Literature Review of Temperature Effects in Biological Wastewater Treatment

—Eckenfelder

Variations in temperature affect all biological processes. There are three temperature regimes: the mesophilic over a temperature range of 4 to 39°C [39.2 to 102.2°F], the thermophilic which peaks at a temperature of 55°C [131°F], and the psychrophilic which operates at temperatures below 4°C [39.2°F]. For economic and geographical reasons, most aerobic biological treatment processes operate in the mesophilic range, which is shown in Figure 6.23. In the mesophilic range, the rate of the biological reaction will increase with temperature to a maximum value at 31°C [87.8°F] for most aerobic waste systems. A temperature above 39°C will result in a decreased rate for mesophilic organisms.

At temperatures above 96°F (35.5°C) there is deterioration in the biological floc. Protozoa have been observed to disappear at 104°F (40°C) and a dispersed floc with filaments to dominate at 110°F (43.3°C).

In the past, hot wastewaters such as those in the pulp and paper industry were pretreated through a cooling tower so that the aeration basin temperature did not exceed 35°C [95°F].

![Figure 6.23](image)

**Figure 6.23**
Effect of temperature on biological oxidation rate constant $K$.

Seasonal variations in temperature can markedly influence the makeup of microbial communities. Just as with pH, each species is characterized by a minimum, optimum, and maximum temperature that will support growth. *Psychrophiles* grow within the range of 0 to 20°C (32 to 70°F), with an optimum of 10 to 15°C (50 to 60°F). *Mesophiles*, which comprise most of the species commonly found in wastewater treatment processes, grow within the range of 10 to 45°C (50 to 115°F), with an optimum of approximately 30 to 35°C (85 to 95°F). *Thermophiles*, found in compost piles and other high-temperature environments, grow within the range of 40 to 75°C (105 to 165°F), with an optimum growth rate at 55 to 65°C (130 to 150°F). A few species of heterotrophic bacteria, classified as *extreme thermophiles*, can grow at temperatures higher than 100°C (212°F). These organisms live in highly specialized environments, such as geothermal vents in the ocean floor, and have not been implicated in wastewater treatment processes.


Optimum temperatures for bacterial activity are in the range from 25 to 35°C [77 to 95°F]. Aerobic digestion and nitrification stops when the temperature rises to 50°C [122°F]. When the temperature drops to about 15°C [59°F], methane-producing bacteria become quite inactive, and at about 5°C [41°F], the autotrophic-nitrifying bacteria practically cease functioning. At 2°C [35.6°F], even the chemoheterotrophic bacteria acting on carbonaceous material become essentially dormant.


Temperature affects the performance of activated sludge systems as a result of its impact on the rates of biological reactions. Procedures for estimating the magnitudes of its effects are presented in Section 3.9. Two additional factors must be considered: the maximum acceptable operating temperature and the factors that affect heat loss and gain by the process.

The maximum acceptable operating temperature for typical activated sludge systems is limited to about 35° to 40°C [95 to 104°F], which corresponds to the maximum temperature for the growth of mesophilic organisms. Even short-term temperature variations above this range must be avoided since thermal inactivation of mesophilic bacteria occurs quickly. Successful operation can also be obtained if temperatures are reliably maintained above about 45° to 50°C [113 to 122°F], since a thermophilic population will develop, provided that thermophilic bacteria exist with the capability to degrade the wastewater constituents. Unacceptable performance will result for temperatures between about 40° and
45°C due to the limited number of microorganisms that can grow within this range. These considerations are particularly important for the treatment of high temperature industrial wastewaters.

One of the factors that affect heat gains in biological processes is the production of heat as a result of biological oxidation. As discussed in Section 2.4.1, the growth of bacteria requires that a portion of the electron donor be oxidized to provide the energy needed for biomass synthesis. Energy is also needed for cell maintenance. This oxidation and subsequent use of the energy results in the conversion of that energy into heat. Although this may seem surprising at first, it is directly analogous to the release of energy that occurs when material is burned; the only difference is the oxidation mechanism. The amount of heat released in the biooxidation of carbonaceous and nitrogenous material is directly related to the oxygen utilized by the process. For each gram of oxygen used, 3.5 kcal of energy are released. Since 1 kcal is sufficient energy to raise the temperature of one liter of water 1°C, the impact of this heat release depends on the wastewater strength. For example, a typical domestic wastewater requires only one gram of oxygen for each 10 liters treated, therefore the temperature rise would be only 0.35°C, a negligible amount. On the other hand, it is not unusual for an industrial wastewater to require one gram of oxygen for each liter treated, in which case the temperature rise would be 3.5°C. This could be quite significant, particularly if the wastewater itself is warm.

Other heat gains and losses occur in biological systems. Heat inputs to the system include the heat of the influent wastewater, solar inputs, and mechanical inputs from the oxygen transfer and mixing equipment. Heat outputs include conduction and convection, evaporation, and atmospheric radiation.


—Jenkins, et al.

Aeration basin temperatures above 35 to 40°C can often cause dispersed growth of floc-forming and filamentous organisms (Norris et al., 2000; Parks et al., 2000). This is an increasing problem in many industrial wastewater treatment plants in which water conservation practices reduce effluent volume without reducing process heat losses, thereby increasing wastewater temperatures. A common observation is the occurrence of episodes of dispersed growth of single bacteria and dispersed filaments, high effluent turbidity, and loss of floc strength as the aeration basin temperature increases from below 35°C [95°F] to above this value. The dispersed growth and effluent turbidity often subside after a few days as a new thermostolerant floc-forming bacteria develop. Dispersed growth episodes occur also as the temperature decreases through this range, perhaps because the thermostolerant floc formers wash out of the system as they are replaced by mesophilic floc formers. For this reason, in activated sludge systems operated at high temperatures (>35°C), it is important to limit temperature variations as much as possible.

With increasing wastewater temperature, bacterial activity increases. Increased production and accumulation of insoluble biological secretions such as lipids and oils accompany this increase in activity. These secretions are adsorbed or entrapped by the floc particles, resulting in a decreased settling rate of secondary solids. When air bubbles or gases become entrapped in these secretions, the settling rate of the secondary solids decreases more.

**Figure 19.1** Impact of temperature upon the activated sludge process. Changes in wastewater temperature have a significant impact upon the activity of all organisms, floc particle structure, and the rate of floc formation.

Because increasing wastewater temperature and increased bacterial activity are critical factors that affect secondary solids settleability, a reduction in MLVSS concentration during warm wastewater temperature may be useful in preventing settleability problems and loss of solids. By reducing the MLVSS concentration, the amount of biological secretions that are produced and accumulated in floc particles is reduced.

If it is not possible to reduce the MLVSS concentration, alternate corrective measures are available to improve settleability. Bioaugmentation products that have bacteria with the enzymatic ability to degrade the biological lipids and oils that are produced during warm wastewater temperature may be added to the aeration tank. The addition of a metal salt or polymer to the secondary clarifier influent to add weight to floc particles or improve floc density may be used.

—von Sperling

The adaptation of the microorganisms to abrupt temperature changes seems to be much slower at higher temperatures. For example, it was observed that several months would be needed for the acclimatization of the biomass to a change of 5°C in the temperature range of 30°C [86°F], while only 2 weeks were necessary for a similar adaptation in the range of 15°C [59°F].


—Nalco

Temperature affects all biological processes. Biological oxidation rates increase to a maximum at about 95°F (35°C) for most treatment systems. At temperatures greater than 95°F, treatment efficiency decreases by reducing bacterial floc formation. Temperatures in excess of 99°F (37°C) show a definite effect on biological systems. It is possible, however, in certain wastes, to operate efficiently at somewhat higher temperatures. Lower temperatures than 50°F (10°C) also affect performance of biological processes, especially nitrification efficiency.

The rate of biological activity is influenced by temperature because of the depth of penetration of oxygen into the floc or film. Oxygen penetration increases as temperature decreases, since oxygen is not used as quickly at floc surfaces and greater numbers of organisms per unit surface can react. Oxygen solubility also increases as temperature decreases.


—Henze, et al.

Temperature has a significant effect on the growth rate of microorganisms. Those operating at a higher temperature range have a higher maximum growth rate than those operating at a lower range. The optimal range of temperature for each group is relatively narrow. With an increasing temperature, a gradual increase in growth rate is observed until an abrupt drop is observed due to the denaturation of proteins at a higher temperature. The generally used terms to describe these microorganisms are psychrophile below about 15°C [59°F], mesophile for 15–40°C [59–104°F], thermophile at 40–70°C [104–158°F], and hyperthermophile which are active about 70°C up to around 110°C [230°F].

Four remaining causes of trouble in biological purification should be avoided: temperature, pH, shock effects, and sludge “leaching.”

Aerobic purification by mesophile bacteria can be carried out in a wide range of temperature from 10 to 35°C [50 to 95°F], but load and efficiency conditions are optimum between 18 and 32°C [64.4 and 89.6°F]. Also to be avoided are dramatic variations in temperature in a time frame of a few hours.


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Biological processes are affected by temperature. Generally speaking, the higher the temperature, the higher the microbial activity until an optimum temperature is reached. Further increase of the temperature beyond its optimum value results in a precipitous decrease of microbial activity.

In addition to the denaturation of proteins at relatively high temperatures, cell lysis has been observed to increase sharply with increasing temperature, especially when substrate is exhausted (Allen 1950).


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LaPara and Alleman (1999) divided the operating ranges of activated sludge into mesophilic (<35°C), transitional (35°C<T<40°C) and thermophilic (>45°C) temperatures. There appears to be a “no man’s land” between 41°C and 44°C. In the mesophilic range, temperature seems to exert little effect on the removal by activated sludge of collectively measured pollutant parameters such as BOD₅ and COD. This was clearly demonstrated by Parks et al. (2000), who found no significant change in the soluble COD removal efficiency in an activated sludge process treating a warm, high-strength pharmaceutical wastewater at temperatures between 24°C and 44°C.

However, when more specific reactions, such as the removal of individual organic compounds, are measured, distinct temperature effects can be seen. For example, the biological removal rate of polyvinyl alcohol (PVA) in the activated sludge process is very sensitive to temperature variations, becoming extremely low at temperatures below about 12°C (Schonberger et al., 1987).

The relative insensitivity of temperature on the removal of collectively-measured pollutant parameters such as BOD₅ and COD is likely due to the fact that there are many groups of heterotrophic organisms in activated sludge, each with its own optimum temperature, that are capable of “BOD₅” or “COD” removal. Thus, when biodegradation by one group of organisms slows down, there is another group ready to take over. For more specialized substrates there may be only one, or a very limited number, of microorganisms
able to carry out the necessary biochemical reactions. In these cases, a more distinct temperature optimum will be observed.


—Cruikshank and Gilles

Biological Treatment Systems are sensitive to temperature as is every other living entity. Conventional mesophilic bacteria has been shown to perform most optimally when the reactor wastewater temperature is maintained between 78° and 95°F (26° and 35°C). Nitrifying bacteria have an even tighter range of optimal reactor temperature between 85° and 92°F (29° and 33°C). Many industrial processes that generate wastewater from such unit operations as distillation bottoms, stripping, tank cleanouts, quenching can produce elevated temperatures that exceed the ideal environment for robust biological treatment. These warmer wastewaters can cause the biomass to operate at a much lower efficiency ultimately lowering the effluent discharge quality from the facility. Elevated temperatures also affect oxygen transfer in the reactor further affecting the performance of the wastewater treatment plant.

During development of process design parameters and preliminary engineering of mechanical systems for new or upgraded wastewater treatment facilities, an engineer should evaluate influent temperature variations, atmospheric conditions, and mechanical inputs that may affect the biological system. This evaluation should be completed using data from different seasons of the year taking into account local weather data, the storage volume of the tanks or basins, materials of construction for these systems, as well as the energy (heat) input to the overall process through aeration and/or mixing.

Source: Cruikshank, Christa L. and David G. Gilles. “Temperature Modeling and Control for Biological Wastewater Treatment Design.” (See the attached paper.)