Iron

The aesthetic objective for iron in drinking water is *≤0.3 mg/L (≤300 µg/L).*

General

Iron is the fourth most abundant element in the earth's crust and the most abundant heavy metal; it is present in the environment mainly as Fe(II) or Fe(III).

The most important commercial iron ores are magnetite, siderite, limonite and haematite. The principal Canadian iron ore deposits are located in Ontario, Quebec and Newfoundland. In 1984, more than 40 million tonnes of iron ores were mined, five million tonnes were imported and nearly 31 million tonnes were exported.[1]

The main use of iron ores in Canada is steel production, which consumed more than 14 million tonnes in 1984, one-half of which was supplied by iron and steel scrap metal recycling.[2] Most of the ore smelting and scrap metal recycling operations in Canada are localized in Hamilton and Sault Ste. Marie, Ontario, and in Sydney, Nova Scotia.[2] Iron is also used in the production of paint pigments, polishing agents and electrical materials.

Occurrence

Iron is generally present in surface waters as salts containing Fe(III) when the pH is above 7. Most of those salts are insoluble and settle out or are adsorbed onto surfaces; therefore, the concentration of iron in well-aerated waters is seldom high. Under reducing conditions, which may exist in some groundwaters, lakes or reservoirs, and in the absence of sulphide and carbonate, high concentrations of soluble Fe(II) may be found.[3] The presence of iron in natural waters can be attributed to the weathering of rocks and minerals, acidic mine water drainage,[4] landfill leachates,[5] sewage effluents[6] and iron-related industries.[7]

The concentrations of iron in Canadian surface waters are generally below 10 mg/L. Data from NAQUADAT stations during the period 1980 to 1985 indicate that iron concentrations ranged from <0.001 mg/L to as high as 90.0 mg/L.[8] In the Experimental Lakes Area of northwestern Ontario, a mean iron concentration of 0.081 mg/L was recorded in September 1973, whereas an iron concentration of 0.035 mg/L was measured in a small acidic lake near Sudbury, Ontario.[9] An average iron concentration of 0.12 mg/L was reported in 1976 for the Great Lakes; near industrial sources, concentrations ranged from 0.3 to 0.7 mg/L.[7] In September 1985, iron concentrations of 0.723 and 0.055 mg/L were recorded in Lake Huron (at Goderich, Ontario) and in Lake Superior (at Thunder Bay, Ontario), respectively.[10]

Data from a limited number of Canadian drinking water stations show that the concentration of iron in drinking water is usually below 1 mg/L and is often less than 0.3 mg/L.[3] Most water treatment processes remove insoluble iron, the principal form found in aqueous systems. Thus, in Ontario, the mean iron concentration of raw water, sampled in 17 stations during 1985, was 0.339 mg/L, whereas treated water had a mean concentration of 0.046 mg/L.[10]

Iron is generally present in the atmosphere as a result of emissions from the iron and steel industry, thermal power plants and incineration.[11] In a 1982 air quality survey across Ontario, the spatial distribution pattern of trace metals, including iron, in precipitation and air was monitored.[12] There was a general decreasing trend across the province, from south to north, for iron concentrations in air and precipitation and for dry and wet deposition of iron. The mean concentration of iron in air ranged from 0.110 $\mu g/m^3$ in the south to 0.091 $\mu g/m^3$ in the north. Similarly, the mean annual dry deposition of iron ranged from 36.22 mg/m^2 in the south to 29.91 $\mu g/m^2$ in the north. The mean annual wet deposition of iron (through precipitation) ranged from 44.8 mg/m^2 in the south to 28.1 mg/m^2 in the north.[12] The results of a 10-year survey showed that the mean concentration of iron in air in Ontario, for the years 1981 to 1985, remained stable at 0.7 to 0.8 $\mu g/m^3$.[13] An analysis of the total suspended particulate matter over Edmonton showed that the mean concentration of iron in air ranged from 1.66 $\mu g/m^3$ in November 1978 to 4.10 $\mu g/m^3$ in July/August 1979.[14]

Foods vary considerably in iron content. Cereals (mean: 0.0295 mg/g) and meat (mean: 0.0262 mg/g) are the main dietary sources of this element.[15] The iron concentration of most other natural foods is less than 0.020 mg/g.[16,17] Concentrations may be somewhat higher in foods fortified with iron or in foods cooked

with iron utensils.[18] Evidence suggests that the iron content of foodstuffs decreases during boiling.[19]

Canadian Exposure

The daily intake of iron from typical Canadian diets has been estimated to be 15.4 mg in Halifax,[20] 19.4 mg in the Ottawa–Hull area,[15] 17.6 mg in Winnipeg[21] and 17.8 mg in Vancouver.[20] The average of these values, 17.6 mg, is comparable to estimates (for food and water) made in the United States (15 mg)[22] and Europe (22 mg).[19]

If the daily water consumption for an average Canadian adult is assumed to be 1.5 L and the average iron content of Canadian drinking water is assumed to be 0.046 mg/L (1985 Ontario mean concentration),[10] the average daily adult intake of iron from drinking water can be calculated to be approximately 0.07 mg. A daily intake of 0.9 mg has been estimated for Europe.[19] The intake of iron from food is, therefore, substantially higher than that from drinking water.

If the average concentration of iron in air in Canada is assumed to be 0.0018 mg/m^3 (the mean of the values recorded in Alberta and Ontario)[13,14] and the daily respiratory volume for an average adult is 20 m^3, then the daily adult intake of iron from air would be 0.036 mg. One estimate of the iron intake from air in the United States is 0.084 mg.[22]

Based on the above considerations, the total daily intake of iron from food, air and water for an average adult would be 18 mg.

Analytical Methods and Treatment Technology

Iron concentrations in water can be determined using atomic absorption spectrometry or by colorimetric methods. The lowest detection limit using these methods is 10 µg/L.[23]

The removal of iron from groundwater supplies is fairly common and is often done in conjunction with manganese removal. Iron removal often consists of oxidation of soluble Fe(II) to insoluble Fe(III) using chlorine, potassium permanganate or ozone as the oxidants.[24,25] This is followed by liquid/solid separation, which usually consists of filtration only, although sedimentation is sometimes employed prior to filtration.[26] Surface water treatment plants designed for turbidity removal will generally reduce iron to acceptable levels as long as the iron is not complexed by organics or natural silicas.[26]

Health Considerations

Essentiality

Iron, an essential element in human nutrition, is an integral component of cytochromes, porphyrins and metalloenzymes. Dietary iron requirements vary according to sex and age; older infants, children and women of menstrual age are most vulnerable to iron deficiency. The Canadian Recommended Nutrient Intake for adults is 8 mg/d for men, 14 mg/d for women of menstrual age and 7 mg/d for post-menopausal women.[27]*

The effects of iron deficiency can include impaired mental development and performance in children,[28] elevated catecholamines and restlessness in children,[29] reduced work performance in adults and, in severe cases, anaemia and impaired oxygen delivery.[30]

Absorption, Distribution and Excretion

The absorption of iron varies considerably, depending on the amount and chemical form of the iron in the diet, the iron status of the body and the presence of other substances in the diet, notably calcium, phytin and phosphate. There are also wide age- and sex-dependent variations. Absorption ranges from 1 to 70% during the first year of life to about 10% in young children. Adults absorb an average of 6.5% (range 3 to 10%), with women absorbing up to four times as much as men.[26,31]

In the bloodstream, iron binds to transferrin and is transported to the spleen, bone marrow and liver, which are the main storage sites for endogenous iron. In the reticuloendothelial cells of the liver, iron is bound to haemosiderin; in the parenchymal cells, it is bound to ferritin.[32]

Because absorption is low and because iron is recycled in the body, the amount of faecal iron is similar to the amount of dietary iron. Less than 1 mg/d of endogenous iron is lost by the skin, faeces and urine.[33]

Toxic Effects

The ingestion of large quantities of iron results in haemochromatosis, a condition in which normal regulatory mechanisms do not operate effectively, leading to tissue damage as a result of the accumulation of iron. This condition rarely develops from simple dietary overloading.[17,34,35] Tissue damage has occurred, however, in association with excessive intake of iron from alcoholic beverages in some cases of alcoholism. Tissue damage has also resulted from prolonged consumption of acidic foodstuffs cooked in iron kitchenware.[35]

Poisoning of small children has occurred following ingestion of large quantities of iron tablets.[36] As adult iron tablets can contain considerably more elemental iron than children's tablets, children who accidentally

*A 1990 report of the Department of National Health and Welfare (*Nutrition recommendations. The report of the Scientific Review Committee*) gives the recommended dietary intake of iron in Canada as 9.0 mg/d for men, 13 mg/d for women of menstrual age and 8.0 mg/d for post-menopausal women.

ingest iron supplements destined for adults risk being poisoned.[37] Three grams of Fe(II) sulphate is regarded as the lethal dose for two-year-olds. Between 14 and 17.5 g is the lethal dose for an adult male.[38] Iron supplements are commonly used (14% of pre-menopausal Canadian women in one study) without reported toxic effects, except for gastrointestinal upset.[39]

There is no evidence of dietary iron toxicity in the general population. Because absorption is regulated, body tissues are generally not exposed to high iron concentrations. Pharmaceutical sources and disease states, such as idiopathic haemochromatosis[40] and thalassaemia major (which requires many blood transfusions), will result in elevated iron concentrations. Those individuals who do develop an iron overload are reported to be at greater risk of developing neoplasms.[41]

Other Considerations

The presence of iron in water supplies intended for domestic use is objectionable for a number of reasons that are unrelated to health.[26,42,43] Under the pH conditions prevalent in drinking water supplies, Fe(II) salts are unstable and react with water to form insoluble hydroxides, which settle out as rust-coloured silt. Water in which this occurs often tastes and appears unpalatable and can stain laundry and plumbing fixtures. In the distribution system, iron can settle out in the mains and gradually reduce the flow rate through the pipe. Iron can also promote the growth of “iron bacteria”; these micro-organisms derive energy from the oxidation of Fe(II) to Fe(III), and, in the process, a slimy coating is deposited in the water distribution pipes. The above problems usually arise when the iron concentration exceeds 0.3 mg/L.

Attempts to derive a taste threshold for iron in drinking water have produced somewhat inconsistent results owing to the subjective nature of human sensory perception. However, in a frequently cited study, Cohen et al. reported that 5% of a 15- to 20-member taste test panel were able to detect ferrous sulphate in distilled water at a concentration of 0.04 mg/L, approximately 20% detected a concentration of 0.3 mg/L, and 50% detected a concentration of 3.4 mg/L.[43]

Rationale

1. Iron is an essential element in human nutrition; however, intake of iron from a typical Canadian diet is more than sufficient to meet the minimum daily requirement. Toxic effects have resulted from the ingestion of large quantities of iron, but there is no evidence to indicate that concentrations of iron commonly present in food or drinking water constitute any hazard to human health. Therefore, a maximum acceptable concentration has not been set.

2. At concentrations above 0.3 mg/L, iron can stain laundry and plumbing fixtures and produce undesirable tastes in beverages. The precipitation of excessive iron imparts an objectionable reddish-brown colour to water. Iron may also promote the growth of certain micro-organisms, leading to the deposition of a slimy coating in water distribution pipes.

3. Generally, only a small percentage of the population will be able to taste iron in drinking water at concentrations below 0.3 mg/L.

4. The aesthetic objective for iron in drinking water is therefore ≤0.3 mg/L.

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