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A new approach to control and monitor coagulation/sand ballasted sedimentation as pre-treatment of water feeding ultrafiltration membranes

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Abstract
The technological and economic efficiency of membrane water purification installations depends largely on the quality of the medium supplied to the devices carrying out the process. For typical technological solutions of desalination and demineralization systems, consisting of reverse osmotic membranes followed by nanofiltration membranes and electrodeionization units, pre-treatment of the feed water is required to meet the requirements of osmotic membrane manufacturers. The preliminary treatment of water aims to limit the phenomenon of membrane fouling, which is mainly caused by suspended solids, colloidal substances, and natural organic matter present in the water.
The paper presents the results of research conducted in the technical coagulation/flocculation with sand ballasted sedimentation system followed by ultrafiltration units, used as preliminary water purification before osmotic membranes. Standard monitoring measurements were unable to detect situations where the process parameters deviated from the values determined during jar tests. Additionally, the obtained results of the research showed that coagulation/flocculation process can be conducted according to the criterion of minimizing the pressure loss during the filtration cycle and the strategy of maximizing pre-treatment effectiveness preceding ultrafiltration membranes. The condition for ensuring such parameters is the use of appropriate tools allowing for effective operational monitoring of the process. The results of the research on the application of a simple vacuum filtration test showed that it is a particularly good tool for monitoring and controlling the operational parameters of coagulation. During the research, high correlation was shown between the filtration time values of samples and the quality of the raw water feeding the treatment system, which affected the subsequent course of ultrafiltration. Similar dependencies were observed in clarified water supplied to UF membranes.

Keywords
sand ballasted sedimentation, sweep coagulation, ultrafiltration, membrane fouling

1. INTRODUCTION

Improper quality of water feeding ultrafiltration membranes, causes the accumulation of impurities on or inside the membrane structure resulting in permeability loss (membrane fouling). Fouling is described according to the type of foulants, such as particle and organic fouling. Particle fouling is formed by two blocking phenomena i.e. accumulation of larger particles on the membrane surface and smaller ones inside the pores of the membrane and cake formation with increasing number of particles precipitated on the initial layer and finally to a concentration causing high membrane flow resistance. If fouling is caused by natural organic matter (NOM) present in the source, it is organic fouling. However, the mechanism is not well explained. NOM is commonly present in natural waters, and removal efficiency depends on the characteristics of organic compounds and hence susceptibility to treatment process (Campinas and Rosa, 2010; Kabsch-Korbutowicz, 2005; Kim et al., 2006; Li et al., 2006; Wang et al., 2025).

The main way to reduce fouling is to use a coagulation process before UF membranes as a pre-treatment stage. Pre-treatment of water supplying an ultrafiltration (UF) system is generally based on conventional coagulation or in-line coagulation with or without sedimentation stage. However, the basic condition for effective protection of membranes against permeability loss is the correct operation of coagulation process. The results of many studies show that optimized dosage of coagulant for maximum removal of contaminants causing turbidity or organic matter in a conventional coagulation process may not be the best for UF (Kabsch-Korbutowicz, 2005; Li et al., 2006; Malkoske et al, 2020; Mao et al., 2013; Park et al, 2006; Wang et al., 2009; Zularisam et al., 2006).

Therefore, it is very important to find a methodology suitable for coagulation tests depending on a coagulation mechanism, with particular attention to monitoring parameters. Basic indicators used to assess the effectiveness of pre-treatment process were turbidity, UV absorbance at a wavelength of 254 nm (SAC254), total and dissolved organic carbon (TOC, DOC). In addition, filtration properties based on Silt Density Index (SDI) and Modified Fouling Index (MFI) were stated (Kim et al., 2006; Li et al., 2006; Malkoske et al, 2020; Nahrstedt and Camargo Schmale, 2008; Park et al, 2006; Schippers et al., 2014).

These indicators only allow to determine the degree of reduction in the concentration of suspensions and colloids in water, which causes increased membrane fouling. The assumptions

of the methodology for measuring MFI or SDI, based on the application of relatively high feed pressure to the membrane (above 200 kPa), reflect quite well the phenomena occurring during in-line coagulation, especially with the usage of pressure membranes (Salinas Rodriguez et al., 2019). However, they do not allow to state a coagulant dose or required conditions for the operation of conventional coagulation, in-line coagulation in a filter bed, and ultrafiltration based on membranes at low transmembrane pressure (TMP). This means that MFI or SDI are only very good indicators of the quality of water feeding ultrafiltration and osmotic membranes but are not very useful tools for setting parameters of the coagulation process. This is caused not only by the dominant mechanism of the separation process itself but primarily by the course of coagulation/flocculation process and the resulting mechanical properties of the formed flocs (Kabsch-Korbutowicz, 2005; Kim et al., 2006; Li et al., 2006; Nahrstedt and Camargo Schmale, 2008; Salinas Rodriguez et al., 2019; Schippers et al., 2014; Zularisam et al., 2006).

The conditions under which coagulation is carried out, both in terms of hydraulic parameters and the chemistry of the process, determine their size, shape, and rheological properties. Depending on the type of coagulant (hydrolyzing or pre-hydrolyzed) and the method of coagulation (charge neutralization, bridging, sweep coagulation), the agglomerates formed during flocculation affect the hydraulics of ultrafiltration membranes differently (Duan and Gregory, 2003; Park et al, 2006; Zhao et al., 2010). It was confirmed by the research which showed that in the case of pre-hydrolyzed coagulants, sweep coagulation allows not only to achieve the best effects in removing organic pollutants measured as DOC and SAC245, but also has the least impact on the decrease of UF membrane flux (Mao et al., 2013; Wang et al., 2009; Zularisam et al., 2006). This means that sweep coagulation is a very good choice as pre-treatment before UF membranes.

However, under sweep coagulation mechanism, when electrokinetic potential is exceeded, a sharp increase of coagulant hydrolysis products in the form of fine particles is noted. Therefore, the produced flocs are significantly smaller, which causes problems with their separation in the clarification process preceding ultrafiltration (Mao et al., 2013; Wang et al., 2009; Zhao et al., 2010). In practice, to improve sedimentation properties of flocs, flocculation aids or additional mineral weighting agents are used, conducting the process based on the principles of sand ballasted sedimentation (SBS). However, dosing of flocculation aids in the form of high-molecular-weight organic polymers is risky because their overdosing can very negatively affect the operational parameters of UF systems. Therefore, a necessary condition to achieve required high treatment effectiveness in such a technological system is the use of correct doses of coagulant and flocculant. Standard methods for determining optimal doses, such as jar tests and the use of stream current analysers, are severely limited in this case. These methods were developed to determine the best conditions for coagulation based on bridging and charge neutralization mechanisms and are not effective in monitoring sweep coagulation.

The article presents a developed method for controlling and monitoring coagulation/sand ballasted sedimentation process of flocs produced based on sweep coagulation mechanism. For process control, the methodology used in determining MFI (Modified Fouling Index) was applied, utilizing a standard suction unit for vacuum filtration. A vacuum filtration test better reflects conventional and in-line coagulation processes compared to commonly used pressure filtration test. In testing only a small amount of water samples is required. No complicated laboratory equipment is necessary, which is particularly important during site tests.

2. MATERIALS AND METHODS

2.1. Technical installation

The research was conducted during the start-up of a technical pre-treatment installation for a membrane water desalination plant. A simplified plant diagram is shown in Figure 1. The pre-treatment installation includes a conventional coagulation system based on the principles of sand ballasted sedimentation and a pressure ultrafiltration unit.

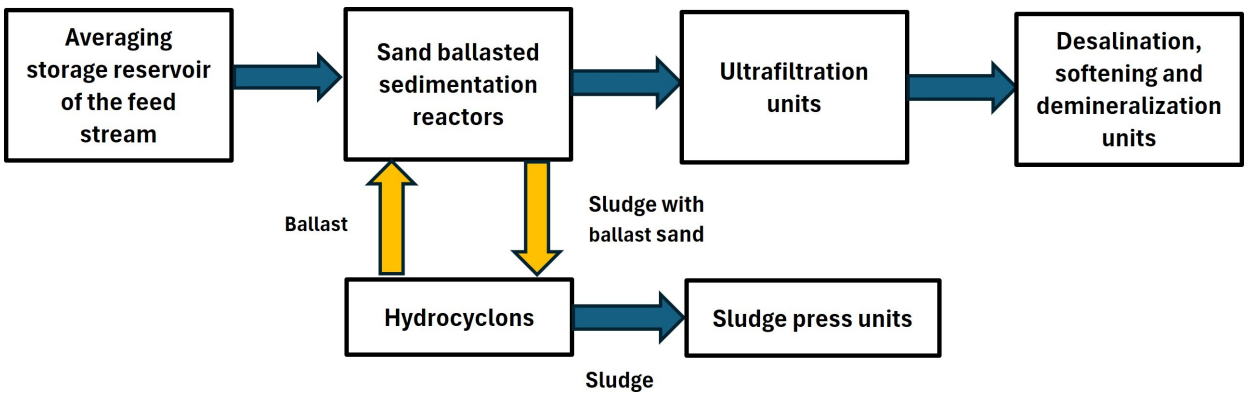

Figure 1. Simplified diagram of the water treatment plant.

The coagulation system consists of a multi-chamber reactor preceded by a mechanical filtration system with a 500 µm cutoff screen and a feed water heating system. Water heating is performed using a plate heat exchanger to a temperature in the range of 23 to 26 °C. The momentary flow of raw water to the reactor is carried out using control valves, controlled by the signal from the flow meter. The range of operational capacity is varied from 60 to 110 % of nominal, designed capacity depending on the actual water demand. An aluminium coagulant is dosed downstream of the reactor, to the feeding pipe. The dosing of the regent is carried out in a proportionally automatic mode at a dose defined by the operator based on the laboratory tests. The reagent is dosed automatically. After coagulant dosing raw water flows to the rapid mixing zone of the reactor. In the rapid mixing chamber, hydrolysis of the coagulant occurs, and precipitation of post-coagulation aggregates (flocs) starts. To ensure proper mixing conditions, the high-speed chamber is equipped with a high-speed stirrer driven by variable frequency drive motor. From rapid mixing (coagulation) chamber, the water flows through a submerged top overflow into the coagulation zone. In the coagulation chamber the formation of agglomerates takes place. These agglomerates are formed by attaching the flocs to neutral grains (sand) using a flocculant. The use of a high-density inert sand enables to produce high-density agglomerates with very good sedimentation properties. Sand grains are added into the coagulation chamber during start-up of the plant and are recovered from the post-coagulation sludge by means of hydrocyclones. To achieve proper mixing conditions, the coagulation chamber is equipped with a high-speed stirrer driven by variable frequency drive motor. The water with the produced agglomerates flows into the flocculation chamber, where post-coagulation aggregates grow, and sorption of dissolved organic pollutants takes place. To ensure adequate mixing energy, the flocculation chamber is equipped with a slow-speed stirrer with infinitely variable speed control to achieve the required mixing gradient. The water with agglomerates flows via a submerged overflow to a lamella settling tank. In this tank flocs are separated from the treated water. The clarified water is directed to the outlet channel. Post-coagulation sediment accumulates at the bottom of the settling tank, in a settling hopper. To improve sludge removal, the hopper is equipped with a sludge scraper. The thickened sludge is recirculated to the sand recovery system. This system operates in periodic mode. Within the recirculation system, sludge pumps feed the post-coagulation sludge to a hydrocyclone, where the aluminium hydroxide sludge is separated from the inert grains. The recovered neutral grains feed the coagulation chamber, and the post-coagulation sludge is directed to the sewage system. The sludge pumps are equipped with adjustable flow rate, allowing the capacity of the recirculation system to be adapted to the amount of sludge generated during the treatment process.

Clarified water from the reactors is directed, via an intermediate tank, to the pressure ultrafiltration units. The installation consists of capillary ultrafiltration modules, operating in an in-out configuration and adapted for in-line coagulation. During the research, the hydraulic load (flux) of the membranes was 105 $dm^3/(m^2 \cdot h)$ when operating in dead-end mode and 94 $dm^3/(m^2 \cdot h)$ when operating in cross-flow mode. Before UF membranes, the same coagulant as in the conventional coagulation system was added at a dose of 1 mg Al/dm^3.

2.2. Laboratory tests

The tests were conducted during a 4-month startup and trial operation of the technological installation. The SBS and ultrafiltration system were supplied with river water and a mixture of river water and rain/meltwater. The quality of the river water during the tests was relatively stable in terms of basic quality indicators. When the system operated based on the mixture of river and rain/meltwater, the quality of the feed water changed depending on the mixing ratio of the individual supply streams. The characteristics of the river water and the mixed water are presented in Table 1.

Table 1. Characteristics of raw water supplied to the technical treatment system.

Raw water quality	Minimum value	Maximum value	Median value
Turbidity [NTU]	1.7	6.9	5.1
SAC254 [1/m]	13.0	28.9	21.3
Color [mg/dm^3]	8	55	43
TOC [mg/dm^3]	3.0	7.6	5.0
TSUVA [dm^3/(mg C·m)]	3.2	6.0	4.4

As a coagulant, pre-hydrolyzed polyaluminum chloride (PACl) with high degree of polymerization and basicity (OH/Al ratio) of 85% was used. The coagulation with PACl was supported by dosing a flocculant (an anionic polymer). The selection of coagulant and flocculant doses during the process was carried out based on two procedures: a standard jar test procedure and a procedure involving the analysis of samples collected with a vacuum filtration apparatus. The standard jar test procedure was conducted in two stages. The first stage involved dosing only the coagulant, followed by rapid mixing (2 min at 200 rpm), slow mixing/flocculation for 10 minutes at 50 rpm, and 15 minutes of sedimentation in a standard 6-beaker mechanical stirrer flocculator. The supernatant after settling was tested for turbidity and subjected to vacuum filtration. Selected quality parameters were analysed in the filtrate: absorbance at a wavelength of 254 nm and TOC in selected samples. The aim of this stage was to determine the coagulant dose allowing for the greatest possible removal of organic compounds and colloids causing water colour.

The second stage of the tests aimed to select the correct flocculant dose to ensure the proper course of the SBS process while minimizing the risk of increased UF membrane fouling

due to residual flocculant in the water after sedimentation. Tests at this stage were conducted based on a modified jar test procedure, adapted for conducting the coagulation process using an inert material acting as a weighting agent for the forming flocs. The same type of microsand that was used in the technical system was utilized in the tests. The procedure involved dosing the coagulant at the dose determined during the first stage of the tests and conducting rapid mixing in the presence of the inert material for 2 minutes, followed by adding the tested flocculant doses to subsequent beakers.

After dosing the polyelectrolyte, the samples were mixed at a speed of 100 rpm for 6 minutes. After switching off the stirrers, the samples were left for sedimentation, and after 5 minutes, the supernatant was collected for analysis. Like at the first stage, the water after sedimentation was tested for turbidity and subjected to vacuum filtration, and the filtrate was analysed for absorbance at a wavelength of 254 nm (SAC254), colour, and TOC in selected samples.

A standard laboratory device was used for vacuum filtration of samples. A vacuum filtration device is a laboratory instrument that uses a vacuum pump to draw liquid through a filter, separating solids from liquids more efficiently than gravity filtration. It consists of a filter cup or funnel, a filter membrane, a collection flask, a vacuum pump, and connecting tubing (Fig. 2). The vacuum pump creates a pressure difference, which forces the liquid through the filter membrane and into the collection flask, leaving the solid residue behind. The filtration process was conducted at a vacuum equal to 50 kPa, and the amount of feed was constant at 200 cm^3. Additionally, filtration times after filtering 50, 100, and 150 cm^3 of the sample were also measured.

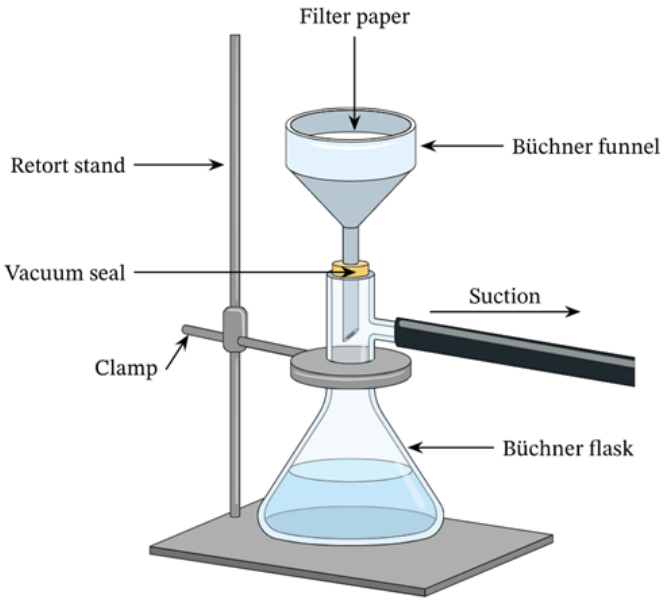

Figure 2. Diagram of vacuum filtration device.

This allowed for preliminary determination of the rate of filter cake formation depending on the coagulation process parameters. As a reference sample, demineralized water with high parameters (ultra-pure water) was used: electroconductivity below 0.1 µS/cm and TOC below 100 µg/dm^3. The filtration time for the reference sample (200 cm^3) ranged from 28 to 30 seconds depending on its temperature.

3. RESULTS AND DISCUSSION

3.1. Raw water

The results of the conducted tests showed that the quality of the water feeding the treatment plant exhibited very high variability in terms of filterability. Filtration times of collected raw water samples varied over a very wide range: from 55 seconds to over 20 minutes depending on weather conditions and the degree of mixing river water with rain/meltwater. Filtration times in raw water samples significantly increased with the increase in the share of rainwater in the water mixture supplying the installation. Very characteristic was the complete lack of correlation between basic water quality indicators, such as turbidity, SAC254 or TOC, and filtration time (Fig. 3).

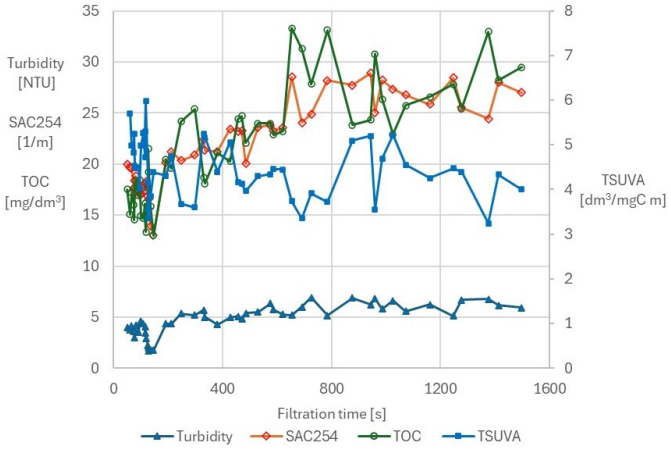

Figure 3. Relationship between filtration time and basic water quality parameters.

During the tests, it was only observed that during periods when meltwater appeared, there was a slight increase in UV absorbance without a clear increase in turbidity or TOC. Nevertheless, these changes were not significant enough to establish any important correlations. This means that substances present in the water could not be detected using basic quality indicators applied in standard water monitoring, although they potentially had a significant impact on the operational efficiency of ultrafiltration membranes. Analysis of Total Specific Ultraviolet Absorbance (TSUVA) values shows that this parameter ranged from approximately 3 to 6 dm^3/(mg C·m), which means that the raw water is susceptible for coagulation carried out according to the mechanism of sweep coagulation.

3.2. Jar tests

The application of vacuum filtration as an additional evaluation element in determining the required reagent doses proved to be a very effective parameter supporting the decision-making process. In the standard interpretation of jar test results, the optimal dose is the lowest effective dose, i.e., one that allows for the best removal of pollutants present in the raw water. The optimal coagulant doses, stated in jar tests, for actual quality of raw water, varied within the range of 15 to 30 g/m^3 of technical coagulant (1.5 to 3.0 g Al/m^3).

Figures 4a and 4b show exemplary results obtained during the first stage of jar tests aimed at determining the optimal coagulant dose, conducted on river water. The maximum values for the removal efficiency of SAC254 and TOC do not coincide with the filtration times. It can be observed that with an increase in the coagulant dose, the filtration resistance increased.

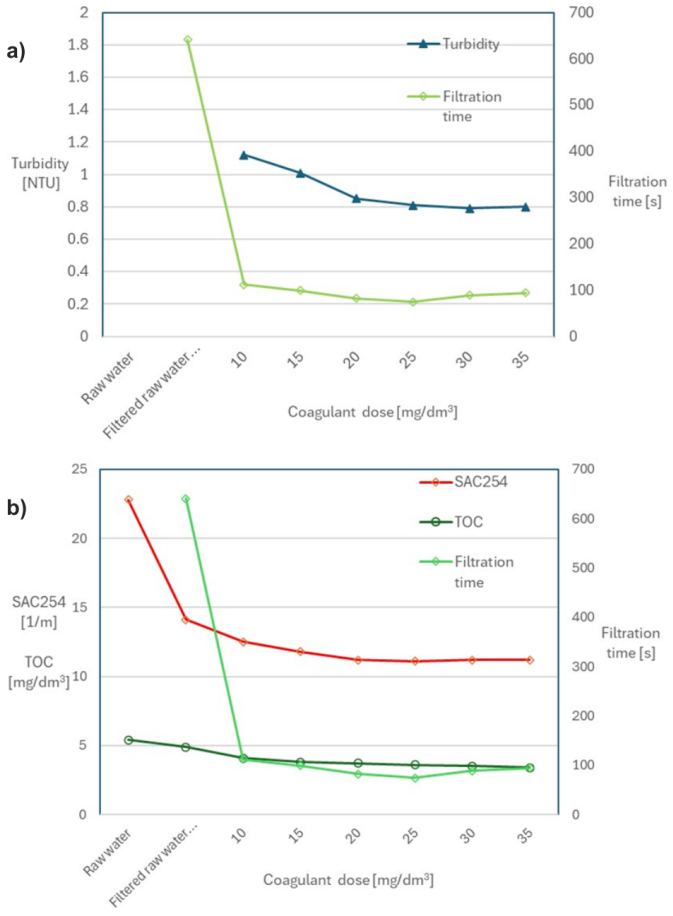

Figure 4. Coagulant dose vs filtration time relationship and basic water quality parameters.

This was probably caused by the appearance of a larger number of fine particles of precipitated coagulant hydrolysis products with increasing coagulant dose. However, which is characteristic for pre-hydrolyzed coagulants, this was not accompanied by an increase in turbidity or a decrease in SAC254 removal efficiency. This results from the size distribution of flocs formed when using this type of coagulant in the initial phase of the process and from the conditions of conducting the process based on the principles of sweep coagulation. In the tests when feed water was a mixture of river water and rainwater, there was still a lack of correlation between the removal efficiency of contaminants determined as SAC254 and TOC and the filtration time.

While at the first stage of jar tests the minimum vacuum filtration times did not coincide with the highest levels of removal efficiency for basic pollution indicators, in the second stage of tests these dependencies were clearer. The second stage of jar tests aimed to determine the flocculant dose allowing for the correct course of enhanced coagulation process while maintaining the concentration of residual flocculant at a concentration not impairing the performance of ultrafiltration membranes. Figures 5a and 5b present the results obtained during the procedure for selecting the optimal flocculant dose using the coagulant dose determined in the first stage of jar tests. The coagulant dose was 20 mg/dm^3 (2 mg Al/dm^3).

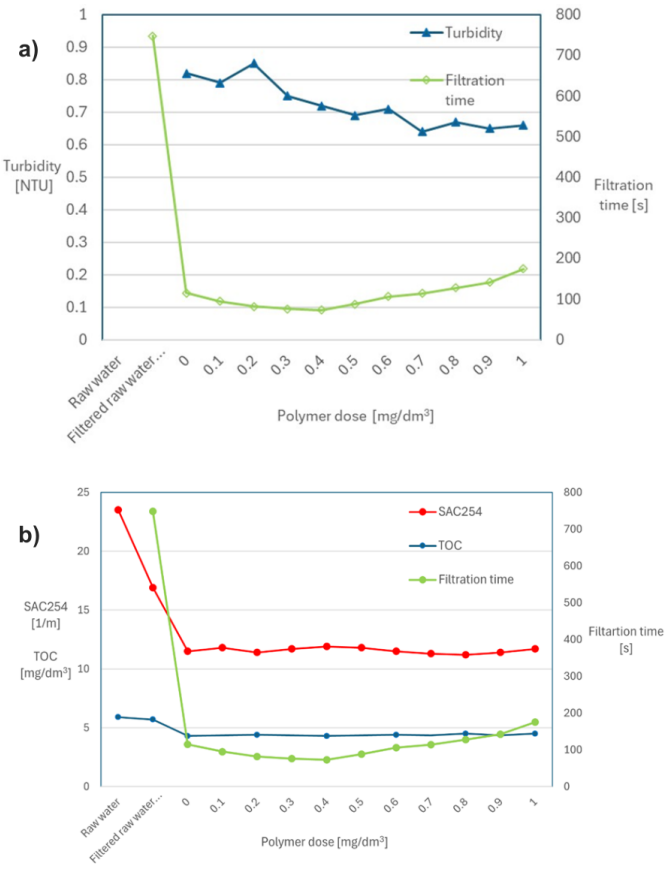

Figure 5. Polymer dose vs filtration time relationship and basic water quality parameters.

From Figure 5, it can be noted that there is a strong correlation between the applied flocculant dose and the filtration time. Like at the first stage of research, the basic parameters used to assess coagulation effectiveness during the jar test

procedure did not coincide with the sample filtration times (Fig. 5a). While the maximum values for the removal efficiency of organic pollutants measured as SAC254 and TOC were practically the same for all flocculant doses, which resulted from using the optimal coagulant dose responsible for NOM removal, relatively low turbidity values were measured in the supernatant for each sample, with the lowest values for a flocculant dose equal to 0.7 mg/dm^3 (Fig. 5b). However, the shortest filtration time was recorded for the sample with the polymer dose at 0.4 mg/dm^3.

The standard interpretation of the results presented in Figures 5a and 5b, based on the analysis of turbidity and SAC254 removal, suggests using a flocculant dose of 0.7 mg/dm^3. However, for this polymer dose, the filtration time is almost 40% longer than that for a dose 0.3 mg/dm^3 lower. The results of the other tests were very similar, showing that the minimum filtration time did not coincide with the lowest values of the standard quality parameters considered when interpreting jar test results.

The interpretation of these data is related to the fact that polymer is used to enhance coagulation/flocculation. Its task is not only to create stable, well-settling aggregates – flocs – inert grains, but also to aggregate very fine particles of precipitated hydrolysis products of coagulant, which appear during treatment carried out by sweep coagulation mechanism. However, to obtain low supernatant turbidity under such conditions, a slight excess of polymer is required, which at the same time blocks the pores of the filter, increasing filtration resistance. This means that from the perspective of conditions required for conducting the filtration process of water following enhanced coagulation, jar tests with filtration time analysis are a very good tool for selecting the required flocculant dose, allowing to avoid the occurrence of too much residual polymer in the water feeding the membranes, the presence of which is undetectable using standard analytical methods (TOC, SAC254).

3.3. Filtration mechanism

As part of the jar tests, samples were also analysed in terms of filtration process kinetics. According to the assumptions of the model describing MFI, the filtration process can be divided into 3 consecutive stages: pore blocking, cake filtration, and cake compression. Figure 6 presents the research results obtained during the filtration of samples analysed during jar tests and samples collected after the reactor from a conventional technical system.

From the graphs, it is evident that the duration of the first phase (pore blocking) depends on the type of sample. For raw water, this phase ends very quickly (after a few seconds), for samples after coagulation, the breakthrough point indicating a change in the type of filtration begins only after 25% of the sample volume has been filtered. The interpretation

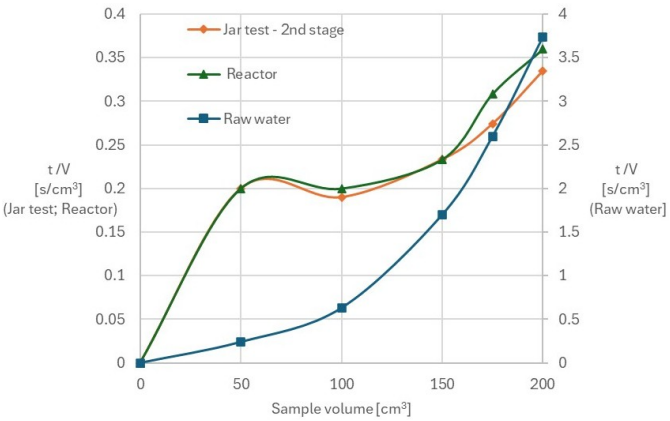

Figure 6. Changes in filtrate flow capacity during filtration test.

of such a graph course suggests that the raw water being treated contains a very large number of fine, membrane-blocking particles that are not aggregated into larger flocs. These fine particles form a layer on the filter surface with low porosity, and thus low permeability, which very quickly reaches limiting filtration resistance values. Application of coagulation/flocculation process changes the structure of the filter layer. The formation of flocs with an extensive spatial structure allows for the building of a filter layer (cake layer), which acts as a filter medium retaining fine particles. The authors' experience with the use of particle counters confirms the observation that the effectiveness of filtration is mainly determined by the degree of aggregation of particles up to approximately 2 µm in size during the coagulation process. In technical systems, this effectiveness can be monitored using online particle counting, but this parameter will not be as accurate as filtration time, which is influenced by other, sometimes unidentified factors.

Similar courses of the curves on the graph based on the data obtained during jar tests and the results of analyses of samples collected after the reactor suggest that the jar test methodology and the process parameters selected during it are very similar to the conditions prevailing in the technical installation. Potential discrepancies between filtration times obtained for samples in laboratory testing and detected in the technical system may indicate that the process parameters deviate from the assumed state and intervention of the treatment plant maintenance staff is necessary. This allows to optimize enhanced coagulation before the negative effects observed during filtration impact the performance and condition of ultrafiltration membranes.

3.4. Application of filtration procedure to monitor UF operational parameters

To assess the impact of feed water quality on the operational parameters of technical UF units, monitored based on filtration time measurement, water samples were periodically collected after the SBS reactor feeding the UF installation. Figure 7

shows a course of transmembrane pressure (TMP) changes during a 12-hour operating period of the unit. During this time, water samples feeding the UF membranes were collected every 2 hours and then analysed. Filtration time was also stated.

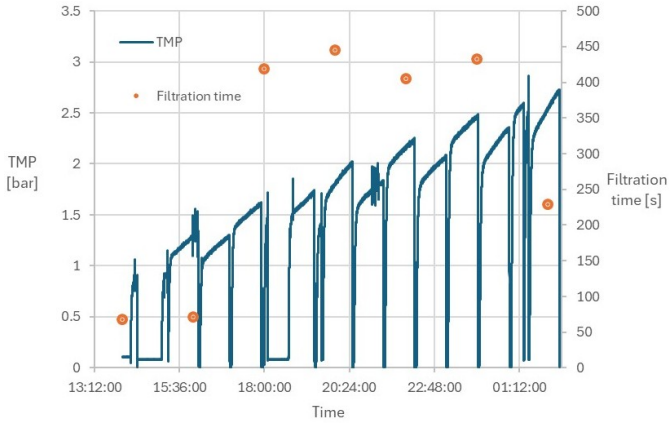

Figure 7. Changes in UF capacity and filtration time during polymer overdosing.

Filtration time values and the TMP changes were plotted. During the testing period, the UF units operated in dead-end mode at nominal capacity and with filtration duration of 60 minutes. From the graph, initially, TMP values were low, ranging from 1 bar at the beginning of the filter run to 1.4 bar until the unit was shut down for backwashing. However, after the first 2 filter runs, a gradual but significant increase in filtration resistance was observed. From the graphs, this increase was relatively constant, and backwashing recover membrane permeability to a small extent. Water samples feeding the UF units collected and analysed during this time did not show significant changes in basic water quality indicators. The only symptom of feed stream deterioration was an increase in filtration time from approximately 70 seconds to over 400 seconds. Not only the filtration time changed but also the curve shape of the decrease in efficiency during filtration. Figure 8 shows that while in a sample with low

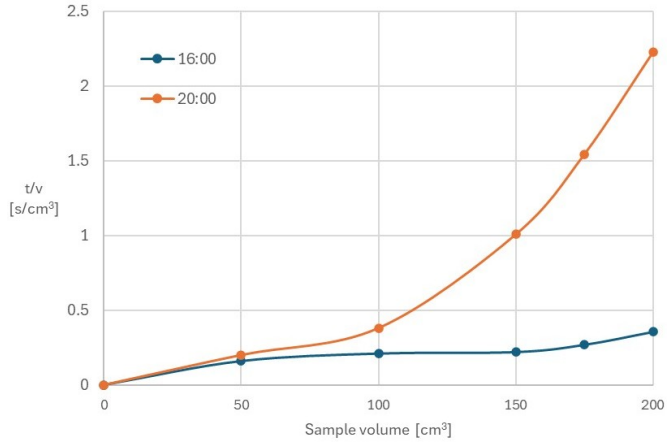

Figure 8. Changes in filtrate flow capacity during filtration test of overdosed samples.

filtration time the curve shape is typical for properly coagulated water, in the sample with a longer filtration time, pores become blocked very quickly and the course of changes is like that observed in raw water.

The course of TMP changes for subsequent filter runs was, however, different from that observed for raw water. In the case of UF units without prior coagulation, backwashing process restored the initial increase in differential pressure. Analysis of the auxiliary installation operation showed that the cause was a failure in the automation of the flocculant dosing system, which resulted in the dosing of an excessively high polymer dose. The flocculant dose was twice higher than the dose determined during the jar tests.

4. CONCLUSIONS

The results of the research on coagulation/SBS process used as pretreatment for a UF system showed that it is a very effective way to ensure proper operating conditions for UF membranes. During coagulation, colloidal pollutants are removed, and very fine particles are aggregated, which, bound in a spatial structure, enable the formation of an appropriate filter layer on the membrane surface, ensuring effective retention of suspended solids. However, a prerequisite for this is the necessity of using appropriate operational parameters for coagulation, particularly optimal reagents doses.

The results of the research show that the best tool for monitoring coagulation/SBS process as pre-treatment of water feeding UF membranes, is the control of clarified water quality based on measuring changes in the permeability of the filter membrane. These assumptions, commonly used in measurements of parameters such as SDI or MFI, however, have certain limitations that make it difficult to use them as a routine procedure for assessing water quality within operational monitoring. Although assumed high TMP values in the methodology of these tests accurately reflect operating conditions in pressure systems, it hinders the identification of the causes of problems occurring at the coagulation stage. This is due to the intensification of the filter layer compression process because of high initial TMP and the consequent rapid change in these parameters. In the case of vacuum membranes, the formation of the filter layer is slower, and potential irregularities can be detected and their causes identified more quickly.

The results of the research on the application of a simple vacuum filtration test showed that it is a very good tool for monitoring and controlling the operational parameters of coagulation. During the research, a high correlation was shown between the filtration time values of samples and the quality of the raw water feeding the treatment system, which affects the subsequent course of ultrafiltration. Quality parameters responsible for the effectiveness of membrane separation technique were difficult to identify using the standard range of quality monitoring (turbidity, SAC254, TOC), and only

sample filtration allowed for the identification of a potentially dangerous stream for the membranes. Therefore, this measurement seems to be a necessary element by which analytical tests conducted as part of jar tests for coagulation in systems where membrane techniques are used should be involved. Similar dependencies were observed in clarified water supplied to UF membranes. Standard monitoring measurements, including turbimeters, SAC254 analysers installed in the technical system, were unable to detect situations where the optimal doses of coagulant and flocculant deviated from the values determined during jar tests. Only the analysis of filtration kinetics allows for their detection and significantly facilitates the identification of causes.

REFERENCES

Campinas M., Rosa J.M., 2010. Assessing PAC contribution to the NOM fouling control in PAC/UF systems. *Water Res.*, 44, 1636–1644. DOI: 10.1016/j.watres.2009.11.012.

Duan J., Gregory J., 2003. Coagulation by hydrolysing metal salts. *Adv. Colloid Interface Sci.*, 100–102, 475–502. DOI: 10.1016/S0001-8686(02)00067-2.

Kabsch-Korbutowicz M., 2005. Application of ultrafiltration integrated with coagulation for improved NOM removal. *Desalination*, 174, 13–22. DOI: 10.1016/j.desal.2004.08.037.

Kim H.-C., Hong J.-H., Lee S., 2006. Fouling of microfiltration membranes by natural organic matter after coagulation treatment: a comparison of different initial mixing conditions. *J. Membr. Sci.*, 283, 266–272. DOI: 10.1016/j.memsci.2006.06.041.

Li T., Zhu Z., Wang D.S., Yao C., Tang H., 2006. Characterization of floc size, strength and structure under various coagulation mechanisms. *Powder Technol.*, 168, 104–110. DOI: 10.1016/j.powtec.2006.07.003.

Malkoske T.A., Bérubéb P.R., Andrews R.C., 2020. Coagulation/flocculation prior to low pressure membranes in drinking water treatment: a review. *Environ. Sci.: Water Res. Technol.*, 6, 2993–3023. DOI: 10.1039/d0ew00461h.

Mao R., Wang Y., Zhang B., Xu W., Dong M., Gao B., 2013. Impact of enhanced coagulation ways on flocs properties and membrane fouling: Increasing dosage and applying new composite coagulant. *Desalination*, 314, 161–168. DOI: 10.1016/j.desal.2013.01.012.

Nahrstedt A., Camargo-Schmale J., 2008. New insights into SDI and MFI measurements. *Water Supply*, 8, 401–412. DOI: 10.2166/ws.2008.087.

Park P.-K., Lee C.-H., Lee S., 2006. Variation of specific cake resistance according to size and fractal dimension of chemical flocs in a coagulation–microfiltration process. *Desalination.*, 199, 213–215. DOI: 10.1016/j.desal.2006.03.051.

Salinas Rodriguez S.G., Sithole N., Dhakal N., Olive M., Schippers J.C., Kennedy M.D., 2019. Monitoring particulate fouling of North Sea water with SDI and new ASTM $MFI_{0.45}$ test. *Desalination*, 454, 10–19. DOI: 10.1016/j.desal.2018.12.006.

Schippers J.C., Salinas-Rodriguez S.G., Boerlage S.F., Kennedy M.D., 2014. Why MFI is edging SDI as a fouling index. *Desalination & Water Reuse*, May-June 2014, 28–32.

Wang Y., Gao B.-Y., Xu X.-M., Xu W.-Y., Xu G.-Y., 2009. Characterization of floc size, strength and structure in various aluminum coagulants treatment. *J. Colloid Interface Sci.,* 332, 354–359. DOI: 10.1016/j.jcis.2009.01.002.

Wang Y., Li M., Yang H., 2025. A review on mitigation of pressure-driven membrane fouling by coagulation/flocculation as a pretreatment in membrane separation processes. *Sep. Purif. Technol.*, 364, 132370. DOI: 10.1016/j.seppur.2025.132370.

Zhao B., Wang D., Li T., Chow C.W.K., Huang C., 2010. Influence of foc structure on coagulation–microfiltration performance: effect of Al speciation characteristics of PACls. *Sep. Purif. Technol.*, 72, 22–27. DOI: 10.1016/j.seppur.2009.12.023.

Zularisam A.W., Ismail A.F., Salim R., 2006. Behaviors of natural organic matter in membrane filtration for surface water treatment – a review. *Desalination*, 194, 211–231. DOI: 10.1016/j.desal.2005.10.030.