CHALLENGE TESTING WATER RECYCLING PLANTS – MAKING SURE WE GET THE BUGS OUT

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KEY WORDS

Water Recycling, validation, membrane, UV.

1.0 INTRODUCTION

Regulators require recycled water treatment processes to be validated to ensure they meet the water quality requirements for the intended water use. Validation will often require challenge testing of processes such as membrane filtration and UV disinfection to demonstrate the ability of the process to remove specific target organisms. Challenge testing is expected to confirm the maximum removal credit that a process is eligible to receive from the appropriate regulatory body. This is achieved by dosing challenge organisms into the feed of a process and measuring their removal by testing the feed and product water. The USEPA has published a Membrane Filtration Guidance Manual (2005) and an Ultraviolet Disinfection Guidance Manual (2006). These manuals are commonly used by Australian regulators to set conditions for validation and challenge testing.

UV disinfection systems are subjected to validation testing by their manufacturers. Australian regulators will generally accept the manufacturer's validation providing the operating conditions are within the validated range. Consequently it is not common for UV systems to require on site validation challenge testing although performance verification testing may be required. Membrane filtration is more likely to be affected by site specific installation and operation and as a result some regulators require site challenge tests to confirm membrane performance of the unit installed.

2.0 DISCUSSION

2.1 Membrane Challenge Testing Outline

Validation testing in accordance with the US EPA Membrane Filtration Guidance Manual is designed to ensure the desired level of Cryptosporidium removal is achieved. This is done by testing the log removal value (LRV) for Cryptosporidium for an integral membrane. Some regulators may also require challenge testing to assess performance of damaged membranes. Although the primary focus under US guidelines is cryptosporidium removal, challenge testing may be used to confirm removal efficiencies for other pathogens including bacteria, viruses, and Giardia. Challenge testing of a membrane filter will include:

- Establishment of challenge testing requirements and suitable operating conditions based on the recommendations of the Regulator and the system operator.
- Development of challenge testing protocols and procedures to the satisfaction of the Regulator and the system operator.
- Selection and procurement of a suitable test organism
- Procurement and set up of all equipment necessary to conduct the challenge test
- Executing an approved testing procedure including dosing, sampling, operational tests
- Laboratory analysis of the process influent and effluent samples

- Analysis of the test results including determination of log removal value
- Reporting of challenge test results.

2.2 Membrane Testing Requirements

The core requirements that a challenge test must meet in order to demonstrate the removal efficiency of a membrane filtration system for cryptosporidium are:

1. ***Full-Scale Module Testing***: Challenge testing must be conducted on a full-scale membrane module identical to the membrane modules used in treatment facilities.
2. ***Appropriate Challenge Particulates***: Although use of the target organism as the challenge particulate offers the advantages of directly measuring removal efficiency for the pathogen of interest it is not practical or feasible to use Cryptosporidium for challenge testing due to economic and safety reasons. The use of surrogates is an acceptable option with an ideal surrogate having characteristics that are likely to result in similar removal efficiency to the target organism. A conservative surrogate has characteristics that result in a lower removal efficiency relative to the target organism. In general, conservative surrogates are used. Bacteriophages are commonly used as surrogates as they are not pathogenic and easily cultured.
3. ***Appropriate Challenge Particulate Concentration***: The feed water concentration used during a challenge test is based on the ability to prove the required LRV. The maximum feed concentration recommended allows an LRV of up to 6.5 to be demonstrated. Higher concentrations can cause aggregation of particles and artificially high LRV's.
4. ***Appropriate Test Operating Conditions***: Challenge testing must be conducted under representative hydraulic conditions at the maximum design flux and maximum design system recovery specified by the membrane module manufacturer. A high-quality feed water provides the most conservative estimate of removal efficiency. Feed water for the challenge test should have turbidity at or below median levels, minimizing the potential for formation of a fouling layer during the test that would enhance removal of the challenge particulate. No oxidants, disinfectants, or other pretreatment chemicals should be added to the test solution unless necessitated by process requirements. Testing should be conducted for water quality parameters that are critical to the test or interpretation of the results.
5. ***Calculation of validated LRV for modules tested***. The removal efficiency of each tested module is calculated according to the equation:

   $LRV = \log Cf - \log Cp$ Where: Cf = challenge test feed concentration
   Cp = challenge test filtrate concentration

   The overall removal efficiency demonstrated during challenge testing is referred to as LRVC-Test. If fewer than 20 modules are tested, then the LRVC-Test is equal to the lowest of the LRVs of the modules tested.

6. ***Verification of Removal Efficiency Criteria for Untested Modules***: Because some membrane modules may not be subject to challenge testing, a non-destructive performance test (NDPT) must be applied to each membrane module that did not undergo challenge testing. Modules with a NDPT that corresponds to that of the tested membranes are eligible for the removal credit demonstrated by challenge testing.

2.3 Challenge Test Equipment and Set Up

There are two approaches commonly used to introduce the challenge particulate into the test solution: batch seeding and in-line injection. In-line injection allows for continuous introduction of challenge particulates into the feed stream entering the membrane filtration system and is the most common seeding approach used in full scale challenge testing. Batch seeding requires an upstream reservoir large enough to supply feed throughout the challenge test and an efficient mixing method. In-line injection requires dosing pumps, an appropriate dosing point and sufficient in line mixing prior to sampling. Suitable injection points will often already exist on treatment plants. The injection port should introduce the challenge material directly into the bulk feed stream to aid in dispersion. Examples of acceptable and unacceptable injection ports are shown in US EPA Membrane Filtration Guidance Manual Figure 3.1. An in-line static mixer or a long length of pipe with turbulent flow should be downstream of the injection port and prior to the feed sampling point. Acceptable sampling valves and mixing are also required for filtrate sampling. Paired grab sampling from the feed and filtrate stream is commonly used with filtered water samples taken one filter residence time after filter feed samples.

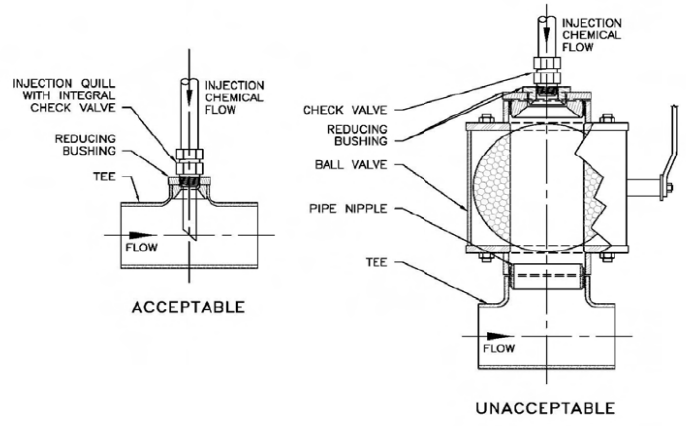

Figure 2: ***Acceptable injection ports (fig 3.1 USEPA Membrane Filtration Guidance Manual)***

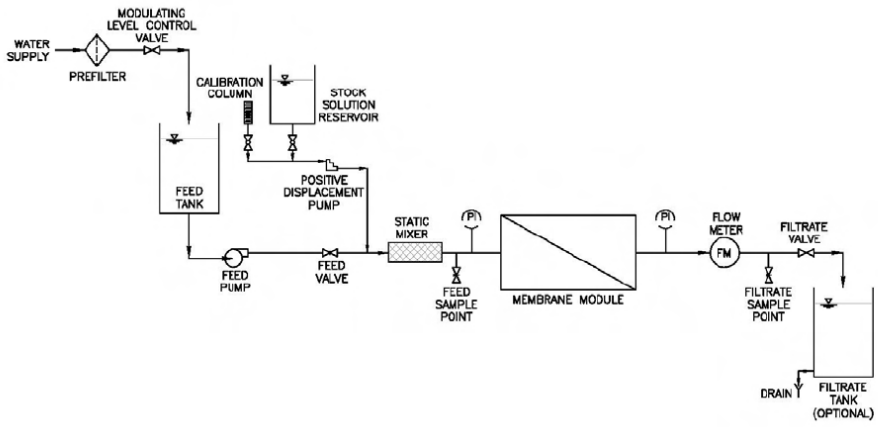

Figure 3: ***Typical continuous seeding and grab sampling schematic (fig 3.3 USEPA Membrane Filtration Guidance Manual)***

2.4 Membrane Challenge Test Reporting

After challenge testing is completed, the results are statistically analysed to determine the established removal efficiency of the module. A challenge test report is produced which includes the testing organization, its credentials, site information, membrane filter type and specifications, target LRV, non-destructive performance testing, challenge test protocol, challenge particulate, operating conditions, sampling plan, QA/QC procedures, data, results, discussion, and conclusions including LRV validated by challenge testing.

2.5 Membrane Challenge Test Case Study

The owners of a 2 ML/d recycled water treatment plant producing Class A water from secondary effluent engaged Ecowise (now ALS Water Sciences Group) to undertake challenge testing on the UF System to confirm 4 log virus removal. The UV disinfection component of the RWTP had been previously validated. The total UF skid was subjected to challenge testing to verify overall virus removal using MS2 as the challenge organism.

Ecowise discussed the scope and logistics of the challenge testing with site staff and the regulator in person and by email during the weeks prior to challenge testing. During this period the testing protocol and other relevant documentation were developed.

The site was inspected prior to the test date and arrangements for set up of the required dosing equipment were discussed. The owner provided the trade and operational staff required for connection of dosing equipment to dosing points. Ecowise installed in-line injection using a diaphragm pump to dose UF feed water. The dosing pump was calibrated to deliver the required dose against the UF filter feed head. The injection port was a modified chlorine dosing point which introduced MS2 directly into the bulk feed stream upstream of the UF feed tank. Sampling valves were available for the skid feed and permeate water.

A challenge test rehearsal was held. During the rehearsal Ecowise tested the dosing pump and delivery system and reviewed the timing and sequences of filter runs in relation to sampling. The site owner made some plant control changes as a result of the rehearsal.

On the test date Ecowise delivered MS2 culture and diluted it ready for dosing. The sampling schedule was confirmed with the start of sampling delayed until membrane cleaning was completed and the absence of residual chlorine in the UF feed and UF product water was confirmed. Integrity testing was conducted. Background phage samples were taken at 3 times during one filter run. MS2 culture dosing then commenced. Sufficient time for 2 complete filter runs was allowed prior to sampling to ensure that water that had received dosed phage was present at the filter inlet and outlet sample points. UF inlet and outlet samples were taken at the beginning middle and end of 4 filter runs at maximum flux. Samples were packed in respective containers for influent and effluent samples and chilled. MS2 dosing was stopped for 2 filter runs to clear dosed phage prior to a 2nd sampling of background phages. Chain of Custody forms were completed and enclosed with samples prior to delivery to the NATA accredited laboratory for phage testing and water quality analysis.

During this process Ecowise took all reasonable steps to provide quality assurance. This included washing down of the UF room and units prior to challenge testing, sampling using aseptic techniques by trained staff, separation of inlet and outlet sampling points,

appropriate sample storage and use of MS2 culture from an accredited source which was tested before use.
The test report produced contained the methodology used for the challenge testing as well as test results for the samples taken and the calculated LRV.

2.6 UV Validation

In circumstances where an ultraviolet disinfection system is required to operate outside its validated operational range it may be required to challenge test the unit to assess performance under all operating conditions. A typical example of this is where the ultraviolet transmittance (UVT) of the water to be treated is at times outside the validated range of the UV disinfection reactor. This requires an onsite validation test at the lower UVT values and appropriate flowrates to determine the UV intensity setpoints required to achieve the nominated pathogen reductions. The challenge test will usually be performed in accordance with the US EPA Ultraviolet Disinfection Guidance Manual for the final LT2ESWTR (2006).

2.7 UV Challenge Testing Outline

The validation protocol in the US EPA Ultraviolet Disinfection Guidance Manual uses biodosimetry. Under this approach, the log inactivation of the challenge microorganism is measured during full-scale reactor testing for the specific operating conditions of flow rate, UVT and UV intensity requested by the client. Log-inactivation values from the full-scale testing are input into a laboratory derived-UV dose-response relationship to estimate the Reduction Equivalent Dose (RED). The RED value is adjusted for uncertainties and biases to produce the validated dose of the reactor and validated pathogen reduction credits.

2.8 UV Validation Method

Because use of the target pathogen during validation testing is not practical, a challenge test microorganism is used. Using a challenge microorganism however, introduces uncertainty which is accounted for by applying a validation factor. The challenge microorganism chosen should be easily cultured and enumerated, stable over long periods of time and not pathogenic to humans. Male-specific-2 bacteriophage (MS2) phage has been used extensively for UV validation testing.

The steps in validation are:

1. Bench-scale testing using a collimated beam apparatus to characterize the UV dose-response relationship of the challenge microorganism.
2. Assessment of UV lamp status and allowances required for lamp fouling and aging
3. Full-scale reactor testing. The challenge microorganisms is injected upstream of the UV reactor. Samples are analysed to determine the log inactivation at the required test conditions of flow rate, UVT, lamp status, and UV intensity as measured by UV sensors and other meters.
4. Calculation of the RED for the reactor tested using the log inactivation of the challenge microorganism measured during the full-scale testing and the laboratory based UV dose response equation.
5. Adjustment for uncertainty to calculate the Validated Dose. The Validated Dose is associated with the test conditions of flow rate, lamp status, UV intensity and

UVT.

6. The validated dose is used to determine the LRV credit for various test organisms.

2.9 UV Challenge Test Conditions

Testing equipment includes injection pumps and ports to introduce the challenge microorganism, the UV absorbing compound used to adjust UVT, and if needed, a disinfectant residual quenching agent into the feed water. In addition calibrated meters and sensors are required to determine all relevant operational parameters.

The water passing through the reactor should not contain disinfectant residuals that inactivate the challenge microorganism during testing. Upstream chlorine dosing should be stopped during the challenge test. If this is not possible then a quenching agent can be injected into the water upstream of the microorganism injection port. The quenching agent should have a minimal impact on UVT. Sodium bisulfite does not influence UVT and can be used if required. A UV-absorbing chemical such as coffee or humic acid can be injected into the flow to reduce the feed water UVT. Additives should be well mixed prior to the feed sampling port. The challenge microorganisms surviving UV disinfection should also be well mixed prior to the reactor effluent sampling port. Mixing can be by static mixers or turbulent mixing in the pipe upstream of the sampling ports. If the feed water is obtained from a large tank, the additives can be premixed in the tank to obtain a uniform concentration for testing.

The sampling points for microorganisms should be located far enough from the UV reactor that the germicidal UV intensity at the point of sampling is < 0.1 percent of the germicidal intensity within the UV reactor. If the outlet sample port is located downstream of a 90^{o} bend and the inlet sample port is upstream of a 90^{o} bend), incident light is not a concern.

2.10 Reporting

The calculation of the validated dose and consequent pathogen reduction credits requires careful consideration of the challenge test results and validation factors. The final result will be validated log reductions for pathogens under various operating conditions over the range of UV intensities. This information is then used to establish the set points required for the designed UV disinfection credits.

3.0 CONCLUSIONS

Validation of membrane filters and UV disinfection systems requires careful consideration of test organisms, dosing requirements, sampling, QA/QC and interpretation of results. Use of guidelines such as the USEPA membrane filtration and ultraviolet disinfection manuals can provide an accepted protocol for testing which meet the requirements of regulatory bodies. Challenge testing requires close coordination of the system owner, operators, regulators and testing contractors in order to effectively validate the performance of treatment processes.

4.0 REFERENCES

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