Hardness

Although hardness may have significant aesthetic effects, a maximum acceptable level has not been established because public acceptance of hardness may vary considerably according to the local conditions. Water supplies with a hardness greater than 200 mg/L are considered poor but have been tolerated by consumers; those in excess of 500 mg/L are unacceptable for most domestic purposes. Because water softening by sodium ion exchange may introduce undesirably high quantities of sodium into drinking water, it is recommended that where such a process is employed, a separate unsoftened supply be retained for drinking and culinary purposes.

General

Water hardness is a traditional measure of the capacity of water to react with soap. Hard water requires a considerable amount of soap to produce a lather, and it also leads to scaling of hot water pipes, boilers and other household appliances. Water hardness is caused by dissolved polyvalent metallic ions. In fresh waters, the principal hardness-causing ions are calcium and magnesium; strontium, iron, barium and manganese ions also contribute.(1) Hardness can be measured by the reaction of polyvalent metallic ions in a water sample with a chelating agent such as ethylenediaminetetraacetic acid (EDTA) and is commonly expressed as an equivalent concentration of calcium carbonate.(1,2) Hardness can also be estimated by determining the concentrations of the individual components of hardness and expressing their sum in terms of an equivalent quantity of calcium carbonate. The degree of hardness of drinking water may be classified in terms of its calcium carbonate concentration as follows: soft, 0 to <60 mg/L; medium hard, 60 to <120 mg/L; hard, 120 to <180 mg/L; and very hard, 180 mg/L and above.(3–5)

Although hardness is caused by cations, it is often discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness.(4) Carbonate hardness refers to the amount of carbonates and bicarbonates that can be removed or precipitated from solution by boiling. This type of hardness is responsible for the deposition of scale in hot water pipes and tea kettles. Non-carbonate hardness is caused by the association of the hardness-causing cations with sulphates, chlorides and nitrates. It is also referred to as "permanent hardness" because it cannot be removed by boiling.

Alkalinity, an index of the buffering capacity of water, is closely linked to hardness. For the most part, alkalinity is produced by anions or molecular species of weak acids, mainly hydroxide, bicarbonate and carbonate; other species such as borates, phosphates, silicates and organic acids may also contribute to a small degree. Although numerous solute species may contribute to the alkalinity of water, alkalinity is expressed in terms of an equivalent quantity of calcium carbonate. As the alkalinity of most Canadian surface waters is due to the presence of carbonates and bicarbonates, their alkalinity is close to their hardness.(5)

Sources and Levels of Hardness

The principal natural sources of hardness in water are sedimentary rocks and seepage and runoff from soils. In general, hard waters originate in areas with thick topsoil and limestone formations.(4) Groundwater is generally harder than surface water. Groundwater rich in carbonic acid and dissolved oxygen usually has a high solvating power; in contacting soil or rocks containing appreciable amounts of minerals, such as calcite, gypsum and dolomite, hardness levels up to several thousand milligrams per litre can result.(4,6)

The two main industrial sources of hardness are the inorganic chemical and mining industries.(4,7) Industrial sources of calcium and magnesium have been briefly discussed in the calcium and magnesium reviews.

In a national survey of Canadian surface waters, conducted over the period 1975 to 1977, average hardness levels computed for each station were found to range as follows: British Columbia, 7 to 180 mg/L; Northwest Territories, 5 to 179 mg/L; Alberta, 98 to 329 mg/L; Saskatchewan, 12 to 132 mg/L; and Manitoba, 15 to 716 mg/L. Hardness levels in the Maritime provinces were not monitored.(8) Waters in the upper Great Lakes had hardness levels ranging from 40 to 80 mg/L.(9) Ontario lakes and streams showed a very broad range in hardness levels; levels from 2 to 1803 mg/L were reported, but most were between 40 and 200 mg/L.(10) In a review of national water quality, 41 locations were chosen as representative of Canadian waters. The median of the values measured at each station rarely exceeded 120 mg/L, except in the Nelson–Saskatchewan and Mississippi basins. The waters of these river systems are considered to be hard, as most hardness levels exceed 180 mg/L. None of the median concentrations for these 41 stations exceeded 500 mg/L.[3]

A survey of municipal water supplies in Canada showed that half of all Canadian municipalities had hardness levels below 80 mg/L, and 20% had levels greater than 180 mg/L.[11] Only in the Prairie provinces and Ontario did levels appreciably exceed 180 mg/L. In Ontario, the hardness of drinking water from surface sources ranged from 3.7 to 296 mg/L, with an average of 95 mg/L; the hardness of groundwater supplies was higher, and levels ranged from 40 to 1300 mg/L, with an average of 294 mg/L.[12,13] In a recent survey of 525 municipalities throughout Canada, only 17 cities had drinking water hardness levels above 500 mg/L.[14] These cities were in Ontario and Saskatchewan.

Health Considerations

The cations that are the major contributors to hardness — calcium and magnesium — are not of direct public health concern. These parameters are discussed further in separate reviews.

A number of epidemiological investigations, including ones in Canada,[11,15,16] England,[17–24] Australia[25] and the United States,[26–30] have suggested that there is an inverse statistical correlation between drinking water hardness and certain types of cardiovascular disease. Other workers [1,31–35] have reported that significant correlations cannot be demonstrated. No conclusions can be made, therefore.

A number of other studies have been undertaken to determine if there are any relationships between drinking water hardness and other diseases, including cancer.[21,23,26,29,34] Again, inverse correlations have been reported, but the significance of these data is debatable.

Domestic water supplies are often softened by the addition of lime and soda ash or the use of ion exchange zeolite. Water softening can result in the addition of high levels of sodium to the water,[20] particularly where certain ion exchange processes are employed. Although a direct relationship between sodium and hypertension has not been established in humans (see review of sodium), it is considered advisable to avoid the unnecessary addition of sodium to drinking water. A World Health Organization working group on sodium in drinking water has recently recommended that "trends towards unnecessary sodium in water supplies should be discouraged."[36] It is therefore recommended that where water softening by ion exchange is considered necessary, a separate unsoftened water supply be retained for drinking and culinary purposes.

Other Considerations

Soft water can lead to corrosion of pipes,[30,37] and, consequently, certain heavy metals such as copper, zinc, lead and cadmium may be present in the distributed water.[38–41] The degree to which this occurs is also a function of pH, alkalinity and dissolved oxygen concentration (see also review of pH). In some communities, corrosion is so severe that the water must be treated.[42]

In areas with hard water, household pipes can become clogged with scale [43]; hard waters also cause incrustations on kitchen utensils and increase soap consumption. Hard water is thus both a nuisance and an economic burden to the consumer. Public acceptance of hardness varies among communities; it is often related to the hardness to which the consumer has become accustomed, and in many communities hardness greater than 200 mg/L is tolerated. It has been suggested that a hardness level of 80 to 100 mg/L (as $CaCO_3$) provides an acceptable balance between corrosion and incrustation.[44]

Conclusion

1. Hard water causes incrustation in distribution systems and excessive soap consumption; soft water may result in corrosion of water pipes. Public acceptability of the degree of hardness may vary considerably from community to community depending on local conditions. Therefore, a maximum acceptable level for hardness cannot be specified.

2. Hardness levels between 80 and 100 mg/L (as $CaCO_3$) are generally considered to provide an acceptable balance between corrosion and incrustation. Waters with hardness levels in excess of 200 mg/L are considered poor but have been tolerated by consumers. Waters with hardness in excess of 500 mg/L are unacceptable for most domestic purposes.

Recommendation

Where softening by ion exchange is considered necessary, it is recommended that a separate unsoftened water supply be retained for drinking and culinary purposes.

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