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EVALUATION OF THE POSSIBILITY OF REPLACING THE RAPID FILTRATION PROCESS WITH ULTRAFILTRATION IN SURFACE WATER TREATMENT SYSTEMS

The presented study aimed to compare the effectiveness of ultrafiltration and filtration through a sand bed during the water treatment process after the coagulation and sedimentation. The study was conducted in two flow-type water treatment systems: the reference and the test system. Both systems functioned continuously with a throughput of 1 m^3/h. The research has shown that both processes ensured a very effective removal of post-coagulation suspensions, however, ultrafiltration was more effective. The filtration process allowed a slightly higher removal of organic substances as compared to ultrafiltration. The effectiveness of the removal of organic substances was determined by the biological activity of sand beds, which is not allowed in the ultrafiltration process. Besides, during the filtration process, aluminum remaining after coagulation was more effectively removed. In turn, the ultrafiltration process ensured an almost 100% effectiveness in reducing the total microorganism cell count, while the effectiveness of the filtration process was approximately half of that. In the end, the possibility of replacing the filtration process with the ultrafiltration process is determined by the costs of both processes.

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1. INTRODUCTION

The necessity of removing organic substances from surface waters makes it necessary to expand water treatment systems and increasing the effectiveness of currently used unit processes. Therefore, it is not always sufficient just to introduce the adsorption process [1–3] into conventional treatment systems, but also to intensify individual processes [4, 5] or introduce additional ones [6, 7]. Low-pressure membrane separation (mainly ultrafiltration) is commonly used for water purification for industrial uses [8–10]. Ultrafiltration not only ensures a practical 100% reduction of suspended matter, but also a significant reduction in the number of microorganisms [11, 12]. Furthermore, depending on the type of membrane used (material, pore size, and pressure used), the concentration of organic substances can be reduced [13]. This means that the ultrafiltration process provides higher efficiencies of removing contaminants from water than filtration through a sand bed commonly used for purification of drinking water [6]. Studies [14, 15] indicate a high sensitivity of the ultrafiltration process to changes in water temperature, which is one of the main drawbacks of the use of this process in treating surface water, which is characterized by high variability of temperature. To ensure stable operation of the membrane modules throughout the year, water heating would be required. This is, however, uneconomical. On the other hand, the water temperature has little impact on filtration through a sand bed. Therefore, studies were carried out aiming to compare the effectiveness of ultrafiltration and filtration through a sand bed included in the water treatment process after the coagulation and sedimentation processes.

2. EXPERIMENTAL

Studies were conducted in two water treatment systems with a throughput of 1 m^3/h each. Water was treated with volume coagulation and sedimentation (under similar process parameters). Then, in one system, the treated water was directed to rapid pressure filters with a sand bed, and in the other – into 3 spiral-wound ultrafiltration modules (PW8040F34-D type, GE Power and Water). The operating parameters of sand filters and ultrafiltration modules are given in Table 1.

The studies were performed from April to July (94 days), which allowed monitoring the quality of treated water in dependence on temperature. The studies were not conducted at periods of the low temperature of water [16]. Water samples for analysis were taken averagely twice a week after the sedimentation process at the settling tank outflow (OS), at the outflow from the filters (OF) and from the ultrafiltration modules (OUF). Within the studies, 54 samples were taken for each treatment system.

Water temperature, pH, oxygen and biogenic substance concentrations (phosphate, ammonium ions, nitrates), the color intensity at 340 nm and 410 nm (corresponding to the maximum absorbance of various organic substances), water turbidity, and the concentrations of total (TOC), dissolved (DOC) and biodegradable (BDOC) organic carbon were determined. UV absorbance was also measured at the wavelengths of 254 and 272 nm (Shimadzu UV-1800 spectrophotometer), which corresponded to the maximum absorbance of refractive substances and precursors of organic disinfection by-products, respectively [17]. Based on the UV_{254} absorbance and the DOC, the specific UV absorbance (SUVA) was calculated. For all water samples, the residual aluminum content after the coagulation process was determined. Flow cytometry was used to determine the total cell count (TCC).

Table 1

Parameters of rapid filtration and ultrafiltration processes

Parameter	Filtration	Ultrafiltration
Filtration surface, m^2	0.2	102
Throughput, m^3/h	1	1[a]
Filtration speed, m/h	5	–
Pressure, MPa	0.1	transmembrane pressure 0.08
Frequency of rinsing,	once a day with air (for 5 min) and water (for 10 min)	backwashing for 20 s every 30 min; additionally the membranes chemically cleaned with sodium hypochlorite (200 g Cl_2/m^3) and citric acid (pH 2.90) once a week
Pore size	0.3–1.5 mm[b]	cut-off 30 kDa
Material	sand	poly (vinylidene fluoride)

[a]Applies to permeate.
[b]Grain range.

The analysis of water quality indicators was performed by standard methods under current Polish Standards. For analyzing a BDOC concentration, characteristic microorganisms were introduced to a given environment in water samples. Sample incubation was carried out for 5 days. Cell count tests were performed in a flow cytometer (BD Accuri, C6 cytometer), with the use of a DNA dye – SYBR Green, which binds to DNA present in the sample. This dyeing allowed obtaining the total cell count (TCC) [18, 19].

In this work, the use of the ultrafiltration process was evaluated only concerning changes in water composition, not taking into account operating costs, which could significantly influence the evaluation of this process [20].

3. RESULTS AND DISCUSSION

Due to pre-treatment during the coagulation and sedimentation processes, water used to filtration/ultrafiltration was characterized by a low variability of composition as compared to that typical for surface water. The greatest variability was found for the turbidity (Table 2). In raw water, the organic substances found were dominated by dissolved substances making up 72.1–100.0% of TOC. The biodegradable fraction made up 6.7–26.7% of DOC. The dominating dissolved organic substances were not susceptible to removal in the filtration processes. Their removal during ultrafiltration depends on the properties of the membranes used [21]. The SUVA values (Table 2) indicated the presence of substances of low molecular weight, which is unfavorable for both processes.

Table 2

Ranges of water quality indicators before (OS) and after (OF) filtration, and ultrafiltration (OUF) processes

Parameter	OS	OF	OUF
T, °C	14.9–23.7	14.6–23.8	15.7–24.0
pH	7.41–7.85	7.25–7.82	7.40–7.93
Turbidity, NTU	0.25–2.25	0.10–0.20	0.01–0.13
TOC, g C/m^3	3.05–4.62	2.35–4.42	2.39–3.70
DOC, g C/m^3	2.93–3.62	2.20–3.03	2.43–3.39
BDOC, g C/m^3	0.23–0.82	0.08–0.68	0.23–0.86
Color$_{410}$, g/m^3	6.55–10.55	5.81–8.81	5.72–9.27
O_2, g/m^3	7.76–11.24	6.56–9.97	7.84–11.04
PO_4^{3-}, g/m^3	0.07–0.14	0.01–0.05	0.01–0.04
NH_4^+, g/m^3	0.05–0.06	0.05	0.05–0.07
NO_3^-, g/m^3	1.31–12.5	1.72–12.30	1.27–12.40
UV$_{254}$, m^{-1}	6.27–8.25	5.24–7.07	5.89–7.78
SUVA, m^2/g	1.88–2.29	2.05–2.46	1.88–2.51
TCC	3,312–51,772	841–19,625	66–7,722
Al, μg/dm^3	56.2–312.1	18.3–84.2	26.8–150.0

It is worth noting that in water coming into the sand filters/membrane modules, biogenic substances were present in concentrations sufficient for microorganism development [22], which could have favored the development of biofilms on the filter surface. Furthermore, the significant number of microorganism cells in water supplying the sand filters/membrane modules testifies to the possibility of biofilm development on the filter surface. However, due to the high frequency of membrane flushing, biofilm development was hampered.

The aluminum in post-coagulation water was present most probably in a colloidal form, which could have significantly limited the effectiveness of the ultrafiltration process [23]. As expected, the effectiveness in reducing turbidity was much larger for the ultrafiltration process than for rapid filtration. This is the result of the efficient retention of inorganic colloids by the membrane used. The ranges of the effectiveness of water turbidity removal were 33.3–95.6% and 62.1–98.7% for filtration and ultrafiltration, respectively (Table 2).

In the significant majority of water samples (90% of the samples taken), greater effectiveness in removing total organic carbon was found for the filtration process (Fig. 1), which was probably caused by the biological activity of the sand beds. Besides, the relatively large pore size of the membranes (with cut-off 30 kDa) made it impossible to retain low molecular organic compounds.

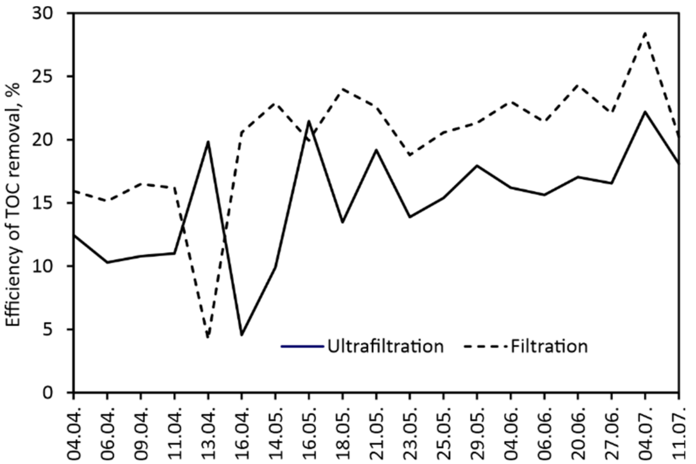

Fig. 1. TOC removal efficiencies in the filtration and ultrafiltration processes

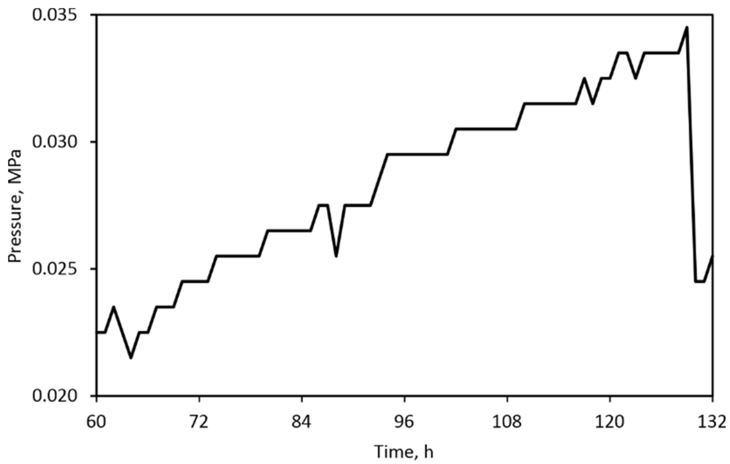

Fig. 2. Fluctuation of transmembrane pressure between backflushing a UF module

During ultrafiltration, the blocking of the membrane pores by colloids present in water, especially by residual aluminum, occurred. It resulted in a gradual increase of hydraulic resistance and, as a consequence, an increase of transmembrane pressure (Fig. 2). On the other hand, the greater effectiveness in removing DOC during the filtration process may result from the biological activity of the sand beds, which would be confirmed by changes in BDOC concentrations. During the filtration process, the average decrease in biodegradable organic carbon content amounted to 37.9%, pointing to the biodegradation of organic substances [24]. The ultrafiltration process did not change the BDOC content for the majority of samples (Table 2). The pore size of the membranes used made prevented retaining these organic substances.

In both systems, substances absorbing UV radiation were among those removed, as evidenced by the decrease in UV absorbances at both 254 nm and 272 nm. However, the ultrafiltration process was almost twofold less efficient than the filtration process (Table 2). The SUVA value in water after ultrafiltration increased (Table 2), which may testify to the low effectiveness of removing UV radiation absorbing substances. The increase in the SUVA after the filtration process was smaller (Table 2), and in the majority of water samples (60%) did not exceed analytical error (5%). A simultaneous lack of change in the SUVA and the decrease in BDOC concentration in post-filtration water indicates biodegradation [24].

In both processes, removal of colored substances (most probably humic ones) absorbing UV radiation at a wavelength of 272 nm dominated, which is shown by the correlation between the color reduction and the UV_{272} absorbance reduction (Fig. 3).

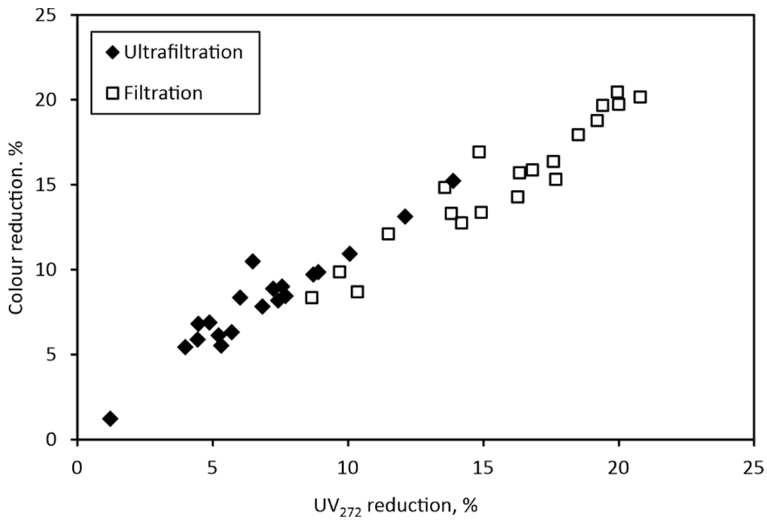

Fig. 3. Dependence of the effectiveness of color reduction on UV_{272} absorbance reduction in the filtration and ultrafiltration processes

The bioactivity of the rapid filters can explain the decrease in the dissolved oxygen concentration after this process, which did not take place during the ultrafiltration process. The reduction of oxygen content during filtration amounted to 9.8–15.9%.

The filtration and ultrafiltration processes caused a comparable decrease in the concentration of phosphate ions, which are food substrates (Table 2). Their removal might be due to biological assimilation (during filtration) and/or by retaining of weakly-soluble phosphates (during ultrafiltration). The nitrate concentration did not change in the ultrafiltration process. Nitrates occurred in a dissolved form and could not be retained by the membrane. After filtration, even an increase in the concentration of nitrates in water was found (Table 2). This could indicate the presence of nitrification, yet this increase was not proportional to the decrease in oxygen content. As shown by Hassan et al. [25] due to the presence of various oxidative processes, the decrease in oxygen is not always proportional to the increase in nitrate content despite the presence of nitrification in the bed, and often the oxygen consumption is greater than the stoichiometric consumption. In the analyzed system, the reduction in oxygen concentration was less than stoichiometric.

The greatest differences between filtration and ultrafiltration concerned the removal of microorganisms present in water. The ultrafiltration process ensured an almost 100% effectiveness in reducing the total cell count (TCC), while the effectiveness of the filtration process was approximately half of that (Fig. 4).

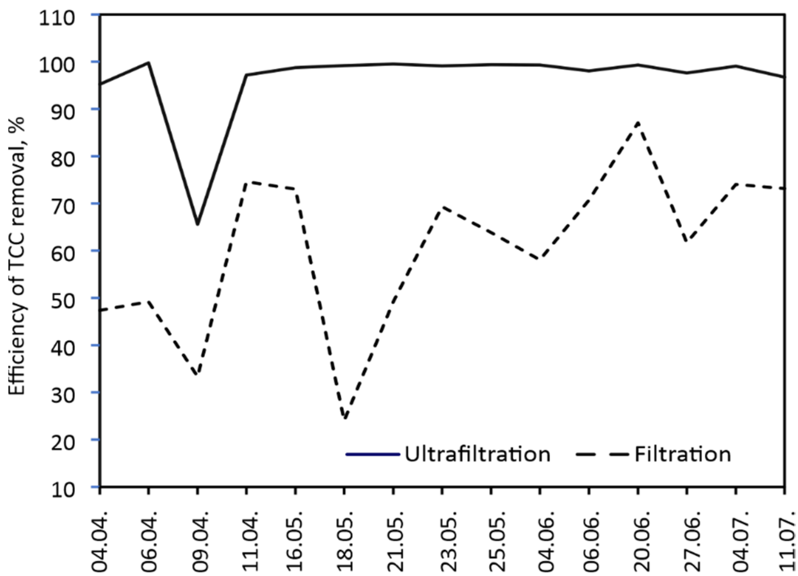

Fig. 4. Efficiency of the total cell count (TCC) in ultrafiltration and filtration processes

Therefore, the ultrafiltration process ensured water disinfection, which may have a significant impact on subsequent unit processes, e.g., for populating adsorption beds [26, 27]. It is also worth noting that in water after ultrafiltration, the DOC content in TOC was close to 100%, while in the filtration it was on average 92% (Table 2). In water after both processes, these percentages were higher than in the input water. However, no differences were found in the intensity of color or UV absorbance in water after both processes.

The filtration process allowed a better elimination of residual aluminum after coagulation, yet water after both processes was characterized by levels of aluminum lower than that allowed for potable water (200 μg/dm^3), with the average effectiveness of these processes in removing aluminum being 75.4% and 56.0%, for filtration and ultrafiltration, respectively (Table 2).

4. CONCLUSIONS

- Both processes: filtration and ultrafiltration, used for surface water treatment, ensured a very effective removal of post-coagulation suspensions, however, ultrafiltration was more effective.
- The filtration process allowed a slightly higher removal of organic substances as compared to ultrafiltration.
- The effectiveness of the filtration process was determined by its biological activity, which is not allowed in the ultrafiltration process.
- Ultrafiltration provides a very effective reduction in the total microorganism cell count, which did not take place in the filtration process.
- Both processes did not provide an effective reduction in the color and UV absorbing substances. The reductions in these parameters were directly proportional to each other.
- During the filtration process, aluminum remaining after coagulation with aluminum coagulant was more effectively removed than during ultrafiltration.
- The possibility of replacing the filtration process with ultrafiltration depends on the expected increase in efficiency. If it is necessary to improve the water quality to a small extent then the ultrafiltration process can replace filtration.
- The possibility of implementing the ultrafiltration process should ultimately be determined by a cost comparison.

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