# PROSPECTS, OPPORTUNITIES, AND CHALLENGES OF USING 3D-PRINTING TO PRODUCE MEMBRANE ELEMENTS

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*3D printing, also known as additive manufacturing, allows the creation of various products, including membrane elements made of different materials, namely polymers, metals, ceramics, etc., ensuring the production of elements with complex and desired geometries. This article proposes to consider the prospects and possibilities of additive technologies for the commercial production of ceramic membranes and membrane modules. The purpose of this work is to present the prospects, opportunities, and challenges of using 3D printing, in particular digital light processing (DLP) and selective laser sintering (SLS), to obtain ceramic membranes and membrane modules. A comparison of traditional methods of ceramic membrane production with additive technologies was carried out and shows that 3D printing is a promising area of development. It is already changing the field of membrane technologies. Analysis of the literature shows that additive technologies allow the creation of more efficient, customized, and multifunctional membranes, which is particularly relevant for high-tech industries. It has been shown that the quality of ceramic membranes obtained by DLP or SLS printing depends on the choice of ceramic material, the optimal settings of the slicer (software for preparing the model for printing), its calibration, and control of printing parameters such as temperature, printing speed, and others. In addition, the quality of printed parts is influenced by model preparation, the specifics of a particular printing technology, resolution, and much more. Despite the existing problems and challenges, both technologies are moving towards mass production and application: 3D printing will allow the production of ceramic membranes for micro-, ultra- and nanofiltration with optimized internal structures, which will increase filtration efficiency and reduce fouling.*

**Keywords:** *ceramic membranes, DLP (Digital Light Processing) technology, prospects for additive technologies, SLS (Selective Laser Sintering) technology, 3D-printing.*

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## 1. Introduction

Membrane technologies play an important role in water treatment, water purification, separation, energy, and other industries (Diachenko et al., 2024; Kyrii, 2023). Polymer membranes have gained the most popularity for practical application, but recently, more attention has been paid to ceramic membranes in scientific literature due to their thermal stability, chemical inertness, and durability.

Although great progress has been made in the creation of membranes, the search for ways to increase the efficiency and duration of filtration processes continues. One such method is 3D-printing, which can create objects of any shape with high precision (Diao et al., 2024). This method can control the size and distribution of membrane pores, is important for effective filtration, create membranes of any size with unique shapes, structures, and textures that are difficult to achieve with traditional technologies, and save materials through precise dosing during printing (Chen et al., 2024).

Thus, 3D-printing opens the possibility of designing membranes with special pore geometries for different tasks. Therefore, it can be argued that additive technologies are the future of membrane technologies, where they do not replace traditional methods, but rather complement them, expanding the possibilities for creating highly efficient membranes.

The purpose of this work is to present the prospects, opportunities, and challenges of using 3D-printing, in particular DLP and SLS technologies, to obtain ceramic membranes and membrane modules.

## 2. Comparison of traditional and additive technologies

Table 1 presents a comparative overview of traditional methods of ceramic membrane manufacturing and additive manufacturing (3D-printing).

***Table 1.*** *Comparative characteristics of traditional ceramic membrane production and 3D-printing (Dommati et al., 2019)*

| Criterion | Traditional methods | 3D-printing (additive manufacturing) |
|---|---|---|
| Geometry and design | Limited to simple shapes such as flat sheets, hollow fibers, or tubes | Design flexibility allows complex, optimized geometries with internal channels, lattice structures, and thin-walled structures |
| Microstructure control | Less accurate control of porosity and pore structure | Allows precise manipulation of the membrane microstructure by controlling pore size, shape, and distribution |
| Scalability | Scales well for mass production with high speed and efficiency | Scaling for mass production is more complex and slower, but ideal for small batches and customization |
| Cost | Generally, it is more cost-effective for mass production. However, setup and design changes can be expensive | High equipment and material costs can be significant. But less waste and the ability to customize can lower overall costs for specialized products |
| Speed | High speed for mass production, but long development and prototyping times | Fast prototyping and on-demand production, but the printing process itself can be lengthy, especially for complex models |
| Environmental friendliness | Some traditional methods may be less environmentally friendly due to the use of toxic chemicals and waste generation | A more environmentally friendly alternative, as it minimizes material waste and reduces $CO_2$ emissions through localized production |
| Customization | Complex and expensive | Allows you to easily and quickly customize the design of membranes for specific customer needs |

As can be seen, traditional methods have advantages for mass production and lower costs, while 3D-printing technologies offer advantages such as flexibility, design control, and greater environmental friendliness.

In conclusion, additive technologies are not just a trend, but a promising direction of development that is already changing the field of membrane technologies. They will enable the creation of more efficient, customized, and multifunctional membranes, which will be particularly relevant for high-tech industries such as biotechnology and medicine. 3D-printing will play an important role in the future of membrane technologies, especially in the production of high-performance and specialized systems after overcoming existing limitations.

## 3. Additive manufacturing (3D-printing) methods for ceramic membranes

According to the standards of the American Society for Testing and Materials (ASTM/F42) and the Technical Committee of the International Organization for Standardization (ISO/TC 261), additive manufacturing methods can be classified according to the aggregate state of raw materials, deposition methods, and melting/solidification methods. Considering the aggregate state of raw materials, AM technologies are divided into technologies to produce liquids, powders, and solids (filaments). SLA (Stereo Lithography Appearance) and DLP (Digital Light Processing) are the most popular 3D-printing methods for producing ceramic membranes. SLA and DLP are based on the process of photopolymerization. DIW (Direct Ink Writing) is based on the extrusion process. SLS (Selective Laser Sintering) uses the selective laser sintering process.

Aluminum(III) oxide, zirconium(IV) oxide, and silicon(IV) carbide (SiC) are most used as ceramic powders (Molchan et al., 2024). The use of the first two is associated with their more in-depth and already existing research in the literature for printing biomaterials, and silicon carbide – with the possibility of creating high-strength ceramic membranes based on it.

## 4. Manufacturing ceramic membranes by DLP-printing

DLP-printing is one of the most promising technologies to produce ceramic membranes due to its high precision, speed, and ability to create complex structures. This process allows the creation of “green” ceramic matrices (preliminary, unfired products) by photopolymerization of a suspension containing ceramic powder. Let's consider the most important parameters that affect the quality of a ceramic product (Swetha et al., 2024).

*Printing parameters*

Layer height – determines the thickness of each layer that is polymerized. Thinner layers (10–50 μm) provide higher resolution and surface smoothness, critical for accurate pore formation in the membrane. Exposure time – the time during which each layer is exposed to UV-light. Insufficient exposure results in incomplete curing, while excessive exposure can cause loss of detail due to light scattering. Platform lift and retraction speed prevent damage to the printed model and ensures even material coverage. Platform leveling provides a perfectly flat surface for printing, which is critical for successful adhesion and preventing delamination. The printing angle or orientation of the model on the platform affects accuracy, material usage, and printing time.

*Suspension characteristics*

The ceramic suspension contains a mixture of ceramic powder and photopolymer resin. Its properties, such as viscosity and solid phase content, affect the uniformity of printing. The wavelength of light, which depends on the DLP-printer (usually 385 nm or 405 nm). The suspension must be photosensitive to the wavelength emitted by the projector. Resin temperature affects the viscosity of the suspension. It is important to maintain a stable resin temperature, typically 20–28 °C, to ensure optimal viscosity and print quality.

*Post-processing parameters*

The product must be thoroughly washed with isopropyl alcohol or another solvent to remove uncured polymer after printing. Next, a debinding process is carried out – a heat treatment during which organic binding materials evaporate from the "green" product before sintering. The final stage of post-processing is high-temperature sintering to obtain a strong ceramic structure. The sintering temperature determines the final pore size, density, strength, and transport properties.

Optimizing all these parameters is a complex but important process that allows us to achieve high-quality, accurate, and functional ceramic membranes.

Fig. 1 shows the appearance of the Anycubic 3D-printer (Photon Mono M5 brand) that we used for DLP-printing of ceramic membranes.

***Fig.1.*** *Anycubic 3D-printer for DLP printing of ceramic membranes*

The first stage of 3D-DLP-printing of ceramic membranes was the design and preparation of the model (creation of a three-dimensional model of the membrane in Fusion 360 and slicing). Next, a ceramic suspension was prepared using kaolin calcined at 300 °C and High-Speed Resin 2.0 (Anycubic, China; viscosity: 75–85 Pa·s). Printing was performed using the parameters shown in Table 2.

***Table 2.*** *Parameters for DLP-printing of ceramic membranes on a 3D-printer*

| Parameter | Value |
|---|---|
| Layer Height | 50µm |
| Exposure Time | 3–4 s |
| Bottom Exposure time | 25–35 s |
| Light-off Delay | 12 s |
| Lift Distance | 6 mm |
| Lifting Speed | 60 mm/min |

Post-processing was carried out according to the procedure described in (Kurylenko et al., 2025). First, the membranes were washed with isopropyl alcohol, then debinding and sintering were carried out at final temperatures of 700 °C in a nitrogen environment and 950 °C in an air environment, respectively. Membranes based on zeolite and silicon(IV) carbide were synthesized in a similar manner. The maximum concentration of ceramic particles in the suspension that could be achieved without the use of surfactants was 26% by mass for kaolin, 30% by mass for zeolite, and 50% by mass for SiC.

Fig. 2 shows photos of kaolin-based ceramic membranes from the model to the finished product.

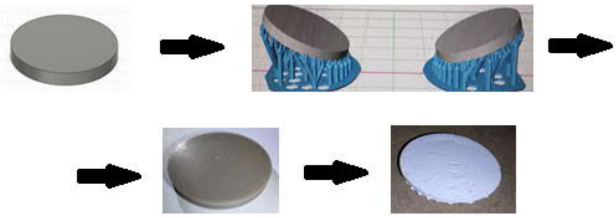

***Fig. 2.*** *Ceramic membranes manufactured using DLP printing – from model construction to finished product*

Our research on the ceramic membranes we obtained showed that DLP-printing produces brittle membranes due to insufficient ceramic powder content in the suspension, which requires further optimization of its composition by adjusting the rheological properties of the suspensions.

## 5. Manufacturing ceramic membranes by the SLS method

The manufacture of ceramic membranes using the SLS method is a promising but technically complex technology that is mainly used in research and for creating products with extremely complex geometries. This technology differs from other 3D-printing methods in that it works with powder materials.

Nevertheless, the SLS-printing process for ceramic membranes has similar stages to DLP-printing and includes the following steps (Wang et al., 2024).

*Preparation of composite powder*

Ceramic powder (e.g., $Al_2O_3$ or SiC) is mixed with a polymer binder. The key step is preparation for a homogeneous mixture, as the quality and microstructure of the final membrane depends on the particle distribution.

*Layer-by-layer sintering*

The composite powder is applied in a thin layer to the printing platform and evenly distributed over it for layer-by-layer sintering. This is followed by laser sintering (the laser beam can vary in power from 5 to 100 W). The polymer binder component is selectively sintered according to the 3D-model, binding the ceramic particles together during laser sintering. It is important to ensure good adhesion between the layers for high-strength and isotropic products.

*Post-processing*

The part is removed from the layer of unfired powder and mechanically cleaned after printing. Unused powder can be reused. Next, thermal post-processing is carried out – debinding and sintering, similar to DLP-technology, where first, through controlled heating, the polymer binder component is removed from the product, and then it is sintered at a high temperature to create a strong ceramic structure with a specified porosity.

Fig. 3 shows the 3D-printer used to print composite green bodies.

***Fig. 3.*** *Lisa PRO 3D-printer and powder mixing station*

The model of the 3D-printer is Lisa PRO. It has a 5 W infrared laser diode (IR Laser Diode). The laser operates at a wavelength of 808 nm.

Samples of composite green bodies were successfully printed. The appearance is shown in Fig. 4.

***Fig. 4.*** *Samples of ceramic membranes printed by the SLS method*

The powder consisted of 50 vol. % polymer powder (polyamide) and 50 vol. % ceramic powder (bentonite and kaolin). The standard profile used for PA12 Smooth v2 at 177 °C with a layer thickness of 0.075 mm. As can be seen, composite membranes were printed in both round shapes (for transport properties research) and rectangles (for mechanical research). The sintered samples (orange samples) practically retained their original shape, indicating a low degree of shrinkage.

The composite membranes had a low flow rate (up to 40 cm$^3$ of water per minute). The pressure was 5 MPa, which allows these membranes to be classified as ultrafiltration materials.

The determined mechanical properties, namely shear strength, were in the range of 20–30 MPa, which indicates their high mechanical properties. Further optimization will be aimed at increasing open porosity and permeability while maintaining mechanical characteristics.

## 6. Other possibilities of 3D-printing

3D-printing can be used for manufacturing not only ceramic membranes, but also many other specialized products, such as devices, cell housing for studying transport properties, mechanism parts, etc. We have successfully printed cells for studying transport properties, pore size, a mechanism for a planetary mill, etc. (Fig. 5).

***Fig. 5.*** *The variety of products can be manufactured by 3D-printing*

## 7. Challenges and problems of 3D-printing ceramic membranes

Although 3D-printing is currently considered a promising and innovative method for producing ceramic membranes, there are still many challenges and problems that need to be overcome before it can be implemented in mass production (Wang et al., 2024).

*DLP-printing*

1. *Optimization of ceramic suspension.* A homogeneous and stable suspension consisting of ceramic powder and photopolymer resin is critical for DLP-printing of ceramics. The main problems in this case are

related to the instability of the suspension, its high viscosity, and the presence of air bubbles.

2. *Fragility of “green” bodies.* Parts printed on a DLP-printer are very fragile and prone to damage during post-processing.

3. *Cracks and deformations.* Cracks often form during debinding and sintering processes due to internal stresses.

4. *High shrinkage during sintering*. Ceramic products printed on a DLP-printer have a high degree of shrinkage during sintering. This requires precise process control and consideration of shrinkage at the design stage.

*SLS-printing*

5. *Process complexity*. SLS ceramic printing does not involve direct sintering but usually uses ceramic powder with a polymer binder. This significantly complicates the process.

6. *Porosity control*. Although SLS allows for porosity control, achieving the desired density and pore distribution can be difficult due to inhomogeneities in the sintering process.

7. *Shrinkage and deformation*. The high temperature of the process and subsequent cooling cause shrinkage, which can lead to deformation, especially for large parts as by DLP.

8. *Polymer binder removal*. Unlike DLP, where the polymer is burned out of the “green” part, in SLS ceramic printing, polymer or binder residues may remain in the final product, affecting its properties.

9. *Energy consumption*. SLS-printing requires significantly more energy to heat the entire chamber compared to DLP.

10. *Hazardousness*. Working with fine ceramic powder requires special safety measures to avoid dust inhalation.

## 8. Conclusions

It has been shown that ceramic membranes can be obtained using the modern and promising method of 3D printing, which allows controlling the pore size, desired geometry, and pore size distribution during their manufacture, as well as saving materials. We believe that DLP and SLS methods are the most promising among the many 3D-printing technologies.

DLP-printing of ceramic materials is characterized by high resolution and accuracy, printing speed, and cost-effectiveness for small parts with complex, thin, and detailed structures not attainable with conventional methods. SLS-printing of ceramic materials is characterized by the ability to create complex, functional products that are also strong and durable. This type of printing also allows printing of products with complex geometry and large sizes. Thus, it has been shown that both technologies are moving towards mass production and application.

It is noted that DLP technology will dominate where high precision, complex geometry, and fine details are required, especially for biomedical implants and electronics. SLS technology will remain relevant for creating large ceramic parts with complex geometry where surface accuracy is not critical. In the future, DLP and SLS printing technologies can be expected to complement each other, covering different areas of ceramic production.

The use of 3D-printed ceramic membranes for water and wastewater treatment is expected to become widespread, as 3D printing will make it possible to obtain ceramic membranes for micro-, ultra-, and nanofiltration with optimized internal structures, which will increase filtration efficiency and reduce fouling.

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## References

1. Diachenko, A.; Hutsul, K.; Dontsova, T. Prospects for using 3D printing to form ceramic membranes: a brief review. *Water and Water Purification Technologies. Scientific and Technical News*, **2024**, *38(1)*, 14-26. https://doi.org/10.20535/2218-930012024315361.

2. Kyrii, S. Materials and methods for ceramic membrane synthesis. Short review. *Water and Water Purification Technologies. Scientific and Technical News*, **2023**, *35*, 26-40. https://doi.org/10.20535/2218-930012023281034

3. Diao, Q.; Zeng, Y.; Chen, J. The applications and latest progress of ceramic 3D printing. *Additive Manufacturing Frontiers*, **2024**, *3(1)*, 200113. https://doi.org/10.1016/j.amf.2024.200113.

4. Chen, T.; Xu, P.; Qiu, M. Construction of anti-fouling ceramic tubular membranes with corrugated inner surfaces using DLP 3D printing. *Journal of Membrane Science*, **2024**, *706*, 122941. https://doi.org/10.1016/j.memsci.2024.122941.

5. Li, J.; Chen, X.; Yan, Z. Structural and molecular aspects of nanomaterials driven 3D printed ceramic membranes for advanced water treatment. *Journal of Molecular Structure*, **2026**, *1350*, 143916. https://doi.org/10.1016/j.molstruc.2025.143916.

6. Dommati, H.; Sinha Ray, S.; Wang, J.C. A comprehensive review of recent developments in 3D printing technique for ceramic membrane fabrication for water purification. *RSC Advances*, **2019**, *9*, 16869-16883. https://doi.org/10.1039/C9RA00872A.

7. Molchan, Y.; Vorobyova, V.; Vasyliev, G.; Pylypenko, I. Physicochemical and antibacterial properties of ceramic membranes based on silicon carbide. *Chemical Papers*, **2024**, *78*, 8659-8672. https://doi.org/10.21203/rs.3.rs-3563364/v1.

8. Swetha, S.; Sahiti, T.J.; Priya, G.S. Review on digital light processing (DLP) and effect of printing parameters on quality of print. *Interactions*, **2024**, *245(1).* https://doi.org/10.1007/s10751-024-02018-5.

9. Kurylenko, V.S.; Tereshkov, M.V.; Fedenko, Yu.M.; Lapinskyi, A.V.; Yanushevska, O.I.; Dontsova, T.A. Prospects of using DLP 3D printing technology to produce membrane ceramic modules. *Journal of Chemistry and Technologies*, **2025**, *33(2)*, 508-518. https://doi.org/10.15421/jchemtech.v33i2.317663.

10. Wang, K.; Yin, J.; Chen, X. Advances on direct selective laser printing of ceramics: An overview. *Journal of Alloys and Compounds*, **2024**, *975*, 172821. https://doi.org/10.1016/j.jallcom.2023.172821.

11. Wang, D.; Ling, D.; Lin, W.; Wang, K. Potential and challenges of 3D printing technology in membrane-based water treatment research. *ACS ES&T Water*, **2024**, *4*, *9*, 3619-3622. https://doi.org/10.1021/acsestwater.4c00616.

# ПЕРСПЕКТИВИ, МОЖЛИВОСТІ ТА ВИКЛИКИ ВИКОРИСТАННЯ 3D-ДРУКУ ДЛЯ ОТРИМАННЯ МЕМБРАННИХ ЕЛЕМЕНТІВ

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*3D-друк або як його ще називають – адитивні технології, дозволяє створювати різноманітні вироби, у тому числі, й мембранні елементи з різних матеріалів, а саме, з полімерів, металів, керамічних матеріалів тощо, забезпечуючи виконання елементів складної та бажаної геометрії. У цій статті пропонується розглянути перспективи та можливості адитивних технологій для комерційного виробництва керамічних мембран та мембранних модулів. Метою цієї роботи є представлення перспектив, можливостей та проблем використання 3D-друку, зокрема цифрової обробки світлом (DLP) та селективного лазерного спікання (SLS), для отримання керамічних мембран та мембранних модулів. Було проведено порівняння традиційних методів виробництва керамічних мембран з адитивними технологіями, яке показує, що 3D-друк є перспективним напрямком розвитку. Він вже змінює сферу мембранних технологій. Аналіз літератури показує, що адитивні технології дозволяють створювати більш ефективні, індивідуальні та багатофункціональні мембрани, що особливо актуально для високотехнологічних галузей промисловості. Було показано, що якість керамічних мембран, отриманих методом DLP або SLS-друку, залежить від вибору керамічного матеріалу, оптимальних налаштувань слайсера (програмного забезпечення для підготовки моделі до друку), його калібрування та контролю параметрів друку, таких як температура, швидкість друку та інші. Крім того, на якість друкованих деталей впливають підготовка моделі, специфіка конкретної технології друку, роздільна здатність та багато іншого. Незважаючи на існуючі проблеми та виклики, обидві технології рухаються до масового виробництва та застосування: 3D-друк дозволить виготовляти керамічні мембрани для мікро-, ультра- та нанофільтрації з оптимізованими внутрішніми структурами, що підвищить ефективність фільтрації та зменшить забруднення.*

***Ключові слова:*** *керамічні мембрани, цифрова обробка світлом, перспективи адитивних технологій, селективне лазерне спікання, 3D-друк.*