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Nanofiltration as a treatment barrier against pathogens

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Nanofiltration as a treatment barrier against pathogens

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1 Introduction

Nanofiltration (NF) for the removal of humic substances/Natural Organic Matter (NOM) has been used for almost 20 years in Norway. In 2006, 98 plants serving more than 50 people were using this process, and in total approximately 120,000 people were supplied from waterworks using NF in this country. The largest of these plants was serving almost 9000 people. Similar plants exist in Scotland and in Ireland.

Nanofiltration has been regarded as a hygienic barrier against pathogens. Recent experiences indicate however that the NF barrier may not always be as efficient as previously assumed.

In the following, typical NF process design and statistical NF process performance data are presented. In addition, two case studies are presented and the requirements for validation and maintenance of NF as a treatment barrier are discussed.

2 Requirements for a hygienic barrier

In Norway, the drinking water regulations state that all water supply systems must contain at least to hygienic (safety) barriers. For a water treatment process to be credited as one barrier, the required removal or inactivation rate is defined as 99.9 % for viruses and bacteria and 99 % for protozoa.

In addition, most water treatment processes that are accepted as a hygienic barrier must comply with specific construction and operational performance criteria given in the national water quality guidelines. Examples of required process performance data are: 1) A detectable residual free chlorine after 30 minutes contact time for chlorination, 2) A minimum biodosimetric UV-dose of 40 mJ/cm^2 for UV-disinfection, and 3) A maximum on-line turbidity of 0.2 NTU, and a maximum total metal coagulant residual of 0.15 mg/L (as Fe or Al) in unit filter effluents for coagulation and contact filtration processes.

For membrane filtration to be credited as a hygienic barrier a set of operational requirements are given:

- The permeate production, or recovery, in a membrane shall not exceed 20 % of the raw water flow into the membrane. With 4 membranes in series in a tube the recovery shall then not exceed 80 %.
- Particle number, turbidity, colour or TOC are listed as possible indicators for membrane integrity and performance, but such monitoring is not stated as an explicit requirement in the national water regulations or guidelines.

3 Typical NF process design

A typical design of a Norwegian nanofiltration (NF) treatment process is shown in Figure 1. This process design is the standard for the plants included in this study, even though the pre-treatment and post-treatment may vary.

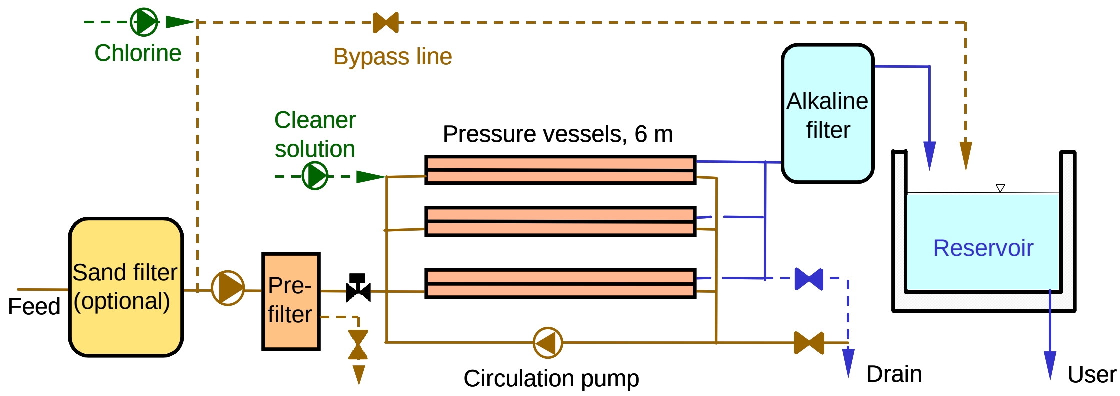

Figure 1. The typical layout of nanofiltration plants for removal of humic substances (Thorsen, 1999)

The typical nanofiltration plant starts with a pre-treatment with a 50 µm pressure filter, and more seldom with sand filter. The next step is the nanofiltration itself, usually with two or more pressure vessels in parallel, each containing 2-4 membranes. Post treatment is pH control, with alkaline filter or dosing of sodium silicate, and disinfection, either regularly with UV or sodium hypochlorite or standby with calcium hypochlorite. Typical sampling points for physical-chemical and microbiological water quality analysis are normally located at the plant inlet and after the treated water reservoir, while the water quality will be changed in several steps in the plant.

4 Operational experiencies with nanofiltration as a hygienic barrier

4.1 Statistical water quality

A survey on the treated water microbiological quality was performed for the years 2001-2005, based on reported water quality from the waterworks to the authority.

Table 1 summarises the treated water microbiological quality after nanofiltration, and for approximately half of the plants also after UV disinfection.

Table 1. Microbial quality of NF treated water. The results are given as % of the plants that did not meet the required quality criteria for one or more samples during one year. (Please keep in mind that half of the plants also had UV disinfection included, and that sampling was performed after all the treatment processes).

Year	**Percentage of plants with plate counts > 100/mL or positive indicator bacteria in at least one sample for the period 2001-2005**				
	Plate count > 100/mL	**Total coliforms**	***E. coli***	**Enterococci**	***Clostridium perfringens***
2005	38	30	6	0	0
2004	29	40	12	2	2
2003	30	20	12	0	0
2002	20	16	6	0	0
2001	25	9	3	0	0

The apparent increase in the number of total coliform bacteria from 2001 to 2004 is partly due to changes in the water quality analysis procedures.

E. coli was detected in treated water once or more at 31 % of the waterworks during these five years. None of the waterworks where *E. coli* was detected in treated water in 2005 had UV disinfection, meaning that among the treatment plants without UV the frequency for positive *E. coli* samples was twice the number given in Table 1.

The percentage of the plants with at least one sample with plate counts > 100/mL was independent of whether the plants had UV disinfection or not, and no relation between raw water and treated water plate counts could be established. This indicates that the plate counts in several plants originate from microbiological growth in the NF-treated water. However, the plants with high plate counts in the permeate were also among the plants with failures in the hygienic barriers. This indicates that the colony forming bacteria contributing to a high plate count number may pass the membrane through the same defects or holes as the pathogens.

Some bacteria present in the environment, and that is not related to contamination from humans or animals, are detected in the total coliform analysis. Some of these bacteria have even been proven to grow in treated water. The significance of detecting total coliforms in treated water is therefore uncertain.

4.2 Information received from the waterworks

A questionnaire was sent to all Norwegian waterworks with nanofiltration. The questions asked were:

- Information on the treatment process in general and the nanofiltration in particular, including age, supplier, operational conditions
- Performance of nanofiltration and pre-treatment
- Sampling frequency and water analysis program
- Information on improper operation or treated water quality, and actions to restore a proper operation

37 of 98 waterworks supplying more than 50 people answered the questionnaire.

All the waterworks employing nanofiltration assumed initially that this treatment process would also be a hygienic barrier against pathogens. 27 % of the plants reported in the questionnaires had one or several NF barrier failures during the period 2001-2006, a lower number than indicated by the results presented in above. The failures in barrier efficiency were not discovered before coliforms were detected in the treated water, showing the lack of reliable indicators for the performance of the NF barrier. Neither colour nor turbidity in the treated water gave any early warning of the failure, partly because the water samples are normally taken from the plant outlet and not from the outlet of each unit membrane module. Thus, failures limited to one membrane or a few membranes are hardly detectable.

Several reasons are identified for the NF barrier failures, including leakages through the contactors between the membranes because of defect O-rings, leakages through the membranes because of breakage, as well as raw water accidentally by-passing the membranes modules. However, the reasons were often unknown. Some plants indicate that failure in the pre-filter unit was the indirect reason, since this caused fouling, high pressure loss and finally breakages. Inappropriate plant design, like intermittent pre-filter designs that caused frequent variations in the inlet pressure, did also cause breakages.

4.3 Case study 1; Mostadmarka Water Treatment Plant

Mostadmarka waterworks supply 300 people. The water treatment is nanofiltration followed by alkaline (marble) filtration. Chlorination is installed, but only as a backup solution, meaning that nanofiltration is the only hygienic barrier in the treatment plant. Coliforms were present in approximately 25 % of the raw water samples, with up to 5 coliforms per 100 mL.

In November 2002, coliforms were detected in the distribution system, with approximately 200 bacteria/100 mL. Most of the coliforms were identified as C*lebsiella oxytoca.* A control the following day showed about the same result in treated water at the water treatment plant, while the raw water contained 110 coliform bacteria/mL. The contamination of the raw water was likely caused by excreta from domestic or wild animals. Water boiling advisory was sent and chlorination was started both of the treated water and in the network. The membranes were chlorinated, but coliforms were detected in the filtrate for several months afterwards.

The waterworks decided to install new membranes, and after that no more coliforms were detected in the NF effluent. It was concluded that a leakage through the membranes was the cause of the incident, and that either a damage of the membrane or a defect O-ring caused the leakage. One particular concern was that no water quality parameter had indicated any failure in the NF barrier before the incident.

4.4 Case study 2; Ask waterworks

Ask waterworks supply 3000 people. The water treatment is nanofiltration followed by alkaline (marble) filtration. 30 NF-tubes, each containing 4 membranes are installed. Chlorination is installed as a backup solution, meaning that nanofiltration is the only hygienic barrier in the treatment plant.

In October 2003 coliforms were detected in treated water, and the cause was a failure in the NF treatment barrier. Water boiling advisory was sent and chlorination was started both of the treated water at the water treatment plant and in the network. Sampling from all tubes showed great variation in both colour and number of coliforms.

All membranes were tested in a pilot with regard to colour reduction, turbidity and coliforms in permeate. The results showed great variations in colour and coliforms, while the turbidity was quite low in the permeate from all membranes. The correlation between colour and coliforms was rather good. The NF membranes from in the end of the tube that was farthest away from the inlet were all damaged. This was explained by the existence of frequent water hammers due to improper design of the pre-treatment unit.

The waterworks has renewed the damaged membranes and replaced all the O-rings, and the NF plant was thus re-established as a hygienic barrier. However, the waterworks and the authorities agreed that a permanent disinfection was required in addition to the NF process in order to ensure hygienic safety.

5 Actions to improve NF barrier performance

Actions to avoid unsatisfactory treated water quality and failures in nanofiltration barrier efficiency can be divided into two different categories:

- Methods to detect failures
- Actions to prevent failures

In many cases, failures in NF barriers are not detected before coliform bacterias, and sometimes even *E.coli*, are detected in treated water. The failure itself may have been present for several months, and even years, before it was detected. This situation is due to the lack of good and reliable indicators for nanofiltration as a hygienic barrier.

Projects are initiated in order to identify indicators or methodologies that can be used to validate NF barrier efficiency.

One approach in order to identify a reliable indicator is to evaluate which compounds or organisms are effectively removed when the plant is operating properly. From this, one may find indicators suitable even for online detection, like UV-absorbance, colour, conductivity, turbidity or particle size distribution. The different indicators may, however, have different sensitivities towards different types and sizes of barrier failures. An ongoing work indicates that UV absorbance and particle size distribution may be advantageous (Pillipenko et al., 2008). The disadvantage of particle size distribution, turbidity and plate counts as potential indicator is that high values in the permeate may be due to biofilm formation at the treated water side of the membranes, and not to failures/imperfections in the NF membranes.

In Scotland they have implemented an integrity test where coliforms and *E.coli* are analysed in raw water and in permeate samples from each tube or module (Brown, 2008). This approach requires, however, a sufficiently high number of coliforms in raw water to be able to detect a leak of for instance 0.1 % of the coliforms.

The reasons for failures in the hygienic barrier include a variety of design and operational issues. Some of these issues are improper pre-treatment, failures in O-rings, damaged membranes and leaking valves.

An issue that should be addressed in the future is the service time of the membranes as well as the contactors and O-rings. Even if the colour removal indicates that the service time may be prolonged, the more specific NF barrier requirements or indicators may give reason to more frequent exchanges of membranes and gaskets (O-rings).

6 Conclusions

A Norwegian survey among water works employing nanofiltration (NF) show that NF may be an efficient treatment barrier.

Athough NF is an efficient barrier in most cases, some events show however, that failures in the safety barrier may occur. The reasons for the failures are mainly improper pre-treatment, failures in O-rings, damaged membranes and leaking valves.

The following items are identified as important tasks to be further addressed in the future:

- The nanofiltration process may often lack a suitable indicator parameter for the barrier efficiency, similar to integrity testing for ultra filtration or turbidity and/or residual coagulant for coagulation processes. Reliable indicators/parameters should be developed and implemented also for the nanofiltration plants.
- The supplier should give better recommendations for the lifetime of membranes and O-rings with regard to the use of nanofiltration as a water treatment barrier. Although a NF plant may work properly with regard to colour removal with a few minor leaks, these leaks may result in a severe failure in the barrier efficiency.
- More focus should be devoted to the development of improved and better adapted pre-treatment processes, since some failures in the NF barrier efficiency results from improper pre-treatment.

7 References

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Thorsen, T. (1999). ”Fundamental Studies on Membrane Filtration of Coloured Surface Water”, Ph.D. thesis, NTNU, Trondheim, November 1999.