Background to membrane fouling and anti-fouling membranes.

Why membranes foul
In cross-flow membrane separation processes, solvent, often water, is selectively permeates through the membrane under pressure from the feed water, leaving solutes and particulate matter behind. Solutes and particulate matter accumulate on the membrane surface, a process referred to as concentration polarisation. The accumulation at the membrane surface is counter balanced by removal of this material by the crossflow. Under some conditions, however, the material accumulating on the membrane surface becomes more agglomerated and is not effectively removed by the crossflow, the membrane has become "fouled". This also reduces back-diffusion of solutes. In the case of reverse osmosis (RO) membranes which reject salt ions, this leads to an enhanced concentration polarisation; a process referred to as cake-enhanced-concentration-polarisation (CECP). This leads to a reduction of the flux of water through the membrane or an increase in the trans-membrane pressure (TMP) required to maintain a constant flux and in RO membranes a reduction in salt rejection.

Eventually, the flux decline or increase in TMP is such that the membranes must be physically and/or chemically cleaned.

Some membrane fouling may be irreversible and membrane performance cannot then be restored by physical or chemical cleaning and the membranes modules have to be replaced. In practice no membrane cleaning is 100% effective.

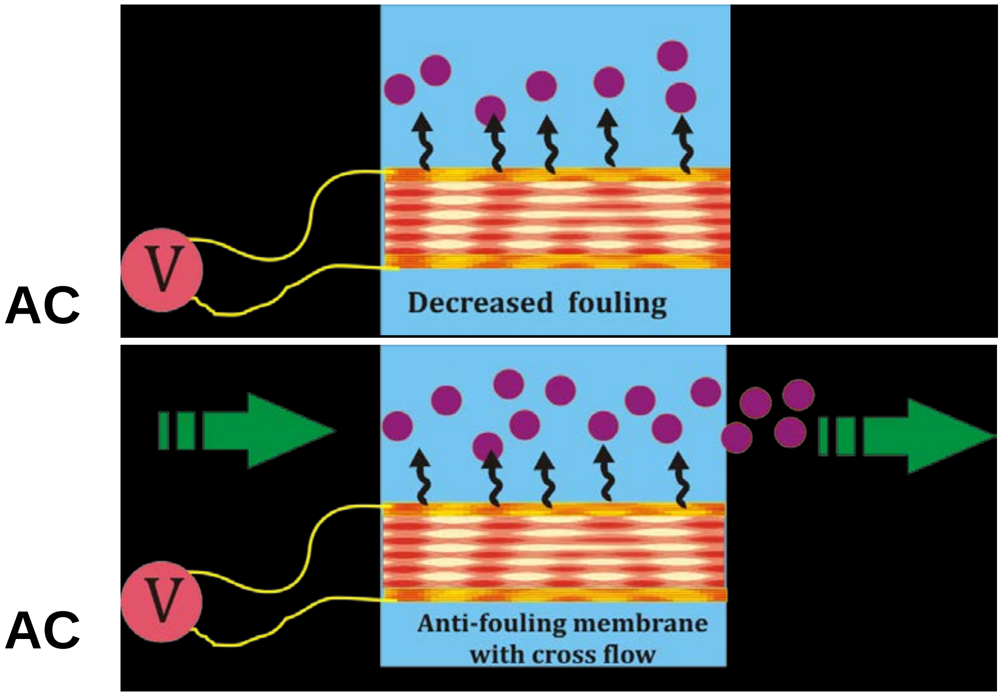
Concept of Critical Flux
Membrane fouling occurs when the forces driving solutes and particles to the surface (determined by the flux) are not counterbalanced by shear forces produced by cross flow of the feed that remove accumulated solutes and particles from the surface. This is the basis for the concept of critical flux which determines when fouling will occur.

The critical flux depends on many parameters including the fluid viscosity, particle size and morphology, surface roughness and hydrophilicity of the membrane surface as well as specific electrostatic and van der Walls interactions between the solutes and membrane surface. The latter two have a particularly strong influence on the reversibility of fouling.

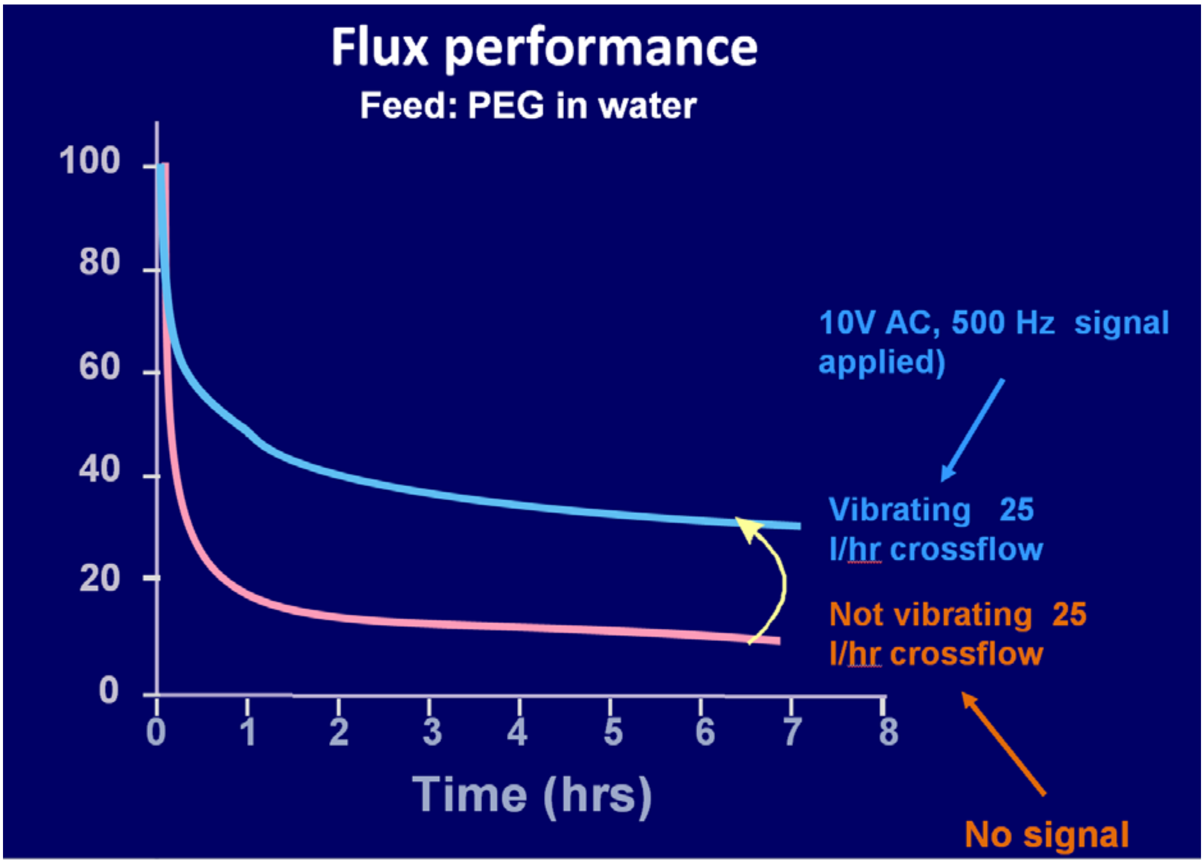
Basic concept of the piezo-electric antifouling mechanism

Vibration of the surface of the membranes in a direction normal to the surface keeps solutes and particles that are accumulating at the membrane surface in suspension and reduces van der Waal and electrostatic forces induced bonding to each other and to the membrane surface. This allows the solutes and particles to be swept away by the crossflow of the feed solution.

This vibration is achieved by applying a small AC signal to the piezo-electric membranes.



Electrically energised membranes would experience less fouling and have higher fluxes than passive membranes. This is illustrated in the figure below, where the flux through a piezo-electric membrane is plotted with and without application of the AC signal.



A second effect relates to oscillatory distortions of the internal structure of the membrane due to contraction and expansion of the membrane thickness (that is dimensional changes normal to the membrane surface). This, in the case of porous membranes such as nanofiltration and microfiltration membranes, reduces internal or pore blocking of the membrane.

Applicability of the technology

The antifouling membranes would be particularly useful in waste water treatment requiring removal of a high concentration of particulates and low concentration of dissolved salts.

Piezo-electric membranes can be produced either post-manufacture or as part of the core manufacturing process.

The production of piezo-electrically active membranes requires that the polymers used in the membranes have molecular components with electric dipole moments that can be aligned using electric fields during the manufacturing process or post manufacturing.

One of the best polymers for producing piezo-electric membranes is PVDF, although there are other polymer types that are suitable.

PVDF membranes are more uniformly porous and are generally restricted to MF or NF because unlike RO membranes, they lack a thin surface layer that is that is tighter and provides high ion rejection. However, it would be possible to deposit a thin (<0.5 micron) layer of another polymer on the surface of a MF or NF PVDF membrane. This is a common manufacturing technique already used in producing RO membranes from polymers other than PVDF. The PVDF base membrane could then provide the piezo-electric active component, whilst the thin polymer film on top provides the salt rejection attributes.

Producing Piezo-electric membranes: Electric “Poling”

Electrical poling was used to produce piezo-electrically active membranes from commercially PVDF membranes. The latter are not piezo-electric although PVDF is intrinsically a piezo-electric material. Poling is achieved by placing the membrane in an intense electric field whilst the membrane is at an elevated temperature, just below the melting point of the PVDF polymer. The intense electric field aligns the electric dipoles of the material. The sample is then cooled whilst still in the intense electric field. The dipoles then remain aligned when the electric field is removed.

The subsequent application of a small electric field will cause the membrane to either shrink (become thinner) or expand (become thicker), depending on the direction of the field. If an alternating (AC) field is applied, the membrane thickness oscillates at the frequency of the applied field.

The State of the Art

Piezo-electric membranes have been successfully made on a laboratory scale and their performance has confirmed the fact that these membranes have a very much higher flux capacity and lower rate of fouling than non-electrically energised membranes. These laboratory studies were performed on PVDF MF membranes which were rendered piezo-electrically active by subsequent electric “poling”.

Further Development

Further laboratory scale work is in progress on PVDF membranes that have been coated with a thin polymer to construct RO membranes and to test their performance. Other implementations and embodiments of the piezo-electric membranes are also being explored in a collaborative research program with the Singapore Membrane Technology Centre at Nanyang Technological University in Singapore.

Production of larger scale membranes suitable for industrial purposes remains to be done. For such industrial production the electrical “Poling” can either be performed during the actual production of the membrane or post-production.

Patents and IP position

CMS holds patents on the production of piezo-electric membranes. Patents have been applied for world-wide and have already been granted in the USA, China and Australia.