Task 1. Monitoring Virus Removal by Membrane Bioreactors during Water Reuse

Task proposed and sponsored by the U.S. EPA Office of Research and Development and CDM Smith.

Task developed by CDM Smith, U.S. EPA Office of Research and Development, and the New Mexico Environment Department Drinking Water Bureau

Background

Communities of all sizes are striving to address increasing water shortages and preserve primary sources of drinking water through water recycling programs. This includes implementing advanced water treatment processes to treat wastewater for indirect or direct potable reuse. Membrane bioreactors are becoming an important part of advanced water treatment efforts due to their small footprint and the high-quality effluent they produce.

Essential to reliable wastewater reuse is the ability to demonstrate effective pathogen removal along each step in the treatment train and to rapidly alert operators if minimum specifications are not met. For a given step in the treatment train the following are required: monitoring the effluent on a regular schedule, rapidly testing for indicators or surrogates of virus removal, and alerting operators in case of failure. Monitoring virus removal during the treatment process has proved challenging, particularly for new and innovative treatment processes.

Log Removal Values and Credits

The goal of this task is to develop a monitoring system integrated with the treatment train/treatment process that demonstrates virus removal. The parameter for crediting virus removal is the Log Removal Value (LRV). Expressed in $\log_{10}$, the LRV describes the reduction in the number of pathogens for a given process in the treatment train. It is calculated by:

$$LRV = log_{10}\left[\frac{Influent\ Pathogen\ Concentration}{Effluent\ Pathogen\ Concentration}\right]$$

Regulatory agencies use demonstrated LRVs to determine 'log-removal credits' for a given treatment process. Log-removal credits reflect the safety of a system and the extent of pathogen reduction that the process can reliably achieve. An LRV credit of 1 indicates 90% pathogen removal; two log credits correspond to 99% pathogen removal; three log credits denote 99.9% pathogen removal, and so on. Across all treatment processes, a facility must achieve a total log reduction commensurate with its intended end-use (e.g., indirect potable reuse (IPR) direct potable reuse (DPR), or non-potable reuse (NPR)).

LRVs are summed along the treatment train. For example, in California, regulations for IPR require an LRV of 12. This value is the sum of LRVs for each applicable process in the train (e.g., biological treatment, filtration, and disinfection). For example, individual processes may each have LRV values around 4, and the LRVs from the individual processes must sum to a total of 12 or more. For DPR, regulators are considering requiring an LRV of 20 for viruses, summed across the treatment train.

Regulators determine the credits assigned for each step in the treatment train based on process validation data. Water treatment facilities must demonstrate that they can meet these log-removal values for each process in their treatment train during ongoing operation. Such validation can be achieved by monitoring indicator viruses directly or by measuring surrogate parameters to verify that the process is operating as designed and validated.

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Membrane bioreactors (MBRs)

This task focuses on developing a near-real-time system (often referred to as inline or online monitoring) to monitor virus removal by membrane bioreactors (MBRs). MBRs used at wastewater treatment plants have gained recent attention as a treatment step within water-reuse treatment trains for both indirect and direct potable reuse as well as non-potable uses. MBR technology utilizes a submerged membrane in lieu of secondary clarifiers to integrate biological wastewater treatment with membrane filtration. MBRs have a smaller footprint and produce reliable, high-quality effluent. A default LRV for MBRs of 1.5 has been proposed (Branch and LeClech 2015)], but current crediting approaches likely undervalue the extent of virus removal that is actually achieved by the MBR.

Without the ability to demonstrate sufficient LRVs from MBRs, communities are required to incorporate additional (and perhaps unnecessary) water treatments, driving up costs and creating challenges for reuse efforts. Conversely, if the reliability of the MBR to remove viruses from wastewater effluent can be demonstrated, this may allow communities looking for reuse sources of water to take advantage of MBRs as part of the treatment train. This can improve effluent quality for downstream uses, reduce the overall cost of an advanced reuse project, and make the project more environmentally sustainable.

In order to receive log-reduction credits, two challenges must be addressed. The first challenge is to demonstrate the pathogen removal that is reliably achieved by the specific treatment process, either by measuring reference pathogens directly or by measuring relevant pathogen indicators. Reference pathogens are typically selected as those that drive risks during water reuse and for viruses may include norovirus, enteroviruses, adenovirus, etc. Pathogen indicators are other organisms that are consistently found in high concentrations in source water (*e.g.*, MS-2 coliphage, Aichi virus, somatic coliphage, or pepper mild mottle virus (PMMoV)) and are considered representative of the removal of reference pathogens of concern.

Once these methods have been used to demonstrate the LRV of an MBR, the second challenge is to develop a process for monitoring treatment performance during ongoing operation. Typically, near-real-time measurement of reference pathogens themselves is not practical; therefore, alternative methods of monitoring treatment performance are needed. Teams may achieve this by measuring indicator viruses or operational surrogates that they demonstrate to be correlated with the removal of reference pathogens (or their representative indicators). Pathogen removal surrogates are parameters for monitoring operation of the reuse process (such as turbidity, total organic carbon, or trans-membrane pressure) that can be correlated with virus removal. These indicator/surrogate measurements should be taken with sufficient frequency and produce rapid results such that out-of-specification conditions can be quickly identified.

Problem statement

Your team will research, evaluate, and design a method that

1. Demonstrates the virus log reduction value (LRV) that can be achieved by an MBR. This can be achieved by measuring reference pathogens and/or pathogen indicators in the influent and effluent from an operational MBR. Selection of reference pathogens/indicators must be justified by the team, and appropriate measurement methods (culture or molecular) must be selected.

   The team is not expected to design, build, or operate an MBR. Testing should be performed on an MBR that is in use at a local wastewater treatment facility, or (if available) an operational bench-scale system.

2. Incorporates rapid measurement of viral indicators and/or surrogates to verify that the MBR step in the treatment train consistently achieves the LRV described in bullet one. The monitoring process should be able to rapidly detect when the demonstrated LRV is no longer being achieved by an operational MBR system.

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Design requirements

Your proposed design should provide specific details and outcomes as follows:

- Identify and research relevant viral reference pathogens and (if needed) indicator viruses for demonstrating MBR LRVs. Select appropriate measurement methods (e.g., culture or quantitative polymerase chain reaction (qPCR)) for LRV determination.
- Identify appropriate indicator virus(es) and/or surrogate parameter(s) for measuring the performance of an MBR with respect to the reference pathogen(s). Note that the solution may include physical/chemical measurements, mechanical parameters, and/or microbiological measurements.
- Identify and research the analytical technique to be utilized to measure the indicators or surrogates;
- Design and build a bench-scale system for near-real-time monitoring of the indicators or surrogates.
- Indicate the measurement frequency and the amount of sample water to be utilized in the rapid measurement process at full scale. Provide a schematic diagram of the designed monitoring system, including how it can be tied into an operational water-treatment system
- Identify the process for alerting operators of out-of-specification conditions and determine how quickly the condition can be identified (an interplay of sample frequency, analytical time, and alert process).
- Use the bench-scale system to demonstrate that your results correlate with the log removal of selected reference pathogens or their indicators. Test your design utilizing an MBR that is in use (*e.g.*, at a local wastewater treatment facility) or, if available, a bench-scale MBR by measuring the reference pathogens and/or indicators in the influent and effluent from the MBR. If necessary, MBR influents and effluents may be transported back to the laboratory for analysis.
- Estimate costs for full-scale deployment of the monitoring system at an operating wastewater treatment facility for each MBR tank. Identify any economies of scale that could be achieved when monitoring multiple MBR units (in practice, several tanks may be used in parallel).
- Present a Techno-Economic Analysis (a.k.a. Techno-Economic Assessment) to construct a full-scale method for rapid measurement of the performance of an MBR during wastewater treatment.

  This will include your estimate of capital costs (CAPEX) and operational costs (OPEX) for a full-scale solution and appropriate graphical representation of your cost data. Costs should be specified on a per-tank basis.

  - Capital expenses typically include, but are not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment process.
  - Operating expenses (OPEX) should be calculated on an annual basis. In addition to other operating costs that your team identifies, include these operating costs: staff labor rate of $70/hour; solids disposal costs ($50/ton); energy requirements using an electricity rate of $0.09/kWh.
  - Visualization tools: Sensitivity analyses, etc. (Recommended: NMSU TEA Short Course).
- Reflect on alternative designs and situations in which those designs might be more viable than your chosen design, recalling that an optimal solution depends on outside factors–the "best" design may be dependent on region and may change over time.
- Address any intangible benefits of the proposed monitoring system.
- Address safety aspects of the wastewater collection, analysis process, chemical use, and system operation. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

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Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above and should demonstrate a process that can be scaled up to an operational MBR tank.

Each team will be provided three 18-liter (5-gallon container) water samples to work with during the bench-scale demonstration:

- A sample of wastewater prior to MBR treatment
- A sample of wastewater after MBR treatment
- A sample representing a membrane failure condition.

You are not required to use the entire amount of the solution during the contest bench-scale demonstration.

The latter two samples will not be identified; it will be each team's challenge to determine which sample represents the failure condition. Operational data from the treatment plant can also be provided if requested in advance.

Your team's bench-scale demonstration will:

1. Use the team's monitoring system to assess the provided wastewaters and indicate the minimum virus LRVs that were achieved for the two treated samples.
2. Determine which of the MBR-treated samples represents failure of the membrane.
3. Demonstrate your procedure for detecting out-of-specification conditions and alerting an operator.

<u>Analytical Testing</u>

Teams LRVs (based on indicators or surrogates) will be compared against WERC's measurement of viruses from the provided samples.

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but shall not be substitutes for the bench-scale demonstration.

Preliminary Report Requirements

The preliminary report describes your proposed approach. It is due February 7, 2022. The report is intended to help your team get early feedback and helpful suggestions from task designers and judges. Their comments will help you prepare a robust technical report and bench-scale demonstration. Your team will receive guidance from the task designers within one week of submission.

Include:

- Selected choice of reference pathogens and/or indicators for assessing the virus LRV, along with their appropriate measurement methods
- Selected choice of indicators and/or surrogates for monitoring, along with appropriate measurement methods
- The preliminary (high-level) design of a system for monitoring the indicators/surrogates
- A discussion of your plans for integrating the monitoring system into an operational treatment process, including the frequency at which samples are analyzed
- A discussion of your plans for developing a bench-scale version of the system for demonstration at competition

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Technical Report Requirements

The technical report should demonstrate your team's insight into the full scope of the issue and include all aspects of the problem and your proposed solution. The report will be evaluated for quality of writing, logic, organization, clarity, reason, and coherence. Standards for publications in technical journals apply.

In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, Evaluation Criteria, and 2022 Team Manual.

Evaluation Criteria

Each team is advised to read the 2022 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in this manual, your response to this Task consists of four parts: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, and a poster that conveys the essence of your work in a concise fashion using a mix of text and graphics. General criteria used by the judges in evaluation of these four components are described in the Team Manual.

Judges' evaluation of your entry will include consideration of the following points specific to this task.

- How quickly your design can detect a failure condition.
- Potential for real-life implementation, including reasonable cost and expected reliability and maintainability. Judges will weigh the cost/benefit of your solution against those for other teams.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The quality of the product produced, based on bench-scale analysis.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs).

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

FAQs/Deadlines

- Mid-December, 2021 EH&S Short Course (watch website for dates and registration info).
- Mid-January, 2022: EH&S Short Course; TEA Short Course
- 1 February, 2022: Experimental Safety Plan (ESP) due
- 7 February, 2022: Preliminary Report due
- 7 March, 2022: Send a draft of the technical report to your auditors (approx. date–see Team Manual)
- 28 March, 2022: Technical Report due
- Weekly: Teams are expected to check the FAQs online weekly for any updates in the task requirements. (wercdesigncontest.nmsu.edu)

Short Courses

WERC is offering two short courses. The optional courses are designed to prepare teams to more effectively complete their technical report and earn digital badges to add to their professional development portfolio. The courses are also available to the general public to gain professional development. Fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration.
Courses offered:

- Health and Environmental Safety (EH & S) (Mid-December and Mid-January)
- Techno-economic Assessment and Analysis (TEA) (Mid-January)

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References

[1] NSW (New South Wales) Department of Primary Industries Office of Water (2015). Indicators, Reference Pathogens & Log_{10} Reductions: What does it all mean? Recycled Water Information Sheet Number 2.

[2] Branch, Amos and Pierre Le-Clech (2015). National Validation Guidelines for Water Recycling: Membrane Bioreactors. https://vuir.vu.edu.au/32073/

[3] Salveson, A., S. Trussell and K. Linden (2021). Membrane Bioreactor Validation Protocols for Water Reuse, Water Research Foundation Report.

[4] Branch, A., et al. (2021). "Log removal values in membrane bioreactors: Correlation of surrogate monitoring and operational parameters." Journal of Water Process Engineering 41: 102032.

[5] Papp, K., D. Moser and D. Gerrity (2020). "Viral Surrogates in Potable Reuse Applications: Evaluation of a Membrane Bioreactor and Full Advanced Treatment." Journal of Environmental Engineering (United States) 146(2).

[6] Fontaine, N. and A. Branch (2020). Validating Virus and Protozoa Removal and Surrogates of a Full-Scale Flat Sheet Membrane Bioreactor. WEFTEC.

[7] Katz, S., et al. (2019). The disinfection capability of MBRs: credit where credit's due. https://www.thembrsite.com/features/the-disinfection-capability-of-mbrs-credit-where-credits-due/

Awards

Each year, the WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes. Successful completion of every stage of the design project qualifies each team for the following awards.

1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. (Minimum: $500, according to funding).

Award amounts listed are minimum amounts and may increase with available funding.
Detailed criteria for each award:
https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/