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Risk management approach for monitoring UF membrane integrity and experimental validation using MS2-phages

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1. Context and objective

Microfiltration (MF) and Ultrafiltration (UF) systems, as an alternative to conventional water treatment for drinking water, have been developed very fast due to their ability for the removal of microbial pathogens, especially *Cryptosporidium* and *Giardia*. One of the most important tasks for the application of UF systems is to monitor membrane integrity during operation, detect and repair the defects because small defects could result in significant reduction of pathogen removal efficiency and consequently reduce UF membrane performance. The full-scale membrane integrity monitoring is complex:

- On large water treatment plants, looking for non integer fibers within several racks equipped with several modules is equivalent to "looking for a needle in a haystack";
- The small water treatment plants spread in a large areas are faced with limited manpower;
- Number of Environmental Agencies (USEPA in United States, DWI in United Kingdom, etc.) request the membrane operators to conduct rigorous integrity monitoring to control the microbial Log Removal Values (LRV) of the membrane plant;
- There are water treatment plants with high risk of filtrate contamination that must show reactivity.

In such a context, the membrane operator thus needs to have at his disposal detection tools that are highly sensitive, quick and easy, with signal that can be interpreted by PLC and that can be done as frequent as possible. Within the various integrity monitoring methods categorized into direct and indirect tests, the air pressure test that is a direct method, is the most reliable. All membrane manufacturers propose air pressure test for membrane integrity monitoring and proceed according to the same sequences: (1) detection of compromised rack(s) in a plant; (2) detection of compromised module(s) in a rack; (3) detection of compromised fiber(s) in a module.

For most of water treatment plants, the current guideline is to repair immediately all the broken fibers detected. Such conservative instructions result in long stops of drinking water production and high operation and maintenance load. The objective of this project is to develop a decision-aid tool for operators that gives them the integrity level of their plant without having to disconnect all the modules and indicates if the measured level puts in danger the plant effectiveness and so if he has to immediately repair or if he can differ the repairing.

2. Material and methods

The project was conducted on pressurized low-pressure membrane module. A model has first been developed based on the equations proposed by USEPA and ASTM that uses the air flow rate throughout a defect during the air pressure test for predicting the microbial Log Removal Value. Then, MS2-Phages were used at bench-scale to validate the model and the selected assumptions with various calibrated defect

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carried out on the membrane fibers. The validity of the model was then evaluated at full-scale.

2.1. Model

The model has been developed for the Aquasource membranes. It is based on the method developed by the USEPA and the ASTM that correlates the air flow rate measured through the defect during the pressure decay test with the water flow rate through this defect during filtration. It uses the Hagen Poiseuille Model proposed by the ASTM to calculate the Log Removal Value (LRV) in microorganisms of a battery of UF racks from the results of the pressure decay tests performed on each racks. It also gives an estimated number of broken fibers with a clear cut at the middle of the fiber(Fig. 1).

2.2. Bench-scale trials

Bench-scale trials were conducted on a pilot rig in order to experimentally validate the model. Two configurations were tested:

- One micromodule containing fibers with calibrated holes made with laser method, installed in parallel to an integer module of 64 m^2 (Fig.2);
- One module of 64 m^2, alone, containing fibers with calibrated holes, in order to be free from the possible problems of hydraulic distribution between the module and the micromodule (Fig.3).

The micromodules contained different sizes of calibrated holes: 20, 40, 60, 200 and 600 µm. The module contained three fibers, each with a calibrated hole of 20 µm (Fig. 2). Then a clear cut at the middle of one fiber was also tested at different operating mode and different flux rate (Table 1).

A pressure decay test was performed for each integrity breach and then a challenge test was conducted with MS2-phages.

2.3. Full-scale trials

Trials were conducted on a water treatment plant in order to check the model validity at full-scale (Table 1). Pressure decay tests were conducted on a ULTRAZUR300 rack of 20 modules (Fig. 4) containing one module with different broken fibers (clear cuts) (Photo 2).

3. Results

3.1. Model resolution

The resolution is defined as the smallest defect that contributes to the response from the direct integrity test. Based on the lower range of Cryptosporidium oocysts, LT2ESTWR requires a direct integrity test to have a resolution of 3 µm or less (USEPA, 2005). Given the theoretical equations (ASTM, 2005), the model theoretically complies with the requirement of LT2ESTWR for a lower than 3 µm resolution when the pressure of integrity test is higher than 500 mbar (Fig. 5).

3.2. Model sensitivity

ASTM test conducted at a water treatment plant at a pressure set-point of 500 mbar detected one broken fiber on one ULTRAZUR450 rack of 20 modules of 35 584 fibers each (total of 711,680 fibers), which guarantees more than 4 log of microorganism removal efficiency.

Table 1
Operating conditions of bench scale trials.

Integrity breach	Filtration mode	Filtration flux (L/h.m^2@20°C)
20 µm hole	Dead-end	135
40 µm hole	Dead-end	135
60 µm hole	Dead-end	135
200 µm hole	Dead-end	135
600 µm hole	Dead-end	135
1 clear cut	Dead-end	160
1 clear cut	Dead-end	310
1 clear cut	Cross-flow	165
1 clear cut	Cross-flow	135

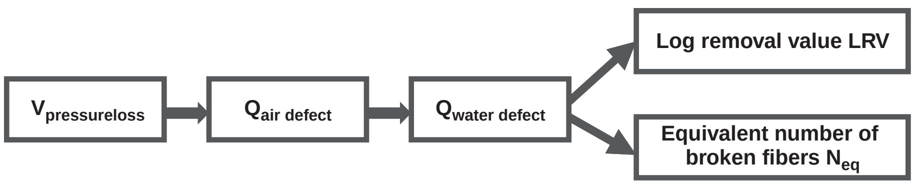

Fig. 1. Model calculation steps.

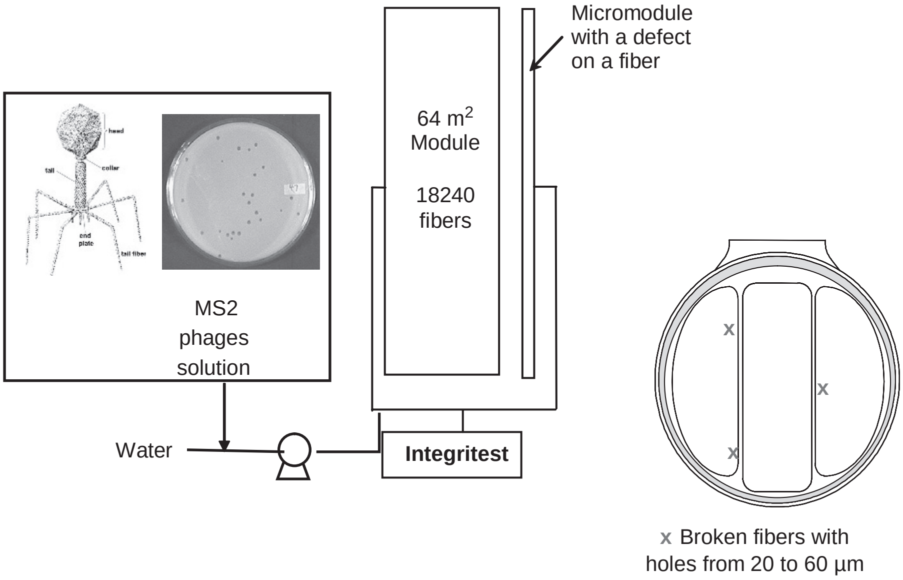

Fig. 2. Bench scale pilot plant—Aquasource module.

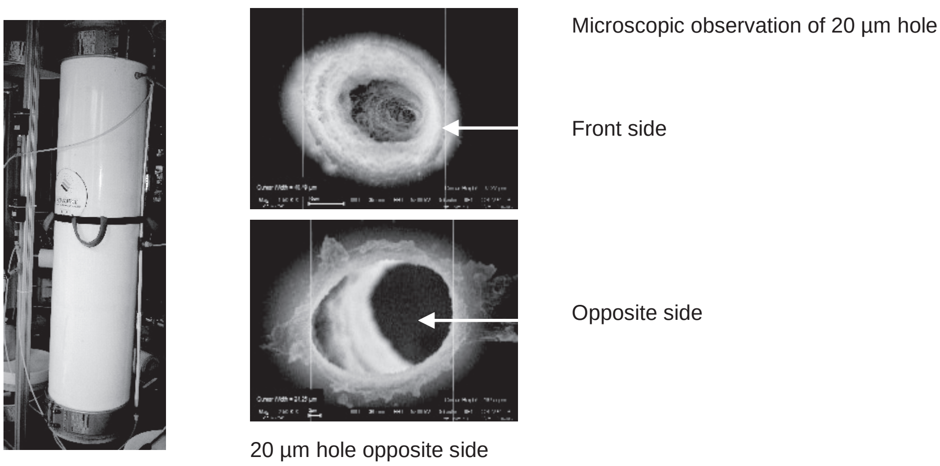

Fig. 3. Head of Aquasource module containing 3 fibers with calibrated holes.

Table 2
Operating conditions of full-scale trials.

Parameter	Unit	Value
Unit	-	1 rack ULTRAZUR300
Unit flow rate	m^3/h	51
Number of modules per unit	-	20 modules
Number of non-integer modules	-	1 module
Number of broken fibers	-	1, 4, 7 and 9
Pressure of pressure decay test	mbar	500
Duration of pressure decay test	min	5

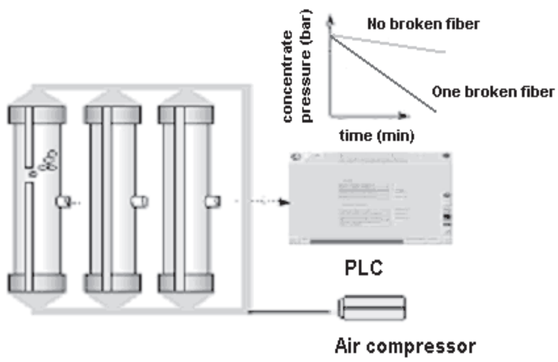

Fig. 4. Full-scale trials on a ULTRAZUR300 rack of 20 Aquasource 64 m² modules.

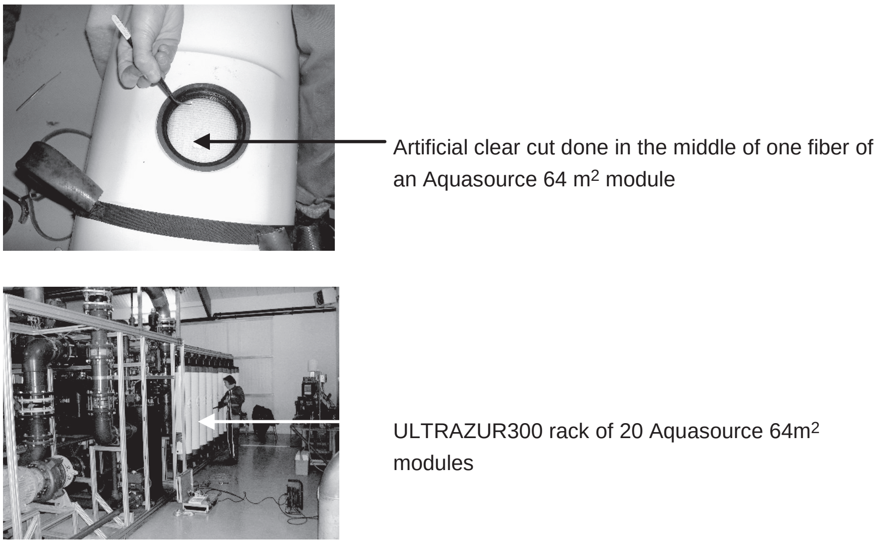

Photo 2: Full-scale trials on a rack of 20 Aqusource 64 m^2 modules.

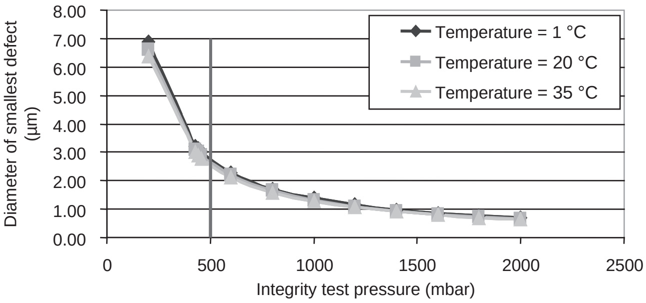

Fig. 5. Smallest diameter of defect that can be detected on an Aquasource module depending on integrity test pressure and temperature.

3.3. Model reliability

It was not possible to experimentally valid that the model can detect 3 µm defect because:

- It was not possible to make holes smaller than 20 µm with laser method;
- The challenge test with MS2 phages does not detect holes smaller than 60–200 µm (Fig. 6);
- Pressure drop is not measurable for hole smaller than 60 µm (less than 50% variation from base line).

However, good experimental validation was obtained for larger holes and clear cuts (Fig. 7).

Once adjusted the air diffusion parameter of the full-scale rack, the model works well for clear cuts: There is a correct correlation between the number of broken fibers estimated by the model and the reality (Fig. 8).

3.4. Model

The developed user-friendly tool is dedicated to membrane operators to assist them in the integrity monitoring: it uses a risk management approach that assess the risk associated with a non-integrity level and define a maximum threshold from which it is necessary to repair the broken fibers (Fig. 9).

4. Conclusions

The model developed for UF Aquasource membranes complies with the USEPA rule that requires a resolution of 3 µm (minimum size of detectable defect) when pressure is higher than 500 mbar. The model is highly sensitive: it can detect one broken fiber out of more than 700,000 fibers (0,00014%) which guarantees more than 4 log of microorganism removal efficiency. The model needs to be calibrated on each full-scale WTP to refine the prediction of the UF log removal value: at the commissioning, it is necessary to measure the air diffusion baseline of an integer rack of the UF plant and check pressure decay of few artificially broken fibers on one rack (without activated carbon).

The user-friendly model can be used as an automatic tool for defining an optimized membrane repairing schedule: it will be a compromise between:

- Reducing non-production times and manpower;
- Maintaining the production of constant compliant treated water quality.

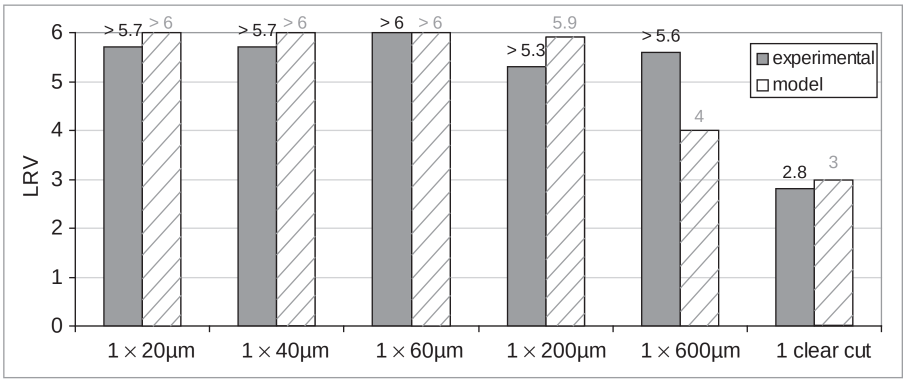

Fig. 6. Bench-scale test: comparison model/reality for small holes (diameters from 20 to 600 µm) and a clear cut.

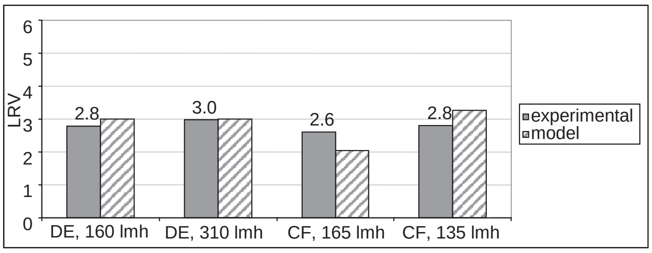

Fig. 7. Bench-scale test: comparison model/reality for a clear cut at different filtration modes (dead-end vs crossflow) and different filtration flux (from 135 to 310 lmh).

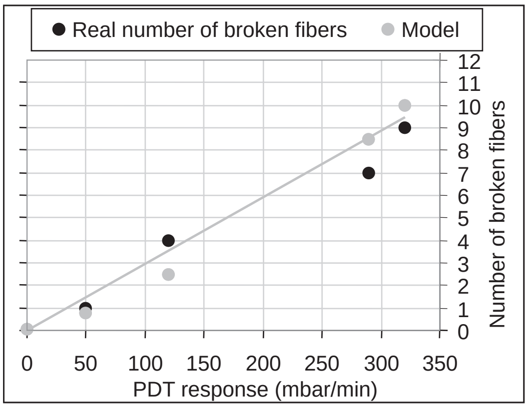

Fig. 8. Full-scale test 2: 1, 4, 7 and 9 broken fibers on one module of one block ULTRAZUR300 of 20 modules.

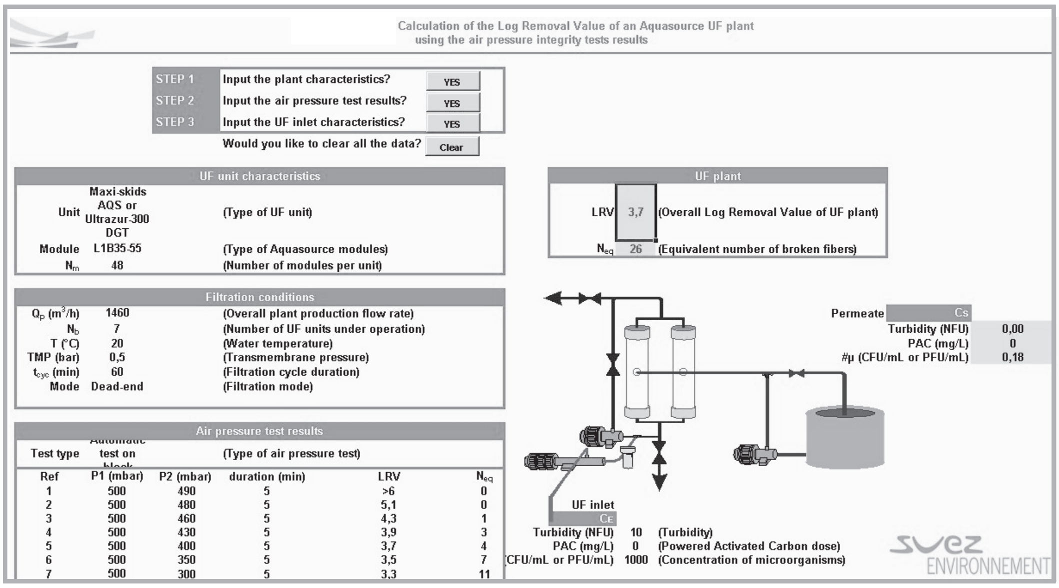

Fig. 9. Model.

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