Microbial Removal and Integrity Testing of High-Pressure Membranes
[Project #435]

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PRINCIPAL INVESTIGATORS: James C. Lozier and Benito Mariñas

OBJECTIVES:
The first objective of this research was to determine the integrity of RO and NF membrane systems with respect to
viral passage using both particulate (MS2 viruses and fluorescent microspheres) and soluble (Rhodamine WT)
surrogates. The second objective was to compare the capability of these surrogates for use in assessing integrity of
intact and compromised RO and NF membranes when evaluated in a number of configurations.

BACKGROUND:
High-pressure (HP) membranes, reverse osmosis, and nanofiltration are used increasingly to treat brackish and
organic laden surface waters as water purveyors are forced to utilize lower quality source waters to meet potable
water demands. In addition, reverse osmosis has become an integral part of the advanced reclamation process for
the indirect potable reuse of domestic wastewaters. In these applications, HP membranes are expected to serve as
a positive barrier to pathogens. To date, integrity methods for full-scale HP membrane systems have been limited to
conductivity and total organic carbon monitoring, approaches that can only assess pathogen removals to two logs
(99%).

HIGHLIGHTS:
Intact (uncompromised) RO membranes, whether in flat-leaf or spiral-wound- element form, demonstrated >6 logs
virus removal (MS-2 phage). Intact NF membranes in element form showed lower removals ranging from 3 to 5.5
logs.

Good correlations were observed between MS-2 phage and the two non-biologic viral surrogates evaluated,
Rhodamine WT and fluorescent microspheres, when used to indicate loss of integrity in spiral wound HP membrane
systems when such systems were compromised by inducing imperfections in both membrane sheet and in o-ring
connectors.

Of the non-biologic surrogate viral integrity methods evaluated, only Rhodamine WT is currently practical for
application at full-scale, although as a solute, it’s application does have limitations.

APPROACH:
At bench scale, five RO and NF membranes were investigated in flat-leaf configuration. Three of these were also
tested in spiral-wound element form. Three major approaches were tested for assessing membrane integrity: (1)
high-rejected and low-rejected solutes, (2) use of MS2 phage as biological surrogate for enteric viruses, and (3)
24-nm fluorescent microspheres as non-biological viral surrogate.

At pilot scale, testing was conducted with spiral wound elements in single and multi-element vessel and in multi-stage
system configurations on three feedwaters (RO permeate, microfiltered secondary effluent (at Orange County Water
District of Southern California) and conventionally-treated river water (at City of Chesapeake, Va.).

RESULTS/FINDINGS:
Intact RO membranes, in flat sheet and element form, provided >6 log removal of MS-2 phage. This removal was
consistently observed whether in single element or multi-stage systems. In contrast, intact NF membrane tested in
this research demonstrated lower removals (3 to 5.5 logs); removal was variable from one intact element to the next.

Of the various chemical and physical approaches used to compromise membrane integrity, only pinholes fully
penetrating both the active rejecting and support layer of a membrane leaf produced significant increases in the
passage of both biological and non-biological viral surrogates, with this passage resulting from advective flow through
the defect.

Fouling of compromised elements increased the log removals of all surrogates to levels of intact elements, indicating
that fouling plugging the induced imperfection.

Chemically cleaning the compromised and fouled elements decreased the log removals of surrogates showing that
the increases in log removal by fouling is reversible. The Rhodamine WT (R-WT) can be considered a practical
surrogate for detecting imperfections in both RO and NF membranes relative to virus removal; it’s utility with intact
membranes is limited, however, to demonstrating 4-log virus removal for RO and 3-logs for NF. Fluorescent
microspheres demonstrated very good correlation to MS-2 phage with respect to both intact and compromised
membranes and, as such, represent a more ideal surrogate than R-WT.

IMPACT:
This research confirms prior findings that intact RO membranes provide good removal (in this case, >6 logs) of virus.
These results should help water utilities gain regulatory approval for RO systems for virus removal credits under the
Enhanced Surface Water Treatment Rule. Since membrane fouling is normal and expected with surface and
wastewater treatment, this benefit should be incorporated into a “best management practice” when developing
regulatory requirements for HP system operation relative to virus removal. Future research and a partnership


between the water industry and manufacturers is necessary and recommended to achieve reductions in the cost of production and analytical complexity of Fluorescent microspheres. In the interim, utilities should consider the use of R-WT for integrity testing, particularly for RO membranes, and engage state regulatory agencies to address issues associated with R-WT use relative to finished water and concentrate discharge issues.

PARTICIPANTS:
- City of Chesapeake, Va.
- Orange County Water District, Fountain Valley, Calif.

RESEARCH PARTNER:
U.S. Bureau of Reclamation