A tale of two scales: The contrast behaviors and mitigation strategies of gypsum and silica scaling in membrane distillation

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Mineral scaling is a major constraint that limits the efficiency of membrane desalination. Different types of mineral scales formed via distinct mechanisms might lead to distinctive consequences. Herein, we present a set of systematic investigations revealing different behaviors and mitigation strategies between gypsum and silica scaling in membrane distillation (MD), a hybrid membrane-thermal technology suitable for hypersaline brine treatment. Gypsum scaling formed via crystallization causes a rapid water vapor flux decline and membrane pore wetting, due to its fast kinetics and intrusive nature. In contrast, slower kinetics and the absence of pore wetting were noticed for silica scaling formed via polymerization. Further, different formation mechanisms result in distinct responses of mineral scaling to membrane surface wettability. Superhydrophobic membrane was able to delay induction time and enhance reversibility of gypsum scaling but not silica scaling. In addition, we demonstrate that anti-scalants with varied functional groups are needed to reduce gypsum and silica scaling in MD. Negatively charged anti-scalants with Ca(II)-complexing moieties are the most effective for mitigating gypsum scaling, whereas anti-scalants enriched with positively charged amino groups possess the best performance to inhibit silica scaling. The mechanisms underlying the above differences are discussed at the molecular level. Therefore, our work promotes the fundamental knowledge on membrane scaling in MD desalination and suggests that scaling mitigation strategies should be tailored to the scaling formation mechanisms.