CMS INNOVATIONS

Creators and suppliers of innovative applications of physics, chemistry and related sciences
In particular the commercial application of Electrical Impedance Spectroscopy

An introduction to CMS's

Membrane Surveillance and Optimisation Service

1 Overview

CMS uses Electrical Impedance Spectroscopy to provide real-time observation of membrane condition. This allows incipient organic and inorganic fouling to be identified and feed flow and recovery rate to be dynamically adjusted to increase the operating efficiency of membrane-based water treatment plants. CMS Membrane Surveillance and Optimisation Service also provides data to accurately evaluate the performance of chemicals used in CIP processes and to prevent the formation of membrane scale.

1.1 Fouling, Efficient Operations and Critical Flux

Sustaining high recovery and minimising the deleterious impact of membrane fouling is the principal operational challenge for RO systems. Fouling increases energy consumption due to decreased permeability, reduces a membrane's ability to reject salt and shortens membrane life due to the damage caused by cleaning chemicals which are themselves expensive and require disposal. The risk of fouling increases capital costs by requiring plants to be oversized to provide spare capacity to deal with regular cleaning.

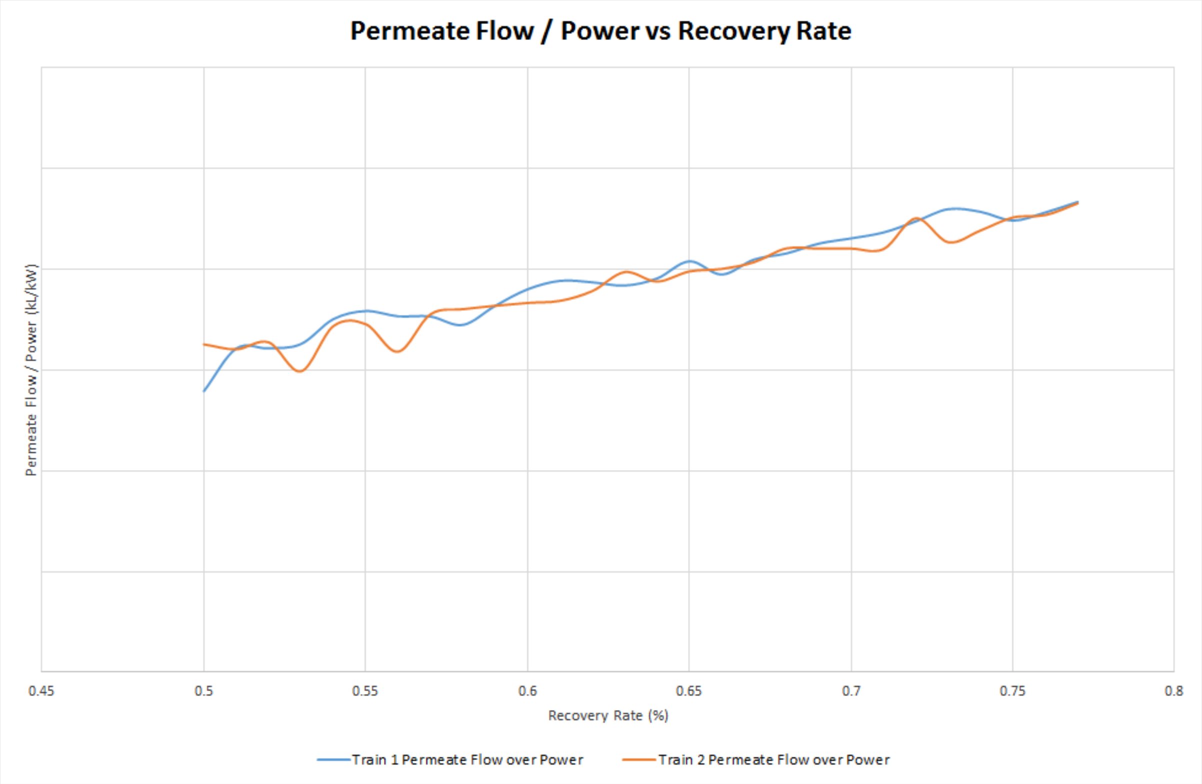
Critical flux is the highest flux when no or negligible fouling occurs, a concept first proposed in 1995. Above this threshold flux, fouling rapidly sets in. The application of critical flux to inorganic fouling is well documented. CMS and its research partners have identified similar trends in the onset of organic fouling.

CMS's technology allows critical flux to be determined in real-time during operation of RO facilities.

The ability to identify critical flux allows RO facilities to operate at the recovery rate that delivers the optimum balance between minimisation of fouling and maximisation of permeate volume per unit of energy consumed.

The figure below shows the correlation between Permeate Flow/Power (kL/kW) and Recovery Rate for a commercial RO water facility. While the marginal gains from increases in recovery rate will decline and ultimately reverse as recovery rate is increased towards its physical maximum, this data shows an 8% increase in Recovery Rate has on average delivered an 8% increase in the volume of permeate produced per kW of power. Incorporating profit margin, the corresponding increase in net revenue would be more than 8%.

CMS's Service allows a plant to be operated at maximum recovery rate with the assurance that any increase in fouling will be immediately identified.



1.2 Electrical Impedance Spectroscopy

EIS utilises an alternating current to probe a membrane to depth scales ranging from the atomic to macroscopic dimensions: roughly from a billionth of a metre up to that visible to the naked eye.

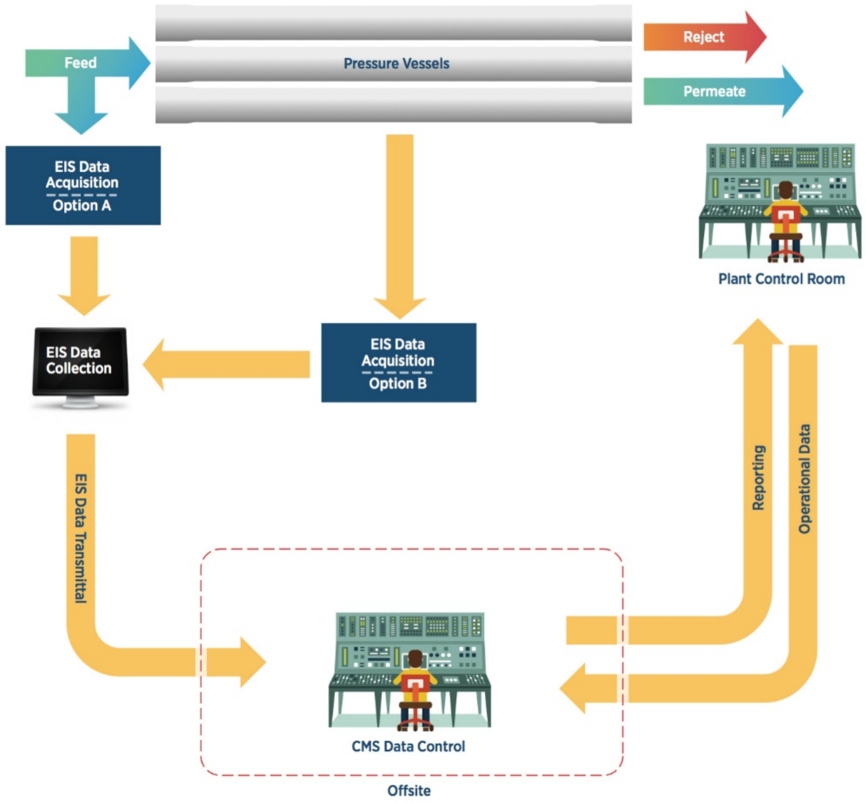
CMS's data acquisition systems are non-invasive and operate in real-time during commercial operations. Data is acquired on-site and the despatched wirelessly to CMS's control room for analysis and evaluation.

1.3 CMS's Service

CMS's Membrane Surveillance and Optimisation Service is the product of over two decade's research and development lead by CMS Technical Director, Prof Hans Coster.

CMS captures and analyses proprietary data relating to membrane condition, conveying that data back to a centralised Control Room, from where clients are provided with real-time actionable information to improve economic performance.

Complemented by existing performance data (including feed and permeate flow, TMP and salt-rejection), CMS provides operators with the information necessary to adjust flux, cross-flow and chemical usage to minimise fouling and maximise plant efficiency.



1.4 Benefits

CMS provides its clients with critical operational insights that lead to:

- A reduction in energy consumption;
- A reduction in CIP frequency;
- A reduction in chemical consumption;
- A reduction in de-scalant consumption; and
- An increase in average membrane life.

CMS also monitors membrane conditions during Clean-In-Place and de-scaling operations, allowing plant operators to better assess their effectiveness, thus minimizing chemical consumption and off-line periods.

Whenever an operational response is indicated, CMS contacts the plant operator to discuss recommended remedial action, thereafter monitoring the effectiveness of the actions undertaken.

A copy of the analytical data used by Control Room personnel is also available to the plant operator.

A suite of monthly reports is provided to plant operators.

CMS's service is applicable to any spiral-wound or flat-bed membrane-based water treatment plant, wherever located, including:

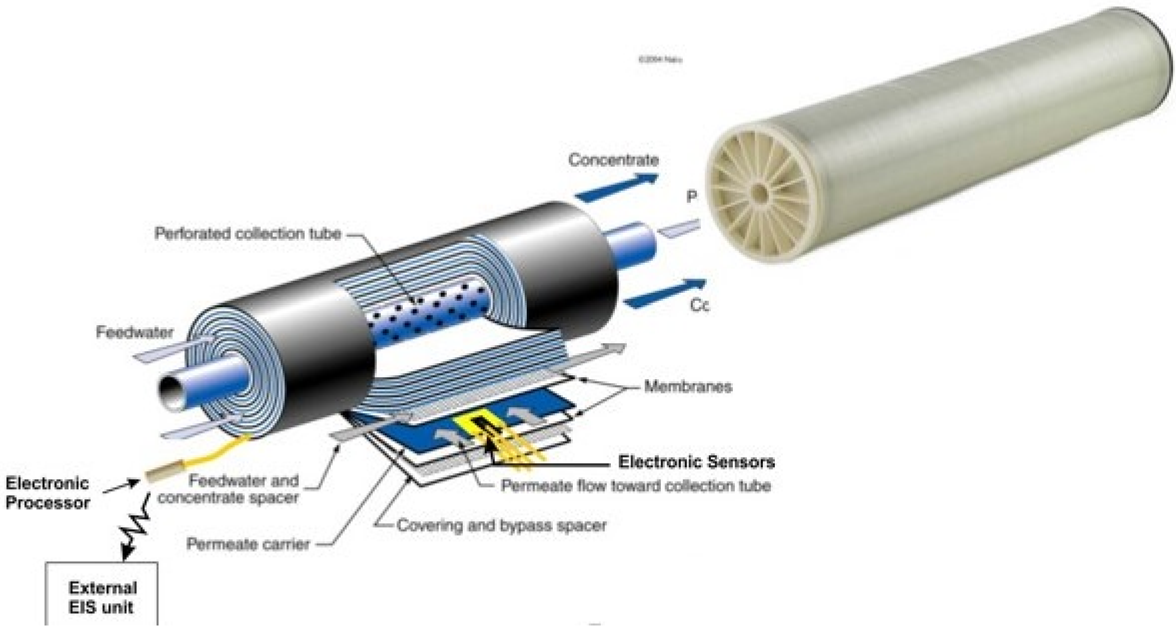
- Reverse osmosis waste water treatment plants;
- Reverse osmosis desalination plants; and
- Micro, ultra and nano filtration water treatment plants.

1.5 CMS Hardware

CMS utilises two on-site data capture systems: CMS eModules and CMS Replicators. The Replicator was the initial system employed during the development phase. The Replicator is currently available and has application for water treatment facilities with identified fouling issues or to evaluate what-if scenarios. The eModule is still in development but will supersede the Replicator for most applications.

CMS eModule

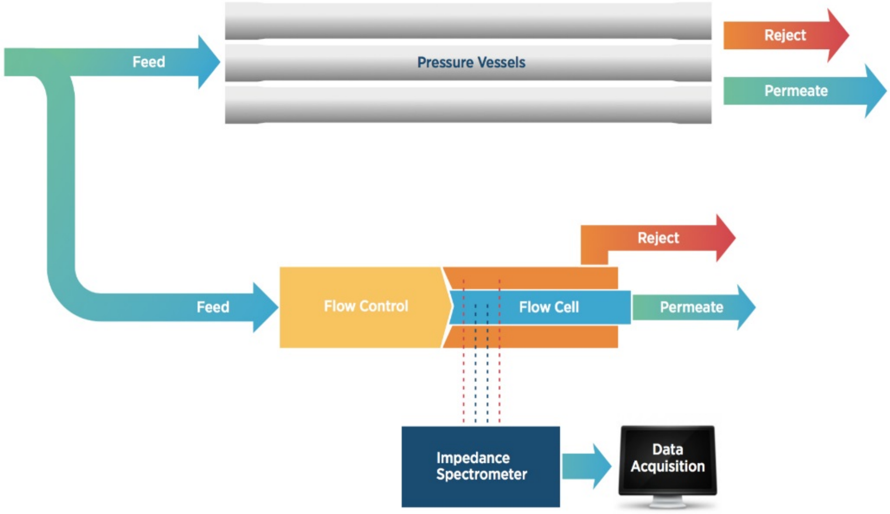
CMS eModules are currently under development. They have embedded EIS sensors to analyse the current fouling state and, save for the passive sensors and connections, will be identical to the existing modules used in the subject plant. CMS will provide its technology to be incorporated in modules from all major membrane suppliers. CMS recommends using at least two eModules per train – one for each stage. These will be inserted into selected pressure vessels and operate alongside existing standard modules. Captured data will be wirelessly transmitted through the pressure vessel wall, thus preserving the structural integrity of the pressure vessels.



The eModule provides a secure connection to the impedance spectrometer by separating its functions into two physically distinct units. The internal unit is physically very small and resides within the pressure vessel, communicating with the external unit using wireless connectivity. It is contemplated that the internal unit will be electrically energised by induction to avoid connection through the pressure vessel. The external unit sits outside the vessel and is connected to CMS's on-site computer, where data is consolidated and transmitted back to the CMS Control Room.

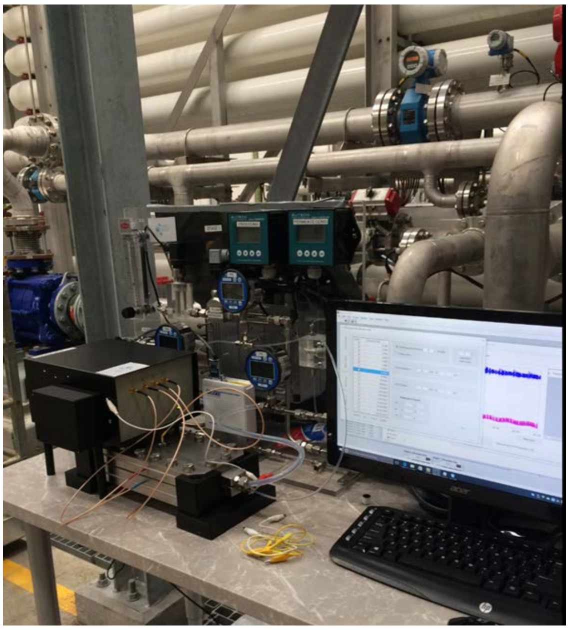
CMS Replicator

The CMS Replicator is a dedicated flow cell and flow control system that effectively creates a mini RO facility to replicate (in an on-line side-stream) conditions in the train to which it is connected. A small volume of feed water is diverted from the train to the Replicator. Flow conditions are matched to ensure that the fouling behaviour of the Replicator's membrane is highly correlated to the fouling behaviour of the associated train.



The flow cell consists of four stainless steel plates. The two outer plates hold voltage electrode mounting channels. An insulating plastic gasket is placed between each plate and a second pair of current-injecting stainless steel plates surround an RO membrane and spacer. The membrane and spacer are identical to those utilised in all other modules.

The electrodes in the flow cell are connected to an external impedance spectrometer that regulates the injected AC signal and records system responses. The impedance data is passed to CMS's on-site computer, where it is consolidated and transmitted back to the CMS Control Room.The image below shows a CMS Replicator installed at a Veolia water treatment plant in Sydney, Australia.



2 SCIENCE AND TECHNOLOGY

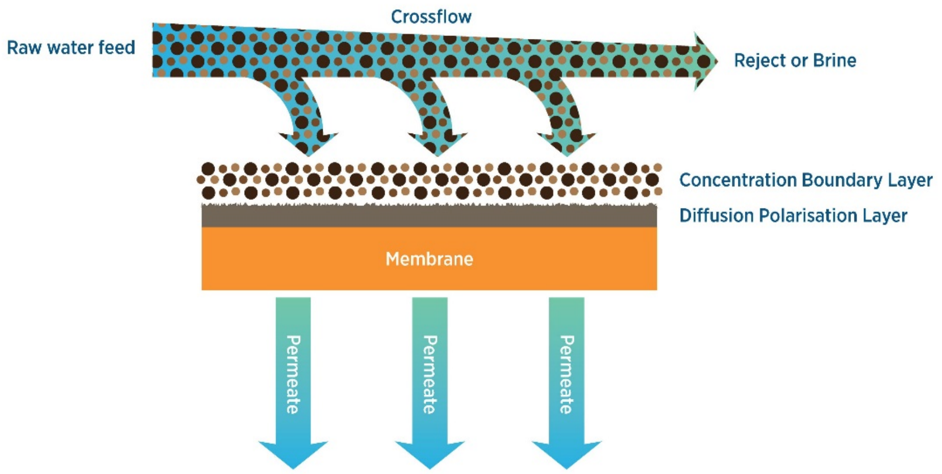
2.1 REVERSE OSMOSIS WATER TREATMENT

Reverse osmosis (RO) is a water purification technology that uses a semipermeable membrane to remove ions, molecules, and larger particles from drinking water.

RO's advantages over other separation technologies include a small footprint with modular construction; process stability; and its ability to produce permeate with excellent water quality with good energy efficiency.

2.2 MEMBRANE FOULING

During RO operations, as water is moved from the feed to the permeate side, the semipermeable properties of the membrane causes a build-up of solutes (including salt ions) and particulate matter at the membrane surface. This is known as concentration polarisation. In steady state operations, the build-up of material at the surface is mostly removed by the crossflow.



Despite cleaning by crossflow, ultimately the material in the concentration polarization layer will agglomerate. This process is referred to "fouling" or cake formation. In the concentration polarisation layer, solutes may reach saturated concentrations, causing the formation of mineral scale, but fouling can also be caused by colloidal particles and by biofilms produced by bacteria in the feed that deposit and proliferate on the membrane.

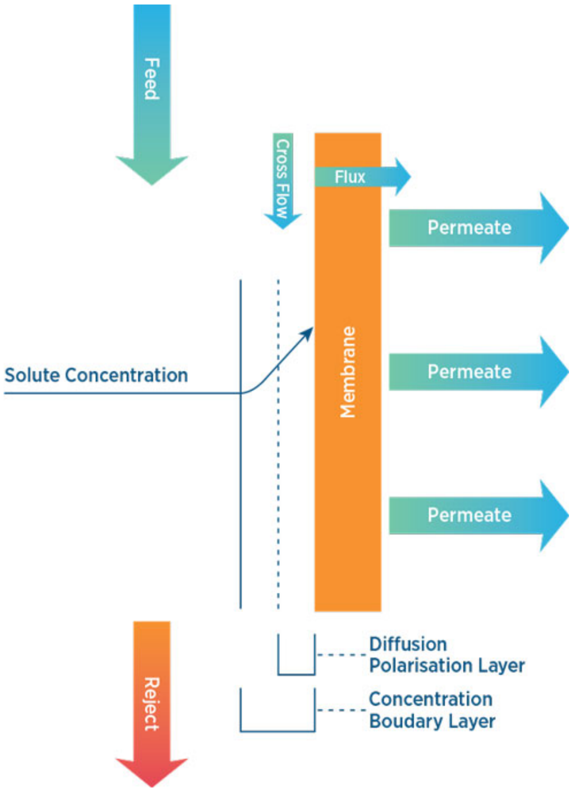
Once a stationary cake forms on the membrane surface, removal of salts by back diffusion and by the crossflow is reduced, leading to an enhancement of salt concentration polarization; referred to as cake-enhanced-concentration-polarization (CECP). The onset of CECP, mineral scaling, agglomerated colloidal particles and biofilms can only be treated by taking the affected membranes off-line and treating them with aggressive cleaning chemicals. To reduce the incidence of CECP and fouling, the RO separation must be conducted below a critical flux.

2.3 Science Behind Membrane Surveillance Using EIS

The use of Electrical Impedance Spectroscopy for the measurement of membrane properties, fouling and performance has been under development for more than two decades.

In EIS, alternating current of known amplitude and angular frequency is injected through the membrane and the potential difference response measured to allow the calculation of electrical impedance.

A filtration membrane is a non-homogenous system composed of distinct layers with different properties. The calculation of impedance across a range of frequencies allows EIS to identify the electical properties of each individual sub-structural layer. Note that in order to obtain high resolution, the measurement of potential difference at each frequency must be extremely accurate.



The layer of critical interest to understanding membrane fouling is known as the diffusion polarisation layer. This layer is near the membrane-solution interface, within the concentration boundary layer. Diffusion polarisation exists only during filtration when a current is applied to the membrane and is observable only at very low frequencies. The electrical properties of this layer are sensitive to the concentration of salt ions near the membrane surface that is, in turn, determined by the accumulation of solutes during filtration.

It is within the diffusion polarisation layer that fouling first arises as the accumulated material becomes more agglomerated leading to CECP and solutes may reach saturated concentrations for formation of mineral scale, agglomerated colloidal particles and biofilm.

The changes in the electrical properties of the diffusion polarisation layer detected by EIS describe the nature of the accumulated material at the membrane surface. This is the mechanism by which EIS-based membrane surveillance can identify the onset of fouling.

CMS holds an exclusive license to patents that allows determination of the critical flux and the state of fouling of a reverse osmosis system using EIS.

2.4 Development, Testing and Validation

The technology employed has been extensively tested in laboratory conditions at the Singapore Membrane Technology Centre at Nanyang Technological University. Industrial trials to validate the technology have been undertaken at the Bedok NEWater facility in Singapore and at a Veolia Water Treatment Plant in Sydney.