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Composite Nanofiltration Membranes for Water Treatment: Implementation and Educational Issues

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1. Introduction

Water pollution by microplastics (MPs, particles < 5 mm) and nanoplastics (NPs, particles < 1 or 0.1 μm) is among the most critical environmental issues of the 21st century. General filtration techniques still struggle to remove particles smaller than 20 μm effectively. Thus, particles, smaller than 5 mm, harm not only the environment but also human health [1], and the particles under 20 μm pose even greater concern. Traditional wastewater treatment plants can eliminate about 75% of MPs particles in the initial treatment stages, increasing to 98% with tertiary treatment, but NPs usually escape removal [2]. Membrane filtration is a widely used method for efficient and eco–friendly removal of MPs. It separates particles depending on size and charge, filtered by pressure differences across the membrane. However, todays filtration technologies require constant improvement, due to the fact that larger MPs can clog the pores of the membrane, reducing its effectiveness.

The integration of novel research into academic curricula is essential for improving engineering education and promoting real world, problem solving challenges. This paper presents an educational implementation of the research, based on composite nanofiltration membranes used in water treatment in master–level course Microelectromechanical System (MEMS) Design at Kaunas University of Technology (KTU). The implementation of the practical work, focusing on polyvinylidene fluoride (PVDF) and metal–organic framework (MOF) MIL-101(Cr) based membranes, was adapted as a case study to teach interdisciplinary design principles involving mechanical engineering and material science. The permanent scientific and technological development requires modern engineering education to go beyond traditional methods. Traditional lecture–based methods often fail to motivate students in complex, interdisciplinary problem solving. Thus, Case Study Analysis [3, 4] and practice integrated education has become powerful pedagogical tool to solve this problem.

The implementation of real challenges in education encourages students to look for opportunities to improve microfiltration technologies and to enhance existing wastewater treatment facilities with a "fourth treatment stage" dedicated to completely removing MP/NPs from drinking water. The membrane is an effective filtration tool. However, it faces issues such as fouling and coagulation, which reduce membrane lifetime and permeation flux [5]. This paper analyses different ways of incorporating dual-charged MOF MIL-101(Cr) into PVDF membranes. The MIL-101(Cr) is one of most popular metal-organic (MOF) compounds [6]. It features chromium (Cr) metal nodes connected by organic linkers to form a highly porous structure. Generally, MOFs can effectively capture neutral NPs/MPs, typically removed through sieving mechanisms, although most of NPs/MPs carry a negative surface charge because of interactions with other pollutants and weathering processes. Interesting fact is that MIL-101 (Cr) could have the capacity to remove neutral and charged MPs/NPs. Design of novel nanocomposite membranes can overcome the limitations of traditional membranes and operate effectively in challenging industrial conditions.

The master's study program Mechanical engineering, Module T210M109 "Microelectromechanical systems design" trains students in microscale device development, integrating material science, mechanical design, and system engineering. The implementation of authentic research experiences in the field of nanofiltration device design practice in the module allows students to analyse and implement various concentrations of designated materials in order to learn and find the relation between the concentration, fabrication techniques and pore size of nanofiltration membranes. Implementation of Case Study Analysis method in Module T210M109 allows students to classify manufacturing methods of micro/nanoelectromechanical systems, better understand theoretical lectures' topics as MEMS modeling and design strategies, Materials, Microfabrication, Microfluidics and etc.

2. Case Study Analysis Method in Experimental Design

The Case Study Analysis of the microfiltration applies in the main challenge – enhancement of membrane selectivity and permeability via MOF integration to reduce membrane fouling. The relation of solution is in membrane design in selecting suitable portions of materials and defining fabrication parameters, modeling, and its characterization.

2.1. Case study analysis implementation in education

The Case Study Analysis method presented in this paper examines the laboratory–scale fabrication process of polyvinylidene fluoride (PVDF) microfiltration membranes using the Nonsolvent Induced Phase Separation (NIPS) technique implemented in Mechanical engineering masters study module "Microelectromechanical systems design". This paper helps to understand how polymer concentration, filler incorporation, and fabrication process parameters affect membrane structure, selectivity, and permeability. It is essential to demonstrate the step-by-step process of preparing PVDF–based microfiltration membranes via the NIPS method and to evaluate how formulation parameters (polymer concentration, additives, and casting thickness) influence the final membrane morphology. Also, it is important to understand how to identify critical safety and procedural considerations for reproducible membrane synthesis and how to analyze the challenges encountered and provide recommendations for optimization of the composite nanofiltration technique.

The Case Study Analysis transforms a complex research challenge, enhancing composite microfiltration membrane performance into a structured learning activity. Students are introduced to a realistic design problem: to optimize membrane selectivity, permeability, and antifouling behavior by modifying formulation and fabrication parameters.

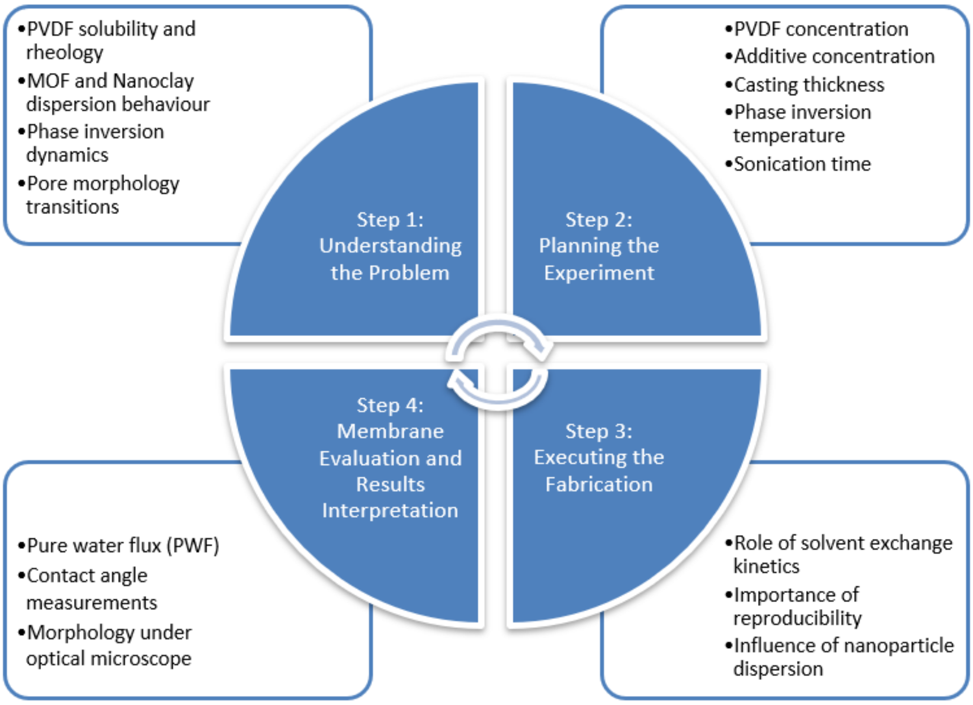

Fig. 1 Four main steps for Case Study Analysis implementation in the module

This four–step case study (Fig. 1) designed based on Case Study methodology [3, 4] enables students to progress from understanding the limitations of PVDF based membranes in design and fabrication of improved composite structures. Students use real-world MEMS design principles and get hands-on experience in the fabrication and analysis of the membrane, when creating their own membranes. Understanding the effects of polymer properties, nanoparticle dispersion and phase inversion kinetics on membrane performance is made much clearer to them by the practical fabrication and characterization. Coming face-to-face with the results of their work and looking up the latest scientific research solidifies the connection between the structure of a membrane and its function. Discussions about fine-tuning and scaling up their results give them the tools to assess real-life applications in modern water treatment systems.

2.2. Materials used in membrane fabrication

Polyvinylidene fluoride (PVDF, average Mw may vary from 180,000–534,000 g/mol) was selected as the base polymer due to its high chemical resistance and mechanical stability. The MOF additive (MIL–101(Cr)) was procured in nanopowder form, while N–methyl–2–pyrrolidone (NMP) serves as the primary solvent. Additional chemicals as acetone, N,N–dimethylacetamide (DMAc), and triethyl phosphate, may be used to improve the pores and filtration parameters. Instead of MOF students may use Montmorillonite (or Nanoclay) in order to get different properties of microfiltration membrane. Partition of materials is recommended to be as follow: between 85–87% of NMP solvent, between 12-15 g of PVDF (depending on Mw), between 0,8-1g. of MOF or between 0.2–0.4 g Nanoclay. The portions are chosen according to defined membrane pore parameters.

MOFs are complex and highly porous nanomaterials, which showed up about twenty years ago but demonstrated versatile capabilities already in wastewater treatment. MOFs are the porous crystalline materials created by coordination bonds that join the central metal ions or clusters with bidentate and multidentate organic ligands [7]. One of the effective ways to enhance the performance of ultrafiltration membranes (UF) is to incorporate hydrophilic nanoparticles into the membrane structure.

Furthermore, the incorporation of MOFs has improved the resistance to fouling, making the membranes more suitable for long term filtration [8, 9]. MIL-101(Cr) is a kind of MOF that could improve the separation properties. The MOF can also remove the neutral NP/MP present in the water and wastewater. Neutral NP/MP does not contain any charges on its surface, therefore, they are mainly removed by a sieving mechanism. However, most of NP/MP contain a negative charge on their surface due to interaction with other co–existing pollutants and filtration processes [7, 10].

2.3. Composite membrane fabrication process

Composite membranes were fabricated by the phase–inversion method. PVDF was dissolved in NMP (15 wt%) under stirring at 60 °C. MIL-101(Cr) nanoparticles (0-2 wt%) were dispersed by ultrasonication for 30 min to achieve uniform distribution. The homogeneous solution was poured on calibrated glass plate to form a thin film, and then immersed in a deionized water bath for phase inversion. The obtained membranes were rinsed and dried at ambient temperature (Fig. 2).

The Nonsolvent Induced Phase Separation (NIPS) technique is commonly employed, when making PVDF membranes. PVDF is dissolved in a solvent like NMP and additives such as MIL-101(Cr) or Nanoclay are thoroughly dispersed in the mixture to form a uniform, clear solution, which is then applied to a glass substrate using a precision-calibrated casting blade to control the initial film thickness.

The film is immediately immersed into the water coagulation bath after casting. In this step, the solvent diffuses out and water diffuses into the polymer matrix to induce instantaneous phase separation. This exchange results in the formation of an asymmetric porous structure that frequently consists of a dense top layer and a porous sublayer with finger–like or sponge–like morphology depending on polymer concentration, temperature, and additive loading.

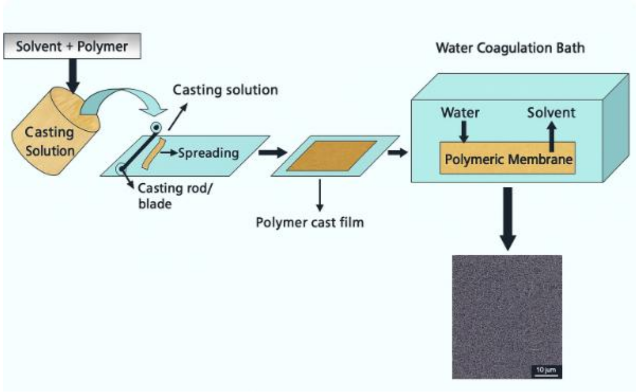

Fig. 2 Schematic diagram of the membrane casting technique

Once this phase separation is complete, the membrane is detached from the substrate, transferred to fresh water to remove remaining solvent, and then dried. The resulting composite membrane has a modified pore distribution, surface properties, and improved filtration performance due to MOF or Nanoclay fillers in consistency with the educational Case Study Analysis goals discussed previously.

Students should clarify their choice based on predicted effects of pore size, hydraulic permeability, mechanical integrity and fouling resistance. The table 1 shows independent decision–making and introduces engineering significance of students.

Table 1

Recommended parameter limits for student membrane fabrication

Parameter	**Low level**	**Medium level**	**High level**	**Significance for membrane behavior**
PVDF concentration, wt%	12%	14%	18%	Controls viscosity, pore density, mechanical strength. Higher PVDF → smaller pores.
MIL–101(Cr) loading, wt%	0%	0.5%	2%	Increases hydrophilicity and antifouling, but excess may cause agglomeration.
Nanoclay, g per 100 ml	0.2 g	0.3 g	0.4 g	Enhances mechanical properties; higher loading reduces pore size.
Casting thickness, μm	100	150	200	Affects permeate flux and structural resistance.
Phase inversion bath temperature, °C	20	30	40	Faster exchange at higher temperature → finger–like structure.
Ultrasonication time, min	10	20	30	Improves filler dispersion; excessive sonication may damage MOFs.
Stirring temperature, °C	60	70	80	Higher T accelerates dissolution but may lead to polymer degradation.

Table 1 lists suggested low, medium, and high values for key parameters in student made PVDF composite membranes and provides a brief explanation of how each parameter impacts membrane structure and performance. Increased polymer or filler loadings generally improves mechanical strength and decrease pore size, whereas processing conditions such as casting thickness, bath temperature, and ultrasonication impact flux improves morphology, and filler dispersion. The main parameters have to be balanced to provide pore formation, strength, hydrophilicity, and structural integrity of nanofiltration membranes.

2.4. Fabrication techniques

Preparation of the polymer solutions, incorporation of fillers, control of film thickness, and formation of the porous structure all depend on precise processing conditions

(Table 2) Therefore, selection of materials, devices and operating conditions are very important in ensuring membrane reproducibility and performance.

Table 2
Summary of equipment and their functions in PVDF membrane fabrication

Equipment	Purpose/ Function	Typical Operating Conditions
Ultrasonic bath	Pre–treatment and dispersion of Nanoclay in NMP	25 °C; 30 min sonication
Magnetic stirrer with heating	Dissolution and homogenization of PVDF in NMP	~70 °C; 500 rpm; ~3 h
Analytical balance & sample tools	Accurate weighing of polymer, filler, and solvent	13 g PVDF; 0.2–0.4 g Nanoclay; 87 mL NMP
Glass plate + doctor blade	Controlled casting of polymer solution into a uniform film	10–15 mL solution; ~200 µm wet gap; ~150 µm dried thickness
Water baths (two–stage)	Phase inversion (bath 1) and rinsing (bath 2); removal of solvent	Replace water after ~4 films; remove trapped air bubbles
Drying & storage setup	Drying of membranes and preservation for testing	Hang ~12 h; then place in sealed bags and label

An ultrasonic bath equipped with temperature control (typically maintained at 25 °C) is used for the pre–dispersion of Nanoclay or other fillers (e.g., MIL-101(Cr)MOF) in the solvent N-methyl-2-pyrrolidone (NMP). Ultrasound promotes the effective breakdown of agglomerates and helps to uniformly suspend nanoparticles, which is crucial to achieve uniform pore morphology and consistent surface properties in the final membrane. Gentle or low-power operation of the bath allows to prevent any structural damage in metal-organic matrix and unwanted polymer chain degradation. The sample container and a sealed glass jar are partly submerged and sonicated for about 30 min to perform dispersion of the filler material.

A digital magnetic stirrer with heating is used for the dissolution of PVDF in NMP and for homogenizing the polymer-nanoclay mixture. It must ensure both stable heating and precise control over the stirring process. Typical processing involves stirring the suspension at 500 rpm while heating to approximately 70 °C, a temperature sufficiently high to promote polymer dissolution yet below the threshold at which PVDF or additives may degrade. A chemically resistant magnetic stir bar is inserted into the closed jar for uniform mixing. Usually, dissolution requires 2-3 hours, followed by cooling in room temperature. Stirring under controlled conditions yields an optimal viscosity and avoids partial gelation and phase separation.

Accurate weighing of PVDF (13 g), Nanoclay (0.2–0.4 g), and NMP (87 mL) require precise analytical tools. Disposable weighing vessels, glass Petri dishes, and antistatic tools are used for safe and accurate material measurement. These tools ensure that the polymer concentration, filler content, and solvent volume are precisely controlled and that the resulting solution meets the specified properties.

Membrane casting is performed on a flat, calibrated glass plate attached to the work surface to prevent movement during film casting. A manual four–sided applicator with adjustable micrometer side of 50 µm, 100 µm, 150 µm and 200 µm is used to control the thickness of the wet polymer layer. A nominal gap of 200 µm produces a dried membrane of approximately 150 µm thickness. It mostly depends on polymer concentration and evaporation conditions. The applicator ensures uniform and controlled film thickness across the entire area. This determines the quality of the composite membrane. In order to eliminate defects such as voids, uneven thickness, or cracks, it is necessary to maintain a constant casting speed, even pressure on the applicator and substrate cleanliness.

Two room temperature water baths are used during membrane formation. Immediately after casting the membrane, the glass plate together with the membrane is immersed in the first bath, where the exchange of solvent and water begins. This causes pores to form in the polymer matrix. When the membrane separates from the glass substrate, it is transferred to the second bath to remove solvent residues and complete the phase exchange. To ensure a low solvent concentration in the water, it is necessary to change the water periodically, e.g., every four films formed. It helps to prevent an increase in the concentration of solvent in the water. It is important, because this can change the pore morphology and reduce the efficiency of the membrane. When transferring the membrane from one water bath to another, it is necessary to use tweezers and avoid mechanical damage to the membrane.

After coagulation, the membranes are removed and hung vertically on a drying rack using clips. The membranes are dried in air for approximately 12 hours. This allows all moisture to be removed without thermal deformation. To avoid surface contamination, drying must be carried out in a clean and dust-free environment. After drying, the membranes are stored in sealed plastic bags to maintain moisture balance and prevent contamination before performing experimental research. These processes are extremely important because solvent residues or stretching can alter the pore structure or membrane thickness.

3. Results

The application of Case Study methodology in the module allowed students to transform concepts of membrane engineering into practice by producing PVDF–based nanofiltration membranes and characterizing how formulation and process parameters impact structure and performance. Results imply both the technical efficiency of the adopted NIPS methodology and the educational objective of improving the development of engineering thinking through experimental and practical decision-making.

3.1. Student's outcomes in membrane fabrication

All student successfully produced composite membranes with thicknesses ranging from 50 to 170 µm, depending on the selected casting gap, polymer concentration, and filler matrix. Membrane size was standardized to approximately 5 × 10 cm to ensure compatibility with drying equipment and further testing. Students also learned that in order to compare the permeability and selectivity of membranes, it is necessary to maintain even film dimensions. Usually, the membranes exhibit typical asymmetric morphology characteristic when NIPS is used, i.e., a dense selective surface on top and a porous base. Qualitative observations by the students indicated differences in transparency, flexibility, and surface morphology. It was related to adding MOF or Nanoclay. This work lays the ground for later experimental and practical testing based on the obtained results.

3.2. Interpretation of fabrication parameters through Case Study Analysis

The Case Study Analysis framework required students to justify their choices of polymer concentration, filler type, and processing conditions. Consequently, a number of trends were consistently identified:

Polymer concentration. Students who chose PVDF close to 12 wt%, made films that were more porous and mechanically softer. In turn, membranes prepared from solutions at 18 wt% were clearly denser and less permeable. Students appropriately linked these observations with the increased viscosity and reduced solvent–nonsolvent exchange at higher polymer content.

Filler incorporation (MOF vs. Nanoclay). Students working with MIL–101(Cr) obtained smoother surfaces and increased wettability, proving the hypothesis that hydrophilic additives enhance antifouling properties. Membranes containing Nanoclay showed greater stiffness with reduced pore size, reflected in lower but more stable permeate fluxes. These results lie with reported effects of nanoparticle reinforcement in nanofiltration membranes.

Ultrasonication and stirring conditions. Groups that applied shorter ultrasonication times of 10–15 min observed visible particle clusters in the dope solution or mottled membrane areas. On the other hand, excessive sonication of ≥ 30 min sometimes resulted in weaker mechanical integrity, which made students discuss the risk of MOF damage, an understanding obtained directly by using Case Study method.

3.3. Interpretation of surface morphology by Optical Microscope and Scanning Electron Microscope

The morphology of the surface of the fabricated nano-filtration membranes was studied by an optical microscope (Nikon Eclipse LV150) and Scanning Electron Microscope (SEM). The optical microscope has a digital CCD camera what allows live observation and the capture of images at several magnifications. This technique also permits students to correlate fabrication parameters directly-polymer concentration, additive loading, and casting thickness-with the resultant pore structure and surface uniformity. Optical microscopy is ideal for rough membrane characterization since it offers fast, non-destructive imaging of microscale surface features, including pore distribution, defects, and inspection of macrovoid zones.

In this study, students observed different membrane samples at three magnifications (typically 25×, 50×, and 100×). It allowed to monitor main surface macro and microstructural properties. Using optical microscope general membrane uniformity, casting defects, large pores and macrovoids were examined. Students looked for the continuity of the top selective layer at medium magnification, identifying regions of non-uniform phase separation or particle agglomeration due to poor MOF/Nanoclay dispersion. High magnification allowed students to observe finer surface properties such as pore formation or collapse zones, as well as layer irregularities.

Using the SEM tool, students observed the morphology of membranes in magnification 10,000× and 5 µm scale bar. Fig. 3 shows the result of SEM image of one sample surface morphology - the produced PVDF/Nanoclay microfiltration membrane by the NIPS method. The image shows membrane surface morphology with pore distribution, shape and topography.

The morphology (Fig. 3) shows a porous asymmetric structure typical for PVDF membranes prepared via rapid solvent-nonsolvent exchange in water. In the image, both macrovoids (large pores) and microvoids (smaller, rounder pores) are randomly distributed on the surface. Their distribution seems quite heterogeneous, with several regions of packed material, interspersed by larger voids. The membrane surface displays spherical and elliptical pores of about 0.1 -2 µm diameter. Larger circular cavities are probably macrovoids created by instantaneous demixing before immersion in a nonsolvent bath. Smaller pores distributed between macrovoids correspond to the microporous regions that result from solidification of the polymer-rich phase. The total absence of cracks or collapsed pores leads to the stability of the film and its good structural integrity.

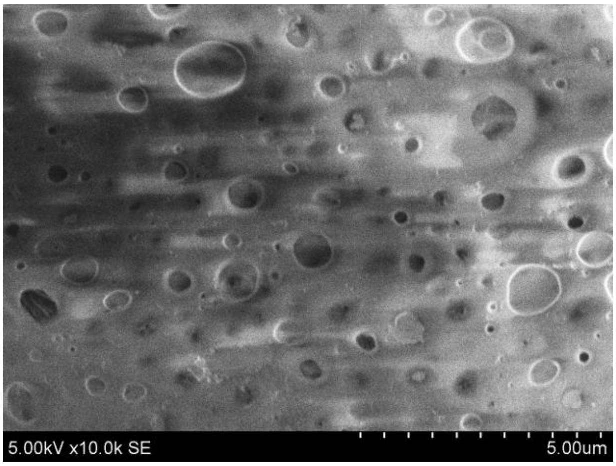

Fig. 3 SEM view of PVDF/Nanoclay membranes morphology

The section of the sample PVDF/MIL–101(Cr) membrane was carried out to show students the pores and their structure inside the membrane (Fig. 4). Thus, the SEM cross-section reveals a highly asymmetric membrane structure. The morphology of the membranes' cut shows a top surface skin layer with small, dense pores; a middle region enriched with elongated finger-like macrovoids and a bottom region shows a sponge-like porous support layer with much smaller, more uniform pores. This gradient from fine to coarse membrane structure reflects the relation between rapid solvent-nonsolvent exchange (producing macrovoids) and polymer-rich solidification (producing sponge-like zones). The voids range roughly from 2 µm up to 20 µm in length and appear interconnected.

Typical observations from SEM and Optical microscope data, demonstrated membranes of relatively heterogeneous pore distribution of PVDF/MIL-101(Cr) and PVDF/Nanoclay composites. The latter showed smoother surfaces and an increased number of finer pores, consistent

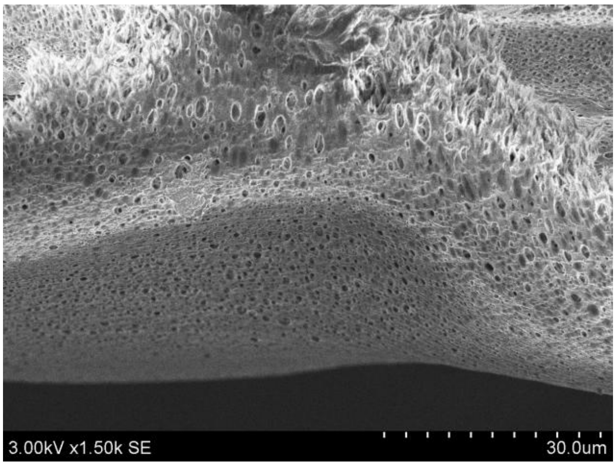

Fig. 4 A cross–section SEM view of the PVDF/MIL–101(Cr) membrane (magnification 1.500×)

with the role of hydrophilic fillers in modifying phase inversion kinetics and promoting more uniform polymer coagulation. These microscopy results therefore validates or challenges student predictions, enabling them to justify their parameter choices and to perform a more informed performance, structure correlation in the final evaluation phase.

3.4. Interpretation of membranes wettability and surface free energy

The fabricated nanofiltration membranes were investigated using contact angle measurements in order to evaluate their hydrophilicity and hydrophobicity. In this lab, students were able to identify wetting behavior of membranes – a surface property that significantly affects membrane permeability, the tendency of fouling and the filtration speed. The measurement tool includes a high-resolution CMOS camera, a convex optical lens system, an adjustable specimen holder, and image-processing software. Further, a 20 µL droplet of selected test liquids (water, glycerol, ethanol/spirit, olive oil) was deposited on each membrane surface, and images were captured to determine the left and right contact angles.

It was possible to highlight clear differences throughout the tested samples, i.e. among membranes modified with MIL-101(Cr) and Nanoclay fillers. Composite membranes demonstrated significantly low contact angles: PVDF/MIL-101(Cr) samples showed reductions to approximately 50-75°, while PVDF/Nanoclay membranes commonly ranged from 60-70°, depending on filler concentration. These decreases reflected enhanced surface wettability resulting from the hydrophilic functional groups present on MOFs and the layered structure of Nanoclay, which modifies surface polarity and increase solid–liquid adhesion.

Further, students analyzed the relationship between $\cos \theta$ and liquid surface tension using the Zisman method, constructing linear plots to identify the critical surface tension (σ_{crit}) of each membrane. Thus, composite membranes showed higher σ_{crit} values, indicating improved surface energy and stronger interactions with liquids. These results are in good agreement with the enhanced permeate flux and reduced fouling behavior during filtration testing and show how surface modification directly affects membrane performance. These wettability measurements allow students understand the importance of material–selection and fabrication choices. Students can observe how additive incorporation or changes in polymer concentration change the contact angle and surface energy to validate their predictions from earlier phases in the Case Study and understand how hydrophilicity affects antifouling and water flux.

3.5. Application-oriented interpretation of results

The data collected from optical microscopy, wettability analysis, and surface energy evaluation helped to encourage students to link the properties observed in the membrane and their possible application fields. It strengthens engineering knowledge-connecting laboratory-scale characterization to real-world membrane technologies.

Integrating results into real application areas, students were able to develop recommendations for membrane usage in different fields. For example, high flux with strong hydrophilicity are suggested as good candidates for point-of-use water purification devices, where membranes with more controlled pore size and mechanical stability are recommended for the pre-filtration units (bioreactors or analytical microfluidic filtration platforms). These suggestions related to application areas allow students search for novel technological areas.

3.6. Students' assessment of the Case Study Analysis approach in Module T210M109

A short and precise questionnaire was designed to evaluate students' experience, understanding, and opinions after completing a Case Study based module on membrane fabrication using different techniques and tools. The questions are suitable to assess the module, reflection, or gained competence of students.

3.7. Recommendations and tips for teachers implementing the Case Study Analysis method in technological modules related to microelectromechanical system design

The Case Study Analysis method provides a powerful pedagogical methodology to teach students of complex scientific research background, such as membrane fabrication, polymer solution behavior, and microstructural analysis [11]. If, implemented correctly, it gives deeper understanding and knowledge, problem-solving capability, and joins theoretical principles with practical experience. For those who would like to implement this methodology for their MEMS or Engineering modules, or laboratory-based courses, the following recommendations are suggested:

- Align Case Study with learning outcomes of module, ensure that each case study directly supports the learning objectives: choosing appropriate manufacturing technologies, identifying the influence of polymer concentration, additives, and process parameters, interpreting results and evaluating membrane performance;
- Provide authentic and relevant scenarios for students, showing the importance of designing the microfiltration tools through the application areas. Best, if those areas would be familiar to student, like pure drinking water, filtering of specified liquids and etc.;
- Encourage hypothesis-driven thinking of students, encourage them to predict how f. e. altering

Table 3
Student assessment questionnaire

Question category	Evaluation scale: 1 – Strongly Disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 – Strongly Agree
Learning experience	1. The membrane fabrication steps (solution preparation, casting, NIPS) were clearly explained. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 2. The Case Study method helped me understand how main parameters influence membrane morphology. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 3. Laboratory instructions were clear and easy to follow. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 4. I felt prepared to do the experiment safely. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Understanding of technical content	1. I understood how polymer concentration and viscosity affect membrane porosity. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 2. I can explain how solvent–nonsolvent exchange is related to pore formation in membranes. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 3. I can interpret experimental results with confidence. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 4. This module helped improve my knowledge to compare different membrane types. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Skills and Case Study application	1. The Case Study method improved my skills in identifying and analyzing membrane defects. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 2. I was able to link experimental investigations (e.g., SEM) to theoretical concepts from lectures. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 3. I successfully applied the Case Study method. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Practical evaluation	1. I found the hands-on membrane fabrication activity interesting and informative. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 2. I understand which parameters have the strongest influence on membrane structure and performance. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 3. Additives (e.g., nanoclay) helped me understand the effect of fillers on membrane properties better. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

polymer concentration changes pore size, to estimate how additional materials might modify membrane hydrophilicity and etc.;

- Promote collaborative work through the discussions in finding alternative approaches, interpreting results or integrating reflection at every stage;
- Provide clear, structured instructions because membrane fabrication involves few dangerous

Table 3
Student assessment questionnaire (Continued)

Question category	Evaluation scale: 1 – Strongly Disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 – Strongly Agree
Genera satisfaction	1. I am satisfied with the overall module. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 2. This module increased my interest in membrane technology and MEMS. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 3. I would recommend using the Case Study method in other laboratory based modules. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 4. I think I will apply skills learned in my future work. 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Open question: Please describe one asspect or suggestion for improving this module.	

steps. Prepare a protocol with min and max ranges for certain procedures (mixing, aging, casting, immersion); prepare safety briefings on handling chemicals and hot surfaces; provide clear instructions to reduce anxiety and prevent experimental failure unrelated to learning.

4. Conclusions

When manufacturing composite nanofiltration membranes, the necessary equipment must work properly to control the preparation, casting and formation of the membranes. In this study, a combination of an ultrasonic bath that disperses fillers, a magnetic hot-plate stirrer for dissolving the polymers, accurate analytical balances for mixing, applicators for precise thickness, water baths for phase inversion and standardized drying systems were used. This guarantees that the fabricated membranes will be of desired porosity, selectivity and strength.

Experimental investigation of membrane surface morphology and wettability gives a deep understanding of how formation parameters and filler incorporation may control the functional behavior of composite nanofiltration membranes. Such results serve as direct support to the Case Study Analysis by showing how student-selected fabrication parameters like polymer concentration, additives, and casting thickness, leads to measurable changes in morphology, hydrophilicity, and other filtration-relevant properties.

Application of Case Study Analysis method in the MEMS and nanofiltration related modules enriches both, conceptual and practical learning by guiding students through authentic problems, reflection, and collaboration. The teacher helps to develop deep knowledge of students in showing how and why the membrane structure depends on fabrication conditions, and how microstructural properties are related to membranes' performance.

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COMPOSITE NANOFILTRATION MEMBRANES FOR WATER TREATMENT: IMPLEMENTATION AND EDUCATIONAL ISSUES

S u m m a r y

This paper implements a Case Study Analysis method within the Mechanical engineering masters' course Module T210M109 Microelectromechanical Systems Design at Kaunas University of Technology. This method guides students through experimental planning, fabrication, characterization, and interpretation, leading to deeper understanding of membrane composition and its structure, and relationship between properties and real-world engineering application areas. The paper examines the implementation and educational issues in design of composite nanofiltration membranes used in removal of microplastics (MPs) and nanoplastics (NPs) from water. It highlights both, the scientific challenges of membrane fabrication and the pedagogical value of integrating Case Study Analysis into engineering. Thus, students demonstrated improved ability to make technical decisions, analyze the cases of different microfabrication techniques and interpret the obtained results with the help of Case Study method.

Keywords: case study analysis, microelectromechanical systems, nanofiltration, membrane.

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