Development of photocatalytic nanocomposite membranes for enhanced treatment of oily wastewaters

Thesis Booklet

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INTRODUCTION AND OBJECTIVES

Membrane filtration is a promising method to treat oily wastewaters due to several advantages like easy integration, and high removal efficiency. The major limitation to the application of membrane-based oily wastewater treatment is fouling, that causes severe flux decline and reduces membrane performance and lifespan.

Based on this, the development of ultra-hydrophilic membranes with structures containing nanomaterials is revolutionizing the separation of oily wastewater by avoiding the attachment of oil droplets on the surface and stabilizing the filtration resistance at a low level, resulting in membranes without significant fouling properties. Photocatalytic nanomaterials promise further advantages for the preparation of highly hydrophilic, self-cleaning membrane.

The most widely investigated photocatalytic material is titanium dioxide (TiO_2) due to its several beneficial properties like low cost, availability in large quantities, high chemical stability and photocatalytic activity, *etc*. However, despite the numerous advantages of TiO_2, it can be activated mainly by ultraviolet light, which takes up a small fraction of solar light, likewise, the significant electron/hole (e^-/h^+) recombination limits the photocatalytic activity. For the suppression of e^-/h^+ recombination, *e.g.* carbon nanotubes (CNTs) can be used as composite component due to their high conductivity.

Utilization of bismuth vanadate ($BiVO_4$) – a well-known visible light active photocatalyst – is also promising to be used for membrane surface modification to reach higher solar light-induced excitability. Based on these considerations, the development of visible-light active photocatalytic materials and their use in the preparation of solar-light active membranes has a huge potential to achieve high-efficiency during pollutant removal and/or membrane surface cleaning. Solar-light active superhydrophilic photocatalytic membranes could be the future's novel solution for advanced oil-in-water emulsion separation as they will be able to minimize the fouling problems and can be cleaned in a chemical- and energy-free manner, by simple solar light irradiation.

In this comprehensive research initiative, the primary objective is to advance the understanding and application of nanomaterial-modified polyvinylidene fluoride (PVDF) membranes for oily wastewater treatment and enhance its filtration performance and photocatalytic activity, contributing to the development of sustainable and efficient solutions for water purification. By integrating advanced materials and innovative fabrication techniques, this research aims to provide an understanding of modified PVDF membranes – using TiO_2, $BiVO_4$, CNT, and PVP –, offering practical insights for their design and application, seeking to compare and discern the advantages and limitations of different immobilization techniques, providing valuable insights into optimizing membrane performance for varied environmental conditions.

The specific objectives of this thesis are:

I. To analyze the influence of TiO_2 on the structural integrity of membranes, focusing on how it affects filtration efficiency and photocatalytic properties;

II. To explore the use of PVP in augmenting pore formation in membranes and examine its subsequent effects on the membranes' structural and functional aspects;

III. To demonstrate the application of statistical methods in determining the optimal conditions for fabricating membranes with specific desired characteristics;

IV. To investigate the integration of $BiVO_4$ into membranes, aiming to improve their activation under visible/solar light while also considering their flux and recovery capabilities;

V. To study the addition of CNT to membranes, assessing its role in enhancing oil-in-water emulsion separation and photocatalytic efficiency;

VI. To comprehensively understand and master various methods of membrane modification and their consequent impacts on the membranes' properties and performance, specifically using blending, coating, and grafting methodologies.

MATERIAL AND METHODS

Initially, $BiVO_4$ was synthesized using our methodology and characterized according to its XRD, SEM, bandgap, and photocatalytic activity under visible light. The material was then used for coating of commercial PVDF membranes to understand its applicability in comparison with TiO_2, the fluxes and recovery ratios were evaluated under natural solar irradiation. Coated membranes were fabricated using immobilization of the nanocomposite by physical deposition onto the membrane surface. The compositions of the membranes were: neat membrane, 100 % TiO_2, 100% $BiVO_4$, 95% TiO_2 and 5% $BiVO_4$, and 80% TiO_2 and 20% $BiVO_4$

Following, PVDF membranes were fabricated in laboratory using different conditions in a Central Composite Design setup: coagulation bath temperature (15, 20, and 25°C), evaporation time (0, 30, and 60 seconds), and contents of PVDF (12.5, 15.0, and 17.5 wt.%), PVP (0.0, 1.5, and 3.0 wt.%), and TiO_2 (0.0, 1.5, and 3.0 wt.%). For this, statistical analysis using Statistica™ software was used to determine intervals in which the membranes can be fabricated to present the desired characteristics and three-dimensional response surfaces were generated using the independent variables. In this case, pure water flux and photocatalytic activities (using methyl orange as model contaminant and UV irradiation) were evaluated.

Material and Methods

Finding the best content of PVDF, PVP and TiO_2, the subsequent experiments were carried out using 15.0 wt.% of PVDF, 1.0 wt.% of TiO_2 or TiO_2 in composite with $BiVO_4$ and/or CNT, aiming to compare oil-in-water filtration performance using different PVDF membrane fabrication methodologies – blending, coating, and grafting. Over the neat membranes, 100%-TiO_2, 98%-TiO_2/2%-$BiVO_4$, 98%-TiO_2/2%-CNT, 80%-TiO_2/20%-$BiVO_4$, and 78%-TiO_2/20%-$BiVO_4$/2%-CNT composite modified membranes were prepared.

Blended membranes were fabricated using the same phase-inversion method as the neat membranes. Coated membranes were fabricated by immobilization using physical deposition of the nanocomposite onto the membrane surface, while grafted membranes were assembled using polymerization and cross-linking to attach the nanocomposite onto the membrane.

The fabricated membranes were characterized according to their pore size, porosity, field emission scanning electron microscopy (FESEM), energy-dispersive X-ray (EDX), and contact angle. For all the fabricated membranes, filtration experiments were set by applying a transmembrane pressure on a dead-end filtration membrane reactor, and the flux recorded with a computer-controlled scale at predetermined intervals to obtain fluxes. 250 mL o/w emulsion was filled into the reactor and filtered until the production of 200 mL permeate (volume reduction ratio: VRR=5). Purification efficiencies were additionally determined by measuring the chemical oxygen demand (COD). Membranes were rinsed with pure water, and the water flux was measured again to check its recoverability and resistances.

For the commercial PVDF membranes coated with TiO_2 and $BiVO_4$, the recoverability was measured using natural solar irradiation.

Finally, photocatalytic activity of the fabricated membranes was measured according to the decolorization rate of a methyl orange solution in a reactor equipped with UV, visible or simulated solar lights. For this experiment flat ceramic beakers were placed onto a multi-position magnetic stirrer. The membranes were placed to the bottom of these ceramic beakers and fixed with O rings, the lamps were turned on (time 0) and samples were taken at regular intervals (time t) during the experiments. The absorbances were recorded with a spectrophotometer and, it was possible to calculate the apparent first-order kinetics rate constant (k), expressed by the slope of the graph (h^{-1}), and the reaction rate (r) of decolorization.

SCIENTIFIC RESULTS

Part I. Characterization of self-fabricated $BiVO_4$ and its use to coat commercial PVDF membranes

The use of our methodology to synthesize $BiVO_4$ proves to form a good material with photocatalytically active properties. While TiO_2 has negligible photocatalytic efficiency under visible light irradiation, the synthesized $BiVO_4$ shows great photocatalytic activity: 88% decomposition after 60 min of irradiation.

Coating with TiO_2 results in significantly higher flux and a considerable reduction of both irreversible and reversible resistances. The reduced fouling and reduced attachment of the oil droplets results in a significant reduction of the total filtration resistance due to the hydrophilic TiO_2 coating.

The pure $BiVO_4$ photocatalyst coating results in highest flux and negligible reversible and irreversible resistances in comparison with TiO_2 alone. Pure $BiVO_4$ and 20 wt% containing TiO_2/$BiVO_4$ composite coatings results in the best cleanability with high flux recovery rates and low flux decay rates, indicating lower fouling and lower flux reduction during the filtration, which shows the general advantage of the presence of this material on the membrane surface for the case of o/w emulsion separation.

Results

For the photocatalytic experiments, pure $BiVO_4$ and 80/20 $TiO_2/BiVO_4$ membranes are the most beneficial both before and after solar irradiation. Among them, the pure $BiVO_4$ coating has higher recovery ratio value but lower recovery after solar irradiation, while 20 wt, % $BiVO_4$ containing $TiO_2/BiVO_4$ composite has lower flux recovery ratio and higher flux recovery rate after solar irradiation, which indicates much higher solar photocatalytic activity for the TiO_2 containing coating. Pure TiO_2 coating demonstrates that it is more effective to decompose oily contaminants than $BiVO_4$ photocatalyst under solar irradiation.

Part II. Effects of fabrication conditions on TiO_2/PVP on PVDF membranes and optimum intervals of fabrication

For the neat membranes, bath temperature and evaporation time does not cause significant effects in the studied intervals. At the same time, the amount of added PVDF and PVP significantly affects both the pure water flux and the pore size. The pore size and pure water flux increase while the concentration of PVP increases and the concentration of PVDF decreases, and the same happens under the opposite circumstances. Hence, for the fabrication of membranes with the desired properties, it is necessary to take into consideration the type of wastewater to be purified. Consequently, the chosen fabrication conditions depend on the required characteristics of membranes. The fitted surfaces show to be suitable to be used as a basis to fabricate membranes with the desired properties.

For the TiO_2-containing membranes, the addition of TiO_2 up to the used limit does not significantly change the pore size of the membranes, only the PVP is responsible for changing the pore size.

For the photocatalytic experiments, all the TiO_2-containing membranes almost completely decomposes the methyl orange dye after UV-light irradiation. Meanwhile, the concentrations of PVDF and PVP have no significant effect on the photocatalytic efficiency. Using TiO_2 in the higher concentration (3.0%) does not increase the decolorization rate of methyl orange due to the agglomeration of the photocatalyst. This shows that using TiO_2 at 1.5% can be the optimum concentration for the conditions investigated in this study.

Part III. Comparison between blending, coating and grafting methodologies and the incorporation of TiO_2, and TiO_2-$BiVO_4$(/CNT) nanoparticles into PVDF membranes

The PVP-modified membranes present the highest photocatalytic activity in all three series (blended, coated, and grafted membranes).

The enhancement of the photocatalytic decolorization is attributed to the ability of PVP to increase the membrane pores.

In addition, combining CNTs with TiO_2 results in a better performance than using only TiO_2 for blended and grafted membranes. The TiO_2/$BiVO_4$ membranes (TB2) exhibited photocatalytic activity similar to that of pure TiO_2 under UV light, meaning that 2% $BiVO_4$ addition does not improve the photocatalytic efficiency. It is important to note that higher $BiVO_4$ concentrations (20% in TB20 and TB20C) does not yield higher photocatalytic efficiency.

Among the three different modification methods, the coating exhibits the highest photocatalytic activity. The second-best photocatalytic efficiencies are observed for membranes prepared by grafting. This is attributed to the fact that both coating and grafting methods primarily modify the membrane surfaces, ensuring the availability and accessibility of nanoparticles for light activation. In contrast, blending places the nanoparticles within the bulk of the membrane, resulting in their reduced availability on the surface and, therefore, reduced photocatalytic activity.

Even though $BiVO_4$ is not beneficial for UV-photocatalysis, under visible light irradiation the 2 wt.% $BiVO_4$-containing membranes demonstrates superior performance than the ones containing only TiO_2 due to the narrower band gap of $BiVO_4$. The TiO_2-CNT membranes has the greatest photocatalytic activity under visible light, demonstrating its capability to facilitate the efficient separation of charge carriers and the suppression of electron–hole recombination. On the other hand, the TiO_2-coated membranes still have better performance for the simulated solar experiments, when compared to the 2 wt.% $BiVO_4$- and CNT-containing composite-coated membranes, due to its high efficiency under UV light.

During the filtration experiments, the grafted membranes exhibit superior filtration performance (2–7 times higher fluxes) compared to the coated and blended membranes. Meanwhile, the utilization of 20% of $BiVO_4$ in the $TiO_2/BiVO_4$ composite results in lower fluxes for the grafted membranes, but a significant enhancement is observed in the case of the blended membranes.

The experiments were also carried out with the PVP-containing TiO_2/CNT membranes, showing a significant improvement at the beginning of the filtration, with high fluxes. For the PVP-containing membranes, the coated membranes benefit from larger pore sizes, which reduces the cake layer formation and enhances the water permeability. Moreover, the dispersion of nanoparticles within the membrane matrix is improved in the blended membranes, resulting in enhanced accessibility and better performance. These factors explain why the coated and blended membranes achieves higher flux enhancements, highlighting the importance of pore size and nanoparticle dispersion to membrane performance. In the case of grafting, further flux enhancement is not achieved by the PVP addition.

Outstandingly, the addition of PVP considerably reduces all resistances in the coated, blended, and grafted membranes. Consequently, the inclusion of PVP leads to higher fluxes in all the modified membranes and lower resistances, highlighting its effectiveness in improving the overall membrane performance. Therefore, the addition of PVP to the membranes offers significant advantages, allowing much higher total volume of filtered wastewater in the same time, enhancing cleaning efficiency, and reducing the time and effort required for membrane maintenance.

The addition of 2% $BiVO_4$ or CNT to the blended and grafted membranes results in improved membrane performance, particularly in terms of enhanced washability indicated by the lower irreversible resistance and higher flux recovery ratios.

Based on Part I, II, and III presented results, the following key findings can be stated:

- **Part I.** TiO_2, $BiVO_4$, and their composites can be used to coat membrane surfaces applied in oil-in-water emulsion separation to achieve favorable filtration properties.

Results

- **Part I.** Pure $BiVO_4$ coating is more beneficial (compared to pure TiO_2 coating) concerning the filtration properties (flux and filtration resistances).

- **Part I.** For photocatalytic regeneration of fouled membranes, TiO_2 coatings offer greater advantages compared to $BiVO_4$ coatings.

- **Part I.** The TiO_2(80%)/$BiVO_4$(20%) composite coated membrane represents a good compromise with both good filtration and photocatalytic properties, showing that it can be purified with solar irradiation with high efficiency without the application of any added chemical.

- **Part II.** Bath temperature and evaporation time do not significantly affect the water flux and the structure of the phase inversion fabricated PVDF membranes within the investigated intervals (15–25 °C and 0–60 s).

- **Part II.** Addition of PVDF and PVP significantly affects the structure, the pore size and the pure water flux of the fabricated membranes:

    - Using more PVDF increases the viscosity of the dope solution, resulting in a smaller pore size and lower pure water flux.

- Using more PVP, the opposite happens: instantaneous demixing results in bigger pore size and higher pure water flux, which should only be used to a limited extent to avoid possible hole formation (3.0 wt %).

- Three-dimensional response surfaces and equations were generated based on which it is possible to predict and define the best conditions for the fabrication of membranes with specific attributes.

- **Part II.** The addition of TiO_2 up to 3.0 wt% does not significantly affect the pore size and the pure water flux of these PVDF membranes (these parameters were rather dependent on the concentration of PVP).

- **Part II.** The addition of 1.5 wt% of TiO_2 presents remarkable photocatalytic properties: rapid decolorization of methyl orange under both natural and acidic conditions.

- **Part II.** Three-dimensional response surfaces and equations can be generated to predict and define the best conditions for the fabrication of membranes with specific attributes.

- **Part III.** The addition of CNT to TiO_2 results in improved performance, as evidenced by the enhanced decolorization of methyl orange for both UV and visible light irradiations on grafted and blended membranes.

- **Part III.** The addition of 2 wt.% $BiVO_4$ shows slightly better performance under visible light. The addition of more $BiVO_4$ (20 wt.%) does not result in enhanced photocatalytic activity.

- **Part III.** In terms of filtration performance, the grafted membranes containing TiO_2 and 2 wt.% $BiVO_4$ or CNT, and 1 wt.% PVP exhibit superior performance, achieving higher steady flux.

- **Part III.** The addition of PVP improves photocatalytic efficiency and, despite causing notable reduction in the flux recovery ratios, it presents outstanding flux during the filtration of the emulsions and after the surface cleaning process.

- **Part III.** The combination of CNT addition and the utilization of grafting modification proves to be the most beneficial in enhancing the performance of PVDF-TiO_2 membranes.

NEW SCIENTIFIC RESULTS

This study demonstrated a complex research about the development of composite nanomaterial modified, photocatalytically active membranes used for the treatment of oily wastewater. Overall, this research underscores the potential of PVDF membranes enhanced with photocatalysts and nanoparticles for efficient oily wastewater treatment. The exploration of different coating materials, fabrication conditions, and modification methods drives avenues for optimizing membrane performance in terms of filtration efficiency, fouling resistance, and photocatalytic activity, catering to various environmental and industrial applications.

Based on the presented results and the already mentioned 14 key findings within parts I, II, and III of this research, it is possible to summarize the discussion with the following thesis points:

1. $BiVO_4$, TiO_2 and their composite also can be used to coat PVDF membranes to achieve enhanced purification of oily wastewaters: $BiVO_4$ coating shows more benefits for filtration properties (ensured lowest flux decay ratio of 45% and highest flux recovery ratio of 66%), the pure TiO_2 coating is more effective in relation to the photocatalytic regeneration of membrane under solar irradiation (increasing double the flux after solar regeneration and recovering 72% of the original flux). Meanwhile, the combination of 80% TiO_2 and 20% $BiVO_4$ in $TiO_2/BiVO_4$ coated membranes represents a good compromise with relatively good filtration properties (relatively low decay ratio of 50% and high recovery ratio of 52%, in comparison with 75% decay and 33% recovery ratios of the pure TiO_2 coated membrane), and high solar photocatalytic regeneration capability, achieving 90% of total flux recovery (**Publication n° 3**).

2. In relation to the production of PVDF-TiO_2 composite membranes by phase inversion, the following statements have been proven: within the investigated ranges, coagulation bath temperature (15-25 °C) and evaporation time (0-60 s) do not significantly impact the water flux and the structure of phase-inversion fabricated PVDF membranes, but the addition of PVP (in 1.5 and 3.0 wt.%) shows a huge influence on membrane structure, pore size and the enhancement of water flux, meanwhile neither the addition of TiO_2 (up to 3 wt.%) changes significantly the structure of the membranes, but the nanoparticle presented in the surface of the membranes provided significant photocatalytic activity. (**Publication n° 2**).
3. By comparing the 3 investigated nanoparticle immobilization methods (coating, blending, grafting), the following general

findings are stated: Grafting methodology ensures relatively high photocatalytic efficiencies (with good enhancement of decolorization rate of methyl orange under UV irradiation: $r_{Gr} = 0.21 – 0.68$ mg L^{-1} h^{-1}) and outstanding filtration properties, presenting highest oil-in-water emulsion fluxes ($J_{o\text{-}Gr} = 50 – 148$ L m^{-2} h^{-1}). Coated membranes, despite their highest photocatalytic activity ($r_{Co} = 0.32 – 0.91$ mg L^{-1} h^{-1}), exhibit the lowest fluxes in o/w filtration experiments ($J_{o\text{-}Co} = 30 – 97$ L m^{-2} h^{-1}), reducing up to 65% of the initial flux. Meanwhile, blended membranes presented moderate performance, with decolorization rate (r_{Bl}) between 0.10 – 0.32 mg L^{-1} h^{-1} and o/w flux ($J_{o\text{-}Bl}$) between 50 – 125 L m^{-2} h^{-1}. (**Publication n° 1**).

4. The integration of carbon nanotubes (CNT) into TiO_2-based PVDF composite membranes results in a marked improvement in their photocatalytic activity (under UV and visible light irradiations). Under UV irradiation, it presented decolorization of methyl orange up to 3 times higher ($r_{TC} = 0.31 – 0.62$ mg L^{-1} h^{-1}) than when only TiO_2 was used ($r_T = 0.11 – 0.42$ mg L^{-1} h^{-1}). Meanwhile, during visible light irradiation it showed enhancement of 89% of decolorization rate ($r_{TC\text{-}vis} = 0.043$ mg L^{-1} h^{-1}) in comparison with pure TiO_2 ($r_{T\text{-}vis} = 0.023$ mg L^{-1} h^{-1}). Overall, the combination of CNT and PVP addition and the utilization of grafting modification (PVDF-TiO_2/CNT 2% grafted membrane) proved to be the most beneficial: it provided relatively high photocatalytic efficiency (r = 0.68 mg L^{-1} h^{-1}) and the best filtration properties, with high o/w flux (J_o= 142 L m^{-2} h^{-1}) and lowest resistances. (**Publication n° 1**).

5. The addition of 2 wt.% $BiVO_4$ into TiO_2-based PVDF composite membrane results in effective oil-water separation, enhancing the o/w flux up to 30% in comparison with TiO_2-membranes, while the photocatalytic activity also slightly increases (by 10%) under visible light irradiation. However, it does not show the same effect in UV and solar light irradiation, as the calculated activity was actually reduced up to 60% compared to the pure TiO_2 containing membrane's activities. Higher proportions of $BiVO_4$ (20 wt.%) do not yield further improvement for both decolorization rate and filtration parameters. (**Publication n° 1**).

LIST OF PUBLICATIONS

MTMT Author ID: 31359338

FIRST AUTHOR PUBLICATIONS

1.) 2024. Nascimben Santos, E., Hodúr C., László Zs., Gyulavári T., Krishnan, S. A. G., Arthanareeswaran, G., Veréb G. 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 Journal.* **Impact factor: 5.80 (Q1/Q2) – under review – Thesis points n° 3, 4, and 5.**

2.) 2021. Nascimben Santos, E., Fazekas, A., Hodúr, C., László Zs., Beszédes, S., Firak, D.S., Gyulavári, T., Hernádi, K., Arthanareeswaran, G., Veréb, G. "Statistical Analysis of Synthesis Parameters to Fabricate PVDF/PVP/TiO2 Membranes via Phase-Inversion with Enhanced Filtration Performance and Photocatalytic Properties." *Polymers*, *14*(1), 113; DOI: 10.3390/polym14010113. **Impact factor: 4.967 (Q1) – 8 Citations – Thesis point n° 2.**

3.) 2020. Nascimben Santos, E., Ágoston, Á., Kertész, S., Hodúr, C., László, Z., Pap, Z., Kása, Z., Alapi, T., Krishnan, S. A. G., Arthanareeswaran, G., Hernadi, K., & Veréb, G. "Investigation of the applicability of TiO_2, $BiVO_4$, and WO_3 nanomaterials for advanced photocatalytic membranes used for oil-in-water emulsion separation." *Asia-Pacific Journal of Chemical Engineering*, 1–15. DOI: 10.1002/apj.2549. **Impact factor: 1.447 (Q3) – 19 Citations – Thesis point n° 1.**

4.) 2020. Nascimben Santos, E., László, Z., Hodúr, C., Arthanareeswaran, G., & Veréb, G. "Photocatalytic membrane filtration and its advantages over conventional approaches in the treatment of oily wastewater: A review." *Asia-Pacific Journal of Chemical Engineering*, 1–29. DOI: 10.1002/apj.2533. **Impact factor: 1.447 (Q3) – 76 Citations – Literature Review section**

CO-AUTHOR PUBLICATIONS

5.) 2022. Gokula Krishnan, S.A., Sasikumar B., Arthanareeswaran G., Laszló Zs., **Nascimben Santos, E.**, Veréb G., Kertész, Sz. "Surface-initiated polymerization of PVDF membrane using amine and bismuth tungstate (BWO) modified MIL-100(Fe) nanofillers for pesticide photodegradation". *Chemosphere,* 304(135286). DOI: 10.1016/j.chemosphere.2022.135286. **Impact factor: 8.8 (Q1) – 16 Citations**

6.) 2020. Veréb, G., Gayir, E., **Nascimben Santos, E.**, Fazekás, Á., Kertész, S., Hodúr, C., & László, Z. "Purification of real car wash wastewater with complex coagulation/flocculation methods using polyaluminum chloride, polyelectrolyte, clay mineral and cationic surfactant." *Water Science & Technology,* 1–8. DOI: 10.2166/wst.2020.008. **Impact factor: 1.915 (Q3) – 18 Citations**

7.) 2020. Veréb, G., Kassai, P., **Nascimben Santos, E.**, Arthanareeswaran, G., Hodúr, C., & László, Z. "Intensification of the ultrafiltration of real oil-contaminated (produced) water with pre-ozonation and/or with TiO_2, TiO_2/CNT nanomaterial-coated membrane surfaces." *Environmental Science and Pollution Research,* 1–11. DOI: 10.1007/s11356-020-08047-1. **Impact factor: 4.223 (Q2) – 36 Citations**

∑ Impact Factor = 22.799 **(+ 5.8)**

∑ Citations = 178

CONFERENCE PRESENTATIONS

1.) 2022. Oral presentation. NPM6 (New Photocatalytic Materials for Environment, Energy and Sustainability) and PAOT7 (Photocatalytic and Advanced Oxidation Technologies for the Treatment of Water, Air, Soil and Surfaces). Ljubljana, Slovenia. "Utilization of carbon nanotube as a composite component of TiO_2 modified PVDF membranes used for oil-in-water emulsion separation". Oral presentation.

List of Publications

2.) 2022. Oral presentation. ICOSTEE (International Conference on Science, Technology, Engineering, And Economy). Szeged, Hungary. “Use of statistical analysis for fabrication of PVDF/PVP/TiO_2 membranes to treat oil-in-water emulsion”

3.) 2021. 3rd Place Prize Award. Oral presentation. M3-S Conference (Membrane Material – Modification and Separation). Torun, Poland. “Design of experiments for fabrication of PVDF/PVP/TiO2 photocatalytic membranes"

4.) 2020. Oral presentation. IV Sustainable Raw Materials (International project week). Szeged, Hungary. “Oily wastewater treatment with photocatalytic membrane filtration”

5.) 2020 Special Award. Oral presentation. 6th SCCS Europe – Student Conference on Conservation Science. Tihany, Hungary. “TiO_2 and $BiVO_4$ nanomaterials and nanocomposites applied for advanced photocatalytic membranes to treat oil-in-water emulsions”

6.) 2019. Oral presentation. 25th International Symposium on Analytical and Environmental Problems. Szeged, Hungary. “Potential development methods of membrane filtration to purify oil-contaminated waters”

7.) 2019 Special Award. Poster presentation. PERMEA – Membrane Conference of Visegrád Countries. Budapest, Hungary. “Utilization of different TiO_2-, $BiVO_4$- and WO_3- nanoparticles for visible light active photocatalytic membrane surfaces"

8.) 2019. Oral presentation. II Sustainable Raw Materials (International project week and scientific conference). Szeged, Hungary. "Purification of oily wastewaters with membrane filtration: opportunities, problems and possible solutions"