Membrane filtration in swimming pools – case study

Filtracja membranowa w obiektach basenowych – studium przypadku

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Rational water and wastewater management in water-intensive public facilities is the basis for sustainable development in the 21st century. Considering that Poland is one of the countries with a high risk of water deficit, the use of membrane technologies for water recovery from washings in highly water-intensive swimming pool facilities is a complementary solution to two environmental engineering problems currently identified in Poland, the need for optimal water management and the reduction of operating costs of public facilities. Membrane filtration makes it possible to reduce water demand, reuse different water streams, and close water and wastewater management in one system. This paper presents the environmental and financial benefits of using the membrane ultrafiltration (UF) process to recover water from washings, using the example of one of Europe's most modern aquaparks, "Suntago". The analysis of water parameters before and after the UF membrane process was the main scope of this study. Separation of pollutants by membrane systems, in conjunction with a reduction in disinfection costs of reclaimed water, is an undeniable advantage of this technology. Selecting the appropriate water recovery system and controlling the parameters of the filtration process, filter bed washing, and membrane cleaning allow optimal operation of the system used, with the relatively highest operating profitability related to the need to replace the membranes in relation to the amount of recovered water.

Keywords: membrane filtration, swimming pool, washings, water recovery, sustainability.

Racjonalna gospodarka wodno-ściekowa w wodochłonnych obiektach użyteczności publicznej jest podstawą zrównoważonego rozwoju w XXI wieku. Biorąc pod uwagę, że Polska należy do krajów o wysokim ryzyku deficytu wody, stosowanie membranowych technologii odzysku wody z popłuczyn w wysokowodochłonnych obiektach basenowych jest komplementarnym rozwiązaniem dwóch problemów inżynierii środowiska identyfikowanych obecnie w Polsce – potrzeby optymalnego gospodarowania wodą oraz obniżenia kosztów eksploatacji obiektów użyteczności publicznej. Filtracja membranowa pozwala na zmniejszenie zapotrzebowania na wodę, ponowne wykorzystanie różnych strumieni wody oraz zamknięcie gospodarki wodno-ściekowej w jednym systemie.
W niniejszej pracy przedstawiono korzyści środowiskowe i finansowe, wynikające ze stosowania ultrafiltracji (UF) membranowej do odzysku wody z popłuczyn, na przykładzie jednego z najnowocześniejszych krytych aquaparków w Europie – „Suntago". W celu oceny efektów UF analizie poddano parametry jakościowe wody przed i po procesie UF. Separacja zanieczyszczeń oraz redukcja kosztów dezynfekcji odzyskiwanej wody stanowią niezaprzeczalną zaletę analizowanej technologii. Dobór odpowiedniego systemu odzysku wody oraz kontrola parametrów procesu filtracji, płukania złóż filtracyjnych i czyszczenia membran pozwalają na optymalną pracę zastosowanego układu, przy stosunkowo najwyższej rentowności operacyjnej związanej z potrzebą wymiany membran w stosunku do ilości odzyskiwanej wody.

Słowa kluczowe: filtracja membranowa, basen, popłuczyny, odzysk wody, zrównoważony rozwój.

Introduction

The 21st century has been marked by significant economic and social changes, political instability, and a pandemic (SARS COVID-19), as well as wars outside the east-ern border of the EU. As a result, prices have risen considerably, and countries within the European economic system have been urged to become independent in terms of energy and raw materials [1-3]. This has highlighted the already clearly defined and emphasized need for rational management, including water and wastewater management [4]. Public swimming pools, being highly media demanded facilities [5-6], are suited to this trend, thus various possibilities are being analysed to reduce maintaining costs [7,8], among others by reusing different water streams [9-12]. While membrane technologies have been already used in industry for many years [13-16], its usage in swimming pool facilities, although already proposed and analysed by few authors [17,18] has been so far considered as very expensive in terms of investment and operation and thus it has not very often been used in practice in operating swimming pool facilities. The application of membrane techniques in the swimming pool branches seems to be particularly important in the context of the latest reports on organic

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micropollutants identified in swimming pool water [19-23], as well as the danger from disinfection products occurrence in swimming pool water [24-28].

The presented case study demonstrates the financial and environmental benefits of application the membrane filtration process for wastewater recovery using an example of the "Suntago" Park in Poland, one of the most modern aquapark in Europe.

The performed research aimed to analyse the system for recovering backwash water and reusing it, monitoring the amount of recovered water, and conducting physicochemical analyses of selected quality parameters of raw washings and two stages of their purification. The obtained results were compared with the values required in the regulation of the Minister of Health on the requirements to be met by water in swimming pools [29]. The study hypothesized that current design guidelines and assumptions should obligate swimming pool facility managers to reuse backwash water and refreshment water. The implementation of an effective water recovery system and its reuse will not only impact the profitability of facilities but will also align with the idea of sustainable development and environmentally friendly technologies, minimizing the negative impact on the environment. Design and assumptions made during the functional and utility programs for modernized and newly designed facilities should be based on the rationalization of the economy, recovery, and closure of the water cycle within one facility. Refreshing water in swimming pool basins should be carried out by supplying toilets or wash basins with the water stream previously intended as a waste. This will enable to limit the amount of sewage. Assumptions that used to be considered as the "technology of the future" are now becoming necessary to implement in practice to ensure media independence of swimming pool facilities.

Materials and methods

Subject of the study

The focus of the presented research was on an innovative water recovery system that has been installed in a swimming pool facility located in the Masovian Voivodeship in Poland, namely the "Suntago" Park of Poland. The advanced system has been designed to allow the recovery of water that results from the reverse rinsing process of pressure filters. It is noteworthy that the analysed facility boasts a total of 44 pressure filters that have varying diameters, which were all taken into account during the comprehensive study.

Characteristics of the facility

The studied facility comprises several functional areas that collectively create a unified establishment. This includes:

- a foyer (main hall) with additional cloakrooms and changing rooms,
- a changing room and sanitary area with office rooms, saunas, technical area and a gallery for guests,
- a thermal part of the spa with a thermal pool and health and therapeutic pools,
- a family part of the spa,
- a restaurant that offers catering services,
- a waterslides – Galaxy.

Furthermore, there are a recreational swimming pool, part of the thermal pool, water playgrounds, and parking lots situated outdoors. The facility was designed and constructed in adherence to the highest standards, implementing the principles of rational management, the use of renewable energy sources, an environmentally friendly approach, and in compliance with all measures of protecting species diversity and environmental protection.

Characteristics of the water recovery system

The wastewater from the backwashing of filters, used to filter fresh swimming pool water, are cleaned and stored as water for the next backwashing of the filters. The washings are discharged through pipelines into two retention tanks, which are filled alternately. These tanks are utilized as settling tanks to collect easily settling suspensions, which are regularly cleaned and pumped out as thickened sludge. The overlying water is then fed to subsequent devices of the backwash treatment system using pumps that are adapted to pump dirty water. It is important to note that the pumps suck water from tanks using floats immersed just below the water surface, which allows for quiet sedimentation of suspensions at the bottom of the tanks while preventing the suction of fats floating on the water surface. The washings are precleaned in a glass bed filter (AFM), after which they are pumped to the buffer tank using a pump. The precleaned washings then flow from the buffer tank to the membrane ultrafiltration system (UF), which is equipped with filter packages (HF – Hollow Fibers). The recovered filtrate (permeate) is collected in the recovered water tank (Fig. 1). All buffer tanks (storage) are equipped with systems for measuring and controlling the liquid level in the tanks, systems that protect against the dry operation of the pump, an emergency overflow, an aeration pipe, and a drain to the sewage system.

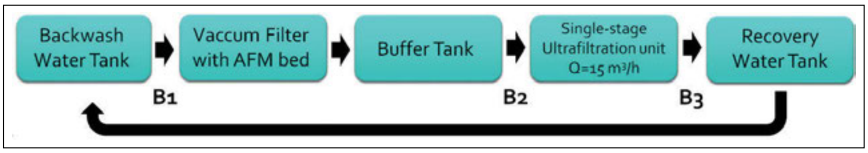

Figure 1.
Block diagram of the water recovery system
Rysunek 1. Schemat układu odzyskiwania wody

Characteristics of the membrane ultrafiltration system

The ultrafiltration system shown in Figure 2 is a single-stage unit that is fitted with a feed pump capable of generating up to 2 bar pressure. The raw water initially passes through a pre-filter that effectively eliminates particles larger than 100 µm. It then flows through modules of hollow fiber PVDF membranes from the outside to the inside, using the out-in method. The membranes are suspended on the upper part of the filter element, which facilitates the release of filtered solid particles. The air is used to clean the membranes. It is essential to note that the required pore diameter of the membranes should not be larger than 0.03 µm, and the filtration accuracy should be above 99.99% (4-log) in removing *Giardia* and *Cryptosporidium parasite* spores. Once purified, the water leaves the device. Over time, particles accumulate on the fibers, reducing filtration efficiency. When the minimum flow level is exceeded, the device switches to backwash mode. During the backwash process, the previously filtered water is used to rinse the modules from the inside out, using the in-out method. The process of moving the retained pollutants with air (air-scouring) is necessary before the rinsing. After the rinsing process, the device goes back to normal operation mode. In the event that the performance of the ultrafiltration package does not improve or only improves minimally, this indicates a blockage in the fibers. Using an integrated chemical cleaning (CIP) solution of strong acids or alkalis, the fibers should be cleaned. An integrity test is carried out to check the condition of the membranes. If the difference in inlet and outlet pressure drops below the limit, the membrane must be serviced or replaced. We have presented the detailed characteristics of the filtration membranes in Table 1.

Table 1. Technical parameters – PURON® MP Hollow Fiber Cartridge
Tabela 1. Parametry techniczne – PURON® MP Hollow Fiber Cartridge

Parameter	Unit	Description
Membrane chemistry	-	Proprietary PVDF
Membrane type	-	Braided hollow fiber for outside-in operation
Fiber support chemistry	-	Polyester
Nominal pore size	µm	0.03
Outside fiber diameter	mm	2.6
Housing shell	-	PVC
Potting material	-	Proprietary Epoxy Compound
Storage solution	-	Glycerin/Water
Membrane area	m^2	51
Maximum pressure (water)	bar	3.0
Temperature range	º C	0 ÷ 40
Maximum production transmembrane pressure	bar	25
Maximum backflush transmembrane pressure	bar	10
Allowable pH range (continuous operation)	-	4 ÷ 9
Allowable pH range (short term):	-	1.8 ÷ 10.5
Maximum total chlorine (25º C) or lower	g/m^3	1,000 (pH <10.5)
Typical air scour rate per cartridge	Nm^3/h	7 (12)
Maximum air scour rate per cartridge	Nm^3/h	9 (15)
Typical backflush flow rate per cartridge	Nm^3/h	9 (4.3)

Figure 2.
The single stage ultrafiltration (UF) in tested facility (fot. Anna Mika-Shalyha)
Rysunek 2. Ultrafiltracja jednostopniowa (UF) w badanym obiekcie (fot. Anna Mika-Shalyha)

Analytical procedures

In accordance with the research objectives and tasks of this project, the physicochemical analyses were conducted. Selected quality parameters of raw washings and samples collected during the two stages of purification. These analyses were carried out using measurement tools available in the laboratories of the Department of Water and Wastewater Engineering and the Centre of New Technologies at Silesian University of Technology. The methodology for these measurements is summarized in Table 2.

Results

The analysed facility employed a pressure multilayer media filter, which ranged in diameter from DN 650 to DN 2800. The filter containers featured a cylindrical design that was crafted using GRP fiberglass, with a dished top and bottom. These containers were manufactured via the winding process and were placed on a round GRP support. The inner fine layer was constructed using a chemical resistant special resin, which boasted an ozone-resistant coating. The height of the multilayer bed measured H = 1200 mm and the structure was designed in accordance with DIN 19643 [30] and DIN 19605 [31], with certification from the National Institute of Hygiene (PZH) and UDT (Office of Technical Inspection). The filter was designed to withstand a maximum pressure of 2.5 bar and featured a sight glass and side hatch for easy access.

Table 3 presents the technical parameters of the filters operating in the tested

Table 2. Methodology and measurement device for the analysis of physicochemical parameters of backwash water
Tabela 2. Metodyka i urządzenia pomiarowe dla analizowanych fizykochemicznych parametrów popłuczyn

Parameter	Unit	Method	Measurement device
Chemical oxygen demand (COD)	mg O$_2$/L	Spectrophotometric	Spectrophotometer UV VIS Spectroquant® Pharo 300 (Merck, Germany)
Biochemical oxygen demand (BOD)	mg O$_2$/L	Dilution	Oxi Top OC 100 (WTW, Wroclaw, Poland)
Total suspended solids (TSS)	mg/L	Spectrophotometric	HACH DR 3900 (Hach®, Loveland, CO, USA)
Total organic carbon (TOC)	mg C/L	Catalytic oxidative ombustion at 680°C	Carbon analyzer TOC-L (Schimadzu, Japan)
Turbidity	NTU	Nephelometric	Turbidmeter TN-100 (Eutech Instruments, Singapur)
Carbonate hardness	mg CaCO$_3$/L	Spectrophotometric	Spectrophotometer UV VIS Spectroquant® Pharo 300 (Merck, Germany)
pH	-	Potentiometric	SensIONmeter+ MM150DL (Hach®, USA)
Total content of calcium and magnesium	mg/L	Spectrophotometric	Spectrophotometer UV VIS Spectroquant® Pharo 300 (Merck, Germany)
Petroleum hydrocarbons measured as index of mineral oil (PH-IMO)	mg/L	Gas Chromatograph	SCION Instruments 8500 GC (SCION Instruments, Netherlands)
Substances extractable with petroleum ether (SEPE)	mg/L	Soxhlet extractor	Soxhlet extractor (Lenz Laborglas, Gemany)

Table 3. Technical parameters of pressure filters installed in the tested facility
Tabela 3. Parametry techniczne filtrów ciśnieniowych zainstalowanych w badanym obiekcie

System name/ circuit no.	Filter diameter (mm)	Quantity (pcs.)	Media type	The volume of water required for washing one filter bed (m^3)	The volume of water required for washing per month* (m^3)
Thermal pool/ I	2800	6	Multi-layer filter bed consisting of: – 15 cm of filter gravel, granulation 3÷5 mm, – 15 cm of filter gravel, granulation 1÷2 mm, – 35 cm filter sand, granulation 0.4÷0.8 mm – 40 cm of activated carbon, granulation 0.5÷2 mm, – 15 cm of hydro-filt PS (silicate filter material)	36.9	2215.6
Floating/ II	1600	1		12.1	120.6
Vital type 1/ III	1200	1		6.8	67.8
Vital type 2/ IV	1200	1		6.8	67.8
Sulfur pool/ V	1200	1		6.8	67.8
Dead sea pool 4%/ VI	1600	1		12.1	120.6
Dead sea pool 12%/ VII	1600	1		12.1	120.6
Dead sea pool 18%/ VIII	1600	1		12.1	120.6
Vital type 2/ IX	1200	1		6.8	67.8
Vital type 1/ X	1200	1		6.8	67.8
Outside bar pool/ XI	2600	2		31.8	636.8
Relax pool/ XII	2800	4		36.9	1477.1
Wave pool/ XIII	2400	4		27.1	1085.2
Bubbling pool/ XIV	2400	2		27.1	542.6
Lazy river pool/ XV	2600	2		31.8	636.8
Water playground/ XVI	2600	3		31.8	955.2
Sliding zone/ XVII	2600	6		31.8	1910.4
Calla pool/ XVIII	1600	1		12.1	120.6
Vital type 3 pool/ XIX	1200	1		6.8	67.8
Vital type 3 pool/ XX	1200	1		6.8	67.8
Fountain/ XXI	650	1		2.0	19.9
Surfing pool/ XXII	1400	2		9.2	184.6
The sum of					10741.7

*The total volume of water necessary to backwash each filter for a given circuit, assuming a washing period of once every three days.

swimming pool facility, the characteristics of the filter bed and the volume of water required for its washing.

To ensure that all filter beds are properly backwashed in a month, a volume of 10,74 m^3 of water is required. Periodic automatic membrane rinsing is essential to maintain their efficient operation. These rinses are designed to quickly and effectively remove debris from the outer surfaces. The backwash frequency varies between every 20 minutes, and the typical backflush cycle lasts between 3.5÷4.5 minutes. Proper maintenance of the cartridges is also necessary to recover membrane permeability. This involves using a Chemical Cleaning (CC) system, which includes both Clean-In-Place (CIP) and Maintenance (MC). When we consider all the water losses associated with the above processes and sum them up, the recovery rate from the membrane is approximately 80% of its nominal efficiency. This means that the recovery of rinsing water amounts to 8,593.4 m^3 per month. Assuming the average cost of water and sewage is EUR 2.5 in Poland, the monthly profit from water recovery is EUR 21,483.40. It is worth noting that the calculation does not include the financial outlays for electricity necessary to power the station, nor does it take into account the revenues from heat recovery from washings.

Figure 3 displays the quality parameter average values of washings samples collected at three different points of the recovery system. The B1 represents the values of raw washing parameters, which were measured in samples taken from washing tanks just after the necessary sedimentation time of 60 minutes. The B2, on the other hand, represents measurement values made for filtrate samples taken at the outflow of a pressure filter with the AFM bed. The values obtained from the analysis of the permeate samples after ultrafiltration (UF) through KOCH membranes are displayed as B3. The total suspended solids (TSS) value before the station was over 10 mg/L, but after pressure filtration, it reduced to only 2.7 mg/L, and after membranes, it went below 1 mg/L. The turbidity measurement showed a significant reduction after the first stage, and after membranes, it approached 0.0 mg/L, which corresponds to both the quality of drinking water [32] and the requirements for swimming pool water [30]. The carbonate hardness decreased by 25%. However, the total content of calcium and magnesium was reduced by almost 50%.

The water samples underwent thorough analysis to identify substances extractable

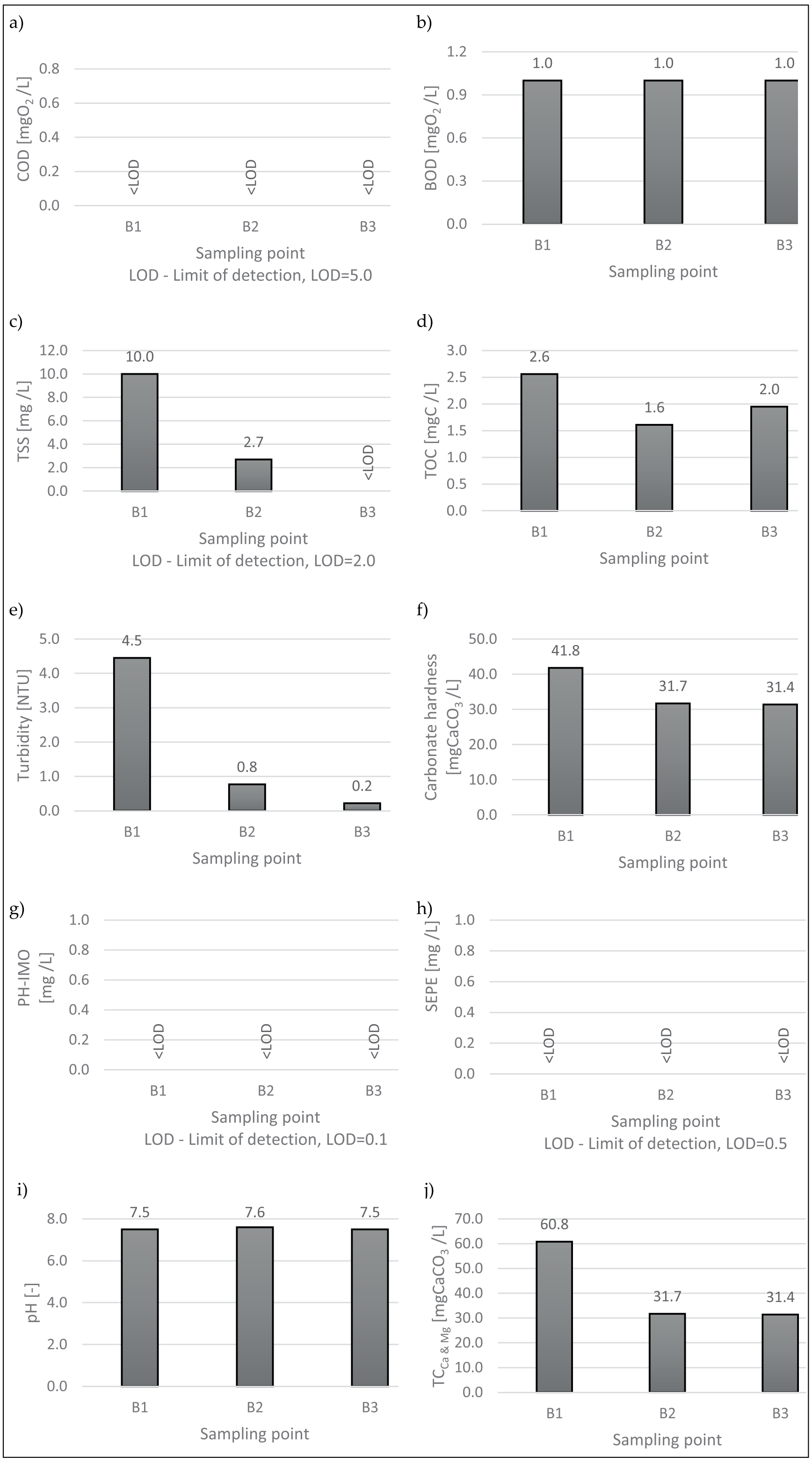

Figure 3.
Average values of the tested parameters: a) COD – chemical oxygen demand, b) BOD – biochemical oxygen demand, c) TSS – total suspended solids, d) TOC – Total organic carbon, e) Turbidity, f) Carbonate hardness, g) PH-IMO – petroleum hydrocarbons measured as index of mineral oil, h) SEPE – substances extractable with petroleum ether, i) pH, j) $TC_{Ca\&Mg}$ – total content of calcium and magnesium, in 3 different sampling points B1 – in the backwashing tank, B2 – after the pressure filter, B3 – after single-stage UF with a capacity of 15 m^3/h

Rysunek 3. Wartości średnie badanych parametrów: a) COD – chemiczne zapotrzebowanie na tlen, b) BOD – biochemiczne zapotrzebowanie na tlen, c) TSS – zawiesiny ogólne, d) TOC – ogólny węgiel organiczny, e) Mętność, f) Twardość węglanowa, g) PH-IMO – węglowodory ropopochodne mierzone jako wskaźnik oleju mineralnego, h) SEPE – substancje ekstrahowane eterem naftowym, i) pH, j) $TC_{Ca\&Mg}$ – całkowita zawartość wapnia i magnezu, w 3 różnych punktach poboru próbek B1 – w zbiorniku popłuczyn, B2 – za filtrem ciśnieniowym, B3 – za jednostopniową ultrafiltracją o wydajności 15 m^3/h

with petroleum ether utilizing the extraction method executed in the Soxhlet apparatus. Petroleum ether, known for its capacity to extract petroleum products, fats, oils, and other anaerobically decomposition-resistant compounds from water, was recognized as potentially impeding the self-purification process. Notably, the study results did not evince the presence of these substances in the tested samples.

Subsequently, the assessment pertained to the measurement of petroleum derivatives, characterized as hydrocarbons encompassing diverse physical, chemical, and biological properties inherent in crude oil. These petroleum hydrocarbons, serving as an indicator of mineral oil, were of interest due to their documented carcinogenic, neurotoxic, hepatotoxic, and teratogenic properties. It is pertinent to note that these particular substances were not identified within the measured water stream.

The obtained results indicate the achievement of a satisfactory level of water parameters after the recovery station. The water goes to the recovered water tank, which is powered additionally by the pool basin refreshing system. Water is drawn from here by pumps that rinse pool filters. To maintain constant water circulation in the tank and prevent it from rotting, an additional circulation pump with a disinfectant in the form of chlorine dioxide solution was used.

Discussion

Water recovery is a fundamental need in the current water management system. Fernandes et. al. in their study [33] have shown that a circular economy in the water sector is a priority for most countries, despite the challenges it presents. Indoor swimming pools are recognised to have a high level of water consumption [34,35] and therefore they present a great potential for water saving. The increasing costs of utilities, especially water, from year to year make it difficult to manage swimming pool facilities, while reducing their profitability [36]. As a properly executed filtration process is essential to maintain the quality of pool water, regular cleaning of the filter beds is required. However, this process demands very large volumes of water and is the main source of water consumption in typical public swimming pools [37,38]. Pool water is circulated through a filter to capture dirt, debris, and other contaminants, which can eventually clog the filter and require cleaning. This is achieved by reversing the flow of water through the filter, dislodging the trapped particles and flushing them out through a waste line. The resulting water is referred to as backwash water . Silva et al. [39] conducted a study to determine the annual water consumption required for the backwash of filter beds in an indoor swimming pool located in Braganca, Portugal. The swimming facility, comprising a sports pool measuring 25 m × 17 m and a recreational pool measuring 10 m × 16.6 m, was examined in order to evaluate it water usage levels. The research found that the total volume of water required for the backwashing of the filter beds was 4197.6 m^3 annually. Contemporary concerns about water scarcity and environmental responsibility have led swimming pool owners and operators to seek ways to reduce water consumption and wastewater discharge.

In this context, the filtration washings, commonly referred to as backwash water have garnered increasing attention [40]. Traditionally, it has been considered as wastewater and discharged into the sewage system. However, given the significant volumes of water used in washing, this practice can put a considerable strain on water resources and environmental sustainability. The discharged backwash water from swimming pool facilities represents a significant opportunity for beneficial reuse. By prioritising the management of backwash water, swimming pool operators can significantly reduce their water consumption and wastewater discharge, while also contributing to the sustainable management of water. This approach aligns with the principles of integrated water resources management, which emphasizes the importance of using water resources efficiently and sustainably. The management of the backwash water from swimming pool facilities presents a significant opportunity for water conservation and sustainable management. By exploring and implementing alternative applications for this water, swimming pool operators can contribute to the broader framework of integrated water resources management while simultaneously reducing their environmental footprint [36,37].

Membrane techniques have emerged as a promising alternative to effectively manage water and wastewater in swimming pool systems. By utilizing semipermeable membranes, these techniques can separate and remove various constituents of the water, including salts, organic compounds, and bacteria [17]. In certain circumstances, the adoption of a membrane based system for the recycling of backwash water has been observed to lead to a substantial reduction in the operating expenses associated with swimming pools. This process involves the use of a specialised membrane to filter the backwash water, which is otherwise disposed of, and reintroduce it into the pool. As a result, the need for fresh water is minimised, which in turn reduces the costs incurred in acquisition and treatment of new water. Additionally, the membrane based system is highly efficient in removing impurities from the water, rendering it safe for reuse. By effectively reducing operating costs while promoting environmentally conscious practices, this technique can significantly benefit pool owners [41,42] There are several ways to reuse the water from swimming pool facilities, rather than just discharge it into the sewage system. The most popular methods include using it to sprinkle sports areas like tennis courts and football fields, using it to power the toilet flushing system, and using it to irrigate plants [39]. The savings in water and the amount of wastewater generated necessary for rinsing the filters are invaluable. The traditional filter washing system, which involves discharging the washings into the sewage system, generates hundreds of thousands of m^3 of water that is lost irretrievably. Recovery of rinsed water and heat is a huge economic benefit, as well as an invaluable ecological aspect.

Conclusions

After conducting research and analysing the results, the following conclusions were formulated:

- The average daily water consumption for the backwashing of the filter beds in the analysed facility was 346.5 m^3, and the monthly average was 10,741.7 m^3.
- It was found that the washings were effective enough to allow recovered water to be used for washing the filter beds without exceeding the recommended values for permeate in the Regulation of the Minister of Health of May 10, 2022, on water requirements for swimming pools.
- The design guidelines should be reviewed, especially the recommended need for water recovery and its use in water purification circuits in indoor swimming pools.
- Newly developed guidelines for the design of sanitary installations in swimming pool facilities should consider the recovery of water from washings and its use for different purposes, such as backwashing filters, toilets supply system, and washing machines, especially during water shortages and with the

increasing costs of treatment and distribution.

- The volume of make-up water for the feet pools should take into account the volume of water that can be recovered from the backwash water and refreshing water.
- The size of the backwash and water recovery tanks should take into account the total recovery of backwash water and water for refreshing and replenishing the pool water circuits.

The authors plan to conduct further research on heat recovery from washings, the possibilities of using grey sewage water (after showers) and expanding the monitoring of water and other media consumption to include additional swimming pool facilities located in Poland.

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