KIDNEY-INSPIRED MEMBRANES WITH SUPERIOR ANTIFOULING PROPERTIES

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Membranes are a versatile separation technology, used in a multitude of industrial settings. They pose several inherent advantages, such as easy scale up and separation with no requirement for additives. This has caused increasing popularity in water purification and bio-separations. However, the major challenge of this technology is fouling, leading to a declining flux, which requires frequent, extensive cleaning to correct. Fouling is influenced by factors on different scales; macroscopically, the characteristics of the feed and the hydrodynamics of the membrane module will influence fouling. Interactions between foulants and the membrane surface, however, also affect fouling and are governed by fundamental physical forces, such as electrostatic interactions. Thus, all scales must be considered when designing membranes that are less prone to fouling.

To solve this problem, we can turn to nature, which provides us with a treasure trove of clever solutions to a wide range of engineering problems, such as those experienced in membrane processes. The kidney, for instance, is a remarkable organ capable of producing over four million liters of effectively protein-free urine over a lifetime with no significant fouling (1). The glomerulus is a bundle of specialized blood vessels, which carries out the first stage of kidney filtration, the stage most comparable to membrane separations. Within the lumen of these blood vessels, a brush-like structure is present, composed of proteoglycans and glycoproteins, which are responsible for the overall negative charge and hydrophilicity of this layer. The glomerulus also has notable macroscopic properties that can create hydrodynamic regimes that promote the back transport of adsorbed foulants. The combination of the brush structure and the resulting hydrodynamics of the system are believed to be key causes behind the superior anti-fouling properties of the kidney.

To translate this inspiration into membrane processes, the design that has been employed in this work is the grafting of polyelectrolyte polymer brushes as an antifouling layer onto commercial membranes. This grafting is achieved through surface-initiated controlled radical polymerization (SI-CRP) using ARGET ATRP (Activators Regenerated by Electron Transfer Atomic Transfer Radical Polymerization). The stimuli-responsive polymer brushes reduce fouling through steric and electrostatic repulsion, due to the negative charge of the layer in solvents. This has been demonstrated, thus far, in the filtration of silica nanoparticles and albumin as model foulants in water purification and bio-separations. In both cases, the flux decline over a fixed time for the polymer brush modified membranes showed significant improvement over the commercial membrane with maximum reductions in flux decline of 43% and 42% in the filtration of albumin and silica nanoparticles, respectively.

The combination of other macroscopic influences, together with further optimization of the polymer brush antifouling layer, has the potential to leverage the superior antifouling properties of the kidney to synthesize a class of next-generation membranes.

1. Hausmann R et al. The glomerular filtration barrier function: new concepts. Curr Opin Nephrol Hypertens. 2012;21(4):441–9.