Temperature

An aesthetic objective of *≤15°C* has been established for the temperature of drinking water.

Definition and Measurement

Temperature is currently defined by the "International Practical Temperature Scale of 1968, amended edition 1975" in terms of the electrical resistance of a standard platinum-resistance thermometer at three calibration points (the triple point of water, the boiling point of water at one standard atmosphere and the freezing point of zinc).(1) Measurement for water treatment purposes may be made with any good-grade mercury-filled Celsius thermometer. As a minimum requirement, the thermometer should have a scale marked for every 0.1°C and should be checked against a thermometer certified by the U.S. National Bureau of Standards. A thermistor may also be used, although higher cost may preclude its widespread use.(2) Thermistors used in some large water treatment plants for continuous temperature monitoring are calibrated using the melting point of water as a standard.

Except under uncommon circumstances — for example, in some Arctic distribution systems in which water is heated(3) — it is not economical to alter the temperature of the water in drinking water treatment plants. The temperature is therefore largely determined by the selection of the raw water source and the depth at which the distribution system is buried.(4) In Canada, surface water temperature shows a wide seasonal variation in most localities (2°C to 25°C).(5) Groundwater has a much more constant seasonal temperature. The temperature of deep wells varies by only 2°C to 3°C; larger variations occur in shallower sources.(6)

Relationships with Other Water Quality Parameters

The temperature dependence of most chemical reactions stems from the activation energy associated with them. In general, the rates of chemical reactions decrease with decreasing temperature. The relative concentrations of reactants and products in chemical equilibria can also change with temperature. The magnitude of this change basically depends on the Gibbs free energy change of the reaction in question. Temperature can therefore affect every aspect of the treatment and the delivery of potable water.

Physical Characteristics

The human senses of taste and smell are intimately related. Palatability involves a complex and predominantly subjective mixture of the two, together with the aesthetic parameter of colour. From the user's viewpoint, cool drinking water is preferable to warm; a temperature of 10°C is usually satisfactory.(7) The figure of 19°C, often quoted as a "limit" above which most consumers complain, is based on an empirical relationship derived about 60 years ago.(8) Pangborn and Bertolero,(9) using distilled water, solutions of mineral salts in distilled water and samples of drinking water, showed that the intensity of taste is greatest for water at room temperature and is significantly reduced by chilling *or* heating; the order of taste intensity is 22°C > 37° C > 55°C > 0°C. Increasing the temperature will also increase the vapour pressure of trace volatiles in drinking water and could thus lead to increased odour. The temperature used for the standard odour test in water is 40°C.(2) This temperature was chosen to increase the detection of those volatiles that produce disagreeable odours.

Turbidity and colour are indirectly related to temperature, because temperature affects coagulation. The efficiency of coagulation is strongly temperature dependent, and the optimum pH for coagulation decreases as temperature increases.(10) This shift is probably important only when coagulant doses are close to the experimentally determined minimum.(11) Because of the complex combination of chemical equilibria involved in coagulation, it is recommended that, in order to achieve the most economical use of coagulant, jar tests be carried out at the temperature of the treated water and not at room temperature.(11)

As temperature decreases, the viscosity of water increases, and the rate of sedimentation decreases.(11) As a longer settling time is not available in a plant with a fixed flow rate and basin capacity, the efficiency of colour and turbidity removal by coagulation and sedimentation may be less in winter than in summer. Very small increases in the temperature (<1°C) of the

raw water source have been reported to decrease the efficiency of the flocculation–sedimentation process; this is due to stratification of warmer water over cooler water in the treatment basin.[12] This problem, however, can be overcome by appropriate plant and process design.

Final removal of suspended matter is carried out after sedimentation by filtration. Lower temperatures increase the viscosity of water, and filtration is slowed down.[8] Furthermore, the efficiency of turbidity removal by filtration is diminished at lower temperatures, possibly owing to a reduction of floc strength or average particle size.[13] Filtration through activated carbon is also affected by temperature; the adsorptivity of activated carbon increases as the temperature drops.[14]

In pure water, the hydrogen ion concentration is the result of the dissociation equilibrium:

$$H_2O \rightleftharpoons H^+ + OH^-,\ pK_w\ (25°C) = 14.0$$

The negative logarithm of K_w decreases with increasing temperature, and hence the pH will decrease (pH in pure water = $pK_w/2$). At 0°C, the pH of pure water is 7.49, compared with a value of 7.0 at 25°C (the hydrogen ion concentration at 0°C is only 32% of the value at 25°C).[15] Buffering action due to the presence of carbonates and other weakly acidic species found in potable water will modify this effect. Langelier has presented a detailed thermodynamic analysis of the change of pH with temperature in solutions containing various amounts of carbonates.[15]

Microbiological Characteristics

Temperature is related to the microbiological characteristics of drinking water through its effect on water treatment processes, especially disinfection, and its effect on the growth and survival of micro-organisms.

In general, disinfection is aided by increased temperature. The majority of the available data relate to chlorination. Working with *Escherichia coli*, Butterfield and co-workers observed a fivefold increase in the bactericidal effectiveness of chlorine between 2°C to 5°C and 20°C to 25°C.[16] In a study for the U.S. Army, Ames and Whitney-Smith found a ninefold increase in effectiveness between 8°C and 40°C.[17] Chambers reported that temperature hardly alters the effectiveness of chlorine at pH values between 7.0 and 8.5; at higher pH values, a four-to eightfold increase in effectiveness was observed over the temperature range 4°C to 22°C.[18] Similar results have been obtained with viruses.[19]

Two other disinfection agents are worthy of mention: ozone, which is widely used in Europe and in approximately 20 treatment plants in Quebec; and chlorine dioxide, which is primarily employed in Canada for taste and odour control. Unfortunately, there is a lack of information regarding the effects of temperature and pH on these agents.[20] In one recent paper, it was reported that the inactivation of *Mycobacterium fortuitum* by ozone increased with temperature with an activation energy of 18.3 kcal.[21] The coagulation and sedimentation stage of water treatment also reduces the number of micro-organisms suspended in water, and, as discussed earlier, temperature affects these processes.

Free available chlorine in drinking water exists primarily as hypochlorous acid and hypochlorite ion. The germicidal efficiency of hypochlorous acid is about 100 times greater than that of hypochlorite ion; in pure water, 96.8% of the free available chlorine is in the form of hypochlorous acid at pH 6, compared with only 2.9% at pH 9.[22] At a given pH, higher temperature leads to greater dissociation of hypochlorous acid. At pH 8, for example, hypochlorous acid concentration decreases by nearly 30% in the temperature range 0°C to 20°C.[23] The magnitude of this effect on the germicidal efficiency of chlorinated water is, however, of secondary importance to the larger, and opposite, effect of increased germicidal action at higher temperatures.

The effect of temperature on bacterial survival in water is not clearly resolved in the literature. Depending on the type of water used in the investigations (distilled water, sterile tap water or raw water) and the bacteria studied, it has been found that the effect of increasing temperature decreases, increases or does not alter the viability of the organism under study.[24] Seasonal variations in coliform counts in raw water sources (maximum counts occur in spring and late summer) have been observed.[25] However, temperature would be only one of a number of factors leading to this variation.

Viruses can survive considerably longer than bacteria at low temperatures, and survival times of up to six months have been reported for poliovirus in tap water at low temperature.[22] However, an epidemiological study of infectious hepatitis in 13 U.S. cities showed no correlation between infection rate and raw water temperature.[26] The temperature range was 9.4°C to 20.6°C.

The survival time in water of the cysts and ova of parasitic worms is shortened by higher temperatures. For example, *Schistosoma* ova die in nine days at 29°C to 32°C, in three weeks at 15°C to 24°C and in three months at 7°C.[7]

The growth of nuisance organisms is also enhanced by warm water and could lead to the development of unpleasant tastes and odours and possible health dangers. Algal growth in surface water normally becomes noticeable only at temperatures above 15°C.[27] It has also been suggested that microfungi can grow inside the internal plumbing systems of buildings,

leading to complaints of musty, earthy or mouldy tastes and odours if the temperature rises above about 16°C.[28] Certain organic growths have been shown to protect bacteria from the effects of chlorination,[22] and it is therefore advisable to keep the growth of such organisms to a minimum by using cool water.

Chemical Characteristics

As with most other chemical reactions, the rate of formation of trihalomethanes in the chlorination of drinking water exhibits a temperature dependence. Stevens and co-workers demonstrated that the rate of formation of chloroform in raw water treated with a chlorine dose of 10 mg/L increased threefold between 3°C and 25°C.[29] In a survey of organics in Ontario drinking water, the authors concluded that water temperature was perhaps the single most important factor influencing seasonal variation in trihalomethane concentrations.[30] There appeared, however, to be no attempt to investigate the influence of other factors, such as the seasonal variation of dissolved organic chemicals in the water supply, the presence of turbidity or the chlorine dose.

In water treatment and distribution systems, corrosion and incrustation are affected by a complex interaction of factors. It is, therefore, difficult to make generalized statements concerning the effect of temperature on corrosion in water treatment systems. Information that is available stems from experimental investigations of specific situations. One such study showed the effect of temperature on the corrosion of cast iron in water produced by the Middlesex Water Company of New Jersey.[31] This study clearly demonstrated that corrosion increased as a function of temperature, with a good correlation between the average monthly raw water temperature and the measured corrosion rate. In the absence of corrosion inhibitors, the corrosion rate increased fourfold over the temperature range of 3°C to 26°C. The use of sodium hydroxide to adjust the pH reduced this increase to a factor of two over the same temperature range; however, at temperatures below 10°C, water containing sodium hydroxide showed a higher corrosion rate than the untreated water. The company therefore discontinued sodium hydroxide use in the winter months. Corrosion rate is also a function of the dissolved oxygen concentration in water. The solubility of oxygen decreases with increasing temperature (10.15 mg/L at 15°C to 7.1 mg/L at 35°C).[32] This change in dissolved oxygen with temperature is small compared with the much larger (and opposite) change in corrosion rates cited above, and it is unlikely that dissolved oxygen is important in the temperature dependence of corrosion.

The solubility product of calcium carbonate decreases with temperature; however, at low alkalinities (<50 mg/L as calcium carbonate), the decrease in pH with increased temperature actually increases the solubility of calcium carbonate. This effect on the saturation index tends to reduce incrustation by carbonate and at the same time to increase the aggressivity of the water, leading to increased corrosion in hot water systems.[13]

Health Effects

Temperature does not bear a direct relationship to health. Of the relationships mentioned above, the effects on chlorination and coagulation efficiency and the effect on the survival of micro-organisms are the most important to health.

Rationale

1. The importance of temperature as a determinant of water quality is derived mainly from its relationship with other water quality parameters. Most of these relationships have a bearing on the aesthetic aspects of water quality; some are indirectly related to health.

2. The palatability of drinking water is to some extent dependent on temperature. The figure of 19°C is often cited as a “limit” above which most consumers complain. At temperatures above 15°C, the growth of nuisance organisms in the distribution system becomes a problem and could lead to the development of unpleasant tastes and odours. The effect of low temperature on water treatment processes is controlled by altering the amounts of chemicals used in treatment; low temperature is not a barrier to the production of water of an acceptable quality.

3. The aesthetic objective for temperature is therefore ≤15°C. Maintenance of the water temperature at or below this level offers several additional advantages. Low temperature aids in the retention of a chlorine residual by reducing the rates of reaction leading to hypochlorous acid removal; economic losses due to corrosion are reduced at low temperature; and cool water discourages the use of alternative sources that may be injurious to health.

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