Chloride

An aesthetic objective of *≤250 mg/L* has been established for chloride in drinking water. At concentrations above the aesthetic objective, chloride imparts undesirable tastes to water and to beverages prepared from water and may cause corrosion in the distribution system.

General

Chloride is widely distributed in nature, generally as the sodium (NaCl) and potassium (KCl) salts; it constitutes approximately 0.05% of the lithosphere.[1] By far the greatest amount of chloride found in the environment is in the oceans.

Underground salt deposits have been found in all Canadian provinces except British Columbia. Bedded deposits occur in southwestern Ontario, Saskatchewan and Alberta; dome deposits are found in Nova Scotia, New Brunswick, Ontario, Manitoba, Saskatchewan and Alberta.[2]

Sodium chloride is widely used in the production of industrial chemicals such as caustic soda (sodium hydroxide), chlorine, soda ash (sodium carbonate), sodium chlorite, sodium bicarbonate and sodium hypochlorite. In 1984, it was estimated that 4 078 000 t of sodium chloride were used by the chemicals industry.[2] Sodium chloride and, to a lesser extent, calcium chloride ($CaCl_2$) are used for snow and ice control in Canada; 45% of all salt consumed in Canada is used for this purpose, compared with 25% in the United States and 14% in western Europe.[2] In 1984, it was estimated that 3 560 800 t of sodium chloride were applied to Canadian roads.[2] Potassium chloride is used in the production of fertilizers.[1,2]

Occurrence

The presence of chloride in drinking water sources can be attributed to the dissolution of salt deposits,[3] salting of highways to control ice and snow,[4–8] effluents from chemical industries,[9] oil well operations,[10] sewage,[11] irrigation drainage,[12] refuse leachates,[13] volcanic emanations, sea spray and seawater intrusion in coastal areas.[1] Each of these sources may result in local contamination of surface water and groundwater. The chloride ion is highly mobile and is eventually transported into closed basins or to the oceans.[1]

Chloride is generally present at low concentrations in natural surface waters in Canada; concentrations are normally less than 10 mg/L and often less than 1 mg/L.[12,14] The mean chloride concentration in 109 lakes in the Experimental Lakes Area (ELA) of northwestern Ontario was 0.8 mg/L in 1973; a chloride concentration of 0.9 mg/L was measured in a small acidic lake near Sudbury, Ontario, in the same year.[15] The Great Lakes and waters in the St. Lawrence lowlands have somewhat higher concentrations of chloride (20 mg/L), largely because of industrial activities in the area.[1] The concentration of dissolved chloride in Canadian waters over the period 1980 to 1984 usually fell in the range <0.1 to 861 mg/L,[14] but concentrations as high as 24 500 mg/L have been recorded in Bench Mark Creek in Alberta.[16]

Drinking water data for several Canadian provinces indicate that chloride concentrations are generally low, often less than 10 mg/L.[14,17] Of 127 stations in Saskatchewan that analysed for chloride in 1975, only one recorded a chloride concentration greater than 50 mg/L; no station recorded a concentration greater than 250 mg/L.[18] The same results were found for 56 stations in Nova Scotia that recorded chloride concentrations in drinking water during 1975.[19] In Alberta, 51 out of 492 stations recorded chloride concentrations greater than 50 mg/L in 1976; 15 stations recorded concentrations greater than 250 mg/L.[20] In a 1987 analysis of 60 samples of treated water from the Lemieux Island water treatment plant in Ottawa, Ontario, the average chloride concentration was 5.5 mg/L (range 4.0 to 9.5 mg/L).[21] The average concentration of chloride in U.S. public water supplies is about 11.5 mg/L[12]; in European water supplies, it is 52 mg/L.[22] Higher concentrations of chloride are most often present in drinking water derived from groundwater sources; this could be due to naturally high concentrations or to contamination. An estimated 25 to 50% of applied road salt enters groundwater.[23]

Only limited data are available on chloride concentrations in air in Canada. A survey carried out in Edmonton over three one-month periods found the geometric means and ranges (in parentheses) of the chloride concentrations in air to be as follows: November 1978, 1.97 μg/m^3 (0.3 to 9.0 μg/m^3); March/April 1979, 0.82 μg/m^3 (0.1 to 3.4 μg/m^3); and July/August 1979, 0.64 μg/m^3 (0.1 to 2.8 μg/m^3). For the total period of observation, the mean chloride concentration was 1.2 μg/m^3.[24] The chloride concentration in air above Lake Michigan was estimated to be 0.5 μg/m^3.[25]

The chloride content of foods varies over a wide range; edible plants generally have concentrations below 0.5 mg/g, whereas meat and fish have concentrations up to 1.0 and 1.5 mg/g, respectively.[26]

Canadian Exposure

Estimation of the daily intake of chloride in food is complicated by the widespread use of salt as a condiment. Approximately 600 mg of chloride per day are ingested in a salt-free diet.[27,28] However, because of the addition of salt to food, the daily intake of chloride averages 6 g and may range as high as 12 g.[29]

If one assumes that daily water consumption is 1.5 L and that the average concentration of chloride in Canadian drinking water is 10 mg/L, the average daily intake of chloride from drinking water can be calculated to be approximately 15 mg per person. The intake from water therefore constitutes only about 0.25% of the average intake from food.

If the average concentration of chloride in air in Canada is assumed to be 1.2 μg/m^3 and the daily respiratory volume is 20 m^3, then the daily intake of chloride from air would be 0.024 mg.

Based on the above considerations, the total daily intake of chloride is about 6 g and comes almost entirely from food. Large deviations from this value are expected because of individual variations in the quantities of salt added to food during cooking and at the table.

Analytical Methods and Treatment Technology

Several analytical techniques may be used for chloride in water, including titration (e.g., potentiometric titration with silver nitrate), colorimetry (e.g., thiocyanate colorimetry), chloride ion selective electrode and ion chromatography.[30] Limits of detection range from 50 μg/L for colorimetry to 5 mg/L for titration.

Because chloride is very soluble in water, it is not easily removed, and conventional water treatment processes are generally ineffective.[31] A removal of 87% has been reported using a point-of-use treatment device employing granular activated carbon adsorption and reverse osmosis.[32] Chloride concentrations in water may increase during the treatment process if chlorine is used for disinfection purposes or if aluminum or iron chlorides are used for flocculation purposes.[17]

Health Considerations

Essentiality

Chloride is an essential element and is the main extracellular anion in the body. It is a highly mobile ion that easily crosses cell membranes and is involved in maintaining proper osmotic pressure, water balance and acid–base balance.

Until recently, it had been assumed that the physiological role of the chloride ion was simply that of a passive counterion. Over the past few years, however, several studies have suggested that the chloride ion may play a more active and independent role in renal function,[33,34] neurophysiology[35] and nutrition.[36]

Absorption, Distribution and Excretion

Absorption of chloride from the diet is considered to be essentially complete. Balance studies in young men have shown that 92% of the ingested chloride is excreted in the urine.[37]

The amount of chloride in the intestinal contents declines as the contents move along the gastrointestinal tract. Typically, 540 mg of chloride enter the duodenum each day.[38] Chloride is absorbed in the jejunum by "solvent drag" and in the ileum and colon by active chloride transport coupled to bicarbonate secretion.[38,39] Both of these processes are linked to sodium-based co-transport mechanisms that create the necessary osmotic and electrochemical gradients.

It has been estimated that the human body contains 0.15% chloride,[40] or 105 g/70 kg bw. Most of this chloride is extracellular, as shown by serum levels of 98 to 106 meq/L, compared with the approximate 1 meq/L for tissue cells.[41] Stomach secretions are high in chloride, with concentrations between 45 and 155 meq/L in gastric residues. All body chloride is considered to belong to an exchangeable pool.[42]

Body chloride concentrations are regulated by excretions, primarily via the kidneys. Both chloride and sodium are regulated by aldosterone.[43] The urinary excretion of chloride for adults is about 4.4 g/d, with a range of 2.2 to 13 g/d; the amount excreted is closely related to the amount of salt in the diet. Chloride loss in the faeces is low, with 14 to 110 mg excreted daily by this route. Significant additional daily losses of chloride occur in perspiration.[37]

Toxic Effects

A role for chloride in sodium-sensitive hypertension has been proposed.[44,45] Evidence seems to indicate that both sodium and chloride are required for a hypertensive effect.[42] Chloride by itself does not appear to cause hypertension in rats,[46] although red blood cells from human hypertensives show altered chloride handling.[47] The role of sodium in hypertension is under investigation (see sodium review); however, there is no evidence that high chloride concentrations would be any more toxic than high sodium concentrations.

Other Considerations

The taste threshold for chloride is dependent on the associated cation and is generally in the range of 200 to 300 mg/L.[31] Chloride concentrations detected by taste in drinking water by panels of 18 or more people were 210, 310 and 222 mg/L from the respective sodium, potassium and calcium salts.[48] The taste of coffee was affected when brewed with water containing chloride concentrations of 400, 450 and 530 mg/L from sodium, potassium and calcium chloride, respectively.[48]

Chloride concentrations above 250 mg/L in drinking water may cause corrosion in the distribution system.[23] The chloride ion's ability to form soluble salts with many metal ions prevents the formation of films that could prevent the further corrosion of metal surfaces.[17]

Rationale

1. Chloride concentrations in the body are well regulated through a complex interrelated system involving both nervous and hormonal systems. Even after intake of large quantities of chloride through food and water, the chloride balance is maintained, mainly by the excretion of excess chloride via the urine. Therefore, a maximum acceptable concentration has not been set for chloride in drinking water.

2. Taste thresholds for chloride from sodium chloride, potassium chloride and calcium chloride in drinking water are 210, 310 and 222 mg/L, respectively; the taste of coffee is affected when brewed with water containing chloride concentrations of 400, 450 and 530 mg/L from the same salts. Chloride concentrations above 250 mg/L in drinking water may cause corrosion in the distribution system.

3. The aesthetic objective for chloride in drinking water is therefore ≤250 mg/L. Chloride concentrations in Canadian drinking water supplies are generally much lower than 250 mg/L.

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