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Evaluation of different Atomic Layer Deposition techniques for pore size tuning of ceramic membranes from ultra- to nanofiltration

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Abstract

Many industrial processes often produce large amounts of aqueous wastes contaminated with solvents and other environmentally hazardous materials. Such effluents need to be treated before they can be discharged into the natural water bodies. The present treatment methods are based on energy-intensive technologies like distillation, evaporation, and drying. Implementing nanofiltration (NF) membranes in treating such effluents can lead to significant energy savings – up to 90 % less energy than distillation [1]. However, the use of commercially available NF polymeric membranes is hampered due to their instability in solvents [2], and the main challenge of ceramic membranes is obtaining a narrow pore size distribution in the nanofiltration range (pore diameter <2 nm) [3].

Atomic Layer Deposition (ALD), an established self-limiting gas-phase deposition technique for growing atomic-scale thin films, has been employed for narrowing ceramic membrane pores to the nanofiltration range. Two different ALD techniques, temporal and spatial ALD (t-ALD and s-ALD)[4], have been applied, and both methods resulted in significant narrowing of the pores (MWCO from 10kDa down to < 300Da)[5].

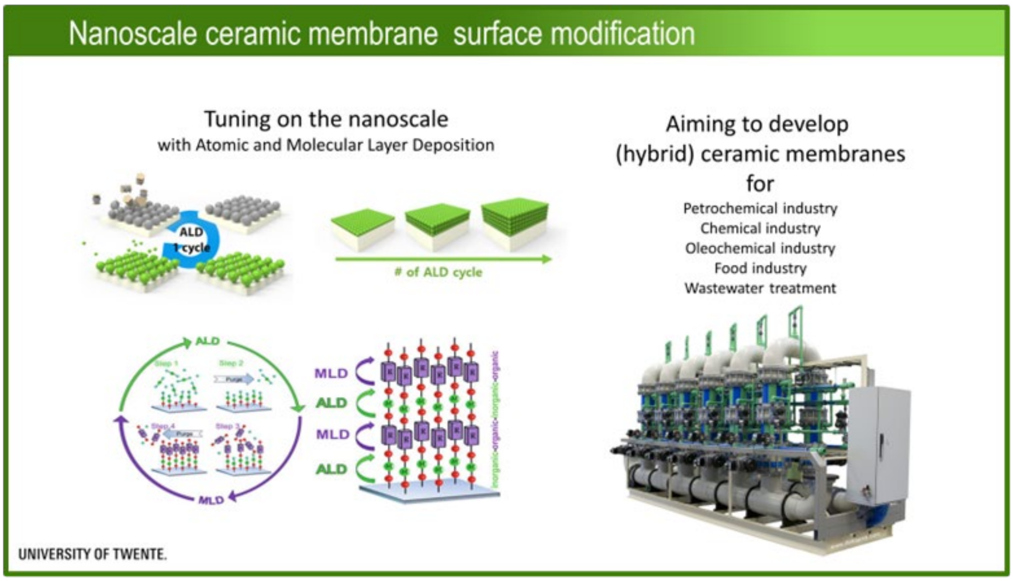

Fig. 1: Schematic presentation ALD/MLD layer formation.

However, large ceramic modules do not fit in state-of-the-art ALD reactors, so a new dedicated atmospheric tubular reactor design [4] is being developed and built. In this design, the reactor wall is formed by the industrial tubular ceramic membrane itself, and carrier gas flows are employed to transport the precursor and co-reactant vapors to the reactive surface groups present on the membrane surface.

Next to this, a combination of ALD and Molecular Layer Deposition (MLD) is currently strongly emerging; MLD is ALD's counterpart to deposit purely organic thin films (e.g., polyimides and polyamides). ALD/MLD allows the deposition of novel hybrid inorganic-organic layers. First, an intermediate hybrid layer is deposited with ALD/MLD, and during a dedicated thermal treatment, narrow pores in the nanofiltration range are constructed to create a semi-permeable membrane. Second, the nanopore can be functionalized by choosing another organic molecule. This allows for tuning, e.g., tuning the hydrophobicity of the membrane.

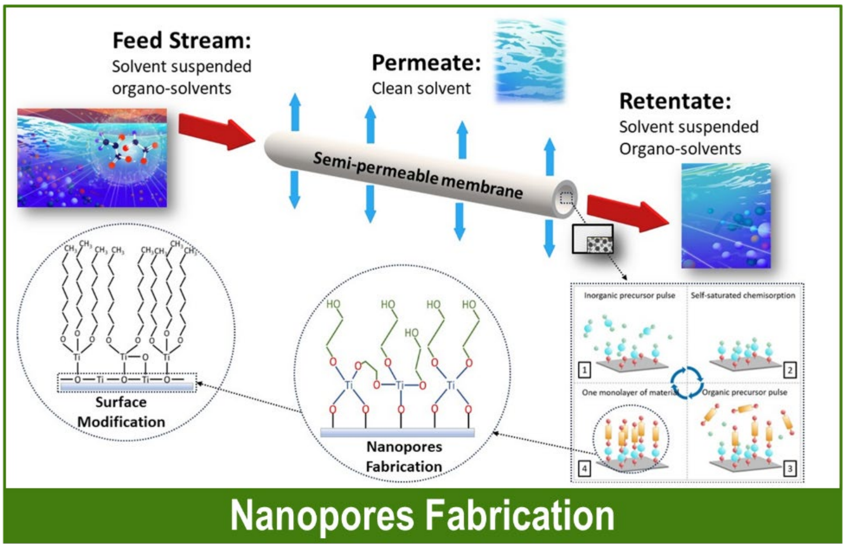

Fig.2: Schematic presentation of the ceramic membrane modification

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