HACCP (Hazard Analysis and Critical Control Points) to guarantee safe water reuse and drinking water production – a case study

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Abstract To obtain a sustainable water catchment in the dune area of the Flemish west coast, the integration of treated domestic wastewater in the existing potable water production process is planned. The hygienic hazards associated with the introduction of treated domestic wastewater into the water cycle are well recognized. Therefore, the concept of HACCP (Hazard Analysis and Critical Control Points) was used to guarantee hygienically safe drinking water production. Taking into account the literature data on the removal efficiencies of the proposed advanced treatment steps with regard to enteric viruses and protozoa and after setting high quality limits based on the recent progress in quantitative risk assessment, the critical control points (CCPs) and points of attention (POAs) were identified. Based on the HACCP analysis a specific monitoring strategy was developed which focused on the control of these CCPs and POAs.

Keywords Drinking water; HACCP; monitoring; protozoa; viruses; water reuse

Introduction In the western part of the Flemish coastal plain in Belgium, the production of potable water has been based on fresh groundwater pumped from the unconfined aquifer under the dune belt. As the groundwater extraction has reached its maximum capacity, further expansion would lead to saline intrusion. To obtain a sustainable water production in the dune belt, the Intermunicipal Water Company of Veurne-Ambacht planned the integration of alternative fresh water resources (Van Houtte et al., 1998). One of the potential sources is effluent from a nearby wastewater treatment plant (WWTP). By introducing artificial recharge of the unconfined aquifer under the dunes, the natural groundwater extraction will be lowered while the production capacity can still increase. When reusing treated domestic wastewater, the associated hygienic and chemical risks cannot be ignored. Therefore, the quality of the produced drinking water must be guaranteed and monitored at all times. In this work, it is shown how HACCP, an existing and even obligatory preventive management system to guarantee food safety, offers an excellent framework for safety evaluation, preventive quality management and implementation of monitoring systems in the context of water reuse and drinking water production. Although HACCP was developed to manage the whole of the chemical, physical and microbiological hazards and risks, in this study the attention is focused on the microbial side of the management.

HACCP – a preventive safety management system

General introduction of the concept

HACCP can be described as a preventive system that helps to assure that all products reaching the consumer are safe for consumption. The HACCP concept was originally developed and applied by the Pillsbury Company in 1960 in order to deliver safe foodstuffs to the NASA space program. From then, HACCP has been more and more used as the basis of quality control management strategies of food companies. HACCP is a systematic...
approach, which leads to the detection, the description and the control of hazards. As soon as a hazard is no longer under control, a quick and sufficient intervention can take place and the risk on the health of the consumers can be minimised. By directly pointing out the critical control points (CCPs) in the production process, the producers are able to demonstrate that they control the production circumstances and that safe products are being delivered. In 1997, the European Council Directive of 1993 on the hygiene of foodstuffs was introduced into Belgian legislation and became obligatory for all food handling sectors. Important steps in every HACCP procedure are: (a) setting up and verification of the process flow; (b) executing the hazard analysis (= hazard identification and risk analysis) and defining plus documenting the control measures; (c) identification of the CCPs; (d) defining standards and critical limits and establishing a monitoring system; and (e) establishing corrective actions (Codex Alimentarius, 1993).

HACCP in the context of drinking water supply
The application of HACCP to drinking water supply was first described by Havelaar (1994) who considered that the major microbiological hazards in drinking water supply are pollution of raw water sources, recontamination of storage and distribution facilities for treated water and growth of pathogens in raw and treated waters. In groundwater supply, protection of the aquifer is essential. The relevance of HACCP with regard to Australian tap water supplies was discussed by Davison and Deere (1999). Today, the World Health Organisation (WHO) is evaluating the inclusion of HACCP principles into the next revision of its drinking water guidelines (Deere and Davison, 1999).

Application of HACCP to guarantee safe water cycle closing at the west coast of Belgium
Description of the complete water cycle
Recent investment in the WWTP at Wulpen, executed by Aquafin (the company responsible for sewage works in Flanders), has improved the quality of the effluent. These improvements made it possible to implement additional treatment of this secondary effluent in order to produce water with a quality sufficient to use it for infiltration. The processes at the WWTP consist of removal of sand, primary sedimentation, biological nitrification–denitrification, aeration and clarification (Figure 1 – activated sludge treatment). Three major aspects were considered when selecting the advanced process to produce infiltration water (Figure 1 – advanced treatment) (Van Houtte et al., 1998): (a) the potable water should be supplied to consumers without any chlorine disinfection; (b) due to the ecological values of the dunes, high quality standards have to be set for infiltration water since in no instance can major ecological disturbances be accepted; and (c) the available space for building constructions is restricted.

In view of the relatively high nutrient and salt content of WWTP effluent, a dual-membrane treatment process was selected: pre-treatment with microfiltration (MF) followed by an additional desalination of the filtrate using reverse osmosis (RO) membranes. Both processes require a small footprint and should produce filtrate that is already microbiologically safe, so that the subsequent soil passage (Figure 1 – infiltration) will only function as an additional security. The aquifer functions to a lesser extent as a temporary reservoir. In case the supply of infiltration water stops, potable water can still be pumped up for a certain period. To obtain a certain level of minerals, 10% of the MF-filtrate will be blended with the RO-filtrate. However, the MF-filtrate will require additional disinfection using UV prior to this blending. The pumped groundwater is purified by aeration and rapid sand filtration (Figure 1 – groundwater treatment) and supplied to the normal potable water distribution system.
There are hundreds of types of microorganisms that may be present in domestic wastewater. The pathogens can be classified into three broad groups: viruses, bacteria and parasites (protozoa and helminths). The major source of pathogens in domestic wastewater is the faecal material of infected individuals. However, urine may also be a source of certain pathogenic viruses. The presence of these pathogens in the final drinking water by membrane leakage in the MF or RO units, absorbance of UV by shielding, or recontamination in the distribution net are considered to be the main risk containing hazards. Regrowth of pathogens in the storage and distribution facilities is not a major concern if recontamination is adequately prevented (Havelaar, 1994).

**Table 1** Overview of literature data on the concentrations in secondary effluent and on the removal efficiencies of the proposed treatment steps with regard to enteric viruses and protozoa

<table>
<thead>
<tr>
<th>Concentrations</th>
<th>Reference</th>
<th>Removal efficiencies</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary effluent (high max. values)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteric viruses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrations</td>
<td>Reference</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>10/L</td>
<td>Haas and Trussell (1998)</td>
<td>100/L (Giardia)</td>
<td>Haas and Trussell (1998)</td>
</tr>
<tr>
<td>Removal efficiencies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microfiltration</td>
<td>&gt; 2.0 log (poliovirus)</td>
<td>Madaeni et al. (1995)</td>
<td>&gt; 4.8 log (Cryptosporidium)</td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>&gt; 6.5 log (MS2)</td>
<td>Iranpour (1998)</td>
<td>&gt; 5.7 (Cryptosporidium and Giardia)</td>
</tr>
<tr>
<td>UV disinfection</td>
<td>5 log (F-specific bacteriophage)</td>
<td>Lazarova et al. (1999)</td>
<td>5 log (Cryptosporidium and Giardia)</td>
</tr>
<tr>
<td>Soil passage</td>
<td>&gt;8 log (MS2 and PRD1 in conditions very similar to the ones applied in this project)</td>
<td>Hoogenboezem et al. (1999)</td>
<td>&gt; viruses (?)</td>
</tr>
</tbody>
</table>

MS2 = F-specific phage; PRD1 = Salmonella phage

**Hazard identification and risk analysis**

There are hundreds of types of microorganisms that may be present in domestic wastewater. The pathogens can be classified into three broad groups: viruses, bacteria and parasites (protozoa and helminths). The major source of pathogens in domestic wastewater is the faecal material of infected individuals. However, urine may also be a source of certain pathogenic viruses. The presence of these pathogens in the final drinking water by membrane leakage in the MF or RO units, absorbance of UV by shielding, or recontamination in the distribution net are considered to be the main risk containing hazards. Regrowth of pathogens in the storage and distribution facilities is not a major concern if recontamination is adequately prevented (Havelaar, 1994).
Treatment steps and control measures

It is increasingly being recognised that safe drinking water supply should not be based on a single barrier such as (chemical) disinfection but that a multiple barrier approach is required to effectively eliminate and/or inactivate the various types of hazardous microorganisms (Havelaar, 1994) and to obtain a high level of reliability.

In Table 1 an overview is given of literature data on the removal efficiencies of the advanced treatment steps with regard to enteric viruses and protozoa (Cryptosporidium and Giardia). Information on the removal of these groups of organisms is considered to be crucial in the context of water reuse and drinking water production because of their low-dose infectivity, their long-term survival in the environment and the difficulties in monitoring them. It is becoming common practice to sum logarithmic removals across multiple barrier treatment processes (Sakaji and Funamizu, 1999). With this approach to assessing safety and reliability, the densities of the pathogens and the removals for each unit process are looked at as static quantities (Haas and Trussell, 1998). The barriers are assumed to be first order and independent of each other. Recontamination can be prevented by adequate construction, by maintaining positive hydrostatic pressure at all times and by hygienic precautions when working on the distribution system (Havelaar, 1994). Prevention of regrowth is mainly done by preventing recontamination and by controlling the residence time and the concentrations of the nutrients.

Identification of the critical control points and points of attention

The proper identification of CCPs is an important issue in HACCP because the major efforts in process control and monitoring will be directed towards these steps. In many food-processing operations a single step can be identified that is a major and ultimate barrier (and thus a CCP) to pathogens, e.g. heating (Havelaar, 1994). As no chemical disinfection of the drinking water is planned, the consecutive treatment steps (MF, RO, UV) are necessary to obtain the desired microbiological quality. It is the philosophy of the Intermunicipal Water Company of Veurne-Ambacht to consider the soil passage as a merely psychological measure to protect the consumer from microbiological exposure. It must be acknowledged that in case of putative microbial outgrowth in subsoil, active correction is difficult to implement and to monitor. Thus, it was decided that the infiltration water should already comply with the hygienic drinking water limits. All process steps before the soil passage are to be considered as CCPs. Abstraction is made of the biological treatment step (WWTP) because of the large variation in concentrations and plant performances depending on the atmospheric circumstances. However, the producer should frequently survey the secondary effluent to check the concentrations of pathogens and to decide whether the advanced treatment is still adequate (Havelaar, 1994). In this respect Odendaal et al. (1998) stated that intake quality control should conceptually be regarded as the first step and an integral part of water reclamation technology. It was decided to consider the intake of WWTP effluent and the soil passage as points of attention (POAs). According to HACCP definitions, POAs are to be seen as activities, places or factors that also need to be controlled but not in the same imperative way as CCPs. On the drinking water side of the cycle the distribution network is the CCP for the hazard of recontamination. The occurrence of regrowth in the distribution net is a POA.

Development of a monitoring strategy

For viruses and protozoa, no limits are mentioned in the Belgian drinking water legislation. Recent developments in quantitative risk assessment have shown that drinking water treatment processes must meet high standards with regard to the removal of pathogenic
micro-organisms. Based on an acceptable risk level of 1 infection per 10,000 consumers per year (US EPA, 1989) and a daily tap water consumption of 1 L/person, recommended target values for enteric viruses, *Giardia* and *Cryptosporidium* are respectively $4.0 \times 10^{-7}$, $1.4 \times 10^{-5}$ and $6.5 \times 10^{-5}$ per litre of drinking water (Haas and Trussell, 1998). Considering the total concentration levels of enteric viruses and protozoa in secondary effluent, as mentioned in Table 1, combined with the removal efficiencies of the advanced treatment steps under normal operating conditions, these limits are met (Figure 2). Ideally, CCPs are monitored on-line so that corrective action can be taken by a direct feedback system. Today microbiological monitoring systems do not fulfil these requirements and are therefore not well suited for monitoring purposes. However, they continue to have a role in the verification stage (e.g. to monitor the POAs).

The following monitoring strategy was developed for this site. (1) The performance and integrity of all advanced treatment steps that are considered CCPs (MF, RO, UV) are followed on-line. When these processes are working properly and in a reliable way, there is a good reason to trust the end product (Janssens and Verstraete, 1996). (2) Demonstrating

<table>
<thead>
<tr>
<th>Process step</th>
<th>CCP</th>
<th>Hazard</th>
<th>Monitoring</th>
<th>Corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF</td>
<td>CCP1</td>
<td>Membrane rupture</td>
<td>Particle counter</td>
<td>Stop module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conductivity</td>
<td>Replace module</td>
</tr>
<tr>
<td>RO</td>
<td>CCP2</td>
<td>Membrane disintegration</td>
<td>Particle counter</td>
<td>Stop module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conductivity</td>
<td>Replace cartridge</td>
</tr>
<tr>
<td>UV</td>
<td>CCP3</td>
<td>Absorbance by shielding</td>
<td>Turbidity</td>
<td>Direct feedback</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UV transmittance</td>
<td>Check MF</td>
</tr>
<tr>
<td>Distribution net</td>
<td>CCP4</td>
<td>Recontamination</td>
<td>Lamp current/lamp age</td>
<td>Replace lamp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pressure changes</td>
<td>Isolate part of the system; purge</td>
</tr>
</tbody>
</table>

**Figure 2** HACCP representation of the water cycle at Veurne-Ambacht (The concentrations of viruses (vir) and protozoa (prot) in the secondary effluent are from Haas and Trussell (1998). The residual concentrations are calculated from the removal efficiency data in Table 1. POA = point of attention; CCP = critical control point; QRA = quantitative risk assessment)
drinking water compliance with the recommended target values for viruses and pathogenic protozoa is analytically unfeasible (Van Breemen et al., 1998). A possible strategy is to monitor and control the general hygienic quality of the intake, i.e. effluent of the WWTP, using a rapid on-line sensor (see below). (3) Monitoring of pressure changes in the distribution system will be carried out to detect putative contamination based on leaks and foul water inputs. (4) Concerning the hazard of regrowth in the net, the key feature is the daily purge through the distribution line. Indeed, for all drinking water lines, daily flow and minimisation of stagnation of water in the pipes is of crucial importance. This aspect demands extra attention in the case of short water cycles. It is conceivable to monitor the daily output at the tap. (5) Molecular biological techniques can be applied to detect qualitative changes in the microbial community of the groundwater and of samples taken from the storage and distribution system (see below). (6) Finally, bacterial testing will be executed by the traditional plate counting on the infiltration water and treated groundwater and on samples from the distribution system.

Laboratory investigations conducted in this context

At LabMET, a pH-based sensor was developed to monitor the general hygienic quality of secondary effluent in a rapid manner (1 hour) (Janssens and Verstraete, 1996). The sensor measures the microbial acidification rate of a water sample after supplementation of a fermentable sugar. This rate can be correlated to the hygienic quality of the water, measured as total plate counts (nutrient agar, 37°C, 48h). Laboratory research is also being conducted in applying the molecular monitoring technique DGGE (denaturing gradient gel electrophoresis) on drinking waters. A deviant DGGE fingerprint is indicative of a change in the bacterial community in the water. In such a case, further in-depth investigation can be carried out to find out what new bacterial species are causing this change.
Summary
In Figure 2, a schematic summary is shown of the conducted HACCP analysis. Table 2 and 3 describe the hazards, monitoring techniques and corrective actions for the CCPs and POAs respectively.

Conclusions
Water cycle closing necessitates rigorous and preventive hygienic safety management. HACCP offers a framework for this purpose. The critical control points and the points of attention in the cycle have been pointed out and a specific monitoring strategy was developed towards these CCPs and POAs. The whole of this HACCP approach should guarantee safe water reuse, technically and also psychologically acceptable to the general public.

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