Information Paper 3.8.1
A Citizen Monitor's Guide to Disinfectants and Disinfection Byproducts

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1.0 About this Information Paper

(This section is essentially common to all DQM Information Papers. If you have seen it already, please skip to Section 2 below). This Information Paper is a new type of guidance. It has been created for our new integrated system of guidance and tools for water quality monitoring called "the Data Quality Management (DQM) System". DQM is implemented by the Clean Water Team (CWT) where needed to support collection of reliable data of known quality in a fully documented, scientifically defensible manner. Most DQM materials are delivered in Parameter-Specific Folders, which provide both the traditional "protocol" materials and new, expanded guidance in three types of inter-related documents: Fact Sheet, Information Paper, and Standard Operation Procedures. Background information on the ecological significance of each parameter and the regulatory benchmarks that have been developed for it is summarized in the FACT SHEET. The technical information on measurement methodology provided in this IP with its method-menu. Then there are several detailed standard operating procedures (SOPs) that provide step-by-step instructions for each instrument or kit, as well as instrument-specific Quality Assurance/Quality Control and CCRR directions and data validation checklists.

This Information Paper (IP), a part of the Parameter-Specific Folder for disinfectants and disinfection byproducts (DDB), provides "big picture" technical information on hydro carbons. If you are a Trainer or a Technical Leader of any monitoring project, this may help you select a good method to measure disinfectants and disinfection byproducts in your water body.

2.0 Introduction

Disinfectants are antimicrobial agents that are applied to inanimate objects to destroy microorganisms in the process known as disinfection (Disinfectant). Some disinfectants are very reactive, such as chlorine, and they react with naturally occurring matter to form compounds known as disinfection byproducts (DBPs). There is an increased concern about disinfectants because of the health risk associated with the range of disinfection byproducts. However, there is no convincing evidence that disinfection byproducts are directly related with health issues, such as cancer and pregnancy outcomes. However it is prudent to take steps to minimize exposure to DBPs whenever this can be achieved without compromising disinfection.

Why are disinfectants used in water?

Disinfectants are used to destroy microorganisms in water that cause serious illnesses, even deaths. In the beginning of the last century, prior to the disinfection of drinking water, tens of thousands of people died from disease-causing microorganisms in water supplies.

Disinfection of drinking water lowered the rates of infectious diseases that spread through untreated water, such as typhoid, hepatitis and cholera. (Why is Drinking Water Disinfected?).

3.0 Commonly Used Disinfectants

There are various types of disinfectants, including, alcohols, aldehydes, oxidizing agents, phenolics, and quaternary ammonium compounds.

Alcohols

Alcohol, usually ethanol or isopropanol, is used for disinfection, but most commonly as an antiseptic on living tissue rather than on non-living surfaces. It is effective against fungal and bacterial spores. In general, alcohol is non-corrosive, is a fire hazard, and is more effective when combined with water (70% isopropyl alcohols is more effective than 90% isopropyl alcohol) since water allows for greater diffusion of the mixture (Types of Disinfectants).

Aldehydes

Aldehydes, such as gluteraldehyde, have a wide microbiocidal activity and are sporocidal (tend to kill spores) and fungicidal (tend to kill fungi) (Types of Disinfectants).

Oxidizing Agents

Oxidizing agents disinfect by oxidizing the cell membrane of microorganisms, which results in their loss of structure, in cell lysis, and death. Oxidizing agents include the following chlorine dioxide, chloramine, sodium hypochlorite, iodine, hydrogen peroxide, ozone and potassium permanganate.

Chlorine dioxide is used as an advanced disinfectant for drinking water. Chloramine is used as a drinking water disinfectant. Sodium hypochlorite, which is in common household bleach, is used in dilute forms for drinking water and swimming pool disinfection. Iodine is used in poultry drinking water. Hydrogen peroxide is most commonly used as an antiseptic, and also used in hospitals for disinfection and in the food packaging industry to disinfect foil containers. Ozone is a common water disinfectant. To disinfect aquariums potassium permanganate is often used. (Types of Disinfectants)

Phenolics

Phenolics are active household disinfectants found in hand wash, soap, and even in some mouthwashes. Chloroxylenol, a phenolic, is the principal ingredient in Dettol a household disinfectant and antiseptic. Thymol is a phenol derived from the herb thyme. It is the active ingredient in the only 100% botanical disinfectant, Benefect (Types of Disinfectants).

Quaternary Ammonium Compounds (Quats)

Quaternary ammonia compounds (Quats), such as benzalkonium chloride, are a large group of related compounds. Some have been used as low level disinfectants. They are effective against bacteria, but not against some species of pseudomas bacteria or bacterial spores. Quats are biocides, which also kill algae and are used as an additive in large-scale industrial water systems to minimize undesired biological growth. Quaternary ammonium compounds can also be effective disinfectants against enveloped viruses (Types of Disinfectants).

4.0 Properties of Disinfectants

The properties of disinfectants vary, and thus, the safety instructions, including uses, printed on the packaging should be read carefully before use. Mixing disinfectants with each other or with other cleaning products should be avoided since chemical reactions can occur. In addition, many of the disinfectants pose fire hazards since they are flammable. Also, many of the disinfectants used are corrosive. Phosphonocarboxylic acids and aminopolycarboxylic acids are added to aqueous or aqueous solvent-containing disinfectant solutions based on Aldehydes and quaternary ammonium compounds for corrosion inhibition and pH-adjustment to 3.5-4.0, respectively (Disinfectant Solutions).

5.0 Disinfection Byproducts

Disinfectant byproducts (DBPs) are formed when chemical disinfectants react in water either with natural organic matter (NOM) or with bromide ions (Br-). Natural organic matter comes mainly from the breakdown of plants and organic matter in soil. Bromide ions come from natural sources and wastewater discharges. However, soil erosion, manure, fertilizer runoff, and municipal sewage treatment plant discharge also contribute to the NOM present in drinking water supplies. In addition, phosphorus from fertilizers can cause algae blooms that create more organic matter in surface waters (Chlorine Pollutants).

The reactions of disinfectants are influenced by the physical characteristics of the water, such as pH and temperature, and by treatment conditions, such as disinfectant dose. When inorganic bromide is present, it can also take part in the reaction to produce brominated byproducts. When the disinfectant is chlorine, the reaction gives rise to halogenated (addition of chlorine or bromine) byproducts, such as trihalomethanes, haloacetic acids, chloral hydrate, haloketones, haloacetonitriles and halogenated hydroxyfuranone derivatives. When bromide is also present in the water, a mixture of different byproducts containing varying amounts of chlorine and bromine will be formed. When the disinfectant is ozone, it oxidizes natural organic matter to form a number of byproducts, with aldehydes being dominant. If bromide is present along with ozone, they can form brominated compounds similar to some of those produced by chlorine, and also inorganic bromate. When the disinfectant is chlorine dioxide, it does not appear to form many byproducts, but it does break down to form chlorite and chlorate. When the disinfectant is chloramine, it generally leads to the formation of cyanogen chloride and significantly reduced levels of chlorine disinfectant by products, but it can also form nitrite in the distribution system if it is not properly controlled (Scientific Facts).

Scientists have identified 600 different kinds of DBPs. Only 11 of the DBPs are actively regulated by the Environmental Protection Agency (EPA), which include the four trihalomethanes (THMs) (chloroform, bromodichloromethane, bromoform, and dibromochloromethane), and the five haloacetic acids, (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid and dibromoacetic acid). After the EPA reformed its standards for the trihalomethanes (THMs) and haloacetic acids (HAAs) in 1999, several utilities decided to alter their disinfection practices by switching to the disinfectant called chloramine (a chlorine and ammonium compound) in the process known as chloramination. Chloramines are more stable than chlorine and thus produce less DBPs, particularly THMs. In 2006, the EPA reported that the Washington Aqueduct's switch to chloramines resulted in an estimated average reduction in monitored DBPs of 47% (Identification 1).

The levels of chlorine disinfectants used can vary during the year, resulting in varying levels of DBPs produced. Almost yearly, utilities perform a "chlorine flush" or "chlorine burn". At these times, higher levels of chlorine are added to the water system to remove residual biofilms, sediment that attaches to the water mains, and bacteria from the inside of delivery pipes (Chlorine Pollutants).

6.0 Causes of Pollution

Disinfectants are widely used for the disinfection of homes, hospitals, industries, etc. After use disinfectant residues can be washed away and end up in water ways, and combine with NOM to produce toxic DBPs. However, these uses are trivial compared to the large scale disinfection that occurs in water treatment plants, such as waste water treatment plants and drinking water treatment plants.

Water from lakes, rivers, reservoirs, or ground water aquifers that are used as municipal water, often contains pathogens, such as giardia, which cause gastrointestinal illness (diarrhea, vomiting, cramps…) and other health risks. This water needs to be disinfected to kill these pathogens. As a result of killing these pathogens with disinfectants to produce drinking water, the disinfectants used, such as chlorine, chloramines, and ozone, react with natural organic matter to create DBPs, which pose several risks for humans and the environment. Likewise, disinfected wastewater can react with the disinfectants used to create DBPs. (Why is Drinking Water Disinfected, 1).
Figures 1 and 2 show general schematics for a drinking water treatment planst and a waste water treatment plants. As seen from the figures, in both drinking water and wastewater treatment, disinfection generally occurs during the last step of treatment. Sediment and NOM is first removed. Sometimes, if chlorine is used as the disinfectant, it is first neutralized before the treated water is distributed or discharged. Nevertheless, even after neutralization, the treated water contains residues of disinfectants that can combine with any NOM remaining in the water or with any NOM downstream.

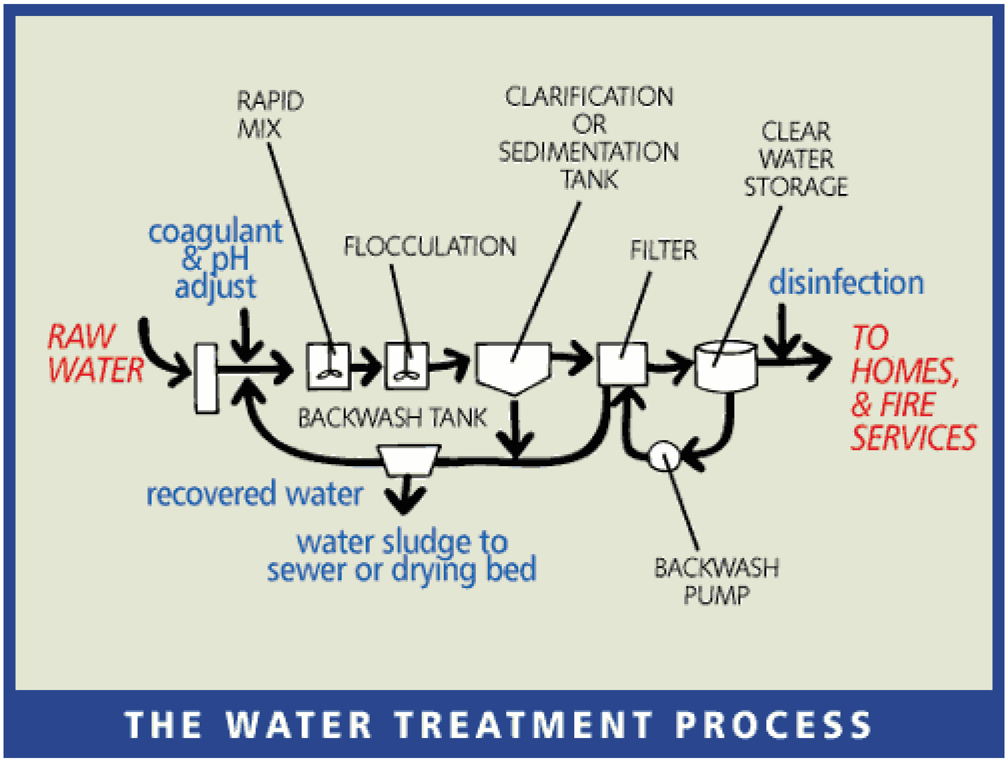

Figure 1: Drinking Water Treatment (Cleaning Water, 1)

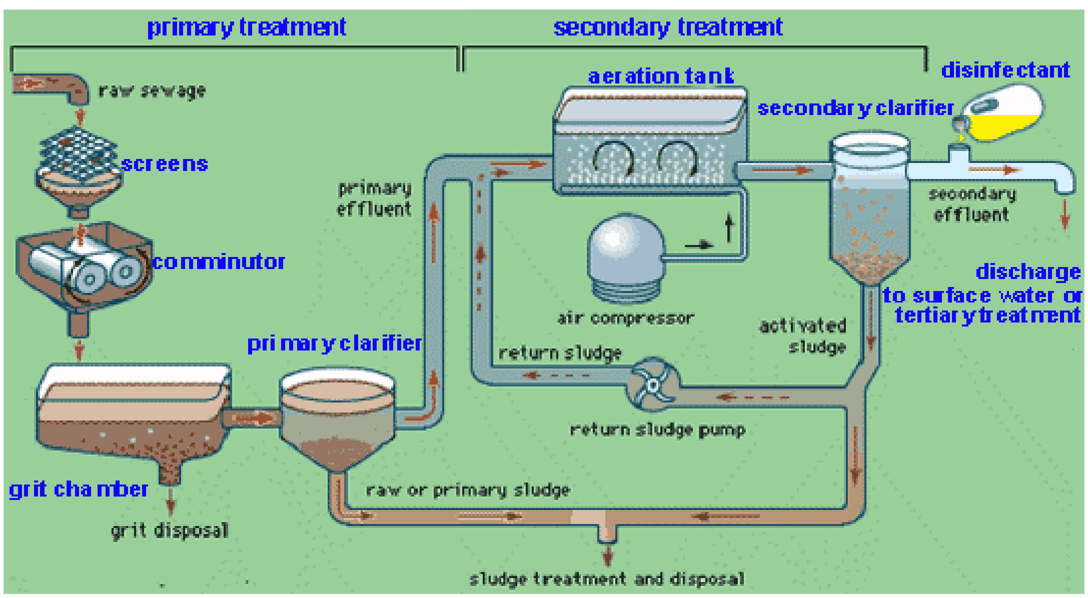

Figure 2: Wastewater Treatment (Wastewater, 1)

7.0 Disinfectant Pollution Identification and Measurement

The presence of disinfectants in water can be identified through a titration, with a reagent tablet, or with an analyzer. Indicators used in titrations or a reagent tablet added to a water sample, react with the water sample and change its color to indicate the presence of a disinfectant (different methods will use different colors for identification). An analyzer can give more detailed information about the amount of disinfectant present.

Disinfectant and Disnfectantion Byproduct Standards and Ranges
In regulating DBPs, the U.S. Environmental Protection Agency has attempted to balance the needs for disinfecting drinking water for public protection against pathogens while also providing safeguards from potentially harmful contaminants.

The Stage 1 Disinfectants and Disinfection byproducts Rule (Stage 1 DBPR) of 1998 set the maximum contaminant level (MCL) for TTHM at 80 ppb and the maximum contaminant level for the five haloacetic acids (HAA5) at 60 ppb. Stage 2 DBPR of December 15, 2005, builds on the other DBP rules.

Under the Stage 2 DBP rule, water systems will conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with high disinfection byproduct concentrations. These locations will then be used by the systems as the sampling sites for Stage 2 DBP rule compliance monitoring. Compliance with the maximum contaminant levels for two groups of disinfection byproducts (TTHM and HAA5) will be calculated for each monitoring location in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from current requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.

The Stage 2 DBP rule also requires each system to determine if they have exceeded an operational evaluation level, which is identified using their compliance monitoring results. A system that exceeds an operational evaluation level is required to review their operational practices and submit a report to their state that identifies actions that may be taken to mitigate future high DBP levels, particularly those that may jeopardize their compliance with the DBP MCLs (Basic Information, pars. 1-3).

8.0 Environmental Impacts

Water systems using source water with high amounts of organic substances will form more DBPs when disinfected than those that do not have high amounts of organic substances. Sources with higher organics levels include: Surface waters, such as lakes, rivers and streams. Springs and wells that are shallow and/or located near surface waters. Groundwater, especially those from deep wells, tends to contain little organic substances. Even if they chlorinate the water, lesser amounts of DBPs are typically found (Disinfectant Byproducts, pars. 1-2).

The commonly used disinfectants and disinfection byproducts are regulated by EPA by defining their limits on drinking water. The maximum contaminant levels (MCL) of water additives used to control microbes and maximum residual disinfectant level (MRDL) resulted as byproduct of drinking water disinfection are tabulated below in Table 1 (National Primary, 1).

Contaminant (Disinfectant)	MRDL (mg/L)	Potential Health Effects from Ingestion of Water
Chloramines	4.0	Eye/nose irritation; stomach discomfort, anemia
Chlorine	4.0	Eye/nose irritation; stomach discomfort
Chlorine dioxide	0.8	Anemia; infants & young children: nervous system effects
Contaminant (Disinfection byproduct)	MCL (mg/L)	Potential Health Effects from Ingestion of Water
Bromate	0.01	Increased risk of cancer
Chlorite	1.0	Anemia; infants & young children: nervous system effects
Haloacetic acids	0.06	Increased risk of cancer
Total Trihalomethanes	0.10	Liver, kidney or central nervous system problems; increased risk of cancer

Table 1 – Contaminant MCL's

Scientists have conducted studies on health effects of exposure to high levels of DBPs on laboratory animals. These studies have shown that several DBPs cause cancer in laboratory animals. In addition, some DBPs cause undesirable effects in the animals' growth and reproduction. It is difficult to estimate how the results of these high dosage studies on laboratory animals can be applied to low dosage, long-term exposure for humans (Disinfectants Byproducts, pars. 3). THMS and haloacetic acids may be linked to a variety of adverse health effects, such as cancer, birth defects, and an increased incidence of miscarriage (EWG).

Scientists have also studied the relationship between drinking chlorinated water and cancer rates. Some of these studies suggest an increased cancer risk to those using chlorinated drinking water, while others found no increased risk. Other studies have investigated whether chlorinated drinking water has an effect on reproduction and development also showed inconsistent results. At the present time, the U.S. Environmental Protection Agency (EPA) does not believe there is enough evidence to state conclusively that DBPs cause these types of health effects. Research on the health effects of DBPs is not complete and the federal government continues funding research on this topic (Disinfectants Byproducts, pars. 4).

Although, chloramination produces less DBPs than chlorination, it also has significant drawbacks. Chloraminated water is toxic to kidney dialysis patients and also extremely toxic to fish, which die if chloraminated water is used in their tanks. In addition, there is little information about the disinfection byproducts (DBPs) alternative disinfectants, like chloramines, produce. Thus, it is not known if the DBPs from alternative disinfectants are safer or more hazardous than those formed by chlorine (Identification, 2).

9.0 Challenges and Preventative Measures

DBP formation is not instantaneous. The amount formed depends upon factors such as chlorine concentration, temperature and length of contact time between the chlorine and water. The rules specify that some or all the samples must be collected at the end of the distribution system from locations that represent maximum residence time.

Sometimes it is possible to reduce the amount of DBPs formed by one or more of the following methods: Removing the organic substances that react with the chlorine to produce DBPs. Avoid maintaining residuals that are higher than necessary for public health protection. Changing the location where the chlorine is added. Using a different type of disinfectant. Neutralization or removal of disinfectant after treatment

Disinfectants other than chlorine have certain advantages and disadvantages and some form other types of DBPs (Disinfectants Byproducts, 1). Research on other types of DBPs from other disinfectants besides chlorine continues.

In addition, increased regulation of DBPs can reduce potential cancer and reproductive and developmental health risks from DBPs. Stage 2 DBP from the EPA, which builds upon existing regulations, strengthens public health protection for customers of systems that deliver disinfected water by requiring such systems to meet maximum contaminant levels as an average at each compliance monitoring location (instead of as a system-wide average as in previous rules) for two groups of DBPs, trihalomethanes and five haloacetic acids. The rule targets systems with the greatest risk and builds incrementally on existing rules. This regulation will reduce DBP exposure and related potential health risks and provides more equitable public health protection (Basic Information, pars. 1-3).
Through regulation and limitations on the quantity of disinfection precursors, such as NOM, allowed to react with disinfectants, reducing urban runoff and fixing infrastructural leaks can reduce the levels of DBPs produced in the environment.

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