.79	5.11-8.58	3.75-6.17	3.87-5.71
UV_{254}	m^{-1}	6.43-15.0	7.09-20.0	5.58-9.52	6.07-7.67
Substances of molecular weight 3.2-2.5 kDa	g/m^3	-	12.7-16.5	5.12-11.02	8.55-13.59
Substances of molecular weight 1.8-2.0 kDa	g/m^3	-	11.4-15.99	7.03-11.92	10.59-14.26
Substances of molecular weight 0.7-0.9 kDa	g/m^3	-	3.7-6.6	1.13-6.44	3.7-6.48
Substances of molecular weight <0.1 kDa	g/m^3	-	1.89-3.98	0.98-3.50	2.03-3.99
SUVA	m^2/g	1.15-2.29	1.28-2.33	1.11-1.69	1.30-1.66
Psychrophilic bacteria	cfu/1 cm^3	1200-66000	7000-30000	800-20000	140-4,300
Enterococci	cfu/100 cm^3	0-51	1.0-36.0	0	0
Clostridium perfringens	cfu/100 cm^3	10-150	26-150	0	0
Coliform bacteria	cfu/100 cm^3	2-430	870-1700	0-150	0-1
Escherichia Coli	cfu/100 cm^3	0-8	56-720	0-1	0

using a Hach TU5200 turbidimeter, while TOC was analyzed using a Shimadzu TOC-L analyzer. Measurements of colour and UV absorbance were performed on filtered samples using a Shimadzu UV-Vis UV-1200 spectrophotometer. "

The molecular weight distribution was determined using chromatographic analysis conducted on an UltiMate 3000 Dionex liquid chromatograph equipped with a DAD detector, with results analyzed at a detection wavelength of 254 nm. Shodex OHpak SB-803 HQ polymer columns (particle size: 13 µm, dimensions: 8 x 300 mm) were used, along with a Shodex OHpak SB-G 6B pre-column (particle size: 10 µm; dimensions: 6 x 50 mm). The analysis was performed with the following parameters: column and pre-column temperatures of 35°C; sodium acetate mobile phase -10 mmol with a correction to pH = 7.0 using acetic acid (filtered with a 0.2 µm membrane filter); injection volume equal to 100 µl; flow rate equal to 0,5ml/min; analysis time equal to 35 min. Backwash samples were filtered using injection filters with a pore diameter of 0.45 µm. Calibration was performed using polystyrene sulfonate sodium salts (PSS, AmericanPolymerStandards Corporation) with molecular masses of: 891, 1600, 3420, 7420, 15650 and 29500 Da. Next, the relationship between particle size as a function of retention time and concentration (g/m^3) was determined for individual particle size ranges (3.2-2.5 kDa, 1.8-2.0 kDa, 0.7—0.9 kDa, < 0.1 kDa).

Microbiological analyzes were performed using culture methods in accordance with applicable standards: PN-EN ISO 6222:2004 - the number of psychrophilic bacteria; PN-EN ISO 9308-2:2014-06 - coliform bacteria and Escherichia coli; PN-EN ISO 7899-2:2004 – Enterococci; and PN-EN ISO 14189:2016-10 - *Clostridium Perfringers.*

The assessment of the investment and operating costs associated with implementing the ultrafiltration process in the plant was conducted based on contractor offers and market prices of consumables, using cost data from 2022. When evaluating investment costs, consideration was given to the potential utilization of existing sewage and sediment management infrastructure at the plant.

The minimum required level for pre-treated backwash water was set to match the composition of the intake water (Table 3), facilitating its reintroduction at the beginning of the technological system. Moreover, achieving higher effectiveness in removing organic substances and microorganisms would enable backwash water recirculation before the ozonation or adsorption processes.

Results and discussion

The analysis (as shown in Table 3) reveals a substantial variability in the composition of backwash water from surface water treatment, with contamination types mirroring those of the input water but at elevated concentrations. This discrepancy is particularly pronounced for the suspended fraction (turbidity) and microorganisms. The recycling of pre-treated backwash water into the water treatment system is justified if it poses no health risks and does not adversely affect other processes.

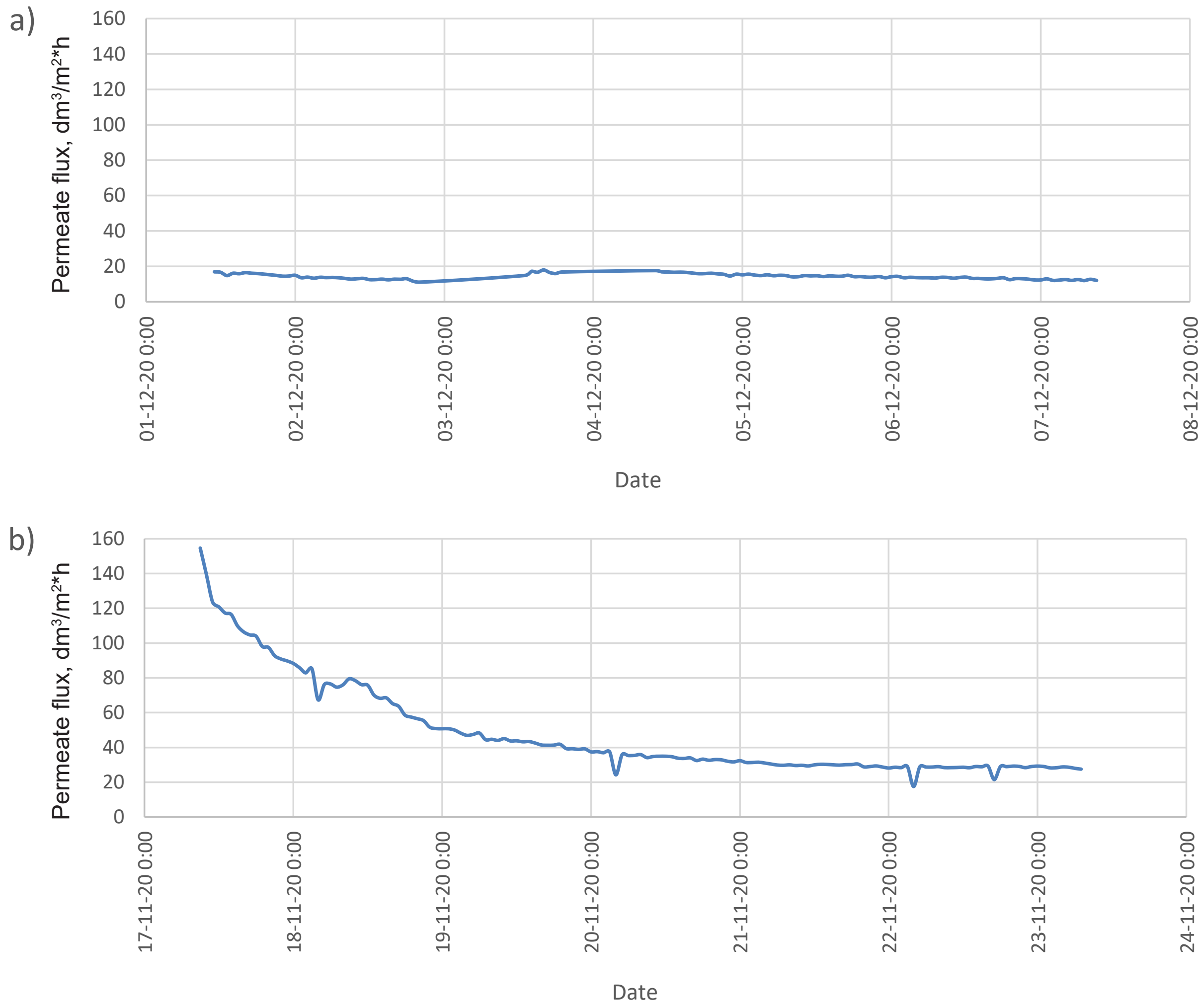

Figure 3. Variability of the permeate flux during the ultrafiltration cycle: a) spiral module (MWCO 200 kDa), and b) capillary module (MWCO 80 kDa).

Hence, in the presented research, it was stipulated that the pretreatment of backwash water must ensure a quality comparable to that of the intake water as a necessary condition for its recycling into the water treatment system.

Considering available literature reports on treatment methods for backwash water from sand filters, the ultrafiltration process was chosen for pretreating the waste stream in the case study. This selection aims to ensure both biological stabilization and effective removal of organic substances (Mahmud et al. 2020, Chen et al. 2022, Cordier et al. 2020).

During each test, the trans-membrane pressure was consistently maintained at 2.5 bar regardless of the membrane used. The spiral module, equipped with a membrane cut-off of 200 kDa, demonstrated remarkably stable transport properties throughout the test cycles (Fig. 3a). In turn, the permeate flux of the capillary module with the 80 kDa cut-off membrane experienced a significant decrease within the first 24 hours of operation, stabilizing at a similar level thereafter (Fig. 3b). Surprisingly, the capillary module with the M2 membrane exhibited significantly better transport properties compared to the spiral module with the M1 membrane. This deviation from the expected outcome, based on the membrane cut-off values provided by the supplier (M1- 200 kDa, M2 – 80 kDa), led to further investigation. It is hypothesized that this discrepancy may be attributed to the different materials used for membrane production. Polyvinylidene fluoride (PVDF), utilized in the M1 membrane, is known for its high mechanical strength, thermal stability, and chemical resistance (Subasi and Cicek, 2017). However, PVDF membranes, due to their hydrophobic nature, often exhibit inferior transport properties compared to membranes made of more hydrophilic polymers (Li et al. 2019; Yaprak et al. 2017).

The decrease in permeate flux, calculated as the ratio of flux at the beginning of the filtration cycle to flux after 7 days, was 0.71 for the module with the M1 membrane and 0.1 for the module with the M2 membrane, with the latter experiencing a decrease of 0.36 after 24 hours. The observed intensity of membrane blocking, notably more significant for the capillary module, is probably the result of internal fouling caused by molecules blocking the membrane pores, particularly those with dimensions similar to the membrane pore diameter. This effect appears to be less significant for the membrane with a larger cut-off value, as seen in the spiral module with the M1 membrane).

Given the criteria for determining the reintroduction location of backwash water into the water treatment system

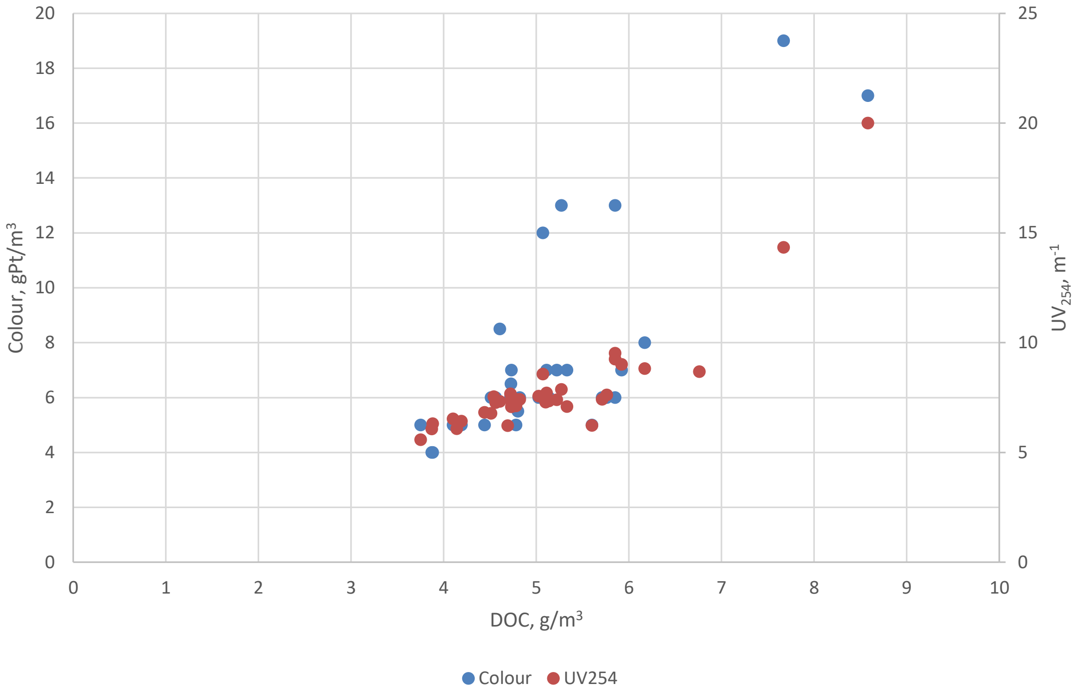

Figure 4. Correlation between dissolved organic carbon (DOC) and colour or UV_{254} absorbance.

based on its physico-chemical and microbiological composition, a comprehensive analysis was conducted on the properties of the raw water, backwash water, and permeates obtained from both types of membrane modules. The composition analysis revealed that the concentration of dissolved organic carbon in the backwash water was 15-50% higher than that found in the raw water, resulting in elevated levels of all analyzed indicators of backwash organic contamination compared to surface water (Table 3). Consequently, these contaminants must be effectively removed before reintroducing the backwash water into the water treatment system.

The presence of refractive substances was predominant in the raw backwash water, as evidenced by high UV_{254} absorbance and SUVA specific absorbance values (Table 3). Moreover, the organic substances in the water not only influenced the UV_{254} absorbance values but also contributed to the coloration of the backwash water (Fig. 4).

The molecular weight distribution analysis revealed the presence of low molecular weight organic substances in both raw surface water and the resulting backwash water, primarily in the range below 3.2 kDa. Membranes withcut-off values of 200 kDa (M1) or 80 kDa (M2) were unable to effectively remove these substances, as confirmed by the molecular weight distribution analysis of the permeates. This analysis showed that after the ultrafiltration process, the particle size distribution remained similar to that of the raw backwash water (Fig. 5). Additionally, the operating time of the membrane within each filtration cycle was observed to influence the effectiveness of eliminating larger particles from the backwash water. This phenomenon is likely attributed to membrane

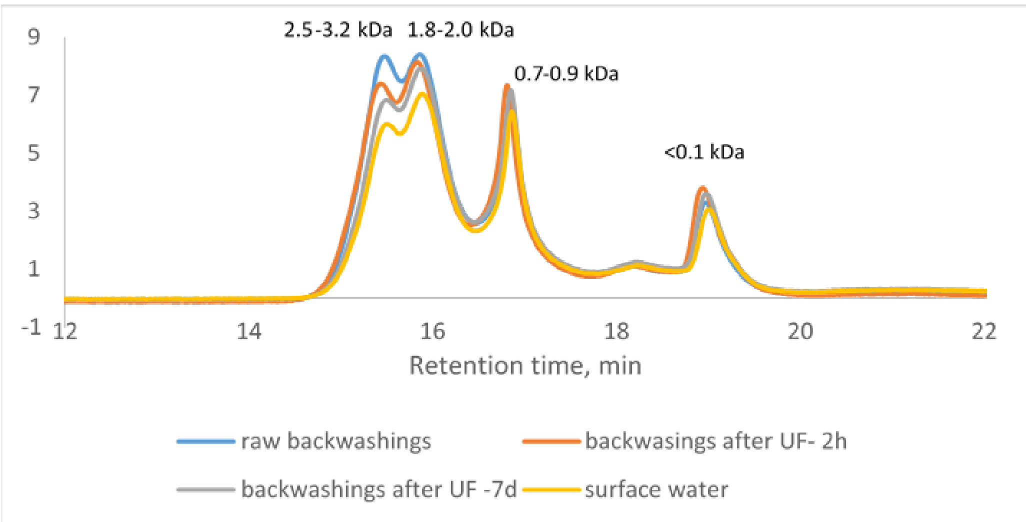

Figure 5. Molecular weight distribution of the organic substances in the surface water, raw backwash water and permeates after ultrafiltration (M2 membrane on the 2nd hour and 7th day of the cycle).

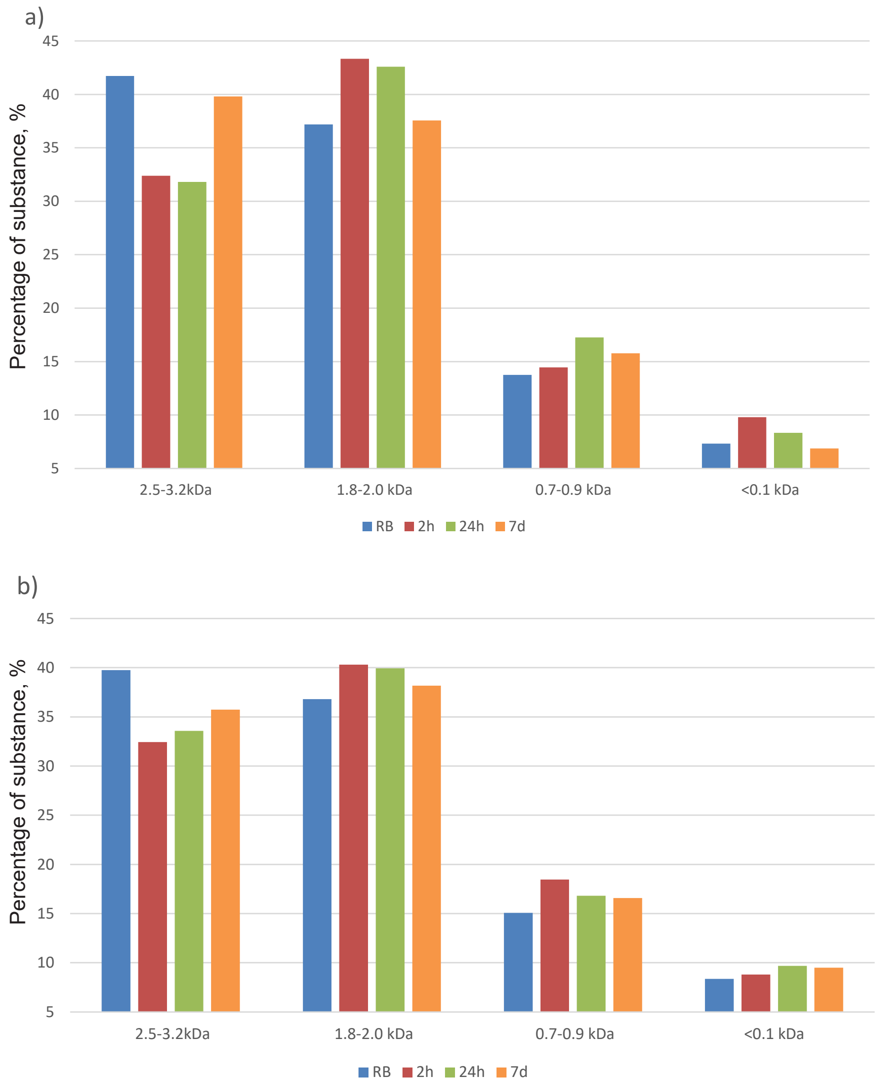

Figure 6. Average contribution of the organic substances fraction in the raw backwash water and the permeates after ultrafiltration using the M1 (a) and M2 (b) membranes.

fouling caused by the formation of a dynamic membrane layer on the membrane surface, leading to increased retention of larger molecules with prolonged membrane operation (Sun et al. 2021).

The analysis revealed that particles with a molecular weight of 2.5-3.2 kDa dominated among the organic substances. Interestingly, the content of this fraction consistently decreased after each ultrafiltration cycle, irrespective of the membrane type used. Notably, this fraction exhibited a decrease in its share in all permeate samples, whereas the share of other fractions increased (Fig. 6).

The analysis revealed a notable decrease in the content of the 1.8-2.0 kDa fraction in individual samples of backwash water after ultrafiltration (UF), particularly evident with the M2 membrane (capillary module) due to its lower cut-off value. However, changes in the concentration of other analyzed organic substance fractions were insignificant and did not exceed the analysis error, consistent with the nominal cut-off values of the tested membranes.

The presence of low molecular weight substances in backwash water, coupled with their low retention (13-60%), resulted in a corresponding low retention of the DOC, ranging from 17 to 45%. However, despite this low retention, the observed DOC concentrations were lower than those found in the surface water. Notably, in the case of the capillary module with the M2 membrane (80 kDa), the DOC concentration fell below the limit value for drinking water (5 g C/m^3) within the first 3 days of ultrafiltration. Conversely, for the M1 membrane permeate (spiral module) (200 kDa), only one of the pre-treated samples met this condition.

The analysis results showed substantial differences between the backwash water and abstracted water, particularly in terms of psychrophilic microorganism count and turbidity levels, which were significantly higher in the backwash water. Moreover, the presence of indicator microorganisms, including pathogenic ones such as coliform bacteria and *Clostridium perfringens*, was detected in the raw backwash water.

Both membranes demonstrated complete elimination of the analyzed pathogenic microorganisms including *Clostridium perfrigens* and *Escherichia coli*, throughout the entire ultrafiltration cycle. Additionally, the M2 membrane (capillary module) successfully eliminated all coliform bacteria. The presence of coliform bacteria in some of the samples of backwash water pre-treated using the M1 membrane limited its potential for recirculation to the beginning of the water treatment system. Furthermore, both membranes exhibited

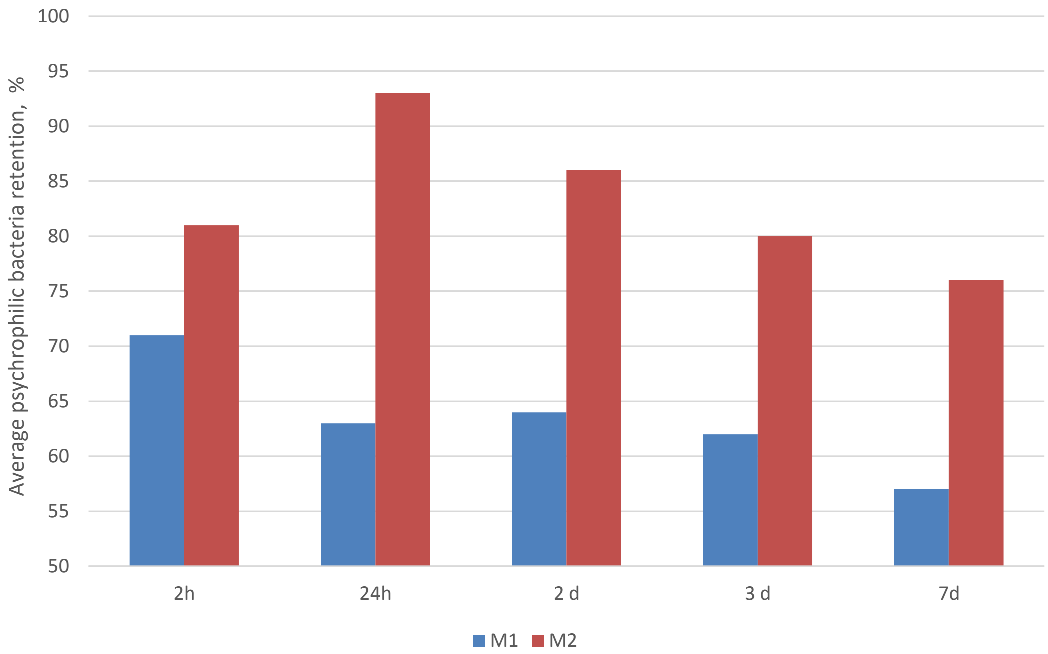

Figure 7. Changes in the retention coefficient of the psychrophilic bacteria in the ultrafiltration cycle.

variable retention factors for psychrophilic bacteria during the cycle, with the M2 membrane in the capillary module showing greater effectiveness (Fig. 7). Interestingly, the number of psychrophilic bacteria in the backwash after ultrafiltration through the M1 membrane (spiral module) was higher than that found in the raw surface water, posing limitations on the return of backwash into the water treatment system.

Considering the membrane pore diameter calculated using the formula proposed by Howe and Clark [2002]:

$$d = 0.09(MWCO^{0.44}),$$

which yielded approximately 19 nm for membrane M1 and 13 nm for membrane M2, the anticipated high effectiveness in eliminating microorganisms such as *Clostridium perfringens* and *Escherichia coli* was expected. This anticipation aligns with the large cell sizes of these microorganisms, which range from 3-8 µm x 0.4-1.2 µm for *Clostridium perfringens* (microbentos) and 1–3 µm × 0.4–0.7 µm for Escherichia coli (Liu, 2014). However, the observed incomplete elimination of psychrophilic bacteria may be attributed to a phenomenon documented by Sosnowski et al. (2004), where microorganisms penetrated membranes with diameters significantly smaller than their cell size due to pressure-induced deformation of the cell plasma during filtration.

The M2 membrane (80 kDa) demonstrated a higher retention coefficient of microbiological water contamination (Table 4), as evidenced by lower microorganism counts post-ultrafiltration compared to the input surface water. Notably, the microorganism counts after ultrafiltration were reported to be similar to those obtained after the filtration process through the sand bed, according to information provided by the water company.

Considering the reduction of all the analyzed components of the backwash water to levels lower than those found in the intake water and the complete elimination of pathogenic microorganisms achieved with the M2 membrane (80 kDa), as opposed to the insufficient elimination of microorganisms observed with the M1 membrane (200 kDa), the M2 membrane was chosen for backwash water pre-treatment. It is worth noting that while the M2 membrane demonstrated higher microbial removal efficiency, further enhancement is possible by installing a UV lamp system on the permeate, albeit at an increased pretreatment cost.

The efficiency of the backwash water pre-treatment using the capillary module membrane enables its reintroduction into the water purification system before the ozonation process (after filtration through a sand bed). This location results from the need to additionally reduce the number of microorganisms in accordance with WHO guidelines (WHO 2017).

An economic analysis of using the proposed solution in a WTP

The implementation cost analysis was carried out for a backwash water pre-treatment system using capillary modules equipped with an 80 kDa membrane. The analysis accounted for the reintroduction of pre-treated backwash

Table 4. Rejection coefficient (%) of selected contaminants from the backwash water treated with the ultrafiltration membranes.

	M1	M2
Colour	24-81	14-43
Turbidity	97-100	97-100
DOC	2-27	17-45
UV_{254}	40-45	0-14
Psychrophilic bacteria	57-94	64-99
Enterococcus	100	100
Clostridium perfringens	100	100
Coli bacteria	96-100	100
Escherichia Coli	100	100

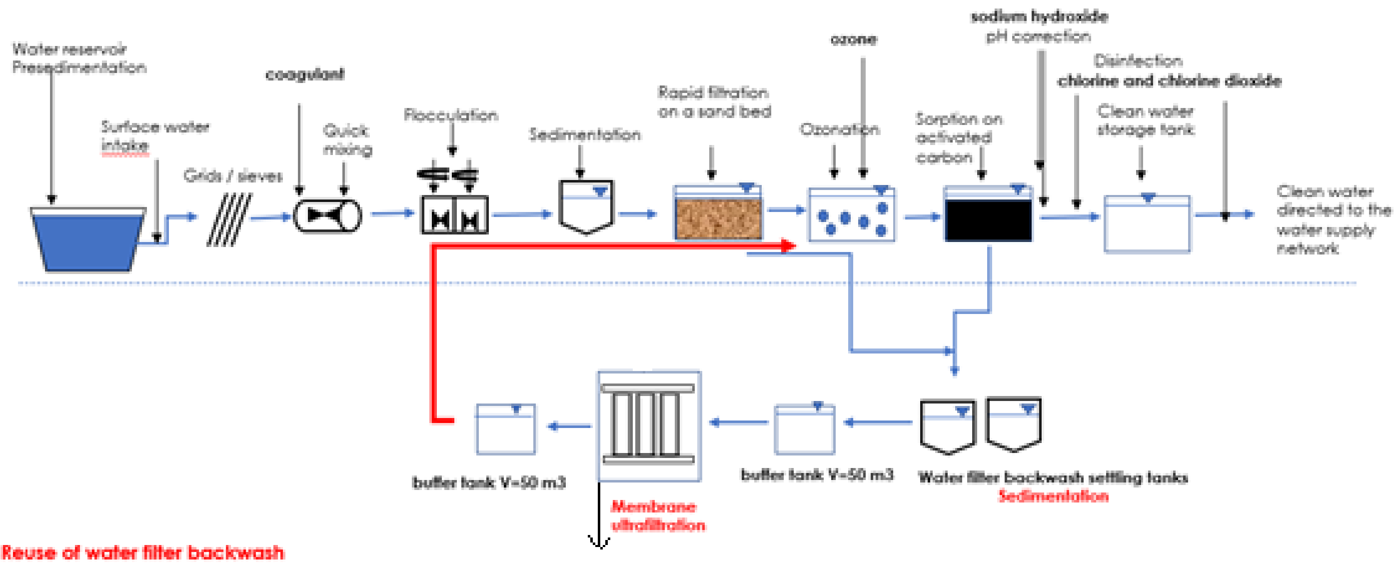

Figure 8. Scheme of the backwash water recirculation for the water treatment trial.

water into the water treatment system after the sand bed filtration process (Fig. 8).

The assessment of the investment costs for implementing this solution within the plant's circular economy encompassed several key components. These included the reconstruction of the existing sewage and sludge management installations, the purchase of an ultrafiltration installation, and construction of a buffer tank and a control system.

The total investment cost was estimated at EUR 1.5 million, based on market offers. This solution entails the purchase of a container-based ultrafiltration installation with a capacity of 70 m^3/h of treated backwash water (permeate). This capacity meets the minimum requirement for continuous operation of the installation [Wolska and Urbańska-Kozłowska 2023]. However, it is important to note that the primary operating cost is electricity, amounting to 4.4 kW per 1 m^3 of treated backwash water. This results in a cost of 0.35€/m^3 (0.01€/m^3 of purified water in the WTP).

Moreover, returning the reclaimed water from the backwash process back into the water treatment system leads to a reduction in environmental fees, specifically water intake and discharged sewage costs, by approximately 645€/month. Additionally, returning the pre-treated backwash water prior to the ozonation process results in a decrease coagulant consumption for water purification (approx. 100 kg/month). With the current cost of coagulant at 0.03 €/m^3 for purified water, this expense would slightly decrease to

Table 5. The impact of the recirculation of pre-treated backwash water on operating costs (€/m^3 treated in WTP water).

	Decrease	Increase
Water intake and sewage discharge	0.0007	-
Energy	0.0002	0.008
Coagulants	0.002	-

0.028€/m^3, yielding savings of 1,680€ per month. However, it is important to note that implementing the ultrafiltration process for backwash water pre-treatment will increase energy demand, leading to a slight increase in the overall cost of water treatment (Table 5). It is worth mentioning that the operating costs outlined do not include the purchase price of reagents used to clean the membranes. During the tests, cleaning was performed after each cycle, rather than when membrane efficiency was compromised, making it challenging to provide an accurate estimation of rational cost.

After factoring in both the investment and operating costs alongside the reduction in environmental fees, it was estimated that the increase in water purification costs per cubic meter of water would be approximately 1.5%. This increase is justified from both economic and ecological perspectives.

Conclusions

The study on evaluating the effectiveness of the ultrafiltration treatment of sand filter backwash water to recover water for reintroduction into the main process line of a surface water treatment plant revealed several key findings:

- Both ultrafiltration membranes, with cut-offs of 200 kDa and 80 kDa, successfully reduced contamination in the backwash water in terms of organic substances and microorganisms. However, the 80 kDa membrane (capillary module) exhibited higher retention of organic matter and microorganisms compared to the 200 kDa (spiral module).
- The 200 kDa cut-off membrane did not completely eliminate coliform bacteria, rendering it unsuitable for water recovery from backwash water;
- The quality of the permeate obtained after ultrafiltration with the 80 kDa membrane allowed it to be reintroduced into the surface water treatment process train and mixed with water treated using coagulation and rapid filtration;
- Pre-treating backwash water with UF membranes and reintroducing the reclaimed water into the water treatment system resulted in reduced environmental fees, despite a 1.5% increase in water treatment costs.

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Ocena możliwości zastosowania ultrafiltracji do recyrkulacji popłuczyn w zakładzie oczyszczania wody powierzchniowe

Streszczenie. .Konieczność ograniczenia zużycia wody oraz racjonalne gospodarowanie zasobami wodnymi wymusza na przedsiębiorstwach wodociągowych konieczność ograniczenia strat wody podczas jej oczyszczania. Dlatego coraz częściej popłuczyny powstające w procesie filtracji stanowią przedmiot badań, których celem jest ponowne ich wykorzystanie w systemie oczyszczania wody. rezentowane badania prowadzone były w dużym zakładzie oczyszczania wody powierzchniowej o wydajności 100000 m3/d, a ich przedmiotem były popłuczyny powstające z płukania filtrów ze złożem piaskowym. Popłuczyny podczyszczone były w procesie ultrafiltracji na modułach: spiralnym z membraną z PVDF (200 kDa) i kapilarnym z membraną z PES (80 kDa). Skuteczność procesu oceniono na podstawie stopnia retencji substancji organicznych i mikroorganizmów, które stanowiły zagrożenie zdrowotne w przypadku recyrkulacji popłuczyn. Skuteczniejsza w retencji tych wskaźników okazała się membrana kapilarna, która zapewniła całkowitą eliminację mikroorganizmów patogennych. W badaniach wykazano, że koszty podczyszczania popłuczyn i ich zawracanie do układ oczyszczania wody przed proces ozonowania pozwoli na ograniczenie kosztów korzystania ze środowiska oraz zwiększy koszt oczyszczania wody o 1,5%.