Part 2. The Hydrosphere

Chapter 16. Water Pollution and Waste: Water Treatment Chemistry

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16.0 Generals

- Definition of water pollution

Pollutant is ‘a substance or effect which adversely alters the environment by changing the growth rate of species, interferes with the food chain, is toxic, or interferes with health, comfort, amenities, or property values of people’

- Guidelines for the alteration of the environment

-Physical properties of T, Colour, Odour, and turbidity

-For general chemical classes of chemical properties such as pH, total dissolved solids (TSS), salinity, hardness, biological oxygen demand (BOD), detergents, and petroleum residues

-For specific elements, complex ions, and organic compounds; for radiological properties, that is levels of radioactivity due to particular isotopes; and

-For microbiological properties, that is, counts of specific organisms and groups of organisms

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16.1 Community waste-water treatment chemistry

- Community waste water = domestic wastes + industrial and other effluents
- Major components of community waste water: being made up of human wastes, solid and dissolved forms of food wastes, soaps and detergents, and soil residues.
- Typical measured properties of untreated sewage include the following

Biological oxygen demand (BOD)	250mg L^{-1}
Chemical oxygen demand (COD)	500mg L^{-1}
Total solids (TS)	720mg L^{-1}
Suspended solids (SS)	220mg L^{-1}
Total phosphorus (TP)	8mg L^{-1}
Total nitrogen (TN)	40mg L^{-1}
pH	6.8

The underlined items are of major concern because they all upset the normal balance of aquatic life

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16.1 Community waste-water treatment chemistry

- The natural levels of dissolved oxygen in water are sufficient to oxidize small amount of animal and vegetative wastes via aerobic microbial reactions. In the process, organic wastes are converted into simple organic and inorganic compounds, and oxygen into carbon dioxide. The carbon dioxide, under the influence of light, takes part in photosynthesis and oxygen is returned to the water. This is

- This cycle of self-purification is broken by the presence of excessive amounts of degradable amounts of OM (high BOD) producing anoxic conditions, by turbidity (high SS) that inhibits photosynthesis, and by unusually large conc of nutrients (most often, high TP) that stimulate plant and algal growth.
- Waste water treatment plants offer primary, secondary, and tertiary treatment. Primary treatment-pulverization to reduce large-sized solid material to smaller dimensions, followed by screening and flowing through clarifier

  Secondary-aerobic biological process, e.g. activated sludge process (ASP). Oxygen is provided together with sludge, which is the previously activated biological mass. C, N, and P are taken up by microbes. Metals and other contaminants are removed by use of coagulants.

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16.1 Community waste-water treatment chemistry

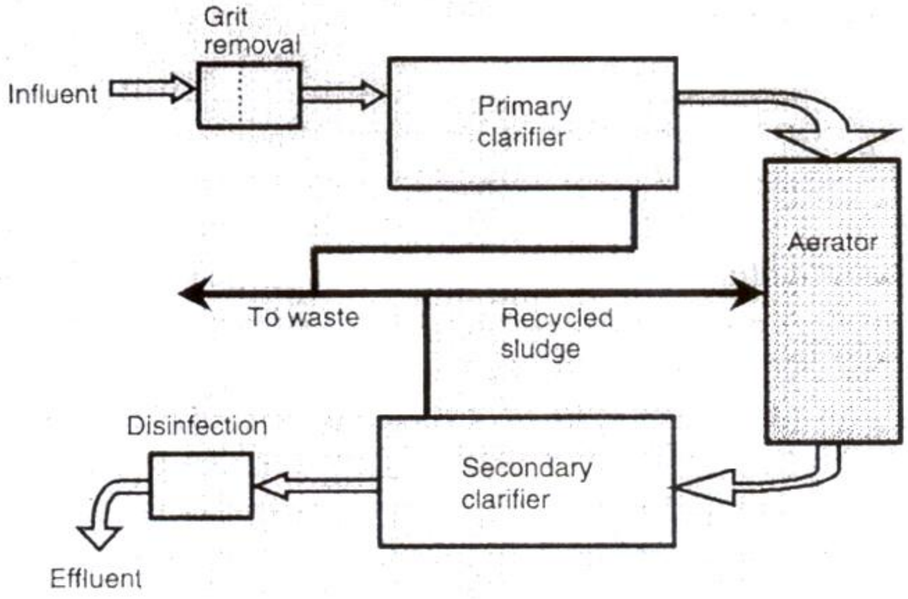

Fig. 16.1 Schematic diagram of an activated sludge waste-water treatment facility. The open arrows show the path of the waste-water stream, while the filled arrows follow the separated sludge.

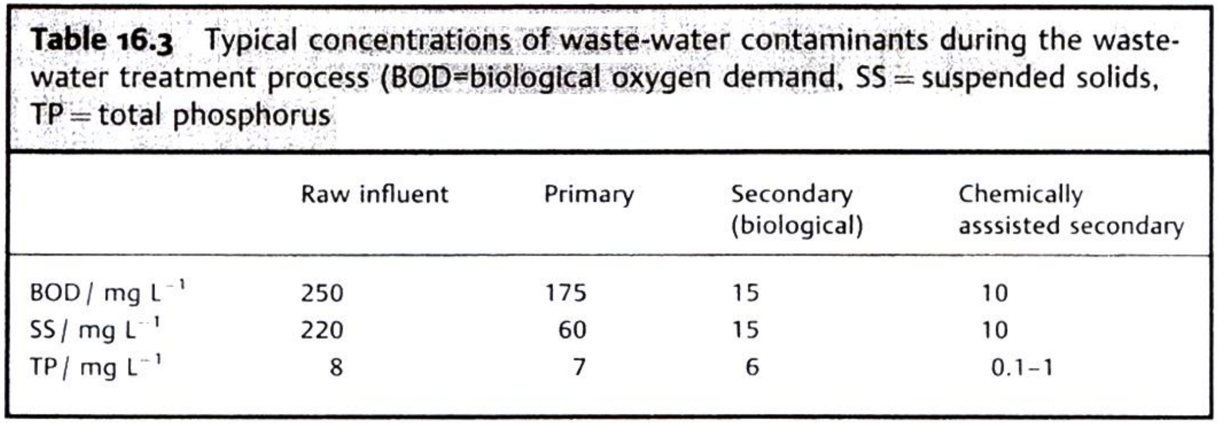

Table 16.3 Typical concentrations of waste-water contaminants during the waste-water treatment process (BOD=biological oxygen demand, SS = suspended solids, TP = total phosphorus

	Raw influent	Primary	Secondary (biological)	Chemically asssisted secondary
BOD / mg L^{-1}	250	175	15	10
SS / mg L^{-1}	220	60	15	10
TP / mg L^{-1}	8	7	6	0.1–1

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16.1 Community waste-water treatment chemistry: Chemical coagulants

- Two principal functions

  -to assist in the coagulation and flocculation processes, in order to maximize removal of very small solid particles of various compositions, and

  -to react with and remove potential pollutant chemical species such as phosphorus in the water.

- Stoke's law

$$v_t = \frac{(\rho_p - \rho_a) g d_p^2}{18\mu}$$

where ν_t = terminal velocity of particles/ m $\mathrm{s^{-1}}$; ρ_p = density of particle/kg $\mathrm{m^{-3}}$; ρ_p = density of water $= 1.0\times10^3$ kg $\mathrm{m^{-3}}$ at P° and 20°C; g = 9.8m $\mathrm{s^{-2}}$; $\mathrm{d_p}$ = particle diameter/m ; and μ = viscosity of water $= 1.0\times10^3$ kg $\mathrm{m^{-1}s^{-1}}$ at P° and 20°C.

If we apply the Stokes relation to a spherical particle of sand, 0.1 mm (10^{-4} m) in diameter, assuming particle density of 2.65×10^3 kg $\mathrm{m^{-3}}$, then

$$v_t = \frac{(2650-1000)9.8(10^{-4})^2}{18\times10^{-3}}$$

$$= 9\times10^{-3} ms^{-1} = 9mms^{-1}$$

Where the settling tank has a depth of 4m, sand particles with these dimensions will settle in $4/(9\times10^{-3}) = 440s$ = about 7.4 min. A typical clarifier has been designed so that water takes an average of 1.5h to pass through it (this is called the detention time ^{2}). Clearly, sand with particle diameters of 0.1 mm will have sufficient time to settle completely in a tank of the specified size.

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16.1 Community waste-water treatment chemistry: Chemical coagulants

- Coagulants: Alum ($Al_2(SO_4)_3$), $FeCl_3$, and hydrated lime ($Ca(OH)_2$)

$$Al(H_2O)_6^{3+}(aq) + H_2O \rightarrow Al(H_2O)_5(OH)^{2+}(aq) + H_3O^+(aq) \tag{16.2}$$

$$Al(H_2O)_5(OH)^{2+}(aq) + H_2O \rightarrow Al(H_2O)_4(OH)_2^+(aq) + H_3O^+(aq) \tag{16.3}$$

$$Al(H_2O)_4(OH)_2^+(aq) + H_2O \rightarrow Al(H_2O)_3(OH)_3(aq) + H_3O^+(aq) \tag{16.4}$$

$$Al(H_2O)_3(OH)_3(s) + H_2O \rightarrow Al(H_2O)_2(OH)_4^-(aq) + H_3O^+(aq) \tag{16.5}$$

$$Al(H_2O)_6^{3+}(aq) + 3HCO_3^-(aq) \rightarrow Al(OH)_3(s) + 3CO_2(g) + 6H_2O \tag{16.6}$$

Rxn 16.6 plays a role in removal of small particles that cause turbidity.

Aluminum hydroxide precipitate carries a net positive charge, so neutralizes the negative charges of the SS. Neutralization of the double layer charge allows the colloids to approach each other and come together into larger aggregates that readily settle in the clarifier (the first function of coagulants)

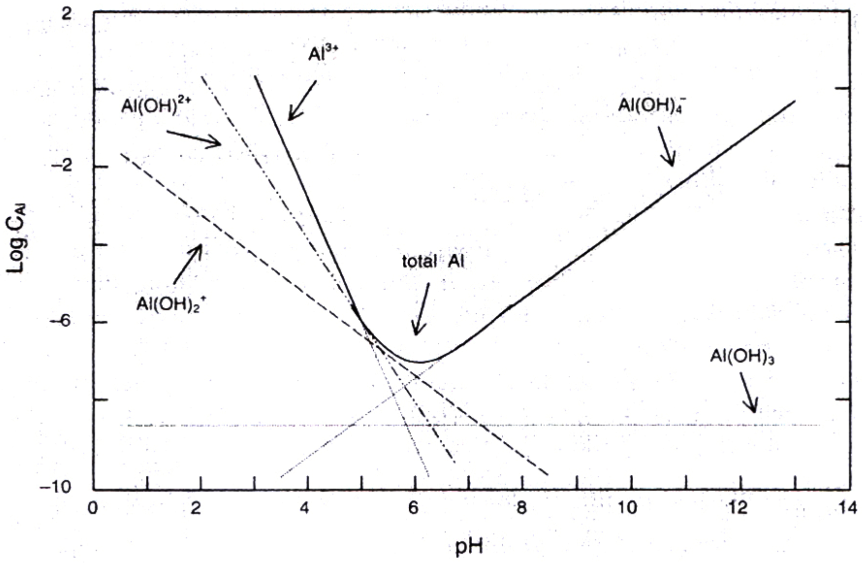

Fig. 16.2 Solubility of individual aluminium species and total aluminium solubility in water as a function of pH.

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16.1 Community waste-water treatment chemistry: Chemical coagulants

- The second function by the Alum ($Al_2(SO_4)_3$) or $Ca(OH)_2$ coagulant is the removal of phosphorus from the waste-water stream. N removal can be done through the reactions 16.10 or from 16.11 to 16.13

$$Al^{3+}(aq) + PO_4^{3-}(aq) \rightarrow AlPO_4(s) \qquad (16.7)$$

$$Al(OH)_3 + HPO_4^{2-}(aq) + H_2O \rightarrow AlOH(HPO_4) \cdot H_2O(s) + 2OH^-(aq) \qquad (16.8)$$

$$5Ca(OH)_2(aq) + 3HPO_4^{2-}(aq) \rightarrow Ca_5OH(PO_4)_3(s) + 6OH^-(aq) + 3H_2O \qquad (16.9)$$

$$NH_4^+(aq) + OH^-(aq) \rightarrow NH_3(g) + H_2O \qquad (16.10)$$

An alternative approach that does not involve pH modification is to remove ammonium ions from the neutral solution by ion exchange using the natural ion exchanger clinoptilolite or systhetic exchangers.

More complete removal of ammonium nitrogen is effected by subsequent chlorination, to form mono-, di-, and trichloramines. Hypochlorous acid is the effective chlorinating species under treatment conditions.

$$NH_4^+(aq) + HOCl(aq) \rightarrow NH_2Cl(aq) + H_3O^+(aq) \qquad (16.11)$$

$$NH_2Cl(aq) + HOCl(aq) \rightarrow NHCl_2(aq) + H_2O \qquad (16.12)$$

$$HOCl(aq) + NHCl_2(aq) \rightarrow NCl_3(aq) + H_2O \qquad (16.13)$$