INDIAN POTABLE WATER CHLORINE LEVELS - THE HIGHS AND THE LOWS

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Abstract

In India, the predominantly used water disinfectant is chlorine. Minimum levels of chlorine residuals must be maintained throughout the distribution system to provide protection against microbial contaminations. However, in the process, chlorine reacts with organic matter such as humic and fulvic acids to form disinfection by-products, some of which are suspected carcinogens. Formation of disinfection by-products depends on the concentration of organic matter in raw water and chlorine added at the treatment plant.

Various national and international organizations like the USEPA and WHO, etc. prescribe both upper and lower limits for chlorine. The EPA standards allow 4.0 mg/l as maximum residual disinfectant level and WHO gives maximum dosage of 5 mg/l. The Indian code for drinking water quality, IS:10500 (1991), states a minimum requirement for residual chlorine in the water supply. There is a perceptible lack of adequate data and guidelines on the upper limits of residual chlorine, which directly affects the formation of disinfection by-products. It is high time that India follows the precedent of these agencies and introduces regulations which are formulated keeping in mind the ill effects of disinfectant/disinfection by-products.

INTRODUCTION

The main focus of water treatment is to produce safe potable water, which does not breed diseases. This makes disinfection the most significant component of water treatment scheme. The goal of water disinfection is to inactivate or destroy pathogenic microorganisms. Some of the major disinfectants being currently used at the treatment plants are chlorine, chlorine dioxide, chloramines, ozone, UV radiation etc.

Chlorine and its compounds are common and popular disinfectants all over the world. In India, these are the only disinfectants used in the treatment plants. One of the desirable properties of a good disinfectant is to leave stable residuals in water, so as to prevent/inhibit the growth and spread of harmful bacteria in the distribution system and the ability to protect against any possible contamination.

Its wide acceptance is based on:

- Good bactericidal properties
- Residual protection - Chlorine leaves a stable residual which can protect against post treatment contamination that may result from cross-connection or pipe mains failure.
- Measurement of microbial activity - Presence of chlorine residual may serve as an indicator of absence of pathogens.
- Well understood, economic operational requirements

Limitations of chlorine disinfection

Presence of residual chlorine, in water leaving the treatment plant, safeguards against

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contaminations in any of the components of the water distribution system. To ensure this, Indian Manual (1999) imposes a minimum residual chlorine concentration of 0.2 mg/l.

However, chlorine usage is not without its share of problems. Very often, in the process of trying to maximize the benefits of chlorination, the concentration of the disinfectant is kept high, which may lead to a whole gamut of health and distribution problems. For example, chlorine reactions with certain constituents of water can cause taste and odour problems. Delayed reactions, with phenolic compounds, in water result in intermediate chlorophenols which are highly odorous. Typical chlorophenolic tastes and odours can result in water that is unpalatable or otherwise unacceptable to many consumers. Even the Indian Manual (1999) states that if a very high dosage of chlorine is applied at the postchlorination stage for maintaining the minimum residual at the farthest end of a long and complex distribution system, it would apart from being costly, make the water unpalatable, at the reaches close to the point of chlorination.

The ill effects of high levels of residual chlorine are also seen in formation of disinfection by-products (DBPs). In some case-controlled epidemiological studies, associations were found between ingestion of chlorinated drinking water and the incidences of colon cancer (Cragle et al., 1985) and bladder cancer (Cantor et al., 1985, 1987). Trussell and Umphres (1978) showed that high chlorine dosage leads to formation of elevated levels of DBPs such as trihalomethanes (THMs), haloacetic acids (HAAs). Possibility of such occurrence is high in countries like India which till date do not have any recommendations on upper limit of chlorine.

Chlorine Disinfection By-Products

In 1974, chloroform, a product of reaction of chlorine and natural organic matter (NOM), was identified in disinfected drinking water (Bellar et al. 1974; Rook 1974). Chlorine and its compounds react with naturally occurring organic and inorganic matter in water (Krasner, 1999) leading to the formation of a number of DBPs such as THMs, HAAs, haloacetonitriles, haloketones and haloaldehydes. Among these THMs and HAAs are the major species. Total THMs are a group of four major chemicals viz. chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The HAAs are normally abbreviated as HAA5, due to five major chemicals of this group viz.: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

Many parameters affect the formation and ultimate concentrations of THMs and HAA5 in drinking water including temperature, pH, residence time and total organic carbon or NOM concentration and type (Adams et al; 2005). The formation of THMs and HAA5 tends to increase with increasing NOM concentrations (Glaze and Rawley 1979; Kavanaugh et al 1980). Residence time is also a factor in DBP formation, with increased reaction in either the treatment plant or distribution systems leading to increased concentrations of THMs (Engerholm and Amy 1983; Fleishacker and Randtke 1983; Nieminski et al. 1983). Studies show that THM concentrations tend to increase with increasing temperature (Trussell and Umphres 1978). For THM this effect is due to increased chemical reaction rates between chlorine and NOM at higher temperature (Singer, 1994). On the other hand, temperature does not correlate well with HAA5 concentration in distribution systems. While the formation of HAA5 does increase with increasing temperature, yet, chemical and biological degradation rates of HAA may also increase thereby limiting maximum concentration reached (Chen and Wiesel, 1999; Carlson and Hardy 1998).

THMs are generally well absorbed, metabolized and rapidly eliminated by mammals after oral or inhalation exposure (WHO, 1998; IPCS, 2000). Chloroform is distributed throughout the whole body, with levels being highest in the fat, blood, liver, kidney, lungs and nervous system. Distribution is dependent on exposure route. For example, tissues receive higher dose from inhaled or dermally absorbed chloroform than from ingested chloroform.

Unmetabolized chloroform is retained longer in fat than any other tissue (WHO, 1998) Brominated substitution would be expected to confer greater lipophilicity on the brominated THMs compared with chloroform, which would affect tissue solubility. Mink et al. (1986) found that liver, stomach and kidneys were the organs containing highest bromodichloromethane levels. THMs are metabolized primarily to carbon dioxide and/ or carbon monoxide. In animals and humans exposed to chloroform, carbon dioxide and unchanged chloroform are rapidly eliminated in the expired air. The fraction of the dose eliminated as carbon dioxide varies with the dose and the species (IPCS, 2000)

Such epidemiological studies have raised concerns regarding the potential effects of DBPs in water producing reproductive and developmental aberrations. Findings say that some chlorinated DBPs cause reproductive and developmental toxicity in laboratory animals, albeit at doses much higher than those to which humans are exposed (Health Canada, 2004). A California study funded in part by the USEPA and conducted by the state health department (Elshorbagy, 2000), found that women exposed to higher levels of chlorine byproducts had a 15.7% risk of miscarriage, while those who had little exposure to THMs had a lower 9.5% risk. Also, THMs have been shown to have carcinogenic effects on laboratory animals (Bull and Kopfler, 1991).

Studies such as these have led agencies like the Unites States Environmental protection Agency (USEPA) and the World Health Organization (WHO) to limit the maximum concentration of chlorine. The USEPA formulated the Disinfectant and Disinfection By-Product (D/DBP) rule, presented as an amendment to the National Drinking Water Standards in 1996 (Pontius, 1997). This rule puts a limit on the concentration of disinfectants and disinfection by-products, as given in tables 1 and 2, respectively.

Also, the World Health Organization (WHO) has formulated guidelines restricting the maximum dosage of chlorine in drinking water to 5 mg/l. Also, it gives guideline values for each of the four major THM species with special remarks that the sum of the ratio of concentrations of each species to its respective guideline value should not exceed 1.

D/DBP Rule for India

Indian Code Of Drinking Water Quality (IS:10500, 1991) states a minimum requirement for residual chlorine in the water supply. Chlorine dosage added during post chlorination at the water treatment plant is the sum of the chlorine demand and the residual intended to be left in water for safeguarding against future contamination. The loss of residual is high in large systems with long residence times in certain components. This leads to the requirement of a large dose at the treatment plant, which may have ill effects as mentioned earlier.

Table 1 Maximum Residual Disinfectant Concentration (USEPA, 1996)

Contaminant	MRDL (*mg/l*)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Chloramines (as Cl_2)	MRDL=4.0	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2)	MRDL=4.0	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2)	MRDL=0.8	Anemia; infants & young children: nervous system effects	Water additive used to control microbes

MRDL - Maximum Residual Disinfectant Level

Table 2 Maximum DBP Concentrations (USEPA, 1996)

Contaminant	MCL (mg/l)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection
Total Trihalome -	0.10	Liver, kidney or central nervous system problems; increased thanes (TTHMs) risk of cancer	Byproduct of drinking water disinfection

MCL - Maximum Contaminant Level (Enforceable standards)

Considering the Indian scenario - frequent disposal of organic waste in water bodies and high organic content of wastewater being disposed off, our water supply sources are undoubtedly rich in organic precursors. Moreover, the Indian Manual (1999) suggests the application of chlorine dose as high as 10-15 mg/l in case of an emergency like a break down or in case of waters which are heavily polluted or fluctuate rapidly in quality. It states that excess chlorine should be removed by dechlorination but does not mention any upper limit of residual. It is high time that India introduces regulations that are formulated keeping in mind the ill effects of chlorine and chlorine DBPs.

This type of rule for disinfectant's maximum concentration can be introduced either on the total dosage or on the residual concentration. Limiting the maximum disinfectant dosage may create a major problem in the form of insufficient residuals at the treatment plant itself, in case of high chlorine demand of raw water. This would consequently be inadequate to supply minimum residual concentration at the far ends of the distribution system.

To address this problem, the following strategy may be useful. The disinfection scheme at the treatment plant may be segregated into two components:

(i) Primary Disinfection; and

(ii) Secondary Disinfection (Residual Maintenance)

Primary disinfection refers to the practice of application of disinfectant to raw water at the treatment plant to inactivate/ destroy pathogens. The primary disinfectant is not thus expected to leave any residual. Secondary disinfection is carried out with the sole aim of leaving residuals to prevent future contaminations. Hence, if the maximum dosage of chlorine is limited under the disinfectant rule, it should only be used for secondary disinfection to provide the residuals. For primary disinfection purposes, other effective disinfectant such as ozone, etc. may be used, which otherwise are not preferred in India due to their lack of potential of leaving the desired residuals.

In case the disinfectant rule is implemented for limiting the maximum residual concentration of chlorine, there can be a problem of unavailability of minimum required residuals at the far nodes of large and complex distribution system with residence time in certain

components. To overcome this problem, booster chlorination may be taken up. Booster chlorination is the technique under which the falling concentration of residual chlorine is boosted at suitable locations in the distribution system. With booster chlorination, maximum concentration at the treatment plant can be limited and whenever there is a shortfall of the residual chlorine, its concentration can be boosted at suitable locations of the distribution system, thus enabling all consumer nodes of the network to receive the minimum recommended levels.

Another aspect of the D/DBP rule shall be to control the DBP concentrations in the chlorinated drinking water. To keep within the DBP maximum concentration limits the following two remedial measures may be adopted:

Removal of DBP precursors prior to disinfection : The most effective approach for reduction of DBPs in drinking water is the improvement of specific conventional water treatment processes, such as coagulation and sedimentation. In addition, specific treatments such as membrane filtration, carbon adsorption and preoxidation may be used to remove organic compounds prior to disinfection. Health Canada (2004) studies showed that initial removal of organic precursors improves the efficiency of the disinfection process while still minimizing the formation of chlorinated organic by-products. The formation of THMs can be reduced with the use of granular activated carbon adsorption. The level of reduction will be a function of the type and adsorption capacity of organic matter in the water as well as the process design criteria.

Treatment for DBP reduction: In a study conducted by Bellar et al (1974) about water quality at various stages in a treatment plant, that used chlorination for primary disinfection, a significant decrease in concentration of THMs was observed after introduction of activated carbon slurry. However, many studies are not available at present and various type of treatment strategies have to be studied thoroughly for better comprehension. Another aspect of such treatment would be to identify the suitable location of treatment. Engerholm and Amy (1983) reported that greater THM concentrations are found at more distant points in a distribution system showing that the concentration of THMs grows with time. If THMs require to be removed, the treatment strategy should be adopted at the faucet level so that the further increase in concentration is not much. On the other hand, once formed, HAA5 compounds tend to degrade with time due to their chemical and biological conversion into other species while transiting in a distribution system (Chen and Weisel 1998; Carlson and Hardy 1998). Thus one would expect to find a peak concentration of HAA5 somewhere close to the chlorination point, after chlorine has been added, with concentrations declining at farther ends of the distribution system. Therefore feasible treatment technologies need to be evolved to monitor and reduce the DBPs at the critical locations.

CONCLUSIONS

Disinfection of drinking water systems is necessary to protect the consumer from potentially dangerous water-borne diseases and is one of the imperative components of the water treatment scheme. Chlorine and its compounds are the most widely used disinfectants due to several advantages offered. However, in the process of disinfection, chlorine may react with NOM to form DBPs, which may pose potential ill effects. DBPs have been of great concern to both public health officials and the public since studies have shown adverse effects of chlorine DBPs on human health. Giving due consideration to all these, agencies like the USEPA and WHO proposed regulations/guidelines for limiting the concentrations of chlorine and its DBPs in drinking water. However, the Indian Code (IS 10500, 1991) and the Indian Manual (1999) by Central Public Health and Environmental Engineering Organization (CPHEEO) are still totally silent on the issue. In this wake, the need for recommendations on the maximum

concentration level of chlorine and its harmful by products cannot be over emphasized. Technically feasible solutions are available for any problems that may arise after imposition of D/DBP rule in India.

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