Investigating the hierarchical structure of reverse osmosis membranes - from the micro to nanoscale

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Reverse osmosis (RO) membranes are used within the oil and gas industry for sea water desalination on off-shore oilrigs. Because of the cost of installing desalination plants at sea, much research is being done to better understand the membranes and so reduce the inherent costs. Although much work has been done on the bulk properties of the membranes, little work has been carried out on understanding how this is related to the microstructure. The membranes consist of three layers of material - a polyester backing layer, polysulfone (PSf) support and a polyamide (PA) membrane. It is generally thought that the PA layer controls ion selectivity within the membrane but little is understood about its complex hierarchical structure. Additionally, because the polymer is soft, characterisation using standard microscopy techniques is challenging. We have used atomic force microscopy (AFM), focussed ion beam scanning electron microscopy (FIB-SEM) and aberration corrected scanning transmission electron microscopy (AC-STEM) to probe the membranes' structure across a wide range of length scales - from the micrometre to nanometre range.

SW30HR (DowFilmtech), a commercially available membrane, was used for this study. To enhance contrast, stabilise the membrane for imaging and reveal information about permeation pathways through the membrane, membranes were stained using RuO_4. FIB-SEM reconstructions and STEM tomography reveal the 3D structure of the PA layer for the first time. This shows large interconnected regions which have not been observed before, as well as discrete voids which range in size from 10 nm to several hundred nanometres. The surface area is much larger than previously estimated from surface microscopy techniques. This large surface area and interconnected regions will result in higher water flow and in turn higher water flux through the membrane than was previously thought.

RuO_4 staining combined with AC-STEM was used to investigate the sub-nanometre permeation pathways of ions through the membrane. Different staining methods were investigated revealing the role of hydration on the permeation of ions. AC-STEM was used to image sub-nanometre precipitates that had become lodged in the membrane giving an indication of the size of the nanopores within the membrane.