Workshop of Students´ Presentations 2020

„Membranes and Membrane Processes“

Organised by Czech Membrane Platform and MemBrain

21th October 2020

Straz pod Ralskem, Czech Republic

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Evropský fond pro regionální rozvoj
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Book of Abstracts

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Organized by:

Czech Membrane Platform

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FOREWORD

Dear participants,

You are opening a book of abstracts of the Workshops of Students' Presentations, which is organized by the Czech Membrane Platform abd MemBrain s.r.o.

It is our pleasure to present you the proceedings of the eighth year of the workshop. The proceedings include the abstracts, which have been revievewed by the members of scientific committee, who are the experts in the field of membrane processes. At the workshop, students will present their work and the quality of it will be assessed by the evaluation committee. The best works will be awarded by the financial prices.

The main benefit for the workshop participants from the ranks of students will be the experience with the presentation of their work in front of a professional audience.

We would like to thank to the chairman of the scientific committee and the members of scientific and evalution committee for their active participation in the reviewing process.

We would like to invite you to the fifth international conference **MELPRO 2020 – membrane and electromembrane processes**, which had to be postponed and will be held in Prague in November 8-11, 2020. If the measures will not allowed to attend the conference personally, you may also join us virtually.

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CHEMICAL CLEANING OF NANOFIBROUS MICROFILTRATION MEMBRANE

A. Gül[1*], F. Yalcinkaya[1], N. Islam[2], J. Hruza[1], L. Dvorak[1]

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Abstract: Membrane systems are one of the most common methods used for wastewater applications. In recent years, researchers have started to focus on electrospun nanofiber membranes due to their versatility such as high porosity, tight pore size, uniform pore size distribution, and a large surface area-to-pore volume ratio[1]. Unfortunately, membrane fouling is the biggest obstacle to use them widespread [2,3]. The fouling problem causes a decline in permeability and flux performance of the membrane. As a result, membrane life time is getting shorter[4]. Membrane cleaning is used to increase membrane life-time and reduce maintenance costs and quite challenge. Cleaning process can be done chemically, physically or by using their combination. The chemical cleaning is often used for foulant that cannot be removed by physical cleaning. Chemical cleaning of the membrane helps to remove the foulants from the membrane surface and restore the membrane permeability and flux[5].

In this study, chemical cleaning of nanofibrous polyvinylidene fluoride (PVDF) and polyacrylonitrile (PAN) nanofibrous microfiltration membrane was used. First, membranes were fouled by oily wastewater (sunflower oil). Later, cleaning process took place. Various chemical agent has been tested on both dead-end and cross-flow filtration system. Sodium Hydroxide (NaOH), Hydrogen Peroxide (H_2O_2), Sodium Hypochlorite (NaClO) and commercial cleaners was used as chemical cleaning agents. Moreover, a nonionic surfactant (triton), and an anionic surfactant (sodium dodecyl sulfate (SDS)) was used to compare the effect on cleaning. The aim of this work is to optimize the chemical agent, concentration of the cleaning chemicals, surfactants, and the physical conditions (cleaning time and temperature) during cleaning process of PVDF and PAN nanofibrous membranes

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FLOW MODELLING IN MEMBRANE SPACERS

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Abstract: The performance of electrodialysis unit can be to a certain extent influenced by flow inside the cells of the unit. Net-like flow distributors (spacers) are heavily used in industry because they enhance solution mixing which reduces concentration polarization close to the membranes. Mostly used polymer spacers are either extruded (ladder-like fibers) or woven (intertwined fibers). Their structure, shape of fiber, and orientation towards the direction of the flow influence the flow of liquid and therefore the mass transfer in membranes. Experimental study of each type of spacers can be very time-consuming and expensive. Thus, mathematical modelling offers a unique tool in spacer analysis and optimization of spacer geometry and performance. In this study, I examine two modes of flow – laminar and turbulent - inside two spacer types – extruded and woven with rounded fibers - as well as in different orientations towards the direction of flow. For all simulations, I utilize open-source computational fluid dynamics (CFD) programme called OpenFOAM. Lower pressure drop was observed for geometry turned by 45° towards the main direction of flow. Hydrodynamic results show almost no difference in flow for laminar and turbulent regime therefore suggest that laminar flow is enough assumption for flow description.

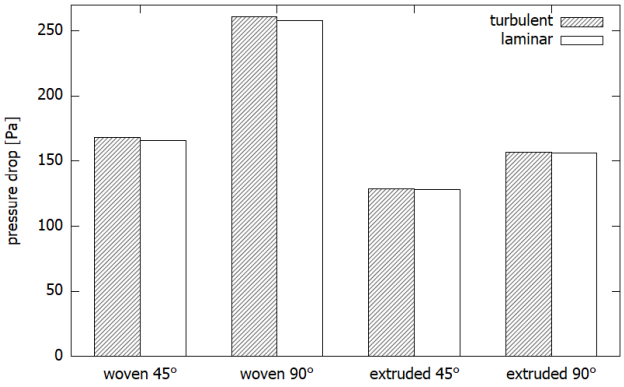

Figure 1: *Comparison of pressure drops for different types of spacers and geometries.*

PREPARATION OF FLAT-SHEET NANOFIBROUS MEMBRANES FOR MICROFILTRATION

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Abstract: Nanofiber membranes by electrospinning engineering are being devo ted to new application for emerging technologies, as demonstrated by rising sci entific and corporate research in recent years. Membranes are so effective due to their properties characterized for instance, narrow pore size and specific surface area and good filtration properties as well. Due to availability of Raw materials of Nano-fibers and special convenient properties this Nano-fibrous filter is the most interesting study in last decade.

Membrane processes are popular in these days because effectiveness of removal bacteria, microorganisms, natural organic material, particulates. In addition, Membrane can impart color, and odors to water, tastes, and it's capable to react with disinfectants to create disinfection byproducts [1]. Micro-filter has been developing at industrial commercial scale for several purposes. Removing of bacteria from milk and selective separation of casein micelles from soluble proteins are the clear example of using micro-filters [2]. Most of the water is filtered for human drinking purpose, but water filtration may also be carried out a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications [3]. The prime aim of filtration is separation of micro particle from liquid.

As the surface area of the Nano-fiber membrane is very low so it's not possible to use directly for water filtration purposes. The lamination process technology is an important method for improving mechanical strength of Nano-fiber webs. We have used a Nonwoven polyethylene terephthalate (PET) sheet and adhesive web (Co-polymer) and different Nano-fiber to create a new multilayer sheet to invent an efficient multilayer filter. Three different pressures and temperatures were applied to heat press lamination in our experiments. Moreover, the effects of laminating pressure on breathability, water permeability, and surface wettability of multi-layered Nano-fibrous membranes were investigated with air permeability, water filtration, surface porosity and contact-angle experiments.

In our work, we used PVDF and PA6 and PAN Nano-fibers with different surface areas i.e. 1.0 GSM, 1.5 GSM, 2.0 GSM, and 3.0 GSM at 110^{o}C, 125^{o}C, and 135^{o}C temperature. After testing the filtration capacity of all membranes we get NPA6-3A-110 AND NPA6-2A-110 are the best particle separation filter of all the membranes with high flux. On the other hand, the contact angel of PA6-3A-110 and PA6-2A-110 are almost similar to PAN and PVDF. Moreover, PA6 Nano-fibers have better adhesion to the surface of the multilayer. Due to its high water permeability and mechanical efficiency, PA6-3A-110 and PA6-2A-110 are chosen as the best candidate for filtration. PA6 multilayer Nano-fibrous membranes showed higher air permeability than PAN and PVDF, which may be better for the possible application of air filtration.

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WATER FILTER CARTRIDGES COVERED BY NANOFIBER MEMBRANE

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Abstract: Water treatment becomes more important day by day, as the global energy demand is expected to increase by 40% and water demand by 50% by 2030 all over the world[1]. For this reason, various water treatment methods are being tried for the future. More recently, nanofibers become popular in membrane technology due to their higher porosity, lower density, higher surface area / volume ratio and smaller pore size compared to conventional fibers. Regarding the effective membrane properties such as high permeability, high rejection, low fouling, easy to clean, easy to use, chemical and mechanically stability, and low cost, nanofiber technology is promising for the separation technology[2]. To use these advantages of nanofibers in water remediation technology, the water cartridges are covered with nanofiber membranes based on nanoporous structures.

Developed water filter cartridges covered by nanomembranes are effective way to remove contaminants. Thanks to the nanofibers and the structure of the cartridges, these cartridges are able to capture many solute particles. The membrane is capable of stopping the suspended substances in the feed before the permeate reach into the cartridge. The filter performance (flux and selectivity) of a water cartridge is related to the amount of substance it holds on its outer surface and inside[3]. Analysis of experimental results showed that the properties and performance of developed membranes are quite high. However, after filtrating 50 L of water, the flux showed up to 6627.39 L / $m^{-2}h^{-1}$.

Herein, the water filter performance of various packing densities PA6 nanofibers combination on different nonwoven substrate was tested. Results indicated that highly permeable membranes were formed. However, membrane fouling which reduces membrane life-span and affects the cost is not evitable. For this reason, it is considered to apply the self-cleaning modification of the membrane in further studies.

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CHEMICAL REGENERATION OF IEMs EXPOSED TO PRODUCED WATER FROM ENHANCED OIL RECOVERY

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Abstract: Electrodialysis (ED) has been successfully used to reduce the salinity of the polymer flooding produced water, although it is still a relatively recent application. In ED process, ions migrate from the dilute compartment through the ion exchange membranes (IEMs) to the concentrated compartment under direct current electric field. However, because of the organic and inorganic matters in polymer flooding produced water, fouling in IEMs can occur and it is a serious issue in ED since it decreases the IEMs exchange capacity, and as a consequence, increases costs related to IEMs regeneration and/or replacement. Therefore, this work investigated the fouling interactions and two different cleaning methods, consisted in acid-base and acid-base-surfactant cleaning. As the surfactant, sodium; 4 dodecylbenzenesulfonate (SDBS) in a form of solution (0.4 wt%) was used. The results demonstrated that the cleaning procedures are promising, although not every membrane sample proved enhanced properties. As for the used membranes, acid-base cleaning improved the area resistance by an average value of 3.5%, resulting in a final area resistance of 11.4 and 6.3 Ω.cm2 for anion exchange membrane (AEM) and cation exchange membrane (CEM), respectively. Acid-base-SDBS cleaning improved the area resistance by 3.0% for AEM and 10.0% for CEM. However, the improvement of area resistance is still low and cleaning methods were not effective enough to be considered successful. Permselectivity results show a decrease in value for all samples regardless the cleaning method, a fact that was expected since the swelling and porous enlargement during the cleaning decreases the membrane's permselectivity. Ion exchange capacity and FTIR evidenced that regeneration using only acid and base is more favorable over the procedure including the surfactant because it could be observed that the surfactant interacts with the membranes, sometimes worsening their properties. This work indicated that acid-base cleaning alone is efficient for the regeneration of the membranes, although acid base surfactant cleaning should be optimized to validate the findings contained in this report.

Acknowledgment
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STUDY OF CROSS-LINKING PROCESS AND ITS INFLUENCE ON PROPERTIES OF FINAL MEMBRANE

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Abstract: Polymeric ion exchange membranes (IEMs) are the main components of electomembrane separation technologies such as electrodialysis. According to the structure, IEMs are divided into homogeneous and heterogeneous. Homogeneous IEMs consist of only one polymer or copolymer matrix with covalently fixed charged functional groups. Heterogeneous IEMs contain ion-exchange resin mixed with inert polymer matrix. Mechanical stability of heterogeneous IEMs could be improved by creating so called semi-interpenetrating polymer network. This structure consists of at least one linear polymer and one cross-linked polymer. This work focused on cross-linking of polyethylene by silane method and its influence on heterogeneous cation exchange membrane (CEM) in a form of semi-interpenetrating polymer network. Sheets of cross-linkable polyethylene and two laboratory CEMs were exposed to defined cross-linking conditions up to 7 days. After the exposition, materials were characterized by melt flow index (MFI) measuring, rheology determination by oscillatory rheometer, FTIR, water uptake ratio, and swelling ratio. The value of MFI of the membrane prepared from conventional HDPE was 7.9 ± 0.3 g/10 min. Unexpectedly, MFI of membrane based on semi-interpenetrating polymer network was not obtained because the sample did not melt. It was also not possible to melt this sample during the pretreatment needed for rheological characterization which disabled to use this technique. FTIR spectra showed predominantly intensive bands of polyethylene. There was no significant difference among spectra of CEMs based on semi-interpenetrating polymer network according to their exposition time. The spectra of neat cross-linkable polyethylene showed low intensive band at 1090 cm^{-1} corresponding to -Si-OCH_3 structure. This band was negligible in spectra of both types of CEMs. Water uptake was of 7 % higher for CEMs based on conventional HDPE, for CEMs based on semi-interpenetrating polymer network it was practically constant during the whole exposition time. According to the experimental data, polyethylene was cross-linked even when it was not exposed to cross-linking conditions. Cross-linking could occur during preparation or CEM storage before their exposition.

Acknowledgement
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DEVELOPMENT OF A QUALITY CONTROL METHOD FOR ION EXCHANGE MEMBRANES PRODUCTION

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Abstract: In the polymer industry, mass flow rate (MFR) and volume flow rate (MVR) are important parameters that are used to characterize the properties of materials through easy measurement. The aim of this work was to develop a quality control method for monitoring characteristics of the LDPE filled with ion exchange resin depending on the moisture content and the type of the filler. LDPE was homogenized with milled cation exchange resin DOWEX HCR S/S or anion exchange resin - Amberlite HPR4800 Cl, Amberjet 4200 Cl, or Tulsion. It was observed that the moisture of granulate (< 1 %) had no significant effect on the rheological characteristics of given polymeric materials. With increasing content of ion exchange particles in the polymer matrix, the values of MFR and MVR decreased. Based on the measured values, it was decided to set the method conditions as follows: temperature 145°C, load 21.6 kg. These conditions enable to save the polymer structure, prevent crosslinking and to maintain the total time of testing below 30 min. Under these conditions, the MFR and MVR of the standard anion exchange granulate were MFR = 5.37 g/10 min and MVR = 5.61 cm^3/10 min and for standard cation exchange granulate MFR = 7.97 g/10 min and MVR = 7.13 cm^3/10 min.

Acknowledgement

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MODELLING AND OPTIMISATION OF NANODIAFILTRATION PROCESS OPERATION

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Abstract: Optimisation of nanofiltration process was achieved for a diafiltration system containing water, and sodium chloride with lactose as solutes. An empirical model of transmembrane permeate flux was proposed based on literature[1]. In comparison to traditional models, being implicit or too simplifying, the empirical model proposed is an explicit function of transmembrane pressure and concentration of the macro-solute, i.e. lactose. Parameters of two traditional models[2] and the empirical model were estimated via nonlinear regression based on a set of experimental data measured on a laboratory plant[3]. Moreover, both the empirical and one of the traditional models were validated and compared in a numerical simulation and an experimental study of optimal diafiltration strategy[4]. Despite higher water consumption during the diafiltration step, optimal filtration strategy based on the empirical model showed significantly reduced overall filtration time compared to the traditional model. Thus, the model proved the practical impact of model accuracy on process optimisation and prediction. The methodology of building the proposed model of permeate flux is applicable in real nanofiltration systems considering large feed volumes, multiple solutes and membrane fouling—e.g. in food or pharmaceutical industries[5].

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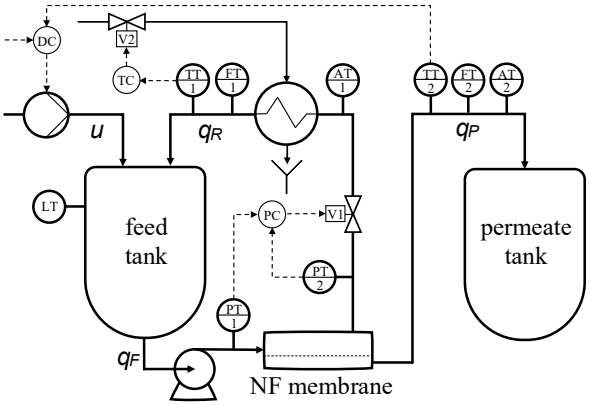

Figure 1. *Simplified scheme of the nanofiltration plant used in experiments*

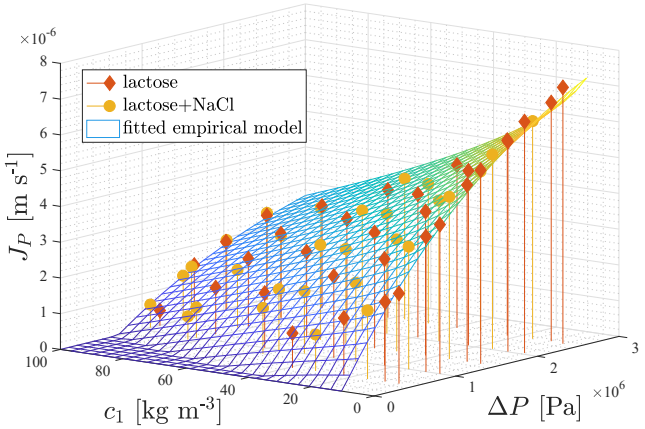

Figure 2. *Empirical model fitted over data measured in systems containing macro-solute (diamonds), and both solutes (circles). Permeate flux, J_P, as a function of transmembrane pressure, ΔP, and lactose concentration, c_1*

Table 1. *Results of a Two-Step Filtration Study Comparing Two Models*

Process characteristics	Traditional limiting-flux model	Proposed empirical model
Time of concentration [h]	3.16	1.46
Time of diafiltration [h]	0.51	1.52
Water consumption [L]	0.99	6.26

IBUPROFEN REMOVAL FROM AQUEOUS SOLUTION USING DIFFERENT COMMERCIAL NONPOROUS POLYMERIC MEMBRANES BY PERTRACTION PROCESS

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Abstract: Numerous researches focus on Emerging Contaminants (ECs) in wastewater as the biggest problem threatening natural water, and ecosystems [1]. The high variety of these ECs, environmentaly persistent and harmful even at trace concentrations, urge scientists to treat this phenomenon as a priority. Membrane separation is one of the most applied water recovery technique from ECs. However, commonly used membranes meet problems like fouling and environmental effects. Using a dance membrane and focusing on compound diffusion through the membrane may be a solution.

A target compound of presented work is Ibuprofen, considered as the most commonly used nonsteroidal anti-inflammatory drug. It persists in used water and affects the environment [2]. Commercial dense polymeric membranes PDMS PERVAP 4060, Polystyrene and Polypropylene clear dense polymeric films were applied and compared to tailor-made membranes Based on Matrimid, Ultem, and 6FDA-DAM:DABA membranes. Pertraction process allowed an evaluation of Ibuprofen diffusion through the membranes. Besides, sorption testes estimated adsorption capacity of allowed membranes.

The tailor-made membranes revieled a higher sorption capacity than the commercial ones. The visible optimum of the filler loading was observed for each membrane material. The tailor-made materials were, however, brittle, difficult to handle, and less homogenous compared to commercial ones. These showed one order of magnitude lower sorption capacity, still, their good mechanical properties allowed good performance in pertraction; Ibuprofen diffusion was the fastest using PERVAP™ 4060 membrane.

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THE USE OF ELECTRODIALYSIS AND ULTRAFILTRATION FOR WHEY PROTEIN CONCENTRATE PREPARATION

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Abstract: This diploma thesis is focused on whey protein concentrate (WPC) preparation using electromembrane processes and pressure-driven membrane processes. Whey protein products are getting very popular these days as a part of a balanced diet. Whey proteins offer many health benefits to consumers. However, as bioactive compounds, proteins are sensitive to heat and precipitate under specific conditions. Concentration and type of present minerals are two of the factors, that influence thermal stability. In general, polyvalent ions destabilize protein structure several times more than monovalent. For thermal processing of the whey proteins, there is an effort to reduce divalent minerals content to the lowest possible amount.

In the first part of the work, there was implemented a new configuration of conventional electrodialysis in order to adjust whey mineral profile. The method was called partial softening and it was used to partially remove divalent ions from whey and to replace these removed ions by monovalent ions from the source stream. Partial softening was carried out using a special module 10x (CM-AM-CM). By this step, good preconditions for thermal stability of the future whey protein concentrate have been created. Next step was the whey demineralization by the means of electrodialysis. Conventional module with the structure 10x (CM-AM)-CM was used for electrodialysis. Finally, ultrafiltration of the demineralized whey was carried out to concentrate the whey proteins. Formed retentate represented the final WPC solution.

Finally, the WPC solution was tested on thermal stability properties. The test itself was carried out by maintaining the sample temperature at 95 °C for 10 minutes. Samples without any pH pretreatment were not heat-stable. However, the WPC samples with pH adjustment were heat-stable. This work revealed a new technology for production of heat-stable whey protein concentrate and it has a great potential for next research and improvements.

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REMOVAL OF BORON FROM GEOTHERMAL WATER BY INTEGRATED REVERSE OSMOSIS AND ION EXCHANGE USING SELECTIVE RESINS

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Abstract: With the ever-increasing population of the world, it has become paramount to find renewable sources of water for drinking and irrigation to conserve the dwindling resources of water that are available.

Geothermal water resource is a promising source of renewable water. The advantage of making use of the geothermal water resource is that it not only provides a source of water but the thermal energy that can also be utilized [1].

The boron sources in the environment are mainly from the weathering of rocks, geothermal activity, volcanic activities, and anthropogenic sources [2]. Boron is an essential mineral that is to be present but only in limited amounts. In humans, boron's presence is essential for the development of bones, immune system, and the activity of brain cells. In plants' case, boron is necessary to regulate the water flow, breathing, and generative organs' growth. Excessive concentration levels become toxic to both humans as well as plants. The use of water with high levels of boron concentrations leads to the accumulation of boron in the soil, which in turn leads to the formation of complex compounds with heavy metals [3,4].

According to a study conducted by the World Health Organisation (WHO), it was determined that the appropriate levels of boron to be present in drinking water is 2.4mg/L [5]. Justin et al. suggest that less than 1mg/L of boron is to be present in water that is to be used for irrigation purposes [6].

Boron can be extracted from water using the following processes:

- Reverse osmosis
- Membrane distillation
- Electrodialysis
- Ion-exchange
- Adsorption[2]

The current study focuses on removing boron from geothermal water by integrated reverse osmosis and ion exchange method using selective resins. Various diffusion and reaction kinetics models were used to determine the limiting step during the process of sorption. Kinetic studies were conducted for the resins, and the data so obtained was compared to pseudo-first-order and pseudo-second-order kinetic models. It was found that performing reverse osmosis to obtain water for drinking and irrigation was not the right approach, as essential minerals like calcium and magnesium were removed. Using novel resins were found to be suitable adsorbents of boron. The use of an integrated system of reverse osmosis and ion exchange produced water with permissible boron concentration levels for irrigation.

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SURFACE MODIFIED NANOFIBERS IN OIL-WATER SEPARATION

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Abstract: Oil emulsions in water are common byproducts of many manufacturing processes. Most of the oil-water emulsion consists of 10% of oil and 90% of water, and hazardous. The impact of oily wastewater can cause (a) reduction of water sources, drinking water, etc. (b) endanger human health, (c) contamination of the soil, (d) harm to nature (1, 2). The oily wastewater must be cleaned before release to nature.

Membrane technology is an effective method to clean oily wastewater (3).

However, membranes suffer from fouling, which reduces membrane performance, flux, increases cost, and minimize membrane life-span. Preparing antifouling membranes is a fundamental strategy to overcome these problems. To reduce membrane fouling and optimize the hydrodynamic conditions of the membrane, different methods such as surface modification have been tried. It has been found that surface modification increases the hydrophilicity and fouling resistance of the membrane (5).

Nanofibers seem to be a good candidate in membrane technology for efficient performance due to their porous structure, tiny pore size, high surface area, and easy to modify surface (4)

The aim of this work is to prepare an anti-fouling nanofiber membrane for oil/water separation. For this purpose polyvinylidene fluoride (PVDF) nanofiber membrane was prepared by a needleless electrospinning system. Two-step modifications were done on the membrane surface. First, hydrophilic hydroxyl groups were formed by using an alkaline solution (PVDF-OH). Then, laser-mediated synthesis of silver and titanium dioxide nanoparticles (NPs) attached to the PVDF-OH nanofiber membrane surface (PVDF-OH/NPs). The preparation of NPs has been introduced in the literature (6). Both low (n-hexan) and high viscosity (sunflower) oils were used to prepare emulsions.

Results indicate that wettability of hydrophobic PVDF membranes remarkably improved after modification for both PVDF-OH and PVDF-OH/NPs membranes. Pristine PVDF membrane had very low flux for both types of emulsion. On the other hand, modified membranes (PVDF-OH and PVDF-OH/NPs) showed high permeability and selectivity against oil droplets. The membrane antifouling test showed that PVDF-OH/NPS membranes had a remarkable improvement in the separation of water from oily emulsions with an exceptional hydrophilic behavior and almost negligible fouling over time.

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USE OF FUNCTIONALIZED ZNO NANOPARTICLES FOR MEMBRANE WITH ANTIBIOFOULING PROPERTIES

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Abstract: Membrane (bio)fouling is limiting factor, which affects application of membrane bioreactors (MBR) for wastewater treatment (Monclús, H.). Lots of studies have been devoted to mitigate this negative phenomenon (Hamedi, H.). Modification of membranes using zinc oxide nanoparticles (ZnO NPs) appears to be a promising option for biofouling mitigation (Jo, Y.J.). Therefore, the main objective of this study was to prepare membranes with antibiofouling properties, and evaluate them while filtrating real activated sludge.

Firstly, membranes matrix based on polyethersulfone (PES) and sulfonated polyethersulfone (SPES) polymers were doped with surface-functionalized ZnO NPs, which gave them antibacterial properties. The surface-functionalization of ZnO NPs was achieved by (3-Aminopropyl)triethoxysilane (APTES) resulting in bonding of $-NH_2$ groups of APTES with $-SO_2Cl$ groups of chlorsulfonated polyethersulfone (SPES-Cl).

PES/SPES, PES/SPES/ZnO and PES/SPES/ZnO-APTES membranes were evaluated in short-term and middle-term test with activated sludge in order to determine their fouling rates. During the short-term test, the critical flux was estimated for each membrane. In the case of reference membrane, the critical flux was 5 LMH, while for membrane with ZnO-APTES nanoparticles was 8 LMH. Due to the very low permeability even at high transmembrane pressure, it was not possible to estimate the critical flux for membrane with ZnO NPs. The middle-term filtration test (5 days) showed slower decrease in permeability for PES/SPES/ZnO-APTES membrane than for reference (PES/SPES) membrane as well as membrane with unmodified ZnO NPs.

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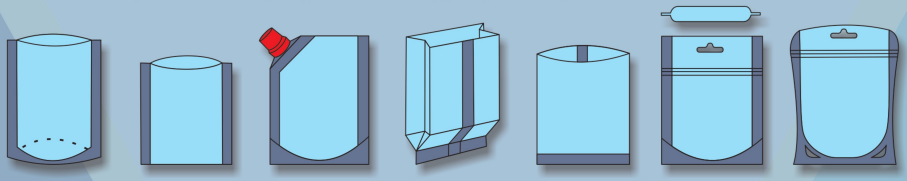

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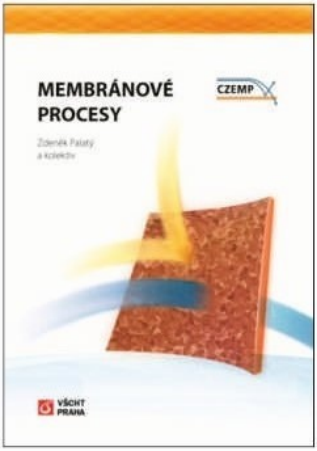
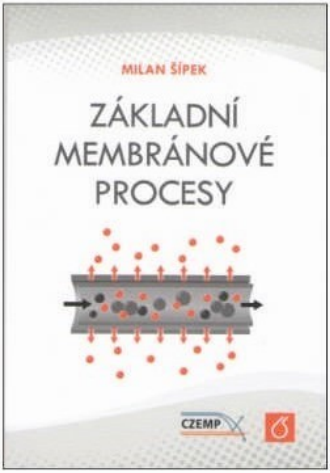
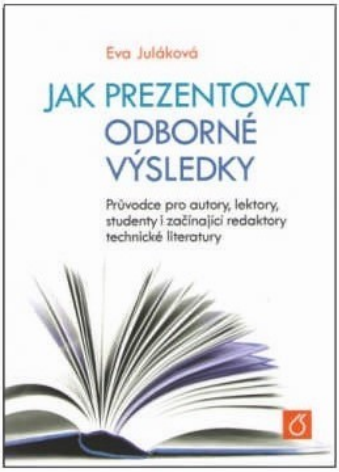


Publikace **MEMBRÁNOVÉ PROCESY** je určena všem pracovníkům, kteří se zabývají možnostmi využití membránových procesů v nejrůznějších oblastech lidské činnosti a studentům přírodovědných a technických oborů. V devíti kapitolách kniha pojednává o teorii transportu látek membránami, membránových materiálech, tlakových membránových procesech (elektrodialýze, elektrodeionizaci, elektrolýze, elektroforéze, palivových článcích), membránových reaktorech a vybraných difúzních procesech (separaci plynů a par, pervaporaci, difúzní dialýze).



Membránové procesy v současné době nacházejí uplatnění v průmyslu chemickém, petrochemickém, potravinářském, vodárenském, elektrotechnickém, automobilovém, ve zdravotnictví, v energetice, v ochraně životního prostředí a mnohých oblastech našeho běžného života. O významu základních membránových procesů, které patří k technologiím 21. století, se lze dočíst právě v této brožuře.

Brožura je určena především učitelům technických předmětů a jejich studentům na středních školách, neboť informuje o nejdůležitějších membránových procesech, jejich principech a využití.



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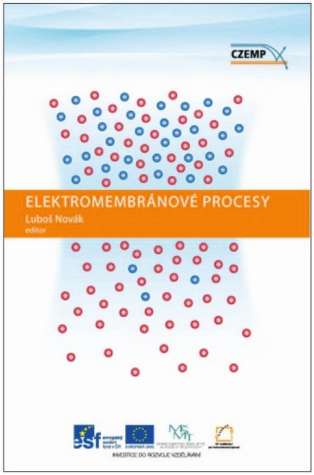
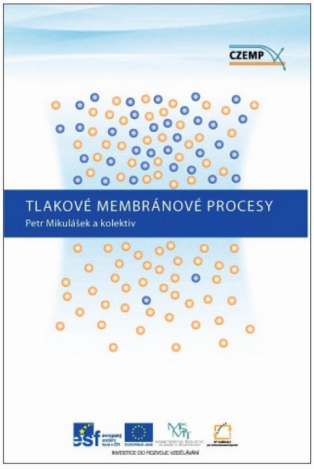
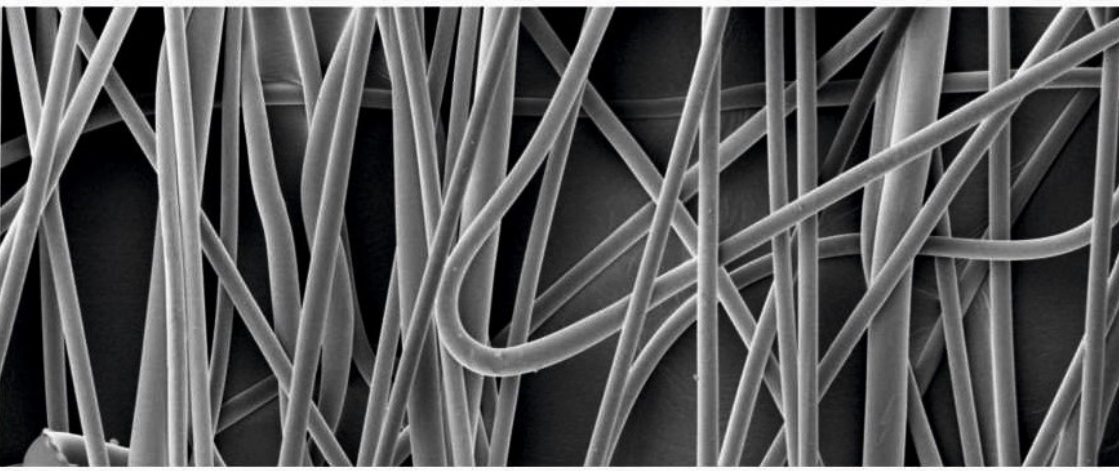


Kniha **ELEKTROMEMBRÁNOVÉ PROCESY** se zabývá problematikou využití iontově selektivních membrán v průmyslu i v ochraně životního prostředí. Značná pozornost je věnována elektromembránovým separačním procesům (elektrodialýze, elektrodeionizaci), membránové elektrolýze a rovněž velmi aktuální problematice elektromembránových systémů pro konverzi energie (palivovým článkům a elektrolýze vody ve vodíkové ekonomice). V monografii je popsána také teorie elektromembránových procesů.

Kniha **MEMBRÁNOVÉ DĚLENÍ PLYNŮ A PAR** popisuje metody, které nacházejí uplatnění v průmyslu chemickém, potravinářském a farmaceutickém a umožňují např. separovat vodík, oxid uhelnatý, oxid uhličitý, sulfan a jiné plyny ze směsí plynů, získávat dusík ze vzduchu, upravovat zemní plyn, odstranit páry organických látek ze vzduchu. V monografii pojednáno také o polymerních membránách pro dělení plynů a par a o teoretických aspektech tohoto procesu.
Do monografie je zahrnuta i kapitola o pervaporaci, velmi důležitém membránovém procesu dělení kapalných binárních směsí, kapitola o zušlechtění bioplynu a kapitola o membránové destilaci.



Kniha **TLAKOVÉ MEMBRÁNOVÉ PROCESY** obsahuje historický vývoj tlakových membránových procesů, popis membránových materiálů, zařízení a jeho prvků, teorii transportu látek membránami a faktorů ovlivňujících výkonnost procesů, teoretický popis (modelování) toku při separaci, metody intenzifikace, návrh membránových jednotek a aplikace tlakových membránových procesů a zařízení v chemickém, farmaceutickém a potravinářském průmyslu, v biotechnologiích a při zpracování odpadních vod.



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