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The role of HPC in managing the treatment and distribution of drinking-water

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12.1 INTRODUCTION

Safety, quality and quantity are of foremost concern when managing drinking-water supplies. Any number of approaches can be taken to ensure effective management during drinking-water treatment and distribution. The focus of this chapter will be on one specific water quality measurement that can be used in a management strategy: the test for heterotrophic plate count (HPC) bacteria.

The use of HPC bacteria, also known as colony counts and previously known as standard plate count bacteria, as an indicator for drinking-water quality dates back to as early as the 1800s. Even at that time, it was known that enteric bacteria were the

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cause of many significant illnesses, but HPC bacteria were used as surrogate indicators because of a lack of specific detection methods for the enteric organisms. With recent advancements in specific methodologies, such as defined-substrate media for *Escherichia coli*, the applicability of HPC in the treatment and delivery of drinking-water needs to be clarified. The information presented in this chapter summarizes the current uses of HPC and is intended to elucidate the logical role of these measurements in treatment plants and distribution systems as part of drinking-water management strategies.

12.2 HPC BACTERIA IN WATER TREATMENT PLANTS

HPC has a long history as a water quality indicator. Over the decades, interpretation of HPC results has shifted from indicating drinking-water safety to a role in determining drinking-water quality. At present, measuring HPC bacteria in water during treatment and immediately upon leaving the treatment plant can be used by plant operators as one of several routine tests to monitor plant operation. Other tests include those for coliform bacteria, turbidity and chlorine residuals. The latter two tests are preferred because they provide real-time information on water quality and treatment processes, whereas HPC measurements can take as long as seven days before they become available. For day-to-day management of plant operations, the waiting time for HPC results renders it impractical.

HPC measurements can play an important role in validation and verification of treatment plant procedures. Validation is used to ensure that any novel or existing treatment process or disinfection practice is operating effectively. For example, HPC can be used as a research tool when designing and testing new or redesigned water treatment systems. Alternatively, verification measures the overall performance of the system and provides information about the quality of the drinking-water. Neither validation nor verification is suitable for continuous control of drinking-water quality; hence, the lag time involved in testing is acceptable. Water utilities can generally achieve heterotrophic bacteria concentrations of 10 cfu/ml or less in finished water (Fox and Reasoner 1999). Low and consistent levels of HPC bacteria in the finished drinking-water add assurance that the treatment process is working properly. Other indicator bacteria, such as *E. coli*, thermotolerant coliforms or total coliforms, should not be found when HPC levels are low, since they are more susceptible than heterotrophic bacteria to disinfection.

An increase in HPC bacteria in finished water above recommended concentrations can indicate a problem with treatment within the plant itself or a change in the quality of the source water being treated. When this occurs, the quality of the finished drinking-water is questionable, and appropriate actions should be taken to ensure that the problem is identified and corrected.

12.3 HPC BACTERIA IN WATER DISTRIBUTION SYSTEMS

As expected, when high HPC levels are found in the water leaving the treatment plant, the HPC levels in the distribution system are usually also high. When the water leaving the treatment plant contains acceptable levels of HPC bacteria but levels in the distribution system water are above the recommended limit, this usually indicates bacterial regrowth occurring in the distribution system. Bacterial regrowth refers to the proliferation of viable organisms present in the water after drinking-water treatment, including the recovery and growth of organisms that were previously injured during the water treatment process. As stated earlier, heterotrophic bacteria acquire nutrients from their surroundings to survive and grow. Biodegradable organic matter (BOM) and assimilable organic carbon (AOC) that are not removed during the treatment process can provide nutrients for bacterial regrowth. Elevated concentrations of BOM can also place a higher demand on the disinfectant being used. In the case of chlorine, chlorine dioxide and chloramine, increased demand can lower the effective concentration of residual disinfectant. At lower disinfectant concentrations, the heterotrophic flora is less adversely affected by the disinfectant residual and better able to proliferate within the distribution system. When ozonation is used as the disinfection process, as is widely popular in Europe, the overall organic carbon levels are reduced but the AOC concentrations are increased, promoting bacterial regrowth in distribution systems (Escobar *et al.* 2001).

The distribution system referred to throughout this section consists of two distinct components: the complex network of pipes transporting water from the treatment plant to buildings and the internal plumbing systems of the structures themselves. Interpretation of HPC measurements differs in these two components. In the external distribution system, HPC testing can identify problem zones where bacterial regrowth is occurring. General regrowth is not of direct significance to public health but can contribute to the deterioration of physical water qualities such as taste and odour. High HPC measurements can occur during a contamination event where a health risk is possible, but HPC measurements are not the preferred indicator of this event. In this situation, faecal indicators, such as *E. coli*, are better markers of recent contamination, as they are unable to grow in the system. High HPC measurements within building plumbing systems may also be caused by bacterial regrowth or by contamination events. In this component, the necessary response will be dependent on the use of the building. All buildings should have water safety plans (WSPs) put into practice, but the actions recommended in these plans will vary, depending on the building. In health care facilities, for example, in-

building WSPs should detail the actions necessary when bacterial regrowth is detected. Although general bacterial regrowth is not a public health concern, in vulnerable populations, such as immunocompromised individuals, some heterotrophic bacteria can cause illness. In general, regrowth bacteria are respiratory pathogens and not pathogens associated with gastrointestinal illnesses. For example, *Legionella pneumophila,* the major cause of Legionnaires' disease, has the ability to regrow in building plumbing systems and infect susceptible populations. Although high HPC measurements have not been found to correlate with illness incidence and no outbreaks have been directly linked to elevated concentrations of HPC bacteria in tap water, they do indicate favourable conditions for bacterial growth and should be remedied.

The density of HPC bacteria reached in the distribution system can be influenced by numerous parameters, including the bacterial quality of the finished water entering the system, temperature, residence time, presence or absence of disinfectant residual, construction materials, surface-to-volume ratio, flow conditions and, as stated above, the availability of nutrients for growth (Prévost *et al.* 1997; Payment 1999). Biofilm formation within water distribution networks provides protection for bacteria by shielding them from chlorine and other disinfectants. In addition to the nutrients available in the water, the biofilm can also contain a readily available supply of nutrients to help maintain viability and promote regrowth (Gavriel *et al.* 1998). Drinking-water, in the absence of a free chlorine residual and in the presence of high turbidity and elevated temperatures, has been found to contain as much as 10 000 cfu/ml of HPC bacteria (Payment 1999).

12.4 HPC BACTERIA IN WATER TREATMENT DEVICES

Health Canada, the US Environmental Protection Agency (EPA), the US Consumer Product Safety Commission and the Italian government have all, at one time or another, proposed banning activated carbon filters used in home drinking-water treatment devices because of the growth of HPC bacteria on the carbon media and subsequent rises in HPC counts in the filtered water (Regunathan and Beauman 1994). After further study, however, all four decided against banning the filters. At Health Canada, the decision was made following consultations with stakeholders and was based on the absence of evidence of any illness linked to such devices. This decision was taken with the proviso that the manufacturers and distributors of activated carbon filters agree to take steps to help prevent the use of these devices on microbially unsafe waters or waters of unknown quality. In addition to growth on the carbon filter, it was shown that the filter media of some new commercial filters were already contaminated with

bacteria and moulds even before being installed in homes (Daschner *et al.* 1996).

Similar to water distribution systems, increased levels of HPC are not generally a health concern in drinking-water treatment devices. Some experimental evidence has shown that the presence of heterotrophic bacteria in point-of-use (POU) and point-of-entry (POE) devices may be beneficial, since ordinary bacterial growth may reduce the number of disease-causing organisms through dilution, competition or predation inside the treatment device — i.e., in carbon filters, resin beds, bladder tanks, etc. (Rollinger and Dott 1987). A US patent was granted for the development of granular activated carbon (GAC) filters containing additives intended to encourage the proliferation of beneficial bacteria inside the filter for health purposes (Lewis and Michaels 1993). This included the intentional inoculation of filters with beneficial bacteria such as those found in yoghurt, as well as providing support for ordinary HPC organisms that are native to the aquatic environment, specifically for the purpose of inhibiting the growth of pathogens inside the filter. These beneficial effects have not been observed in distribution systems where HPC increases are undesirable because of water quality issues related to regrowth and lowered disinfectant residuals. A properly maintained and operated treatment device should not have water quality problems associated with regrowth bacteria. Some heterotrophic bacteria are secondary pathogens, meaning that they can be problematic for immunocompromised individuals. These organisms may grow in the treatment devices. In most cases, these secondary pathogens are associated with inhalation and wound infections and are not a concern for water treatment devices used solely for consumption.

12.5 HPC BACTERIA IN BOTTLED WATER

In bottled waters, the HPC bacteria can grow to high concentrations within a few days of bottling. In a quantitative study of bacterial populations in mineral water, HPC bacteria (following incubation at 22 °C) increased from the initial 10^1–10^2 cfu/ml found in the source water to 10^5–10^6 cfu/ml in the bottled water after three days of storage. The bacterial growth was not stopped even when the water was stored at 6 °C (Gonzalez *et al.* 1987). There do not appear to have been any outbreaks of infectious illness associated with high concentrations of HPC bacteria in bottled waters.

12.6 STANDARDS AND GUIDELINES

The current standards or guidelines for HPC bacteria in tap water vary slightly between different nations. In general, HPC monitoring is used as a tool to gain information on the water treatment process and the general bacteriological quality of the water leaving the water treatment plant and within the distribution system. Examples of specific guidelines from several countries and agencies are listed below. The current requirements for bottled water are also included for each country.

12.6.1 World Health Organization (WHO) guidelines

The WHO *Guidelines for Drinking-water Quality* (WHO 1996) list HPC bacteria as an indicator of the general bacterial content of the water at incubation temperatures of 22 °C and 37 °C. [Editors' note: A revised third edition of the WHO *Guidelines for Drinking-water Quality* will be finalized in 2003.] Within the WHO drinking-water guidelines, HPC results at 22 °C are described as being of little sanitary value, but are a good indication of the efficiency of water treatment, specifically the processes of coagulation, filtration and disinfection, where the objective is to keep counts as low as possible. Also, these results may be used to assess the cleanliness and integrity of the distribution system and the suitability of the water for use in the manufacture of food and drink, where high counts may lead to spoilage. An increase in HPC bacteria recovered at 37 °C compared with those normally found may be an early sign of pollution, especially if it is not accompanied by a similar rise in HPC numbers at 22 °C. Sudden or progressive increases in HPC results in piped water may indicate enrichment of the water with AOC in a catchment or may be due to ingress in distributed water. In treated drinking-water that is not biologically stable, regrowth associated with increases in water temperature is frequent and can lead to taste and odour problems. It is suggested that an increase at 37 °C should prompt an investigation of the treated supply or of the catchment if the water is untreated. The draft revised WHO guidelines include recommendations for large buildings, including health care facilities, with respect to regrowth organisms that are a potential health concern, such as *Legionella*. The guidelines recommend implementation of preventative WSPs. These plans should specify adequate control measures previously shown to be effective in ensuring water quality and safety.

Although no specific numerical guidelines are recommended for HPC bacteria in drinking-water, it is suggested that they be maintained at the lowest level possible for aesthetic reasons and as a demonstration of treatment sufficiency.

The Codex Alimentarius Commission (1994) develops some bottled water standards, specifically those for natural mineral waters. These standards are developed based on the WHO *Guidelines for Drinking-water Quality*. The Codex Alimentarius Commission is also developing a draft codex for packaged water other than mineral waters. Currently, only the WHO *Guidelines for Drinking-water Quality* are applied to the latter products, and therefore the same HPC requirements are used as stated above.

12.6.2 European guidelines

In Europe, the current drinking-water guidelines in many countries (pertaining to water intended for human consumption) are based on recently revised directives from the European Union (1998). The current recommended microbiological standards include HPC limits for private supplies, i.e., no significant increase over normal levels when incubated at 22 °C and 37 °C, and for bottled water within 12 h of bottling, i.e., 100 cfu/ml when incubated at 22 °C for 72 h and 20 cfu/ml when incubated at 37 °C for 48 h (Barrell *et al.* 2000). Although the previous EU Council Directive specified non-mandatory numerical limits for HPC bacteria, the current EU directives do not specify numerical limits for HPC bacteria in public supplies but rather recommend no abnormal change when incubated at 22 °C.

12.6.3 United Kingdom regulations

The United Kingdom Water Supply (Water Quality) Regulations (Anonymous 2000) require colony count testing on water taken from public supplies, private supplies and bottled water as part of their required microbiological monitoring, based on the directives set by the European Union. Testing locations include treatment works, service reservoirs and water supply zones. For public water supplies, i.e., those that are provided by water purveyors via mains distribution systems, and private supplies, no maximum allowable value for HPC is set, but the regulations do state that there should be "no abnormal change" — i.e., measurements should show no sudden and unexpected increases as well as no significant rising trend over time.

The regulations for HPC in bottled waters in the United Kingdom are the same as those stated in the European Union directive above (Anonymous 1999).

12.6.4 German regulations

Similar to other countries, the German Drinking Water Regulation requires HPC monitoring of public water supply systems. This regulation is enforceable prior to individual consumer water meters but does not apply to water within the consumer's system. Water quality at the consumer's taps is included in other public health regulations.

The German Drinking Water Regulation states that drinking-water can contain no more than 100 cfu/ml of HPC bacteria (Hambsch 1999). Included in the law is the standard method required for HPC analysis. It specifies incubation temperatures of 20 °C and 36 °C for a period of 48 h on defined substrate media. The standardized method was integrated into the law to allow for comparison of HPC results.

12.6.5 Canadian guidelines

Drinking-water quality guidelines in Canada are established by the Federal-Provincial-Territorial Committee on Drinking Water. These guidelines (Health Canada 1996) are not enforceable by law but are developed for use by each province and territory for setting provincial standards. Because drinking-water regulations fall under provincial and territorial jurisdiction, the enforceable standards may vary between provinces and territories.

The current *Guidelines for Canadian Drinking Water Quality* do not specify a maximum allowable concentration for HPC bacteria but recommend that HPC levels in municipal drinking-waters should be less than 500 cfu/ml. If the acceptable HPC value is exceeded, an inspection of the system should be undertaken to determine the cause of the increase in heterotrophic bacteria. After analysis of the situation, the guidelines recommend that appropriate actions should be taken to correct the problem and special sampling should continue until consecutive samples comply with the recommended level. Originally, the HPC guideline was established not to directly protect human health; instead, it was based upon the knowledge that higher counts of heterotrophic bacteria interfered with the lactose-based detection methods used for total coliform bacteria. New total coliform methods, such as those using media containing chromogenic substrates, are not affected by high numbers of heterotrophic bacteria and therefore do not require a set upper limit for HPC. Under these circumstances, water treatment plant operators are encouraged to use HPC bacteria as a quality control tool.

Bottled water in Canada falls under the jurisdiction of the Canadian Food Inspection Agency and is regulated by the *Food and Drugs Act* (Health Canada 2000). These regulations do not require monitoring of HPC bacteria in water

represented as mineral water or spring water. Mineral water and spring water are defined as potable waters obtained from an underground source, but not obtained from a public community water supply, that have undergone no chemical modification with the exception of allowable addition of carbon dioxide, fluoride and ozone. All bottled water not designated as mineral water or spring water must contain no more than 100 cfu/ml of heterotrophic bacteria (referred to as total aerobic bacteria within the *Food and Drugs Act*). The official testing method is outlined in method MFO-15 (Health Canada 1981).

12.6.6 Regulations in the USA

Regulations for drinking-water quality from both private systems and public water utilities in the USA are provided by the US EPA. Drinking-water is under federal jurisdiction, so these regulations are enforceable across the country.

In the USA, acceptable HPC levels in municipal drinking-water have been set at less than 500 cfu/ml. Historically, as is the case in Canada, this level was recommended because higher colony counts interfered with the detection of total coliforms in lactose-based tests. During the development of the Surface Water Treatment Rule, it was decided that maintaining an HPC concentration below the allowable 500 cfu/ml limit could be used as a substitute for maintaining a detectable disinfection residual (US EPA 1989). More recently, the US EPA's National Primary Drinking Water Standards (US EPA 2001) express HPC as a method of measuring the variety of bacteria present in a water sample but with no health significance. In this secondary standard, no maximum contaminant level goal is set, but the maximum contaminant level is still 500 cfu/ml. This is not an enforceable federal standard.

Other agencies, such as the American Water Works Association, have not recommended an operating level or goal for HPC bacteria in drinking-water. They do recommend minimizing HPC levels in water leaving the treatment plant and for water in the distribution system. It is suggested that each utility should establish baseline data for their water source based on at least two years of sampling of plant effluent, points of mean residency time in the distribution system and problem areas, such as dead-end reservoirs and sites downstream from pressure-reducing valves (AWWA 1990).

In the USA, bottled water is monitored by the Food and Drug Administration, and no HPC standards have been established (FDA 2001).

12.6.7 Australian guidelines

As in other countries mentioned previously, HPC is used as an indicator of general water quality. HPC results can be used to assess the water treatment process specifically for assessing coagulation, filtration and disinfection, since these processes reduce the bacteria present. Measuring HPC is also useful for determining the cleanliness and integrity of the water distribution system and for determining the suitability of the water for processing food and drinks where high bacterial content could lead to spoilage. The Australian drinking-water guidelines (National Health and Medical Research Council and Agriculture and Resource Management Council of Australia and New Zealand 1996) have set acceptable HPC (incubation at 35–37 °C for 48 h) limits at less than 100 cfu/ml for disinfected supplies and at less than 500 cfu/ml for undisinfected supplies. If colony counts exceed these recommended limits, remedial action (including cleaning storage tanks and inspection and repair of distribution systems) should be taken. The Australian guidelines also recommend identifying dominant bacterial species in the case of regrowth problems in the distribution system.

Bottled water in Australia is the responsibility of the Australian New Zealand Food Authority (2001), and it has set no HPC limits.

12.6.8 Regulations in other countries

Many countries, in addition to those described in detail above, include HPC testing as a routine method for measuring water treatment efficiency and, therefore, water quality. For example, the Netherlands has set limits for HPC bacteria in drinking-water of 100 cfu/ml following 48 h of incubation at 22 °C (Anonymous 2001). The Japanese drinking-water quality standard also includes a numerical limit of 100 cfu/ml (National Institute of Health Sciences 2002).

12.7 CONCLUSIONS

The role of HPC measurements has changed since the method was first introduced in the 1800s as a public health indicator. As science advanced, specific indicators of health risk were introduced, and HPC monitoring became more useful as an operational rather than a health-based indicator. At present, within the water treatment plant, HPC results can be used for validation and verification of drinking-water production. Abnormal changes in HPC bacteria can be an indicator of problems in the treatment process. When this occurs, the quality of the finished drinking-water is questionable, and appropriate actions should be taken to ensure that the problem is identified and corrected. In the distribution system, in both the complex network supplying treated drinking-water and in the internal plumbing of buildings, HPC can

identify problem areas for regrowth. Regrowth can cause aesthetic problems involving tastes and odours, discoloured water and slime growths. Drinking-water within the distribution system should comply with applicable standards and guidelines. All of the guidelines or standards reviewed in this chapter for private and public drinking-water recommend HPC bacteria levels of no more than 100 or 500 cfu/ml or no appreciable change in the concentration of heterotrophic bacteria in the system.

As mentioned previously, HPC is not an indicator of health risk, but can indicate problem areas for regrowth. In plumbing systems of buildings such as health care facilities, where the clientele includes immunocompromised individuals, some regrowth organisms, such as *Legionella*, are a health concern. Although high HPC measurements have not been found to correlate with illness incidence, they do indicate favourable conditions for bacterial growth and should be remedied.

Bottled water, for the purpose of drinking-water, does not follow the same guidelines as those set out for municipal and private water supplies. In many countries, bottled water is considered under food and drug regulations. Monitoring for HPC in bottled water products depends on the specific nation and on the source of the bottled water.

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