Lecture 13 - Wastewater Screening, Primary Treatment

General layout for wastewater treatment plant:

```
   "Headworks"  Primary Treatment  Secondary Treatment  Disinfection
          |                      |                |
          | Screening             | Treatment       | Biological Treatment
          | Grid removal          | Settling        |
```

Screening
- Removes large material to:
  1. Protect process equipment
  2. Prevent interference with treatment
  3. Prevent discharge to waterways

Types of screens: (Figure 5.2 from M&E - page 2)

- Coarse screens: (bar rack - Figure 8.1 from Mara - pg 3)
  - May be hand raked for small systems
  - Most are mechanically cleaned
  - Often subject to mechanical problems

Design requires minimum velocity - 0.4 m/s - to keep grit suspended - maintained by downstream weir or flume

Screenings are disposed by landfilling or incineration; sometimes passed through grinder and into waste stream (grinder also called comminutor)

Coarse screens usually have ~5 cm openings
SCREENING

Coarse Screens 6 to 150 mm
  - Hand Cleaned
  - Chain Driven

Microscreens < 50 µm
  - Mechanically Cleaned
  - Reciprocating Rake

Fine Screens < 6 mm
  - Static Wedgewire
  - Drum
  - Step
  - Catenary
  - Continuous Belt

Simple Manually Raked Screen (flow is from left to right)

Figure by MIT OCW.

Adapted from: Mara, D. Domestic Wastewater Treatment in Developing Countries. London, UK: Earthscan, 2005, p. 79.
Coarse screens are sometimes followed by fine screens (≤ 6 mm opening, usually 6 mm).

Fine screens are expensive, high in maintenance. Not used commonly for municipal wastewater.

Fine screens can remove 10-80% TSS. Average removal = 65%.

Grit chambers.

Designed to remove sand, gravel, cinders, coffee grounds, egg shells, other high-density organics and inorganics.

Purposes: 1. Protect moving equipment from abrasion. 2. Reduce deposition in pipelines, channels. 3. Reduce frequency of digester cleaning.

Grit characteristics:

- 0.004 - 0.04 m³ grit/m³ wastewater (higher with combined sewers).
- Solids content = 36 - 80%.
- Volatile content = 1 - 55%.
- Typical density = 2.6 gm/cm³.

Grit chamber design:

Design goal: Provide sufficient detention time for grit to settle and maintain constant velocity to scour organics.
Velocity needed to scour organics given by Camp-Shields equation (Camp, 1942, Grit Chamber Design, Sewage Works Journal, Vol 14, pp. 368-381)

\[ V_c = \sqrt{\frac{8Kgd}{f} \left( \frac{\rho_p - \rho_w}{\rho_w} \right)} \]

- \( V_c \): scour velocity \([\text{L/T}]\)
- \( g \): gravitational acceleration \([\text{L/T}^2]\)
- \( d \): particle diameter \([\text{L}]\)
- \( f \): Darcy-Weisbach friction factor \([-\text{]}\)
- 0.002 for domestic sewage
- \( \rho_p \): particle density \([\text{M/L}^3]\)
- \( \rho_w \): water density \([\text{M/L}^3]\)
- \( K \): empirical constant related to stickiness of organic particles = 0.04 - 0.06

Typically, \( V_c = \) 15 to 30 cm/s for organic particles

Challenge in grit chamber design is to maintain \( V_c \) through fluctuations in flow rate

One alternative = design outflow weir to maintain velocity in rectangular channel

\[ V_c = \frac{Q}{wh} = \text{constant} \]

- \( w \): channel width = constant for rect channel
- \( h \): elevation above weir crest

\[ \Rightarrow wV_c = \frac{Q}{h} = \text{constant} \]

Flow over a weir = \( Q = C_w \sqrt{2gh} \cdot h^{3/2} \cdot W \)

- \( L \): length of weir \perp to flow
- \( C_w \): weir coefficient, which varies with characteristics of weir
- \( C_w \approx 0.4 \) for sharp-crested weir
**Refresher on Weirs:**

Weir = obstruction in channel over which fluid must flow

**Example:**

![Diagram of a sharp-crested weir](image)

**Bernoulli eqn for approach to weir:**

\[
\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + (H+P_W-h) \tag{1}
\]

since at atmospheric P

Total head at surface at Section A is everywhere the same. Therefore, assuming uniform V:

\[
\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_A'}{\rho g} + \frac{V_A'^2}{2g} + Z_A' = \frac{V_A^2}{2g} + H+P_W \tag{2}
\]

Replace L.H.S. of Eq. 1 with R.H.S. of Eq. 2.
\[ \frac{V_A^2}{2g} + H + P_n = \frac{V_B^2}{2g} + H + P_n - h \] (3)

or
\[ \frac{V_B^2}{2g} = \frac{V_A^2}{2g} - h \] (4)

\[ V_B = \sqrt{2g \left( H + \frac{V_A^2}{2g} \right)} \] (6)

For weir with uniform width \( L \)
\[ Q = L \int_{h=0}^{h=H} V_B \, dh \] (6)

\[ = L \int_{h=0}^{h=H} \sqrt{2g \left( H + \frac{V_A^2}{2g} \right)} \, dh \] (7)

\[ = \frac{2}{3} \sqrt{2g} \ L \left[ \left(H + \frac{V_A^2}{2g}\right)^{3/2} - \left(\frac{V_A^2}{2g}\right)^{3/2} \right] \] (8)

If \( \frac{V_A^2}{2g} \ll H \):
\[ Q = \frac{2}{3} \sqrt{2g} \ L \ H^{3/2} \] (9)

To correct for approximations in getting to Eq. 9, add weir coefficient.
\[ Q = C_{wr} \frac{2}{3} \sqrt{2g} \ L \ H^{3/2} \]
\[ = C_w \sqrt{2g} \ L \ H^{3/2} \] (10)
Constant flow velocity is achieved by proportional or Sutro weir

Opening has this shape:

Consider flow in height increment \( \Delta h \):

\[
\Delta Q = V \Delta h \frac{2x}{2gh} \quad \text{From pg 7, eq 5}
\]

\[
= C_w \sqrt{\frac{2gh}{h}} \Delta h \cdot 2x \quad \text{From pg 7, eq 10}
\]

Total flow is

\[
Q = \int_{0}^{h} C_w \sqrt{\frac{2gh}{h}} \cdot 2x \, dh
\]

where \( 2x = \) function of \( h = \frac{K}{\sqrt{h}} \)

\[
Q = \int_{0}^{h} C_w \sqrt{\frac{2gh}{h}} \frac{K}{\sqrt{h}} \, dh
\]

\[
= \sqrt{2g} C_w K \int_{0}^{h} \frac{1}{\sqrt{h}} \, dh = \sqrt{2g} C_w K h
\]

\[
\frac{Q}{h} = \sqrt{2g} C_w K = \text{const}
\]

Thus, weir built to specification \( 2x = \frac{K}{\sqrt{h}} \) will produce constant velocity in upstream channel

Pg 9 (Reynolds & Richards, 1996, Fig 7.9) shows actual vs. theoretical proportional weir design

Pg 10 (Reynolds & Richards, 1996, Fig 7.7) shows grit chamber design with proportional weir

Weir coefficient for proportional weir \( C_w = 0.98 \)
Figure by MIT OCW.
A Horizontal-Velocity Grit Settling Chamber with a Proportional Weir Control Section

Proportional weir
Stop gate
Grit storage

A PLAN

Proportional weir
Weir opening
Weir plate
Section A-A

B PROFILE & CHANNEL CROSS SECTION

Figure by MIT OCW.

Alternative is to have outlet be a Parshall Flume to measure flow into WWTP.

Parshall flume has less head loss than proportional weir and is often preferred for that reason.

Flume design eliminates sediment traps like that before a sharp-crested weir.

Fig 12 shows Parshall Flume (From Henderson, F.M., 1966, Open Channel Flow, MacMillan Publishing Co., NY)

Flow converges, creating critical flow, then diverges, going back to subcritical flow. Critical to subcritical flow creates standing wave.

\[ Q = 4W^{1.522}H_a^{0.026} \]

For flume width \( W = 1 \) to 8 ft

This can be approximated as

\[ Q = KW^{3/2}H_a \]

Configuration in wastewater plant is shown on page 13 (Figure 7.6 from Reynolds & Richards):

Grit removal chamber is followed by Parshall flume which creates head \( H_a = h \) at grit chamber outflow.

As with proportional weir, goal is to design grit chamber to maintain constant velocity over range of \( Q \).
Parshall flume for measuring flow in an open channel by measuring the free-flowing upper head h.

Figure by MIT OCW.

A horizontal-velocity grit settling chamber with a Parshall flume control section.

Figure by MIT OCW.

Flow and head in flume are related as \( Q = K W h^{3/2} \).

Note \( h \) in flume establishes \( h \) in grit chamber.

In grit chamber \( V_c = \frac{Q}{A} \).

Need to find chamber x-section shape such that \( Q/A \) is constant for all \( Q \).

Differentiate weir equation to get incremental flow over depth interval \( dh \):

\( dQ = \frac{3}{2} K W h^{1/2} dh \quad \text{W is flume width} \)

Flow through channel x-section must be the same:

\( dQ = V_c x dh = \frac{3}{2} K W h^{1/2} dh \)

\( x = \text{width of x-section at height } h \)

\( x = \left( \frac{3 K W}{2 V_c} \right)^{1/2} \times 15 \text{ channel width (upstream of flume)} \)

This defines parabolic x-section:

In practice, parabolic section is approximated by trapezoidal section for ease of construction—see Figure 7.10 of Reynolds & Richards — pg. 15.
Ideal parabolic cross section and design cross section for chamber with a Parshall flume.

Figure by MIT OCW.

Flow equalization

WWTP performance is improved if difference between nighttime low flow and morning high flow is reduced.

This is achieved by in-line or off-line flow equalization (pg 17 - Figure 7.17 from R1R).

Equalization basins store excess flow for later treatment.

Design by examining cumulative flow over one day.

Alternatively, integrate part of $Q$ vs. $t$ curve for $Q > Q_{ave}$ (pg 18, Figure 7.19 from R1R).
FLUCTUATING VOLUME DETERMINED BY HYDROGRAPH

Figure by MIT OCW.