Thesis of Doctoral (Ph.D.) Dissertation

Application of nanoparticle-modified PVDF membranes for the efficient treatment of oil emulsions

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1. Introduction and Research Objectives

Global water management is one of the most urgent and multifaceted challenges of our time, bearing outstanding significance from environmental, social, and economic perspectives alike. Due to the growing global population, along with the simultaneous expansion and increasing technological advancement of industrial and agricultural activities, the demand for water has risen substantially. This not only intensifies the quantitative pressure on water resources but also exposes their quality to ever greater risks. The removal of emerging contaminants in wastewater – such as micropollutants, pesticides, pharmaceutical residues, or oil-derived components – is often not feasible, or only achievable with limited efficiency, using conventional wastewater treatment processes. Consequently, it has become indispensable to develop and implement advanced, targeted water treatment technologies that can serve either as a complement to, or an alternative for, traditional methods in effectively addressing such diverse contaminants.

Modern water treatment technologies play a particularly important role in the purification of oil-contaminated waters, given that numerous industries generate large volumes of oil-containing wastewater. Such effluents often contain toxic or even carcinogenic compounds, thereby posing significant risks to the environment, wildlife, and human health alike. While so-called "floating" and larger dispersed oil pollutants (oil droplet diameter: >5 μm) can be removed using conventional methods – such as flotation, grit chambers, or oil separators – the effective removal of smaller, finely dispersed, emulsified (oil droplet diameter: <5 μm), or dissolved oil contaminants requires the application of more advanced, targeted technologies. Membrane filtration offers a promising method for the removal of micro- and nanosized oil droplets, providing several advantages such as outstanding purification efficiency, low chemical demand, and relatively easy integration with other techniques. However, its economic applicability poses a serious challenge, since oily contaminants cause rapid membrane fouling, which reduces the membranes' water permeability (flux) and lifespan, while simultaneously increasing energy consumption.

The primary objective of my doctoral research is, on the one hand, the development of membrane surfaces modified with TiO_2-based nanocomposites through physical immobilization, which are less prone to fouling and provide an effective solution for the removal of smaller-sized oil droplets. On the other hand, it aims to investigate how the different surface properties (hydrophilicity, surface charge, surface roughness) of membranes modified with various nanocomposites influence the main membrane filtration parameters, including flux values, flux decline and flux recovery ratios, different filtration resistances, and purification efficiency.

Among my main objectives was the fabrication of various titanium dioxide/carbon nanotube (TiO_2/CNT) nanocomposite-modified polyvinylidene fluoride (PVDF) membranes containing different amounts of carbon nanotubes (1, 2, and 5 w/w%), and their comparison in terms of achievable water flux as well as flux obtained during the filtration of oil emulsions. Furthermore, I aimed to investigate the effect of surface modifications on the types of resistances formed during filtration, which can provide insights into the nature of membrane fouling. I also aimed to thoroughly examine and compare the filtration parameters and purification efficiencies achieved at different transmembrane pressures, considering both unmodified and surface-modified membranes. In addition, I developed TiO_2/fCNT composite modified PVDF membranes using functionalized carbon nanotubes containing various polar, oxygen-bearing functional groups and analyzed how the changes in hydrophilicity and surface charge resulting from functionalization affect the filtration parameters. I also aimed to design membrane surfaces that not only improve filtration parameters during the purification of oil emulsions but also enable the effective degradation of oil pollutants. To investigate this, I fabricated membrane surfaces modified with silver-containing titanium dioxide and examined both the role of silver as a component enhancing photocatalytic degradation efficiency (in the case of methyl orange solution and oil emulsion degradation), as well as its impact on the membrane surface and, consequently, on the filtration parameters.

2. Materials and Methods

2.1 Modification of Membrane Surfaces with Nanoparticles and the Preparation of TiO_2/CNT and TiO_2-Ag Nanocomposites

For the modification of membrane surfaces, I used commercially available PVDF flat-sheet membranes, either ultrafiltration (250 kDa) or microfiltration (0.2 µm) type (*New Logic Research Inc., Minden, Louisiana, USA*). The modification of the membrane surfaces with TiO_2 (*Aeroxid P25, Evonik Industries, Germany*), TiO_2/CNT and TiO_2/fCNT nanocomposites containing functionalized carbon nanotubes, as well as TiO_2-Ag nanoparticles, was carried out through physical immobilization. Homogeneous suspensions of nanoparticles were prepared at a concentration of 400 mg/L and subsequently filtered onto the membrane surface under a transmembrane pressure of 0.3 MPa. Among the functionalized carbon nanotubes, two were commercially available (carbon nanotubes functionalized with –COOH and –OH groups; *Nanografi Nanotechnology, Ankara, Turkey*), while the functionalization of the other two types (*Alfa Aesar, Waltham, USA*) was carried out by myself through treatment in 15 M nitric acid solution and in a 3:1 (v/v) mixture of 10 M sulfuric acid and nitric acid solutions. During the synthesis of silver-modified TiO_2 particles, silver was deposited onto the surface of TiO_2 nanoparticles through the reduction of $AgNO_3$.

2.2 Characterization of Functionalized Carbon Nanotubes and Silver-Modified Titanium Dioxide

To determine the chemical properties of the functional groups formed on the surface of carbon nanotubes during oxidation, a JASCO 4100 Fourier-transform infrared spectroscope (*Jasco, Tokyo, Japan*) was used. The silver content of the silver-modified TiO_2 particles was determined with a HITACHI S-4700 Type II scanning electron microscope (*Hitachi High-Tech Corporation, Japan*) equipped with a Röntec QX2 EDS detector (*Röntec GmbH, Germany*).

The optical properties of the photocatalysts were determined by diffuse reflectance spectroscopy (DRS) in the range of 200–800 nm using a CHEM 2000 UV–VIS spectrophotometer (*Ocean Optics Inc., Orlando, FL, USA*). The photoluminescence (PL) of the nanoparticles was measured with a Horiba Jobin Yvon Fluoromax-4 spectrofluorometer (*Horiba Ltd., Kyoto, Japan*) at an excitation wavelength of 350 nm.

2.3 Preparation and Characterization of Oil Emulsion

The oil emulsions were prepared from crude oils provided by MOL Nyrt. (*Algyő, Hungary*). First, a 1 w/w% crude oil–ultrapure water dispersion was produced by high-speed (35,000 rpm) mixing (*Einhell TC-MG 135 E, Germany*). Subsequently, the dispersion was diluted and ultrasonically homogenized (*Hielscher UP200S Teltow, Germany*) to obtain oil emulsions with a final oil concentration of 100 mg/L (TOG/TPH) in all cases. The oil droplet diameters ranged between 50 and 1500 nm (*Malvern ZetaSizer NanoZS, United Kingdom*).

2.4 Characterization of Membrane Surfaces

The hydrophilicity of the membrane surfaces was characterized using a Dataphysics OCA 15EC instrument (*DataPhysics Instruments GmbH, Germany*). Contact angle values were determined with the Dataphysics Contact Angle

System OCA15Pro software. The zeta potential of the membrane surfaces was measured with an Anton Paar SurPASS 3 instrument (*Anton Paar GmbH, Graz, Austria*). The surface roughness of the membranes was determined using a PSIA XE-100 atomic force microscope (AFM). The morphology of the membrane surfaces was examined with a Hitachi S-4700 Type II cold cathode field emission scanning electron microscope (SEM).

2.5 Gas Chromatography–Mass Spectrometry (GC–MS) Analysis of Crude Oil Samples

The composition of the crude oil samples used for the preparation of oil emulsions was determined with an Agilent 5975C VL-MSD mass spectrometer (*Agilent Technologies, Inc., USA*) coupled to an Agilent 7890B gas chromatograph.

2.6 Characterization of Photocatalytic Activities

The photocatalytic activity of the TiO_2-Ag nanocomposite-modified membranes was investigated through the photocatalytic oxidation of methyl orange solution (c = 10^{-5} M) and oil–water emulsion (c = 50 mg/L). The experiments were carried out in a double-walled glass photoreactor under continuous stirring. The light source was a UV-A compact fluorescent lamp (*P = 10 W, λ_{max} = 360 nm, LightTech Kft., Dunakeszi, Hungary*).

2.7 Membrane Filtration Experiments

The filtration experiments (as well as the modification of membranes with nanoparticles) were carried out in a cylindrical, laboratory-scale membrane filtration reactor (V = 250 mL, Millipore XFUF07601) up to a fivefold volume reduction ratio (VRR = 5), until 200 mL of permeate and 50 mL of concentrate were obtained. During the filtrations, transmembrane pressures of 1–3 bar (0.1–0.3 MPa) were applied. The filtrations were carried out at room temperature. The permeate leaving the filtration unit was collected in an open glass vessel placed on an analytical balance (*KERN EG-N, KERN & SOHN GmbH, Germany*). The balance was connected to a computer, which automatically recorded the changes in permeate mass every 5 seconds. From these data, the flux values characterizing the filtrations were determined, followed by the calculation of different filtration resistances (the membrane resistance, as well as the reversible, the irreversible, and the total filtration resistances), along with the flux decline ratio (FDR) and the flux recovery ratio (FRR) values.

2.8 Characterization of the Purification Efficiency of Membrane Filtrations

To characterize the purification efficiency of the membrane filtrations, turbidity was measured by nephelometry (*Hach 2100N, Hach Company, USA*), chemical oxygen demand (COD) was determined using a Lovibond ET 108 digester and a Lovibond PCcheckit COD Vario photometer (*Lovibond /Tintometer Limited, Egyesült Királyság*), and in some cases the extractable oil content was measured with a WILKS InfraCal TOG/TPH analyzer (*WILKS Enterprise, Inc., USA)*. The purification efficiencies were calculated based on the ratio of the respective parameters (turbidity, COD, TOG/TPH) of the initial oil emulsions and the permeates.

3. New Sicentific Results

T1) I have determined that during the membrane filtration of oil emulsions (with an extractable oil content of 100 mg/L), PVDF membranes (250 kDa molecular weight cutoff) surface-modified with TiO_2/CNT composites – containing 2 w/w% carbon nanotubes – at a surface coverage of 1 mg/cm² showed the most favorable properties. This composition provided the best performance in terms of filtration parameters, including achievable fluxes, filtration resistances, and purification efficiencies.

- At a transmembrane pressure of 0.1 MPa, I have found that the TiO_2/CNT composite modified PVDF membrane containing 2 w/w% carbon nanotubes resulted in nearly a fourfold increase in flux compared to the unmodified PVDF membrane (510 vs. 130 L/(m²·h)) during the filtration of a 100 mg/L oil emulsion. In contrast, flux values of 310 and 170 L/(m²·h) have been measured for the composites containing 1 and 5 w/w% carbon nanotubes, respectively. I have found that because of surface modification with the $TiO_2/CNT_{2\%}$ nanocomposite, the total resistance decreased by 75%, the irreversible resistance by 60%, and the reversible resistance by more than 90%. These represent the most significant reductions among the examined carbon nanotube contents (0, 1, 2, and 5 w/w%).
- I have found that the adhesion of oil contaminants onto TiO_2/CNT composite membranes is determined by the combined effect of the hydrophilicity of the membrane surfaces and the repulsive forces resulting from their negative surface charge. While at lower CNT contents (1 and 2 w/w%), I have measured significantly higher fluxes (310 and 510 L/(m²·h)) compared to those provided by the unmodified and TiO_2-modified membranes (130 and 185 L/(m²·h)), the membrane modified with the $TiO_2/CNT_{5\%}$ nanocomposite exhibited a relatively lower flux (170 L/(m²·h)). This is because the lower hydrophilicity of the $TiO_2/CNT_{5\%}$

composite membrane – being the lowest among the composites – counterbalanced the favorable electrostatic interactions resulting from the presence of negatively charged CNTs.

- The results have shown that the PVDF membrane surface-modified with the TiO_2/CNT nanocomposite containing 2 w/w% carbon nanotubes has achieved higher pollutant removal in terms of turbidity, chemical oxygen demand, and extractable oil content (99.8%, 96.0%, and 98.1%, respectively) compared to the unmodified membrane (98.5%, 95.4%, and 97.7%).

T2) I have demonstrated that the positive effect of the TiO_2/CNT composite containing 2 w/w% carbon nanotubes on the filtration parameters of the PVDF membrane with a 250 kDa molecular weight cutoff becomes increasingly significant with rising transmembrane pressure during the filtration of oil emulsions with an extractable oil content of 100 mg/L.

- For the unmodified PVDF membrane, I have measured fluxes of 130, 155, and 190 L/(m^2·h) at transmembrane pressures of 0.1, 0.2, and 0.3 MPa, respectively, when reaching a fivefold volume reduction ratio (VRR = 5). In contrast, for the membrane modified with the TiO_2/CNT composite containing 2 w/w% carbon nanotubes, flux values of 510, 900, and 1340 L/(m^2·h) have been obtained under the same conditions. This corresponds to nearly 4-, 6-, and 7-fold higher fluxes as a result of surface modification at 0.1, 0.2, and 0.3 MPa transmembrane pressures, respectively.

- For the unmodified membranes, the results have shown that the irreversible filtration resistance increased nearly sevenfold when the transmembrane pressure was raised from 0.1 to 0.3 MPa, which also resulted in extremely low flux recovery ratios (FRR): 20% and 9% at 0.1 and 0.3 MPa, respectively. In contrast, for the membranes modified with the $TiO_2/CNT_{2\%}$

composite, the irreversible resistance has only doubled under 0.3 MPa transmembrane pressure, corresponding to flux recovery ratios of 68% and 47% at 0.1 and 0.3 MPa, respectively.

- Whereas for the unmodified PVDF membrane the application of a higher transmembrane pressure (0.3 MPa) has resulted in a significant decrease in purification efficiency – down to 82.5%, 79.8%, and 88.5% for turbidity, COD, and extractable oil content, respectively – the membrane modified with the $TiO_2/CNT_{2\%}$ composite has maintained excellent purification performance even at 0.3 MPa, achieving values of 98.9%, 95.1%, and 96.8% for the same parameters.

T3) I have demonstrated that the use of functionalized carbon nanotubes in TiO_2/CNT composites for the surface modification of PVDF(MF) membranes has a beneficial effect during the filtration of oil emulsions (with an extractable oil content of 100 mg/L). This can be attributed to the increased hydrophilicity and/or the more negative surface charge of the membrane surface. I have also found that, with respect to the adhesion of oil contaminants to the surface and the recoverability of flux, the more negative surface charge plays a more significant role than superhydrophilicity, particularly at higher oil concentrations and volume reduction ratios.

- By applying PVDF(MF) membranes modified with TiO_2/CNT nanocomposites containing carbon nanotubes functionalized with polar groups (CNT_a series: commercially available non-functionalized, –COOH- and –OH-functionalized; CNT_b series: self-prepared non-functionalized, HNO_3- or H_2SO_4/HNO_3-functionalized), I have measured 1.6–3.8 times higher flux values in the initial stage of oil emulsion filtration (VRR = 1.5) – ranging from 194 to 455 L/(m^2·h) for the TiO_2/CNT_a series and from 774 to 678 L/(m^2·h) for the TiO_2/CNT_b series –compared to those of PVDF(MF) membranes modified with TiO_2/CNT nanocomposites lacking functional groups (117 L/(m²·h) for TiO_2/CNT_a and 333 L/(m²·h) for TiO_2/CNT_b).

- It can be stated that significantly higher flux recovery ratios (58–72%) have been achieved with TiO_2/CNT_a nanocomposite membranes, which, although showing considerable hydrophilicity (contact angle values between 5–20°), are also characterized by high surface charge, i.e., zeta potentials of –20 to –40 mV. In contrast, the TiO_2/CNT_b series membranes have exhibited FRR values of only 42–44%, despite being even more hydrophilic than the TiO_2/CNT_a membranes (contact angle of 0° for all three membranes). This lower performance can be attributed to their low zeta potential values (only –4 to –5 mV).

T4) I have determined that the composition of the oil pollutant—particularly the presence or absence of polar/amphipathic hydrocarbons—has a significant influence on the cake layer formed on the PVDF membrane surface and, ultimately, on the extent of flux decline. This is because hydrocarbon constituents, as reported in the literature, fundamentally determine the stability of emulsions and/or their tendency to coalescence.

- I have demonstrated that components of oil emulsions containing polar, amphipathic functional groups act as natural surfactants, stabilizing the oil droplets and resulting in lower reversible filtration resistance and flux decline ratio even at higher volume reduction ratios ($R\text{-reversible}_{TiO_2/CNT2\%} = 9.4 \times 10^{10}\ m^{-1}$, $FDR_{TiO_2/CNT\ 2\%} = 41\%$). In contrast, oil emulsions lacking in polar/amphipathic hydrocarbons exhibit lower stability, which can lead to more pronounced coalescence among oil droplets and, consequently – especially at higher volume reduction ratios – to the formation of a more significant cake layer on the membrane surface. This, in turn, results in higher reversible resistance and flux decline ratio compared to emulsions containing polar components (R-reversible$_{TiO_2/CNT2\%}$ = 3.3 × 10^{12} m^{-1}, FDR$_{TiO_2/CNT\ 2\%}$ = 97%).

T5) I have demonstrated that the PVDF microfiltration membrane surface (pore diameter 0.2 µm) modified by physical immobilization with a TiO_2-Ag nanocomposite (surface coverage of 1 mg/cm²) containing 0.2 w/w% silver exhibits significantly higher photocatalytic activity – approximately 1.9- and 1.5-fold – not only in the photocatalytic degradation of a methyl orange model solution (c = 10^{-5} M) but also in that of an oil emulsion (50 mg/L extractable oil content) prepared from crude mineral oil, compared to the membrane surface modified with TiO_2 alone.

- Based on my experimental results, the chemical oxygen demand (COD) of a 50 mg/L oil emulsion has been reduced by 30% during 8 hours of irradiation with a 10 W UV lamp (λ_{max} = 360 nm), using two PVDF membranes (surface area of 36 cm² each) surface-modified with 1 mg/cm² TiO_2-Ag nanocomposite. This corresponds to a 1.5-fold improvement in efficiency compared to the 20% COD reduction measured with membranes modified only with TiO_2. Under similar experimental conditions, after 300 minutes of irradiation, the silver-containing TiO_2-modified membranes have exhibited an 87% photocatalytic degradation of methyl orange solution (c = 10^{-5} M), whereas the membranes modified solely with TiO_2 achieved only 46%, representing a 1.9-fold increase as a result of silver modification.

T6) I have determined that TiO_2-Ag nanocomposites containing 0.2 w/w% silver form a more uniform and homogeneous nanoparticle coating on the surface of the PVDF membrane (pore diameter 0.2 µm) compared to silver-free TiO_2 nanoparticles. This has positively influenced the filtration

parameters achievable with the membrane during the separation of oil emulsions (100 mg/L extractable oil content).

- The significantly negative surface charge (–37.6 mV) of the hydrophilic TiO_2-Ag nanoparticles has reduced nanoparticle aggregation in the suspensions used for membrane surface modification, resulting in smoother and more homogeneous surfaces. In addition, the negative surface charge has enhanced the electrostatic repulsive forces between the membrane and the likewise negatively charged oil droplets, thereby reducing oil adhesion on the membrane surface. As a result, the flux has increased more than threefold compared to the reference (nanoparticle-free) membrane and more than 1.5-fold compared to the TiO_2-coated membrane. The flux recovery ratios (FRR) have also improved significantly: while the reference membrane showed an FRR of 45%, the TiO_2-coated membrane achieved 71%, and the TiO_2-Ag-coated membrane reached 92%, indicating reduced irreversible resistance and improved cleanability of the membrane with water.

4. Scientific Activities and Publications (MTMT Identifier: 10062260)

4.1 Scientific publications related to the thesis

- Fekete, L.; **Fazekas, Á.F**.; Hodúr, C.; László, Z.; Ágoston, Á.; Janovák, L.; Gyulavári, T.; Pap, Z.; Hernadi, K.; Veréb, G.: *Outstanding Separation Performance of Oil-in-Water Emulsions with TiO_2/CNT Nanocomposite-Modified PVDF Membranes.* Membranes **2023**, 13, 209.

  https://doi.org/10.3390/membranes13020209

  Q2; IF=4.2; WOS-citations = 13

https://www.webofscience.com/wos/woscc/full-record/WOS:000941497200001

- **Á. F. Fazekas**, T. Gyulavári, Zs. Pap, A. Bodor, K. Laczi, K. Perei, E. Illés, Zs. László, G. Veréb: *Effects of Different TiO_2/CNT Coatings of PVDF Membranes on the Filtration of Oil-Contaminated Wastewaters*, Membranes **2023**, 13, 812.

  https://doi.org/10.3390/membranes13100812

  Q2; IF=4.2; WOS-citations = 3

  https://www.webofscience.com/wos/woscc/full-record/WOS:001099410600001

- **Fazekas, Á.F**.; Gyulavári, T.; Ágoston, Á.; Janovák, L.; Kopniczky, J.; László, Z.; Veréb, G.: *Enhanced Photocatalytic and Filtration Performance of TiO_2-Ag Composite-Coated Membrane Used for the Separation of Oil Emulsions.* Separations **2024**, 11, 112.

  https://doi.org/10.3390/separations11040112

  Q3; IF=2.6

  https://www.webofscience.com/wos/woscc/full-record/WOS:001211176300001

∑ IF = 11.0

∑ WoS-citations = 16

4.2 Other scientific publications

- E. Nascimben Santos, **Á. F. Fazekas**, L. Fekete, T. Miklós, T. Gyulavári, S. A. Gokulakrishnan, G. Arthanareeswaran, C. Hodúr, Zs. László, G. Veréb: *Enhancing membrane performance for oily wastewater treatment: comparison of PVDF composite membranes prepared by coating, blending, and grafting methods using TiO_2, $BiVO_4$, CNT, and PVP.* Environmental Science and Pollution Research 2024, 31

  Q1; IF=5.8

- K. Sebők-Nagy, Z. Kóta, A. Kincses, **Á. F. Fazekas**, A. Dér, Zs. László, T. Páli: *Spin Label Electron Paramagnetic Resonance Spectroscopy Reveals Effects of Wastewater Filter Membrane Coated with Titanium-Dioxide Nanoparticles on Bovine Serum Albumin.* Molecules, 2023, 28, 6750.

  Q1; IF=4.6

- A. N. Al-Tayawi, N. Sz. Gulyás, G. Gergely, **Á. F. Fazekas**, B. Szegedi, C. Hodúr, J. R. Lennert, Sz. Kertész: *Enhancing ultrafiltration performance for dairy wastewater treatment using a 3D printed turbulence promoter.* Environmental Science and Pollution Research 2023, 30.

  Q1; IF=5.8

- E. J. Sisay, **Á. Fazekas**, T. Gyulavári, J. Kopniczky, B. Hopp, G. Veréb, Zs. László: *Investigation of Photocatalytic PVDF Membranes Containing Inorganic Nanoparticles for Model Dairy Wastewater Treatment.* Membranes, 2023, 14, 656.

  Q2; IF=4.2

- E. Zs. Kedves, C. Fodor, **Á. F. Fazekas**, I. Székely, Á. Szamosvölgyi, A. Sápi, Z. Kónya, L. C. Pop, L. Baia, Zs. Pap: *α-MoO3 with inhibitive* *properties in Fenton reactions and insights on its general impact on OH radical based advanced oxidation processes.* Applied Surface Science, 2023, 624, 1569.

Q1; IF=6.7

- J. E. Sisay, Sz. Kertész, **Á. F. Fazekas**, Jákói Z., Zs. Kedves, G. Veréb, Zs. László: *Application of $BiVO_4/TiO_2$/CNT composite photocatalysts for membrane fouling control and photocatalytic membrane regeneration during dairy wastewater treatment.* Catalyst, 2023, 13, 315.

  Q2; IF=3.9

- E. N. Santos, **Á. F. Fazekas**, C. Hodúr, Zs. László, S. Beszédes, D. S. Firak, T. Gyulavári, K. Hernádi, G. Arthanareeswaran, G. Veréb: *Statistical Analysis of Synthesis Parameters to Fabricate PVDF/PVP/TiO_2 Membranes via Phase-Inversion with Enhanced Filtration Performance and Photocatalytic Properties.* Polymers 2022, 14, 113.

  Q1; IF=5.0

- C, Hodúr, V. Nagypál, **Á. Fazekas**, E. Mikó: *Blue and grey water footprint of some Hungarian milking parlors.* Water Pratice and Technology, 2022, 17,7.

  Q3; IF=1.6

- Zs. László, **Á. Fazekas**, C. Hodúr, G. Arthanareeswaran, G. Veréb: *Cost estimation of combined membrane separation and different advanced oxidation processes pre-treatment of oily wastewater.* Geosciences and Engineering: A publication of the University of Miskolc, 2021, 8, 12
- J. Elias, K. Bagi, **Á. Fazekas**, Sz. Kertész, G. Veréb, Zs. László: *Filtration of BSA through TiO_2 photocatalyst modified PVDFmembranes*. Desalination and Water Treatement, 2020

Q3; IF=1.4

- G. Rózsa, **Á. Fazekas**, M. Náfrádi, T. Alapi, K. Schrantz, E. Takács, L. Wojnárovics, A. Fath, T. Oppenlander: *Transformation of atrazine by photolysis and radiolysis: kinetic parameters, intermediates and economic consideration*. Environmental Science and Pollution Research, 2019

  Q2; IF=3.0

- G. Veréb, V.E. Gayir, E. Nascimben Santos, Á. Fazekas, Sz. Kertész, C. Hodúr, Zs. László: *Purification of real car wash wastewater with complex coagulation/flocculation methods using polyaluminum chloride, polyelectrolyte, clay mineral and cationic surfactant*. Water Science and Technology, 2018, 80, 10

  Q2; IF=1.9

  ∑ **IF = 43.9**

4.3 Conference presentations

- **Fazekas Ákos Ferenc**, Veréb Gábor, László Zsuzsanna: *TiO_2 és TiO_2/CNT nanokompozittal módosított membránok alkalmazása olajszennyezett vizek tisztítására*, XV. Környezetvédelmi Analitikai és Technológiai Konferencia, Balatonszárszó (2024) – oral presentation

- **Ákos Ferenc Fazekas,** Sándor Beszédes, Szabolcs Kertész, Cecília Hodúr, Zsuzsanna László, Gábor Veréb: *Surface modification of polyvinylidene-difluorid (PVDF) microfiltration membranes by polydopamine grafting for more effective filtration of oil emulsions*, 30th International Symposium on Analytical and Environmental Problems, Szeged (2024) – poster presentation

- **Ákos Ferenc Fazekas**, Gábor Veréb, Zsuzsanna László: *Immobilization of TiO_2 and TiO_2/CNT nanoparticles using polydopamine to fabricate photocatalytically active PVDF membranes for filtration of oil emulsions,* International Conference on Science, Technology, Engineering and Economy (2024) – poster presentation
- **Ákos Ferenc Fazekas**, Kata Hochner, Zoltán Jákói, Szabolcs Kertész, Sándor Beszédes, Cecília Hodúr, Tamás Gyulavári, Zsolt Pap, Klára Hernádi, Zsuzsanna László, Gábor Veréb: *Effects of the composition and pH of oil emulsions on their membrane separation with photocatalytic TiO_2/PVDF composite membranes*, The 28th International Conference on Advanced Oxidation Technologies for Treatment of Water, Air and Soil, Limassol, Ciprus (2024) – best poster presentation
- **Ákos Ferenc Fazekas**, Tímea Miklós, Zsuzsanna László, Gábor Veréb: *Fabrication of TiO_2 and TiO_2/CNT modified PVDF membranes by in situ polymerization and characterization of their photocatalytic activity and filtering properties,* 29th International Symposium on Analytical and Environmental Problems, Szeged (2023) – poster presentation
- **Ákos Ferenc Fazekas,** Dávid Mag, Szabolcs Kertész, Sándor Beszédes, Zoltán Jákói, Gábor Kovács, Zsolt Pap, Cecília Hodúr, Zsuzsanna László, Gábor Veréb: *Separation of oil in water emulsion with TiO_2 and different TiO_2/(f)CNT composite modified microfilter membranes,* International Conference on Science, Technology, Engineering and Economy, Szeged (2022) – oral presentation
- **Fazekas Ákos Ferenc**, Ágoston Áron, Janovák László, Kertész Szabolcs, Beszédes Sándor, Hodúr Cecília, László Zsuzsanna, Pap Zsolt, Veréb Gábor: *Ag és Cu adalékolt TiO_2 bevonatú membránok szűrési és fotokatalitikus tulajdonságai olajtartalmú szennyvizek tisztítása során,*

XXVIII. Nemzetközi Vegyészkonferencia, Nagyvárad, Románia (2022) – poster presentation

- **Fazekas Ákos Ferenc**, Elias Jigar Sisay, Erika Nascimben Santos, Beszédes Sándor, Kertész Szabolcs, Veréb Gábor, Hodúr Cecília, László Zsuzsanna: *Nanorészecskékkel módosított membránok a szennyvízkezelésben*, Dulovics Junior Szimpózium, online (2021) – oral presentation

Co-Author's Declaration of Waiver

I, the undersigned, Laura Fekete, hereby consent to Ákos Ferenc Fazekas making use of the results presented in our publication (Outstanding Separation Performance of Oil-in-Water Emulsions with TiO_2/CNT Nanocomposite-Modified PVDF Membranes, Fekete, L.; Fazekas, Á.F.; Hodúr, C.; László, Z.; Ágoston, Á.; Janovák, L.; Gyulavári, T.; Pap, Z.; Hernadi, K.; Veréb, G., Membranes, 2023) in his doctoral dissertation submitted within the framework of the Doctoral School of Environmental Sciences, University of Szeged, in partial fulfillment of the requirements for the PhD degree. I further declare that I have not used these results for obtaining a scientific degree in the past, and I will not do so in the future.

I also affirm that the contribution of the candidate to the aforementioned publication was of decisive importance.

2025. 09. 22.

Fekete Laura

signature