# Environmental Chemistry

# Water Treatment

## Objectives of Water Treatment

- The objectives for water treatment derive from two concerns:
- Preventing wastes from entering aquatic ecosystems
- Possibly cleaning up water for human use
    - Irrigation
    - Drinking water?

## Water treatment for domestic and commercial uses

| Pollutant | Corresponding removal measures |
|---|---|
| Odorous gases | Aeration to remove odor gases |
| Particles | Addition of $Fe^{3+}$ and $Al^{3+}$ to trap particles |
| Organic materials | Bacteria metabolism |
| Dissolved N, P inorganic | Chemical precipitation<br>NH3 stripping |
| microorganisms | Addition of disinfectants |

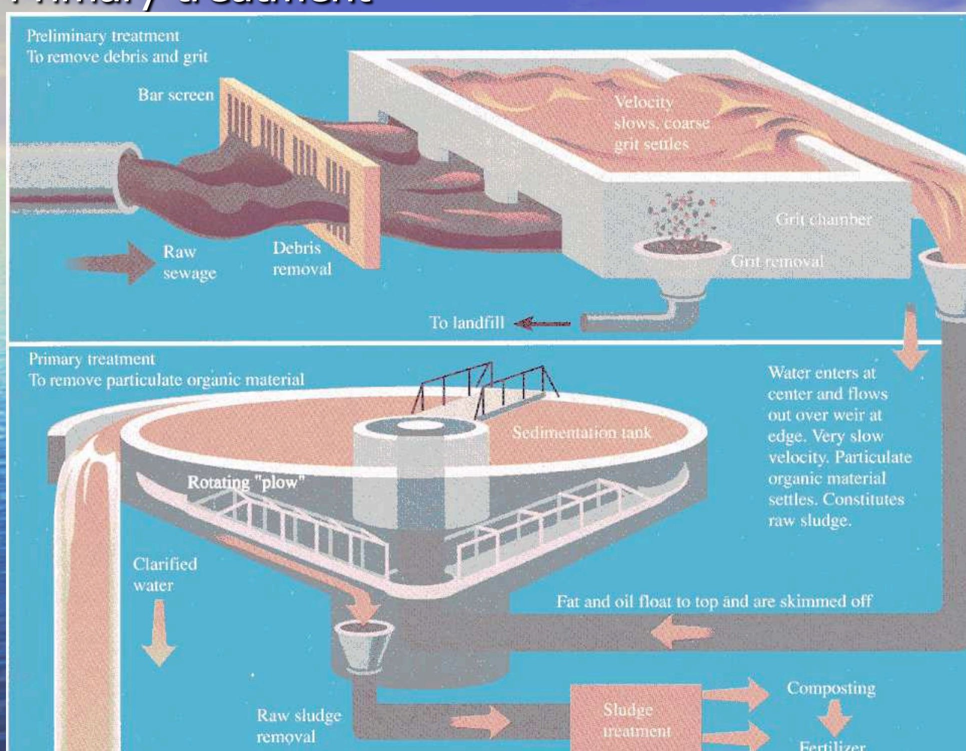
## Primary water treatment

- Primary treatment: Remove solids by screening and settling
  - The sewage is passed through a screen to remove large pieces of debris (e.g. sticks, stones, rags, and plastic bags).
  - Next, the sewage enters a grit chamber, where the water flow is slowed just enough to allow coarse sand and gravel to settle out on the bottom.
  - Water then enters the sedimentation tank, its flow rate is further decreased to permit suspended solids to settle out as raw sludge.

## Primary water treatment (Continued)

- $Ca(OH)_2$ and $Al_2(SO_4)_3$ are often added to speed up the sedimentation process.
- Oily material floats to the surface and is skimmed off.
- The grit is collected and disposed in landfill.
- The raw sludge:
  - Old way: incinerated, disposed in landfill or dumped at sea.
  - New way: composted to produce a nutrient-rich, bacteria-free material for use as fertilizer.

## Primary treatment



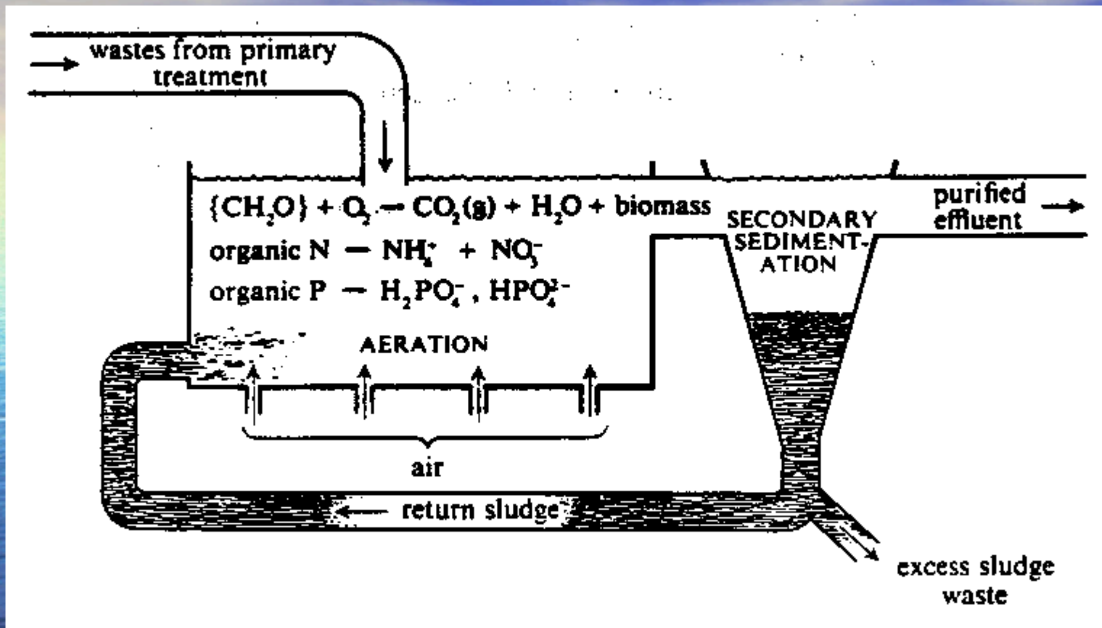
In older sewage-treatment plants, the discharged water after primary treatment is often chlorinated to kill pathogens and then discharged into a natural waterway.

The discharged water at this stage still contains a large amount of oxygen-consuming wastes, which may deplete dissolved oxygen in the water way and cause eutrophication.

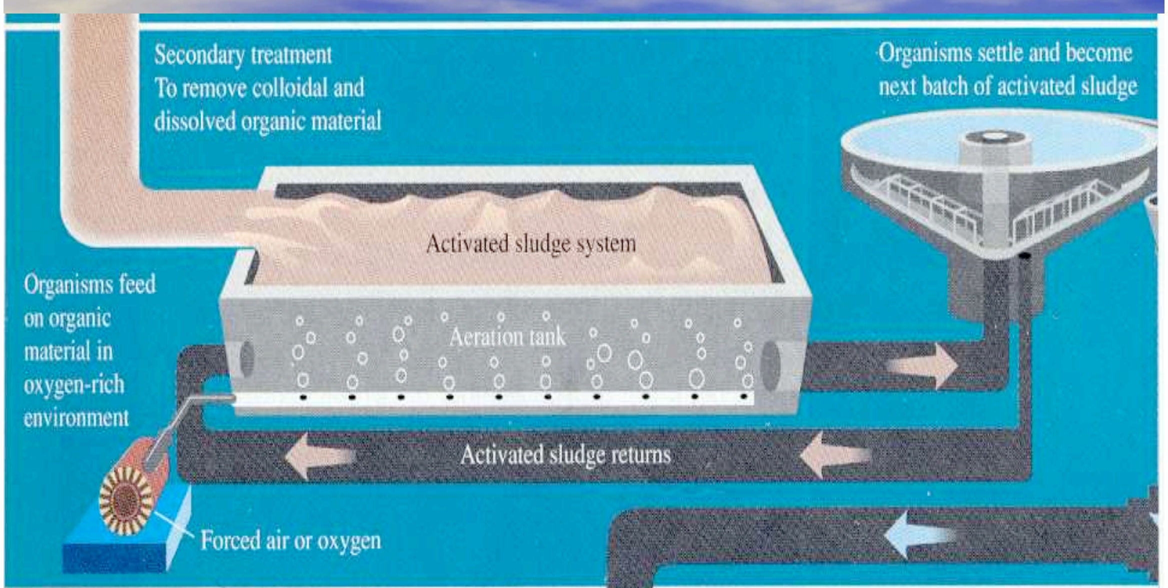
## Secondary treatment

- Secondary treatment, also called biological treatment: Use bacteria to break down organic compounds to $CO_2$.
  - A mixture of organisms – termed activated sludge– is added to the sewage effluent.
  - Air or oxygen is vigorously bubbled through pipes into the effluent.
  - The aerobic bacteria digest the organic material and break it down into ___ and ___.
  - The bacteria and any remaining undecomposed material are returned to the aeration tank and reused.

# Activated sludge process




# Secondary treatment of municipal wastewater



Most municipal plants chlorinate the water after secondary treatment and then release it into waterways.

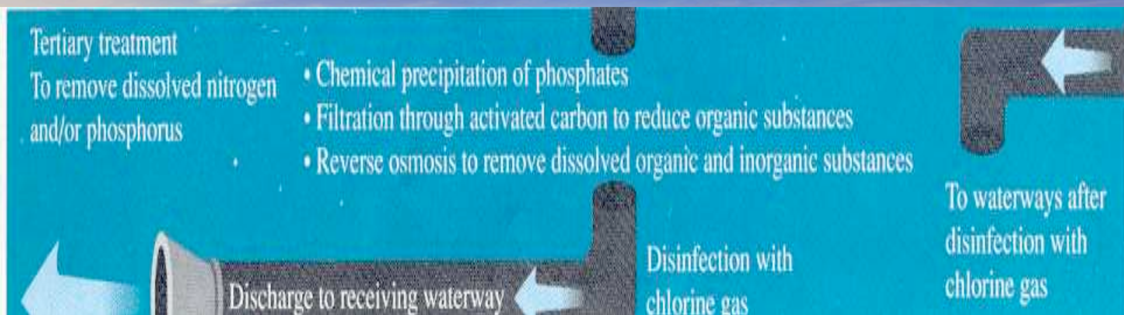
The discharged water at this stage has ~ 90% of the original organic matter removed, but over 50% of N, P species remains, and metal ions and many synthetic organic compounds are incompletely removed.

## Tertiary treatment

Tertiary treatment, also called advanced waste treatment, includes a variety of processes performed on the effluent from secondary waste treatment.

- Remove N and P nutrients.
  - P removal by precipitation with lime
    $3\ PO_4^{3-} + CaO\ (\text{lime}) \rightarrow Ca_5(PO_4)_3(OH)\downarrow$ Hydroxyapetite
  - Phosphate can also be removed by microorganisms that absorb phosphate.
  - $NH_4^+$ removal by ammonia stripping.
    $NH_4^+ + OH^- = NH_3\uparrow + H_2O$ (Excess OH- from lime)
  - Alternative $NH_4^+$ removal: nitrifying bacteria convert $NH_4^+$ to $NO_3^-$ followed by denitrifying bacteria to convert $NO_3$- to $N_2$.
- Remove organics through filtration by activated carbon

## Tertiary treatment of municipal wastewater




## Performance of primary and secondary stages of sewage treatment

| | Pollutants Removed | |
|---|---|---|
| Component removed | Primary treatment | Secondary treatment |
| Biological oxygen demand | 30% | |
| Suspended solids | 60% | |
| Nitrogen compounds | 20% | |
| Phosphorous compounds | 10% | |

Source: American Chemical Society

## Sludge disposal

- Sludge is an excellent fertilizer in principle: rich in organic material and nutrients.
- Sludge often contains toxic metal species, which restricts the application of sludge to cropland.
- Sludge can be a low-quality fuel for generating electricity.
- Sludge could be converted to methane by anaerobic bacteria, but this option suffers poor economics.

## Disinfection

- Common disinfectants:
- Disinfectants kill microorganisms by oxidizing vital molecules (often with unsaturated carbon bond) in them.

$Cl2 + H2O = HOCl + H^{+} + Cl^{-}$

Hypochlorous acid

Active disinfection component

## Pros and cons of various disinfectants

- $Cl_2$:
  - $Cl_2$ is effective and relatively cheap.
  - HOCl can act as a chlorinating agent to produce a variety of chlorinated organic compounds (e.g., $CHCl_3$).
  - Many of the Cl-containing organics are toxic and non-biodegradable. Some (e.g. CH2Cl2, CHCl3, C2HCl3) are suspected carcinogens.
- $O_3$ and $ClO_2$:
  - More expensive than $Cl_2$.
  - Need to be generated on-site → add on to the capital cost.
  - Are fast-acting and rapidly decompose.

    (On the contrary, persistence of disinfectants (HOCl) allows them to disinfect surrounding water infiltrated through old and leaky pipes.)

## Generation of ClO2 and O3

- ClO2

  2 NaClO2 (s) + Cl2 (g) = 2ClO2 (g) + 2 NaCl (s)

  Sodium hypochlorite
- O3

  Subject pressurized air to an electric discharge of ~20,000v.

## Chemical & Engineering News

*December 10, 2001*

ANTHAX CLEANUP

Hart Senate Office Building Decontaminated (STEVE RITTER)

Chlorine dioxide gas was pumped into the offices of Senate Majority Leader Thomas A. Daschle (D-S.D.) in the Hart Senate Office Building on Dec. 1 during one of the final steps of EPA's anthrax decontamination efforts on Capitol Hill (C&EN, Nov. 26, page 24).

Anthrax spores initially were detected in several Capitol office buildings after an anthrax-laden letter, addressed to Daschle and opened by an aide on Oct. 15, had passed through the congressional mail system. Some buildings were temporarily closed for testing and some sections of the buildings subsequently decontaminated using chlorine bleach and an antimicrobial foam.

The Hart Building, home to 50 senators, had the highest exposure to spores and presented the greatest challenge. EPA decided to limit the use of $ClO_2$ to Daschle's 3,000-sq-ft office suite, while only bleach or the foam were used elsewhere in the building.

Daschle's offices were sealed off and then exposed to as much as 800 ppm of $ClO_2$ for about 20 hours, followed by treatment with sodium bisulfite vapor to neutralize the residual gas. Postdecontamination test results to check the effectiveness of $ClO_2$ against spores were expected back after a week. The Hart Building is slated to reopen by the end of the year.