Experimental and theoretical analysis of spontaneous ion exchange by diffusion-kinetic ion concentration polarization

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In this presentation, we suggested a "diffusio-kinetic ion concentration polarization (diffusio-kinetic ICP)" for a spontaneous ion exchange system. The diffusio-kinetic ICP utilized the mechanisms of an ion diffusion, a spontaneous ion depletion and a spontaneous solute exclusion [1, 2] so that the ion exchange system would be accomplished without any external power source.

When saline water was introduced into the microchannel of which side walls were composed of cation-selective membrane, the ion exchange process occurred and then the desalted diffuse layer was formed nearby the membrane. Because of the flow of saline water, the desalted diffuse layer would be deformed but retain finite thickness. If we gather the water adjacent to the membrane surface at outlet, we can get the desalted water through the spontaneous manner which means that any external electrical source is not required, whereas the ICP needs the electrically driven ionic flux through the membrane.

Through the rigorous theoretical analysis, the diffusio-kinetic ICP was characterized by the Sherwood number which is the ratio of convective transfer and diffusion rate. When $Sh \ll 1$, the second term the transport phenomenon became the diffusion-dominant mass transport. On the other hand, when $Sh \gg 1$, convective transport was dominant. For each case, the desalted layer would be overlapped depending on Sh as shown in Fig. 2.

Furthermore, the desalted layer was experimentally visualized in micro/nanofluidic platform. When the desalted layer was developed near the membrane surface, the concentration gradient was generated inside the desalted layer. Under a diffusiophoretic mechanism [3], the charged particles would be excluded from the nanoporous membrane as shown in Fig. 3. Thus, the spontaneous ion depletion was able to be verified by the direct visualization with various cases of Sh. Note that the thickness of the desalted layer was usually larger than the thickness of the particle exclusion zone because of the working mechanism of the diffusiophoresis.

The fact that the diffusio-kinetic ICP platform can work without any external power source implied the merits in terms of the power consumption and the low-cost operation compared with the conventional technologies so that the diffusio-kinetic ICP would be an effective mean in remote and resource-limited settings.
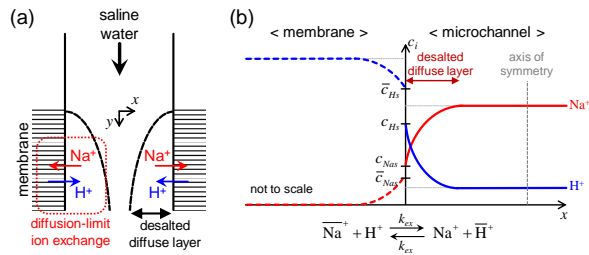
Fig. 1 (a) Schematic diagram for diffusio-dialysis. (b) Conceptual image for ion concentration distributions near the interface of the membrane and the microchannel. Upper bar means the ionic species inside the nanoporous membrane.
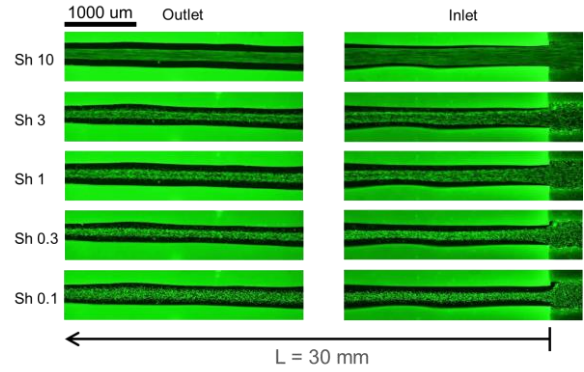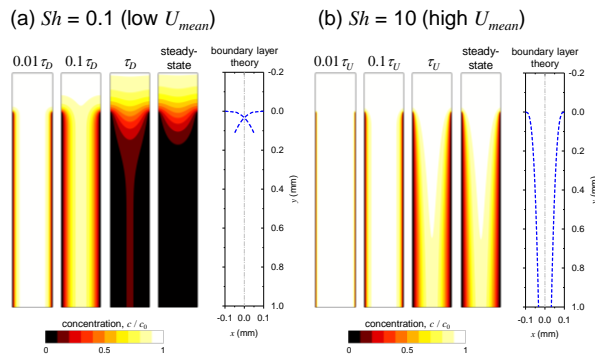

Fig. 2 Simulated spatiotemporal concentration change inside the microchannel when (a) $Sh = 0.1$ and (b) $Sh = 10$. In each figure, τ_D and τ_U were diffusion and convection time scales respectively.
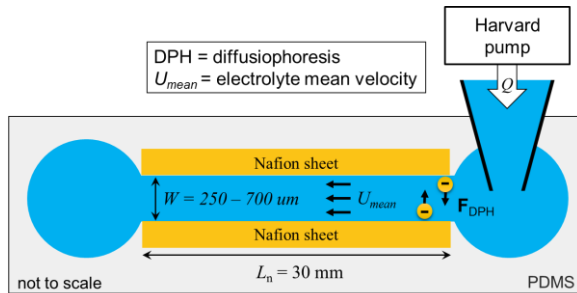

Fig. 3 (a) Schematic of the proposed devices with characteristic length scales (not to scale).

Fig. 4 Visualization of particle exclusion zone with various Sh.

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