CIVE 3331 - ENVIRONMENTAL ENGINEERING
Spring 2003

Document Name: CIVE3331_Lecture011.doc

Purpose: Lecture #11 CIVE3331

Waste Water Treatment

Goal is to remove pathogens, BOD, solids, nutrients before returning the "reclaimed" water back to the hydrologic cycle. Methods used are similar to water treatment except that loads (concentrations) are much greater in wastewater and nutrient removal and BOD removal are not common in drinking water treatment.

Solids Characterization

Solids in wastewater are comprised of dissolved (ions) solids, suspended solids (filterable), volatile solids (those that are burned upon ignition), and non-volatile solids (residue after ignition). The relative amounts of each are important is design of treatment processes.

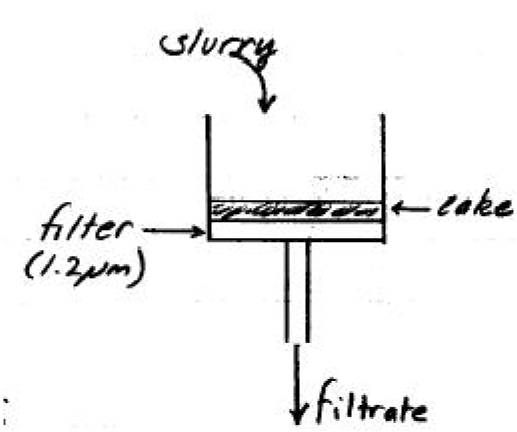


Figure 1. Diagram of TSS filtration

TSS is determined by filtering known volume of slurry (WW) through a 1.2 micron filter, then drying, then weighing the filter cake. Mass cake per volume filtered is the TSS (mg/L).

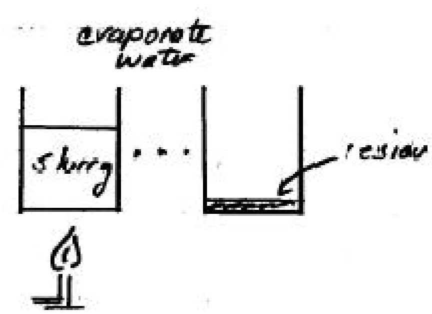


Figure 2. Total solids determination

TS is determined by taking a known volume of slurry and evaporating the liquid. The residue is weighed. The mass residue per original slurry volume is the total solids (TS) (mg/L).

[Add VSS and Non-Volatile next typeset]

Typical raw wastewater is about 2-5% total solids, the bulk being biosolids.

Treatment levels

1. Primary – principal focus is solids removal.
2. Secondary – principal focus is BOD removal
3. Tertiary (advanced oxidation) – focus is nutrient removal and any special chemicals.

Primary Treatment

Remove solids – typically employ various SLS technologies; Screening for larger solids and flotables; Grit removal for smaller solids(cm to mm range); Settling (Clarifiers) for smaller solids.

SLS can be classified into a handful of generic operating principles including:

1. Filtration: Screening (size exclusion) such as wastewater bar screens, or mineral exploration vibrating screens; Media filtration (size exclusion, interception, aggregation) such as swimming

pool filters, vertical sand filters, and backwashed filters; Bag filtration (size exclusion, interception, aggregation) such as in a vacuum cleaner; a candle filter (thin tubes); Plate-and-frame (similar to bag, but filtration is accomplished at the septum); Moving media such as a belt press or rotary vacuum filter.

2. Clarification: Settling basin (density gradient) such as an oxidation pond (also has biological treatment) or primary wastewater clarifier; Flocculation/coagulation same as settling basin except with chemical addition to increase settling rate; Baffled septic-tank type separators such as oil-water separators (liquid-liquid), corrugated plate coalescers (liquid-liquid where oils “float” on a “settling” water layer), and some of the “proprietary” multi-chamber stormwater devices; dissolved air flotation.
3. Centrifugation: High speed horizontal and vertical axis bowl centrifuges, with and without backdrive (continuous solids removal); Hydrocylones such as in mineral exploration/extraction industry.
4. Physio-chemical processes: Adsorbtion such as in activated carbon, removes chemicals with high affinity for carbon (i.e. many organic compounds, and some inorganic constituents); Ion-exchange using resins, zeolites, and other synthesized and geologic chemically active materials – generally these processes can be pictured as any of the separation processes combined with chemical (or biological) treatment.

In wastewater treatment filtration and clarifiers are common on the liquid side and centrifuges and belt presses common on the solids side. The other devices are relatively exotic (in the USA) in wastewater treatment.

The key design parameter is the hydraulic retention time that in turn helps choose the geometry and performance of the clarifier.

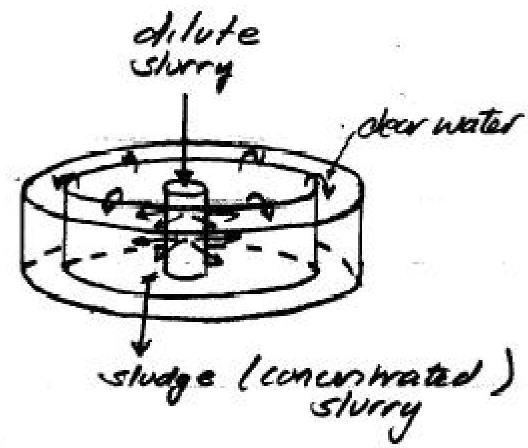


Figure 3. Sketch of typical cylindrical clarifier

Figure 3 is a sketch of typical clarifier geometry. The inner cylinder distributes flow radially across the clarifier. The second cylinder forms the overflow weir, and the outer cylinder contains the clear water overflow and directs it further downstream (in the plant).

Typical loading rates are:

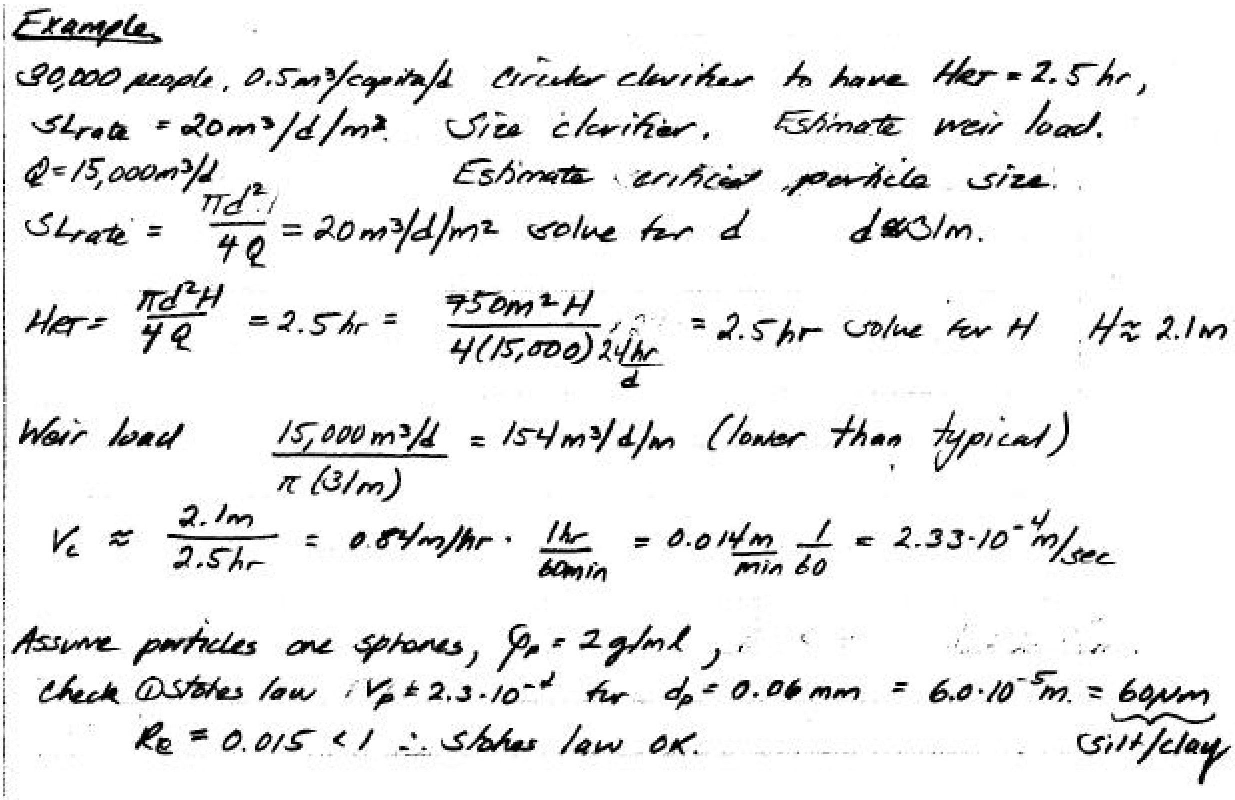
Surface Loading (Q per surface area) = 15-30 $m^3/d/m^2$

Weir loading (Q per weir length) = 180-260 $m^3/d/m$

HRT (retention time) = at least one hour.

These loading rates and the HRT minimum establish the volume, depth, and area of the clarifier. Figure 4 is an example of typical clarifier conceptual calculations.

Figure 5 is a diagram of a wastewater treatment plant. It indicates the liquids rich and solids rich components of the system. Each are similar, but employ different processes. The solids are usually a resource, either as a source of energy or fertilizer, once the pathogens are inactivated. In the USA, Hawaii generates a meaningful proportion of its electricity by the burning of biosolids from municipal wastewater treatment as well as from sugar cane waste.



Example

30,000 people, 0.5 m^3/capita/d circular clarifier to have HRT = 2.5 hr,

SLrate = 20 $m^3/d/m^2$. Size clarifier. Estimate weir load.

Q = 15,000 m^3/d Estimate critical particle size.

$SLrate = \frac{\pi d^2}{4Q} = 20\,m^3/d/m^2$ solve for d $d \approx 31m$.

$HRT = \frac{\pi d^2 H}{4Q} = 2.5\,hr = \frac{750\,m^2 H}{4(15{,}000)\,24\frac{hr}{d}} = 2.5\,hr$ solve for H $H \approx 2.1\,m$

Weir load $\frac{15{,}000\,m^3/d}{\pi(31m)} = 154\,m^3/d/m$ (lower than typical)

$V_c \approx \frac{2.1m}{2.5hr} = 0.84\,m/hr \cdot \frac{1hr}{60min} = 0.014\frac{m}{min}\frac{1}{60} = 2.33\cdot10^{-4}\,m/sec$

Assume particles are spheres, $\rho_p = 2\,g/ml$,

Check @ Stokes law $V_p \approx 2.3\cdot10^{-4}$ for $d_p = 0.06\,mm = 6.0\cdot10^{-5}\,m = 60\,\mu m$

$Re = 0.015 < 1$ ∴ Stokes law OK. silt/clay

Figure 4. Example clarifier calculations

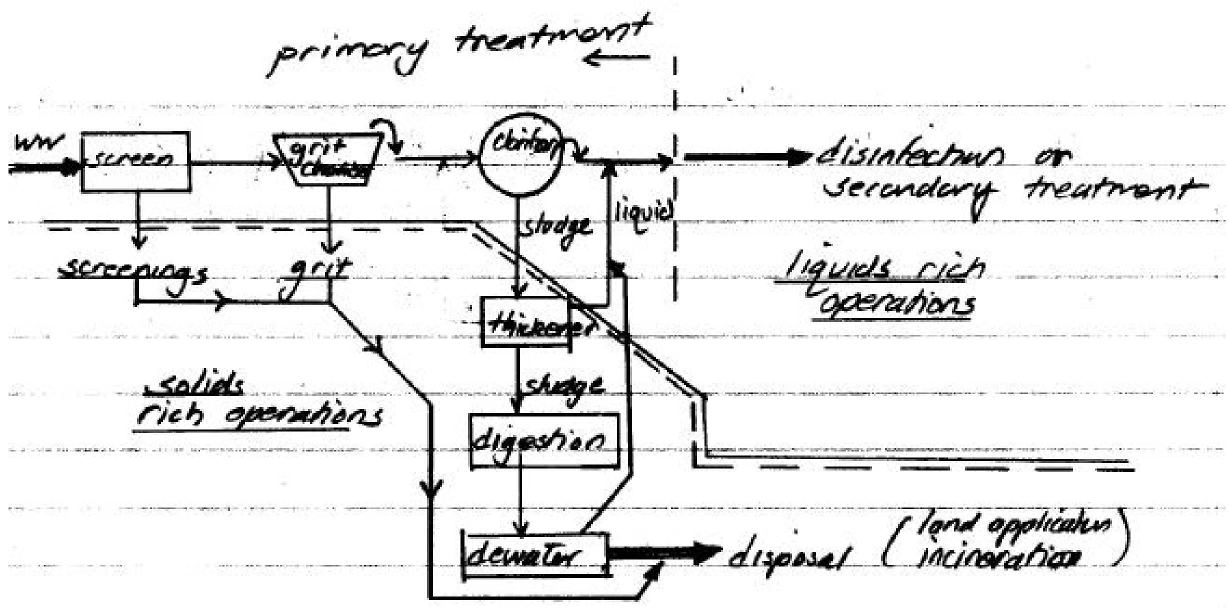


Figure 5. Wastewater treatment flow chart

Primary treatment can achieve 35% reduction in BOD and 60% reduction in TSS. There is still enough BOD and nutrients to impact the environment (fish-kill and eutrophication).

Secondary Treatment

Goal is BOD reduction by microbiological oxidization and further solids removal. Devices used include trickling filters, biological contacters, and activated sludge process.

$$\text{organic matter} + O_2 \xrightarrow{\text{microbes}} CO_2 + H_2O + \text{New Cells} + \text{By-Products } (NO_3, PO_4, SO_4 \cdots$$

Common concept is the aerobic decomposition of waste. Methods differ in how O2 is supplied and how fast the process procedes. In the USA, activated sludge is the most common process for large volume plants.

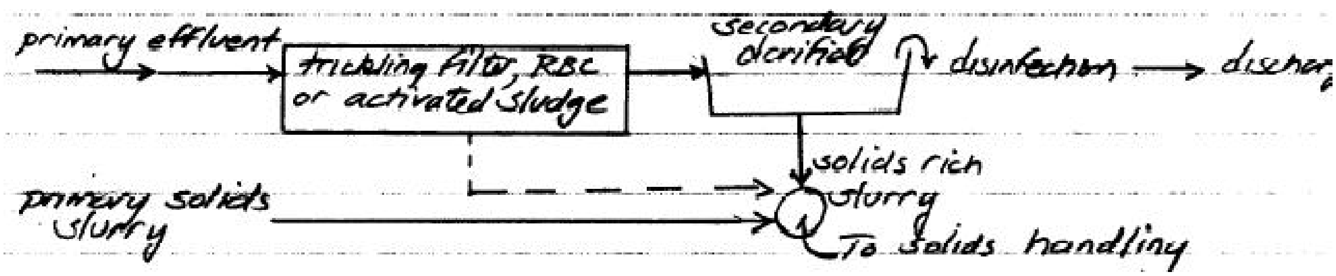


Figure 6. Schematic secondary treatment

Solids handling – remove remaining liquid, inactivate pathogens reduce solids volume, sell dried solids. Municipal sludge (Class A) is agriculturally useful. Industrial solids are usuallyburned or landfilled for business liability protection.

Removing the liquid – use same SLS as above on the solids stream, usually can get concentrations up to 10% solids, sometimes better – at this content, mechanical expression or drying is required for further liquid removal.

Inactivation of pathogens – the thick slurry is digested aenerobically in a digestor or oxidation pond.

Extracts remaining energy form waste by anaerobic decomposition.

$$\text{organic matter} \xrightarrow{\text{microbes}} CO_2 + H_2O + \text{New cells} + \text{By Products } (H_2S, NH_3, CH_4 \ldots)$$

NH_3 ↑ valuable nutrient (for soil, not water); CH_4 fuel

After digestion, the slurry is further deliquored by filtration, filter press, centrifuge, drying beds, incineration.

Oxidation ponds accomplish this task in bottom of pond. Use a lot of real estate. May still need a clarifier and disinfections on overflow water. Flood and strom wash-out is a serious problem.

Advanced Oxidation

Focus is nutrient removal. Secondary effluent is still high in TKN and orthophosphate.

Nitrification/denitrification

$$NH_4^+ + 2O_2 \xrightarrow{\text{microbes}} NO_3^- + 2H^+ + H_2O \quad \text{(requires days to reach this point)}$$

$$2NO_3^- + \text{organic} \xrightarrow[\text{No-air}]{\text{microbes}} N_2\uparrow + CO_2 + H_2O \quad \text{(anaerobic – sometimes requires addition of carbon source)}$$

Phosphorous removal

$$Al_2(SO_4)_3 + 2PO_4^{3-} \rightarrow 2\,AlPO_4\downarrow + 3SO_4^{2-}$$

Typically by flocculation and clarification of filtration.

Additional processes to treat specific toxic compounds are also considered as part of advanced processes. Often avoided by pre-treatment processes at the generator’s location (industrial pre-treatment).

Hazardous Materials

Public health priorities

i) Infectious disease

ii) Toxic materials

iii) Carcinogens

Environmental engineering focuses on (i) for most of the 20^{th} century. Today (~2000) most developed nations have (i) under control and are expending resources on (ii) and (iii). Most hazardous materials fall into (ii) and (iii). Hazardous materials are defined by regulatory documents.

CERCLA (Comprehensive Envrionmental Response, Compensation, and Libality Act) – already contaminated sites (Superfund)

RCRA (Resource Conservation and recovery Act) – new (and currently active) generators of hazardous materials.

Hazardous materials:

-listed (appear on a list)

-characteristic:

i) ignitable (flash point 60C or less)

ii) corrosive (pH<2; >12.5; corrodes metal)

iii) reactive (produces heat, explosion, poison fumes, vapors, or gasses)

iv) toxic (fatal if ingested, fails TCLP)

listed wastes

i) source specific (related to industry; SIC)

ii) generic

iii) commercial chemical products

Relevant laws

TSCA – toxic

CERCLA – past ractices

RCRA – current practices

RCRA

- Manifest document ; records properties of materials, source, destination.
- Permits
- Disposal rules – ideal is “complete destruction”
- NOS – “not otherwise specified”

Waste reduction priorities

i) Eliminate generation

ii) Reduce generation

iii) Reuse/recover (includes energy recovery)

iv) Treat

v) Disposal (includes destruction)

CERCLA/SARA

Priorities – human and environmental health (imminent threat); remediation. Introduced new legal concepts: retroactive, strict,joint-and-several liability.

Retroactive – acts prior to the law are NOT exempt.

Strict – diligence is not a defense; if acceptable in past, still liable into the future.

Joint-and-several – if no single suspect, then all are liable.

Repeated court challenges have failed to strike the new concepts from the law, and CERCLA stands. Engineers must accept provisions and design to meet future regulatory requirements.

Hazardous waste treatment

i) chemical destruction

ii) biological destruction

iii) thermal destruction

iv) phase change

v) stabilization

vi) encapsulation

Physical Methods

i) Sedimentation

ii) Air stripping

iii) Filtration, osmosis, ion exchange

Chemical Methods

i) neutralization (adjust pH)

ii) precipitation

iii) oxidation/reduction

iv) UV oxidization

Biological Methods

Use existing WW treatment technology

Incineration

Thermal destruction

Document History:

Author	**Action**	**Date**	**Archive File Name**
Theodore G. Cleveland	Created	January 24,2003	CIVE3331_Lecture_005.PDF