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Application of HACCP to water reuse in the food industry

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Abstract

Reuse of water in the food industry is attracting much attention due to the increasing cost of water and water discharge. A major obstacle for extensive reuse is the associated risk of microbiological contamination of food and the production environment. A hazard analysis critical control point based generic model has, therefore, been elaborated for implementation and evaluation of systems for the reuse of water in the food industry. The model includes information on food and water borne pathogens and their sensitivity towards various water treatment methods. Previous implementation of the pre-requisite programs and combination of knowledge from very different research areas are also required for safe implementation of water reuse in the food industry. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: HACCP; Water reuse; Food industry

1. Introduction

According to Sleeman and Barret (1996), 16% of fresh water consumption in industrial nations is water for industrial supply. The rising concern over continued availability of high quality fresh water and the need for minimizing pollution of the environment have resulted in increasing costs for clean water and, in particular, for discharge of waste water (Birks, 1999; Hägg, 1998). Reuse of water has, therefore, become an important issue also within industry. Process water is used for many purposes in the food industry, i.e., as an ingredient, as part of the manufacturing process and in direct contact with the foodstuff, or in any indirect contact with the food product (Poretti, 1990). Food processors are following two strategies in order to save water: the development of process unit operations that use less water and the reuse of water. Despite the tremendous potential for reusing water in food processing plants (Mavrov, Fähnrich, & Chmiel, 1997), there is relatively little published information in this area and few food processing operations employ reconditioned process water (Palumbo, Rajkowski, & Miller, 1997).

According to the last Drinking Water Directive of the European Community (Directive 98/83/EC, 1998), process water used in the food industry should be at least equal to the highest standard for drinking water required by the local authorities. Many food processing plants are looking to increase the reuse of process water beyond the currently approved uses which include initial cleaning of vegetables and scalding water of meat and poultry (Rajkowski, Rice, Huynh, & Patsy, 1996). There are, however, several obstacles to greater implementation of water reuse in the food industry, the most important being microbiological risks and regulations established by the public health authorities on use of water in the food industry. The microbiological quality of the water to be reused must be guaranteed and monitored at all times, and it is therefore obvious to use a hazard analysis critical control point (HACCP) system, which is a systematic safety management tool (Notermans, Zwietering, & Mead, 1994). The HACCP principles have been employed in food processing industries in the Member States of the European Community for some years to assure safe food production (Jouve, 1994; Vanne, Karswoski, Karppinen, & Sjöberg, 1996). The application of HACCP to drinking water supply was described by Havelaar in 1994 and recently by Dewettinck, van Houtte, Geenens, van Hege, and Verstraete (2001), and the World Health Organisation (WHO) is evaluating the inclusion of HACCP principles

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into the next revision of its drinking water guidelines scheduled for year 2003 (Deere & Davison, 1999; Hayward, 2000). However, this management tool has not been formally introduced for the reuse of process water.

This paper presents a HACCP based approach for evaluating the requirements for microbiologically safe and acceptable water quality for different purposes when reusing process water in the food industry. This includes both reconditioned and non-reconditioned process water to be reused in the food industry as well as some supporting tools such as information on pathogens of potential importance and on water treatment methods and their effect on food and water borne microorganisms. This work is loyal to the definitions given in a discussion paper on proposed draft guidelines for the hygienic reuse of processing water in food plants (Codex Alimentarius, 1999; Table 1), and it only focuses on the microbial hazards or risks associated with the reuse of process water in the food industry.

2. Preliminary steps of the application of HACCP to water reuse in the food industry

The HACCP plan to be applied when reusing process water in the food industry requires that some preliminary steps are taken before the implementation of the seven principles (NFPA, 1993; USDA, 1999), and these are shown in Fig. 1.

The purpose of preliminary steps three and four is to provide as much information as possible to the HACCP team on previously used water and its intended use. A microbiological mapping of the process water at the different steps of the food production chain will be very helpful in the HACCP implementation. Microbiological mapping is a good tool for both evaluating the potential for reuse and for facilitating the identification of microbiological hazards (first of the seven principles of a HACCP system).

After these preliminary steps, one should evaluate the feasibility of the possible reuse/s and treatments of the previously used process water. It should be taken into consideration whether the recovered water can be used following recycling, be reused elsewhere within the food processing plant or whether reconditioning is necessary before recycling or reuse. Some suggestions for reuse of process water from various unit operations in the food industry are shown in Table 2. Actual reuse is dependent upon the nature of the water, the recovery and water treatment method and the end-use of the water. Nevertheless, process water originating from many of the sources listed in Table 2 may be reused in a pattern opposite to the flow of the product (counterflow pattern), providing that established levels of food hygiene are not compromised, e.g., for initial washing of vegetables, fluming of unprepared products such as beets or tomatoes, and scalding water for meat and poultry (Codex Alimentarius, 1999; Rajkowski et al., 1996). Generally, process water can also be reused for general facility cleaning (floors, walls, ceilings), cleaning of the exterior of equipment (provided there is no possibility for contamination of the product or product contact surfaces of process equipment), fire extinguishing and similar purposes (Katsuyama, 1979). However, in some cases, e.g., water that has been in contact with human, animal or agricultural sewage, or reclaimed water that may have been in contact with bacteriophages, e.g., at dairies, should not be considered for reuse in the food processing plant (Codex Alimentarius, 1999). It should also be mentioned that recovered water should not be regarded as potable water, and it should be distributed in separated and independent systems. Cross-contamination by backflow and cross-connections shall be avoided.

3. HACCP steps

Once the preliminary steps have been completed, the seven principles of the HACCP system are applied. The following steps or principles provide a HACCP model for process water to be reused in the food industry.

Table 1
Definitions (Codex Alimentarius, 1999)

Reuse	The recovery of water from a processing step, including from the food component itself; its reconditioning treatment, if applicable; and its subsequent use in a food manufacturing operation
Reconditioning	The treatment of water intended for reuse by means designed to reduce or eliminate microbiological, chemical, and physical contaminants, according to its intended use
Recycled water	Water, other than first use or reclaimed water, that has been obtained from a food manufacturing operation and has been reconditioned when necessary such that it may be reused in a subsequent manufacturing operation
Reclaimed water	Water that was originally a constituent of a food, has been removed from the food by a process step, and has been subsequently reconditioned when necessary such that it may be reused in a subsequent manufacturing operation
Reused water	Recycled and reclaimed water
Food manufacturing operation	Any operation intended to clean, sort, process, or package a food product or its ingredients including the cleaning of equipment and facilities

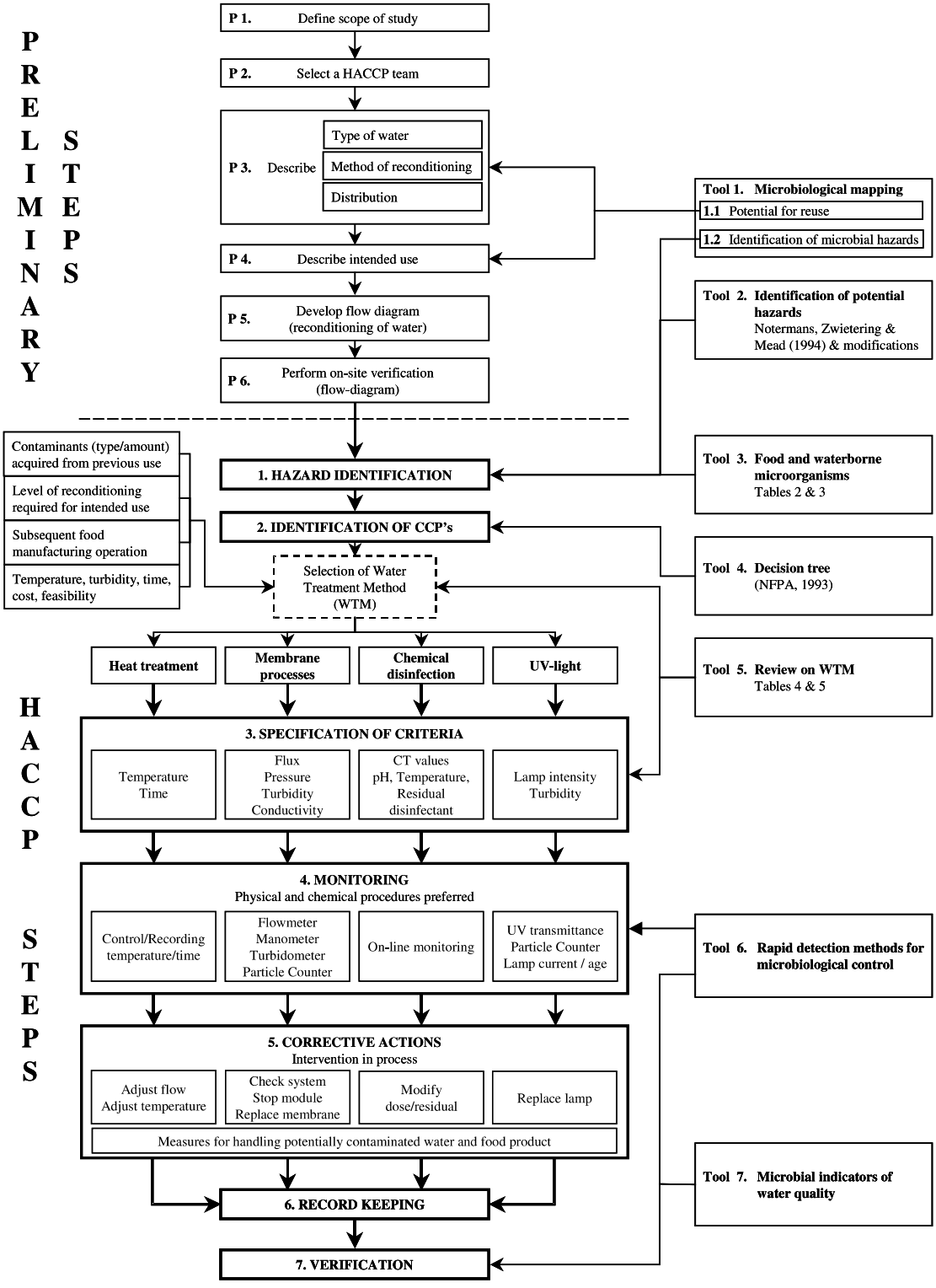

Fig. 1. Scheme for establishing a HACCP plan for reconditioning of process water to be reused in the food industry.

3.1. Hazard analysis

Hazard identification implies listing of the hazards of potential significance. For inclusion in this list, the hazards must be of such a nature that the prevention, elimination or reduction of these to acceptable levels is essential to the production of a safe product, water in this case (NACMCF, 1992). The potential hazards are identified by following the method proposed by Notermans et al. (1994) with some modifications as described

Table 2
Suggestions for reuse of process water from various unit operations in the food industry

Unit operation/ process		Use of water	Suggestions for reuse of recovered water
Washing and rinsing	Washing of raw material	First wash	Water recovered from washing or fluming, except for water used to flume waste products, may be directly reused employing a counterflow pattern. For example, water used for fluming washed vegetables can be reused without reconditioning for fluming unwashed raw materials or for washing raw materials. In some cases, e.g. water recovered from fluming unwashed unprepared fruits and vegetables or from washing curd during manufacture of caseinates, butter or cheese can be recycled within the same food processing operation. Water used for e.g. carcass pig washing should not be reused without reconditioning. Final washing or rinsing should be done with fresh water. Water recovered from fluming waste products may be recycled without reconditioning
		Final wash	
		Rinsing	
	Washing of product	Start rinse	
		Final rinse	
Fluming	Transport	Unwashed raw materials	
		Washed materials/ products	
		Waste products	
Blanching	Inactivation of enzymes	Original filling water	May be recycled or reused following reconditioning
		After blanching	
Heat treatment	Scalding	Direct (e.g. poultry)	Scalding water may be reused directly (counterflow pattern). Pasteurisation water (indirect contact) may be recycled or reused for different purposes. In both cases, temperature/time profiles will determine the end-use of the recovered water
	Pasteurisation	Indirect (e.g. sous vide)	
Cooling	Cooling of food product	Direct	Water recovered from e.g. cooling of sausages requires reconditioning prior to reuse
		Indirect (e.g. cans)	Cannery cooling water may be recycled after addition of chlorine
	Cooling of equipment	(e.g. containers)	Recovered water may be reused for the same purpose provided that build-up of microorganisms and organic matter is prevented in the cooling canal system
Direct preparation of product	Brines (e.g. Surimi processing brine, cucumber pickling brine)		May be recycled after partial reconditioning (removal of proteins, addition of NaCl)
	Reclaimed water (e.g. cheese production)		Permeates from membrane filtration may be reincorporated into the food product or reused elsewhere in the food processing plant except for disinfection purposes
Steam production	Condensate	Direct contact with product (e.g. dried milk)	The product condensate may be reincorporated into the food product or reused elsewhere in the food plant except for disinfection purposes. Steam condensate may be recycled or reused directly elsewhere in the food processing plant
		Indirect/no contact with product	
Cleaning and rinsing	Cleaning of food handling equipment		Recovered water from rinsing equipment may be reused for cleaning purposes
Disinfection	Disinfection of food handling equipment		Recovered water may be reused for cleaning purposes

in the following. For each specific case of water reuse, the hazardous relevant microorganisms that may have been in contact with the water prior to reuse are listed. Listing all microorganisms that are known to cause food borne diseases and determining whether they are likely to be present in the raw materials used is the first step. The list of pathogenic bacteria should be compiled from an analysis of actual outbreaks of food and water borne diseases, and the yearly summaries produced by WHO on such incidents are good tools for this purpose, although the rate of under-reporting and the lack of information on the incidence and the causes of foodborne diseases are extremely large (Notermans & Hoogenboom-Verdegaal, 1992). According to Notermans et al. (1994), the microorganisms that are completely destroyed during processing should then be deleted from the list. However, quantifications of the degree of desired safety seem necessary, since this may not be the same for all pathogens. Pathogenic organisms that may be involved in re-contamination during and after processing should also be included in the list (Hansen, 1996). It is also suggested to delete the organisms that have never caused problems in the past with identical or related products. Although focusing on the most relevant pathogens may be an obvious approach, caution should be exercised since "first time" pathogen-food matrix combinations are regularly observed. Some caution is also required when dealing with novel food processes. Finally, this method distinguishes between infectious and toxigenic organisms, and the possibility of growth in the product is only considered for the toxigenic organisms. It could be argued that growth potential should also be included for known low virulent bacterial pathogens. Therefore, it is suggested that the infectious organisms are divided in two groups: a high infection dose group and a low infection dose group. The high infection dose group should then follow a similar approach as for the toxigenic organisms (Hansen, 1996).

According to Geldreich (1990), the infectious agents associated with drinking water may be classified within four broad groups: bacteria, viruses, protozoa and helminths or parasitic worms. These infectious agents derive principally from infected persons and other warm-blooded animals, and the diseases associated to these agents are primarily transmitted through human and animal excreta. Some examples of human pathogens that have been transmitted by drinking water are listed in Tables 3 and 4 together with a summary on their degree of pathogenicity, mode of transmission, infective dose, reservoir and other relevant sources, and persistence in water and/or drinking water supplies. Some of these microorganisms represent a serious risk for disease whenever present in drinking water, such as *Campylobacter*, *Salmonella*, a number of viruses, *Giardia* and *Cryptosporidium*, and these are designated pathogens. Pathogens of moderate priority include opportunistic pathogens such as *Pseudomonas aeruginosa* and *Aeromonas* spp. (WHO, 1996). These organisms may cause disease in subjects with low immunity, may be primarily transmitted by contact or inhalation (rather than ingestion) such as *Legionella*, or may be responsible for occasional outbreaks or found exclusively in some regions. The dose–response varies depending on the pathogen and the host involved and it is also affected by a large number of factors (Baird-Parker, 1995; Untermann, 1998). Many bacterial infections require high numbers of cells (10^7–10^8), whereas the infective dose for viruses, protozoa or helminths is very low (WHO, 1996). Pathogenic bacteria and parasites normally lose viability and the ability to infect after leaving their host. Therefore, most of the microorganisms are not expected to stay infectious in water, and some will simply disappear over time since they are unable to multiply in these conditions. An exception among the parasites is *Cryptosporidium* spp., whose oocysts may stay viable in aqueous suspensions for up to 12 months at 4 °C (Current & Haynes, 1984). Bacteria may respond in different and complex ways depending on factors such as temperature and presence of nutrients (Palumbo, Pickard, & Call, 1999). Some species of *Pseudomonas*, *Aeromonas* and *Serratia* may even multiply in drinking water (Kristensen, 1984; Szewzyk et al., 2000; WHO, 1996). It should be also taken into account that water borne bacteria, in contrast to viruses, parasites and prions, are capable of multiplying rapidly when introduced into foodstuffs (Untermann, 1998). This increases their inoculum potential enormously and makes even initially low and non-infectious doses of bacterial pathogens a hazard in food production.

Microbiological mapping of the process water may be a suitable supporting tool for the identification process. After identification, the potential hazards are listed and grouped according to common properties such as their minimum growth temperature or their sensitivity to water treatment methods. The location of the potential hazards is indicated on the flow diagram. In this generic model, the factors that might cause the occurrence of microbial hazards will be referred to as risk-enhancing factors.

3.2. Establishment of critical control points (CCPs) in the process

When reusing reconditioned process water in the food industry, the obvious CP is the step in the production involving water treatment or reconditioning. When reusing non-reconditioned process water in the food industry, the CP is the step prior to reuse and decisive factors are the way the water is collected and transported to the place of reuse, and the holding time and the temperature at which the water is kept. In order to establish whether these CPs are critical, the decision tree from NFPA (1993) is an excellent tool. Treatment of process water to be reused will be considered as a critical CP, since the aim of this step is to eliminate or reduce the hazards to acceptable levels. The choice of a given treatment process is not an easy task, since it is driven by several criteria (Table 5). The selection of a proper water treatment method for microbiological decontamination of process water in the food industry depends on:

1. The degree and type of contamination of the source water and on the understanding of the type and nature of the microbes to be removed. For example, if faecal contamination is possible and the target organisms are oocysts from *Cryptosporidium*, chlorination should not be used since this water treatment method has been found to be ineffective within a short period of exposure (Birks, 1999; Taylor, 2000). Examples of various sensitivities towards chlorination and UV-radiation are shown in Table 6.
2. The requirements to be met before and after reuse. For example, in several countries including Denmark, hypochlorite is not recommended for treatment of process water to be used in contact with the food product due to the potential formation of human carcinogens.
3. The subsequent food manufacturing operations.
4. Other factors such as temperature and turbidity. For example, UV is not recommended for treatment of water that is turbid or contains particulates, since the organisms found in the shadow of particles are protected from the lethal effects of the irradiation (Codex Alimentarius, 1999). Time is also important. If only a short contact time is possible, chloramines should not be used since contact times of some hours are needed to produce appreciable inactivation of most water borne pathogenic bacteria (Cliver, 1990).

Table 3
Examples of potential pathogenic bacteria in drinking water and their significance in water and drinking water supplies

	Pathogenicity[1,2]	Transmission		Infective dose		Reservoir and other relevant sources[a]		Persistence in water or drinking water supplies[b]	
			Reference		Reference		Reference		Reference
Gram-negative bacteria									
Campylobacter jejuni, *C. coli*	Pathogen	Ingestion	1, 3	Low-moderate	1, 3	A, F, W, E	1, 3, 4	Moderate	1, 3
Pathogenic *E.coli*	Pathogen	Ingestion	1	High[c]	1, 5	H, A, F, W[d]	1, 3, 4, 6, 7	Moderate[e]	1, 8
Salmonella typhi	Pathogen	Ingestion	1, 7	High	1, 3, 6	H	1, 3, 4, 7	Moderate	1
Other *Salmonella* spp.	Pathogen	Ingestion	1, 7	High	1, 3	H, A, F	1, 3, 7	Long	1
Shigella spp.	Pathogen	Ingestion	1, 9	Low-moderate	1, 3, 9	H, F	1, 4, 7, 9	Short	1, 7
Vibrio cholerae	Pathogen	Ingestion	1	High	1, 10	H, F, W[f]	1, 6, 7, 11	Short	1
Yersinia enterocolitica	Pathogen	Ingestion	1	High	1, 10	H, A, F, W, E	1, 3, 7, 12	Long	1
Pseudomonas aeruginosa	Opportunistic	Contact or inhalation	1, 13	High	1, 2	H, W, E	1, 2, 11, 13	May multiply	1, 5
Aeromonas spp.	Opportunistic	Contact, inhalation or ingestion	1	Moderate-high	1, 3, 10	W, E	1, 13, 14	May multiply	1, 5
Flavobacterium spp.	Opportunistic	Contact or inhalation	1	?[g]	6	A, W, E	6, 15	NA[h]	
Acinetobacter spp.	Opportunistic	Contact or inhalation	1, 2	High	2	H, E, W	2, 13, 16	NA	
Klebsiella spp	Opportunistic	Contact or inhalation	1	?	6	H, A, F	17	Long	
Serratia spp.	Opportunistic	Contact or inhalation	1	?	6	E, W	13	May multiply	13
Legionella spp.	Opportunistic	Contact or inhalation	1, 18	Low	2, 6	W[f], E	5, 6	May multiply	5
Gram-positive bacteria									
Listeria spp.	Opportunistic	Ingestion	7, 19	High	20	H, A, F, E	7, 12, 19	Long	7
Bacillus spp.	Opportunistic	Ingestion	3	High	3, 7, 21	H, A, W, E	3, 7, 12, 21	NA	
Clostridium perfringens	Opportunistic	Ingestion	3, 4	High	3, 10	H, A, F, W, E	3, 4, 7, 12	Long	1
Coryneforme spp.	Opportunistic	Contact or inhalation	17	NA		H, A, W, E	11, 17	NA	
Mycobacterium	Opportunistic	Contact or inhalation	18	Low-moderate	2, 18	H, A, W, E	2, 11	May multiply	2, 5, 13

References: (1) WHO (1996); (2) Rusin, Rose, Haas, and Gerba (1997); (3) ICMSF (1996); (4) Untermann (1998); (5) Szewzyk, Szewzyk, Manz, and Schleifer (2000); (6) Hazen and Toranzos (1990); (7) Anonymous (1988); (8) Wang and Doyle (1998); (9) Smith (1987); (10) Granum, Tomas, and Alouf (1995); (11) Notermans et al. (1994); (12) Vanne et al. (1996); (13) Kristensen (1984); (14) Palumbo, Stelma, and Abeyta (2000); (15) Holmes, Owen, and McMeekin (1984); (16) Anonymous (1994); (17) Stiles (2000); (18) Pascual et al. (1998); (19) Brackett (1988); (20) McLauchlin and van der Mee-Marquet (1998); (21) Granum and Baird-Parker (2000).

[a] H: Human; A: Animal; F: Faeces or Intestinal tract; W: Water; E: Environment.

[b] Detection period for infective stage: short, up to 1 week; moderate, 1 week–1 month; long, over 1 month.

[c] Low for verotoxinogenic *E.coli*.

[d] Polluted water.

[e] Long for *E.coli* O157:H7.

[f] Nutrient-rich waters.

[g] Uncertain.

[h] No data available.

Table 4
Examples of potential pathogenic viruses, protozoa and helminths in drinking water and their significance in water and drinking water supplies

	Pathogenicity[1]	Transmission		Infective dose		Reservoir and other relevant sources[a]		Persistence in water or drinking water supplies[b]	
			Reference		Reference		Reference		Reference
Viruses									
Adenoviruses	Pathogen	Ingestion	2	Low	1, 3	H	1	?[c]	1
Enteroviruses	Pathogen	Ingestion	2	Low	1, 4	H	1	Long	1
Hepatitis A	Pathogen	Ingestion	1, 2, 5, 6	Low	1, 3, 7	H, F	1, 5, 8	Long	6
Enterically transmitted non-A, non-B and E hepatitis viruses	Pathogen	Ingestion	2	Low	1	H, A	1, 9	Long (hep. E)	9
Norwalk virus	Pathogen	Ingestion and inhalation	1, 2, 10	Low	1, 3, 10	H, F	1, 5, 10	?	1
Rotavirus	Pathogen	Ingestion	1, 2	Moderate	1	H, A, E	1, 5, 11, 12	Long	11
Small round virus	Pathogen	Ingestion	10	Low (?)	1	H, F	1, 10	Long	12
Coxsackie virus	Opportunistic	Ingestion	2	Low	3, 4	H	8	Long	13
Reovirus	Opportunistic	Ingestion	2	NA[d]		H	8	NA	
Protozoa									
Entamoeba histolytica	Pathogen	Ingestion	1, 5	Low	1, 3	H, A, F	5, 14, 15	Moderate	1
Giardia intestinalis	Pathogen	Ingestion	1, 5	Low	1	A, F	1, 15	Moderate	1
Giardia lamblia	Pathogen	Ingestion	1, 5	Low	1, 3	H, A, F	1, 5, 14, 15	Moderate	1
Cryptosporidium spp.	Pathogen	Ingestion	1, 5	Low	1	H, A, F, W	1, 5, 15, 16	Long	1, 15
Naegleria fowleri	Opportunistic	Contact or inhalation	1	Low	17	F, W[e]	15	May multiply	1
Acanthamoeba spp.	Opportunistic	Contact or inhalation	1	Low	17	F, W[e], E	15, 18	May multiply	1
Balantidium coli	Opportunistic	Ingestion	15	?	3	H, A, F, E	1, 14, 15	Moderate	15
Cyclospora	Opportunistic	Ingestion	5	NA		H, A, F, W	5, 15	Moderate-long	15
Helminths									
Dracunculus medinensis	Pathogenic	Ingestion	1	Low	3	A, H	1	Moderate	1
Ancylostoma duodenale	Opportunistic	Ingestion	18	NA		H, A, F, E	1, 19	NA	
Ascaris lumbricoides/suum	Opportunistic	Ingestion		Low	3	H, F, E	1	NA	
Echinococcus spp.	Opportunistic	Ingestion	19	Low	21	H, A, F, E	1, 20	NA	
Necator americanus	Opportunistic	Ingestion and contact	18	NA		F, E	1	NA	
Strongyloides stercoralis	Opportunistic	Ingestion and contact	21	Low	22	A, H, F, E	22	NA	
Taenia solium/saginata	Opportunistic	Ingestion	8	Low	8	H, A, F, E	1, 8, 23	Long	24

References: (1) WHO (1996); (2) Gerba and Rose (1990); (3) Hazen and Toranzos (1990); (4) Sattar and Tetro (2001); (5) Untermann (1998); (6) Cromeans, Favorov, Nainan, and Margolis (2001); (7) Sattar and Bidawid (2001); (8) ICMSF (1996); (9) Smith (2001); (10) Appleton (2001); (11) Sattar, Springthorpe, and Tetro (2001); (12) Lüthi (2001); (13) Vivier, Ehlers, Grabow, and Havelaar (2001); (14) Taylor (2000); (15) Fayer (2001); (16) Isaac-Renton, Fogel, Stibbs, and Ongerth (1987); (17) Lloyd (1998a); (18) Foronda (1990); (19) Prociv (1998); (20) Gottstein (2001); (21) Gemmell and Roberts (1998); (22) Nolan, Genta, and Schad (1998); (23) Pawlowski and Murrell (2001); (24) Lloyd (1998b).

[a] H: Human; A: Animal; F: Faeces or Intestinal tract; W: Water; E: Environment.

[b] Detection period for infective stage: short, up to 1 week; moderate, 1 week–1 month; long, over 1 month.

[c] Uncertain.

[d] No data available.

[e] Nutrient-rich waters.

Table 5
Comparison of water treatment methods for microbial decontamination of process water

	Membrane processes	Heat treatment	UV-radiation	Hypo-chlorite	Chlorine dioxide	Chlor-amines	Ozone
Recommended concentration/intensity	NR[a]	NR	25–40 mW s/cm^2	50–100 mg/l	>2 mg/l	1–2 mg/l	<1 mg/l
Contact time	NR	80 °C/10 min (cells) 121 °C/15 min (spores)	0.5–5 s	10–20 min	15 min	Hours	2–4 min
Temperature (T)	<80 °C	65 °C/10 min (oocysts)	Better at low T	Wide range	Wide range	>20 °C	Low T
pH tolerance	1–13	–[b]	NA[c]	<7	<10	Low	6[d]
Sensitivity to turbidity	Low	None	Highest	High	Medium	Medium	High
Effect on gram negative bacteria	Good	Good	Good	Good	Good	Good	Good
Effect on gram positive bacteria	Good	Limited	Limited	Limited	Limited	Limited	Good
Effect on spores	Good	Limited	Limited	Poor	Poor	Poor	Limited
Effect on viruses	Good[e]	Good	Limited	Good	Good	Poor	Good
Effect on protozoa	Good	Good	Good	Limited	Limited	Very limited	Good
Protection to further contamination after treatment	None	None	None	Good	Good	Good	Medium
Bacterial regrowth	Possible	Possible	Possible	Inhibited	Inhibited	Inhibited	Possible
Occupational health hazards	Low	Low	Low	High	High	Medium	High
Potential for formation of toxic by-products	None	None	None	Highest	High	Medium	Medium
Induced corrosion	None	None	None	Highest	Medium	Medium	High
Investment cost	High	High	Low-medium	Lowest	Low	Low	High
Operation cost	High	High	Low	Lowest	Lowest	Lowest	High
Ease of use	Medium	Medium	Medium	Good	Good	Good	Medium
Maintenance problems	Membrane	Fouling	Lamp	Corrosion	Corrosion	Corrosion	Elec-trode

[a] Not relevant.
[b] Higher efficiency at pH values other than the optimum growth pH for the microorganisms to be killed.
[c] No data available.
[d] Optimal pH.
[e] Especially for reverse osmosis, nanofiltration and ultrafiltration.

The main risk-enhancing factors for the reconditioned process water to be reused are failures in the treatment procedure, e.g., membrane leakage in filtration processes or lack of exposure to UV because of shielding.

Distribution or storage of both reconditioned and non-reconditioned process water to be reused is considered as a CCP, since control measures can be applied in order to avoid an increase on the hazards' occurrence. For instance, process water should be reused as soon as possible after being collected, and it shall be collected, kept and transported in a proper way, so that this does not constitute a deterioration of the quality of the water. If prolonged storage is unavoidable, the water temperature should be kept as low as possible or, alternatively, as high as possible in order to avoid further growth of the microorganisms present. For example, maximum growth temperature for *Clostridium perfringens* is 50 °C (ICMSF, 1996).

The major risk factors for both non-reconditioned and reconditioned process water, which is stored and distributed before reuse, are recontamination in the distribution network and regrowth in the storage and distribution facilities (Havelaar, 1994). Recontamination may be prevented by, e.g., adequate hygienic design, maintenance of positive hydrostatic pressure at all times, and hygienic precautions when working on the distribution system. These measures belong in the pre-requisite programmes, which shall be put into practice before developing and implementing the HACCP system. Regrowth may be controlled by preventing recontamination, by applying the control measures mentioned previously, e.g., short residence time, temperatures either too low or too high to support rapid growth, low concentration of nutrients, and by eliminating bacteria by reconditioning water in an efficient way.

After identification, the CCPs are located on the flow diagram and documented on the HACCP worksheet for critical control points.

3.3. Specification of criteria or establishment of critical limits for each CCP

Every CCP has one or more measures that must be properly controlled, and each preventive measure has critical limits, which indicate whether an operation is

Table 6
Examples of potential pathogenic organisms in drinking water and their resistance to chlorination and UV-treatment

	Resistance to chlorine[1,2]	UV D_{10}[a,3] (mW s/cm^2)
Gram-negative bacteria		
Campylobacter jejuni, C. coli	Low	NA[b]
Pathogenic *E.coli*	Low	3
Salmonella typhi	Low	8
Other *Salmonella* spp.	Low	4
Shigella spp.	Low	2
Vibrio cholerae	Low	6–7
Yersinia enterocolitica	Low	<2[4]
Pseudomonas aeruginosa	Moderate	5–6
Aeromonas spp.	Low	5
Legionella spp.	Moderate-high[5]	2–5
Gram-positive bacteria		
Listeria spp.	Low	3–4
Bacillus spp	Low	4–8
Bacillus subtilis (spores)	High	5–12
Clostridium botulinum (cells)	Low	12
Staphylococcus aureus	Low	2–3
Mycobacterium paratuberculosis	High[6]	5–6
Viruses		
Adenoviruses	Moderate	1–2
Enteroviruses	Moderate	NA
Hepatitis A	Moderate	5–8
Norwalk virus	Moderate	NA
Rotavirus	Moderate[7]	7–8
Protozoa		
Cryptosporidium parvum (oocysts)	High	3[8]
Helminths		
Dracunculus medinensis	Moderate	NA

References: (1) WHO (1996); (2) ICMSF (1996); (3) Ellis (1991); (4) Butler, Lund, and Carlson (1987); (5) McKay (1992); (6) Whan, Grant, Ball, Scott, and Rowe (2001); (7) Sattar et al. (2001); (8) Cairns and Wright (2000).

[a] UV-doses required to inactivate 90% of the population.

[b] No data available.

under control at a particular CCP (NFPA, 1993). For instance, if process water is reconditioned by means of filtration, e.g., Ultrafiltration or Microfiltration, a control measure is to maintain the flux within a certain range (critical limits). The flux should not reach higher values than the upper limit, since this could indicate that the membrane is either broken or misplaced, allowing microorganisms to permeate through or past the membrane indicating an unacceptable risk to safety. However, other control measures such as the measurement of the turbidity or particle counts are recommended in order to assure the safety of the reconditioned process water by means of any membrane process. If process water is reconditioned by addition of chemical disinfectants, control measures are the concentration of disinfectant added to the water, the contact time and the concentration of the residual disinfectant in the water. The concentration of a given chemical disinfectant, e.g., hypochlorite, when added to process water, should be high enough to inactivate the pathogens present in the water, but, at the same time, reduced as much as possible to minimise the formation of disinfection by-products. For UV-irradiation, a control measure will be estimating the UV dose by chemical actinometry or biological assays (Loge, Darby, Tchobanoglous, & Schwartzel, 1999). Fig. 1 shows a scheme for establishing a HACCP plan for reconditioning of process water including some examples of water treatment methods. A similar approach shall be followed when establishing a HACCP plan for distribution and storage of process water to be reused in the food industry. This would have to include time and temperature as control measures.

3.4. Implementation of a monitoring system

For each CCP, monitoring procedures, including frequency, are established, and the personnel responsible are identified on the HACCP worksheet. The parameters that define the microbiological quality of process water for a certain use need to be defined in the monitoring system, and critical limits assigned for every parameter. These values should be set at levels that ensure no risk for human health.

The monitoring system of water quality should be fully integrated in the overall quality management system used for raw materials, hygiene and finished products. On-line and continuous monitoring is always preferred, when feasible, so that corrective actions can be taken by a direct feedback system. The plan defined for each parameter of the monitoring list will delineate the analytical history of the quality of water, and this may be helpful when a quality failure occurs. The following points are to be considered when choosing the analytical methods for the determination of any given parameter and when establishing a monitoring programme (adapted from Poretti, 1990):

1. The detection limit required by the guide levels or limit values.
2. The accuracy, precision and rapidity required (monitoring vs. verification).
3. The availability of equipment and methods.
4. The technical and scientific education and skills of personnel in the factory laboratory.
5. The cost of the equipment.
6. The feasibility of the procedure.
7. The possibilities for maintenance and repair of equipment.

It should also be mentioned that sometimes the legislation in a country requires an official reference method. When establishing monitoring procedures and frequency, there is a need for rapid, real time feedback.

Microbiological methods are not suited for rapid intervention since they are both labour-intensive and do not produce results in a timely manner that would permit their use for monitoring purposes. In addition, concentrations of pathogens constituting a hazard in drinking water may be below the detection limits of current microbiological techniques (Havelaar, 1994). It should also be taken into account that microbiological methods, equipment, facilities as well as qualified personnel capable of performing this type of analysis are not always available and feasible within the food industries. Therefore, physical and chemical procedures are normally preferred over microbial approaches for monitoring. Recording of flux with a flow-meter and monitoring pressure changes in the system with the help of manometers may be part of the monitoring system when reconditioning process water by any membrane process. Particle counters have also been suggested as sensitive tools for monitoring filter performance and for assessing membrane integrity and efficiency removal (Glucina, Do-Quang, & Laîné, 1997; Hargesheimer, Mc Tigue, Mielke, Yee, & Elford, 1998). The results obtained when using particle counters or when monitoring turbidity can be used as an indirect measure of microbial contamination of the reconditioned water. Other examples include checking the state of the lamp when reconditioning process water by UV-light, and controlling temperature and time during distribution and storage of both reconditioned and non-reconditioned process water prior to reuse. pH and temperature may be important parameters to monitor in all cases.

There are some key attributes that any system for microbiological monitoring would need to become acceptable. These relate to performance, costs and support (Fung, 1995; Sartory & Watkins, 1999):

1. *Sensitivity and specificity*. The system must be able accurately to detect the target organisms from high concentration of background and competing organisms. Sensitivity must be at least 1 organism per 100 ml. False-positives and negatives must be as close to zero as possible.
2. *Speed*. Operational actions need to be undertaken within normal working hours.
3. *Non-destructive*. The system must allow easy retrieving of isolated bacteria for further study.
4. *Analytical skills*. The system should not be so sophisticated that it requires operation by other than analysts with basic microbiological training. Automation may offer advantages.
5. *Costs*. This includes the cost of initial purchase, cost per test and cost of reagents.
6. *Manufacturer's reliability and technical service*. The more complicated the equipment, the more the company will be depending upon the manufacturer's services.

Very few microbiological methods fulfil all the required key attributes mentioned above for monitoring purposes. Some of the automated systems may comply with many of the key attributes mentioned, i.e., high sensitivity, specificity, speed and simplicity. However, the cost of this type of systems might be too high for most food industries. Therefore, checking for bacterial indicator organisms plays an important role for verification purposes.

The sampling plan should include the frequency of tests, the choice of sampling points in the factory and information on the nature of the sample. In a critical situation, each parameter may need to be monitored closely at a higher frequency. All records and documents for CCP monitoring must be signed by the individual actually doing the monitoring (NFPA, 1993).

3.5. Establishment of corrective actions

Deviations from critical limits may occur, and a plan consisting of defined corrective actions is needed for each CCP (NFPA, 1993). Some of the questions to be checked when a deviation from a critical point occurs include (adapted from USDA, 1999):

1. Has the cause of the deviation been identified and eliminated?
2. Will the CCP be under control after the corrective action has been taken?
3. Have measures to prevent recurrence of the deviation been established?
4. Do the corrective action procedures make sure that no water, which may be injurious to health because of the deviation, enters the food production chain?

For each CCP, the HACCP team needs to devise a standardised set of actions that company employees shall follow when there is a deviation from a CCP. It should be decided in advance who to inform, who should decide what to do with the water affected by the deviation, how to decide the cause of deviation, how to get the process back in control and prevent recurrence of the deviation, who shall sign off modifications of the original plan, and who shall be the responsible for keeping the records of everything that it is done in response to a deviation from a CCP. The set of corrective actions should be feasible at all times. Examples of intervention strategies for some of the identified CCPs when reconditioning process water to be reused in the food industry are shown in Fig. 1.

3.6. Establishment of effective record keeping procedures

Record keeping is an essential feature of a HACCP system and requires the development and maintenance of records about both plan development and the oper-

ation of the system. According to NFPA (1993), HACCP documentation should include the following: listing of the HACCP team, product description and intended use, flow diagram of the entire process indicating CCPs, hazards and preventive measures for each CCP, critical limits for each CCP, monitoring systems, corrective actions for deviations, record keeping, and procedures for verification. Documentation can be shared with regulatory officials to demonstrate that the process is under control.

3.7. Establishment of procedures for verification

It is necessary to decide how to verify that the HACCP system is working effectively. Verification uses procedures in addition to those used in monitoring to see whether the HACCP system is functioning or needs modification. There are three stages of verification (USDA, 1999):

1. Validation is the initial phase in which the plan is tested and reviewed.
2. On-going verification ensures that the HACCP plan is working effectively on a day-to-day basis.
3. Reassessment is an overall review of the plan that must be performed at least annually, or whenever any changes may occur that could affect the hazard analysis or alter the HACCP plan.

Information on microbial indicators of water quality and on rapid microbiological methods for detection and enumeration of microorganisms in water are helpful when choosing microbiological methods for monitoring or verification purposes. However, the relation between the microbiological water quality indicators now used and public health is unclear. Indicators of faecal contamination, such as *E. coli*, will normally indicate possibility of the presence of pathogens. However, several works have shown that the presence of some pathogenic bacteria, e.g., *Campylobacter*, is not well correlated with the presence of the indicator microorganisms (Carter, Pacha, Clark, & Williams, 1987), and that outbreaks caused by water borne viruses and protozoae have occurred in water where the indicators were not detected (CDC, 1979). Furthermore, coliform colonies are extremely widespread on the interior surfaces of water distribution systems and these have not been found to be related to any health effect (Pipes, 1990). WHO is currently reviewing the correlation between the microbiological water quality indicators and public health (Hayward, 2000). Codex Alimentarius (1999) suggests testing for total bacterial counts, total coliforms, faecal coliforms, *Staphylococcus aureus*, *Listeria monocytogenes* and *Legionella* spp. for validation and verification purposes when assessing the quality of water to be reused in the dairy industry. Although such general suggestions for microbiological validation and verification are helpful, the application of HACCP will help to determine the relevant choice of test microorganisms according to the specific combination of water, process and end-use.

Finally, it may be helpful to use a HACCP plan checklist such as the one found in HACCP User's Manuals (Corlett, 1998). This checklist helps the HACCP team both to indicate the general parts and requirements for the HACCP as well as serving as a progress checklist when developing the HACCP plan for water reuse in the food industry.

4. Conclusions

Due to the increasing costs of water and water discharge, reuse of water in the food industry is likely to become important. Similarly to the HACCP applied to food production in general, potential reuse of water should be evaluated and eventually managed using this approach. A generic model strategy dealing with the microbiological hazards has been developed. Planning, implementation and control require a high degree of knowledge of food and water microbiology, process technology, monitoring options and hygienic design. Systematic exchange of information from case studies is still lacking.

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