Sedimentation

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Simple Sorting

- Goal: clean water
- Source: (contaminated) surface water
- Solution: separate contaminants from water
- How?

Where are we?

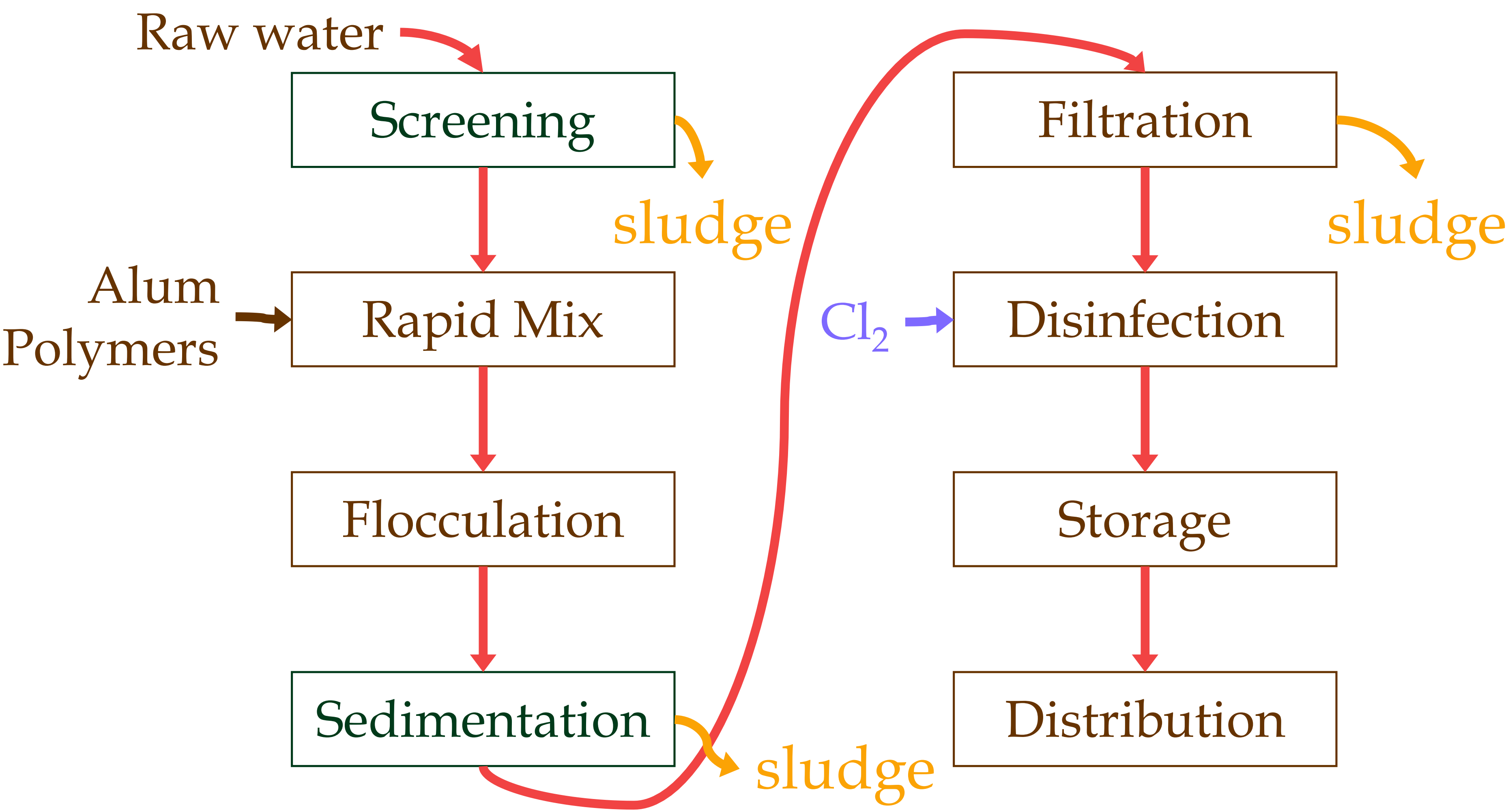
- Unit processes* designed to
  - remove _Particles and pathogens_
  - remove _dissolved chemicals_
  - inactivate _pathogens_
- *Unit process: a process that is used in similar ways in many different applications
- Unit Processes Designed to Remove Particulate Matter
  - Screening
  - Coagulation/flocculation
  - Sedimentation
  - Filtration

Empirical design

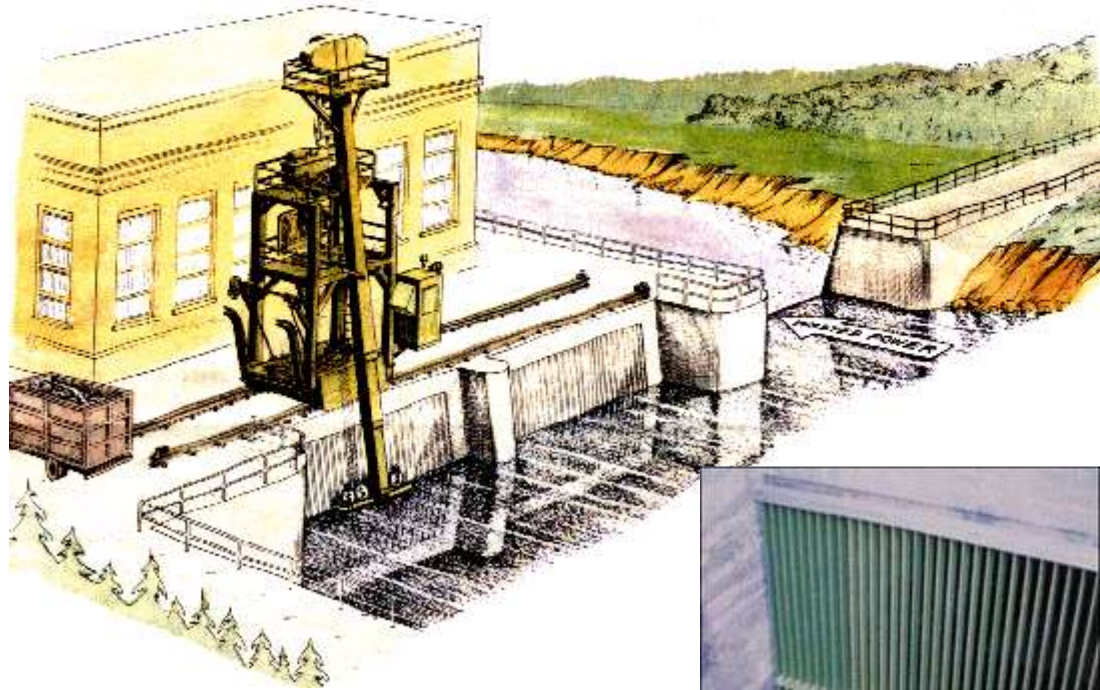
Theories developed later

Smaller particles

Conventional Surface Water Treatment



Screening

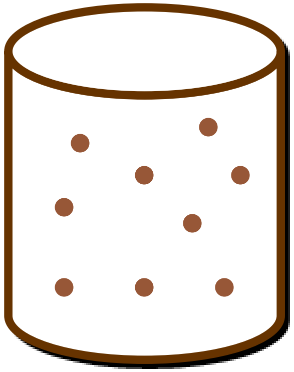


- Removes large solids
  - logs
  - branches
  - rags
  - fish
- Simple process
  - may incorporate a mechanized trash removal system
- Protects pumps and pipes in WTP

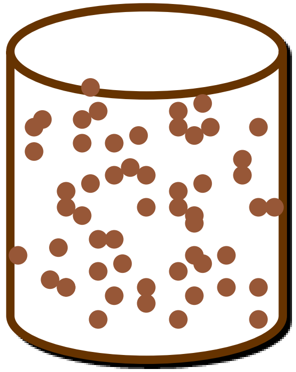
Sedimentation

- the oldest form of water treatment
- uses gravity to separate particles from water
- often follows coagulation and flocculation

Sedimentation: Effect of the particle concentration



- Dilute suspensions
  - Particles act independently
- Concentrated suspensions
  - Particle-particle interactions are significant
  - Particles may collide and stick together (form flocs)
  - Particle flocs may settle more quickly
  - At very high concentrations particle-particle forces may prevent further consolidation



Sedimentation:
Particle Terminal Fall Velocity

$$\sum F = ma$$

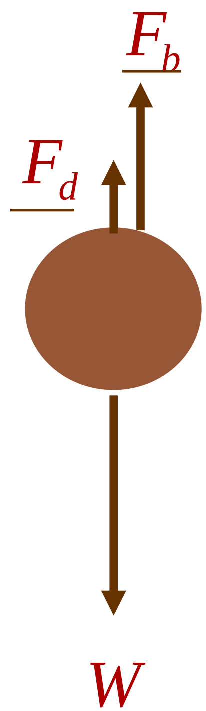
$$\underline{F_d + F_b - W = 0}$$

$$W = \underline{\forall_p \rho_p g}$$

$$F_b = \underline{\forall_p \rho_w g}$$

$$F_d = C_D A_P \rho_w \frac{V_t^2}{2}$$

Identify forces



$\forall_p$ = particle volume

projected

A_p = particle cross sectional area

ρ_p = particle density

ρ_w = water density

g = acceleration due to gravity

C_D = drag coefficient

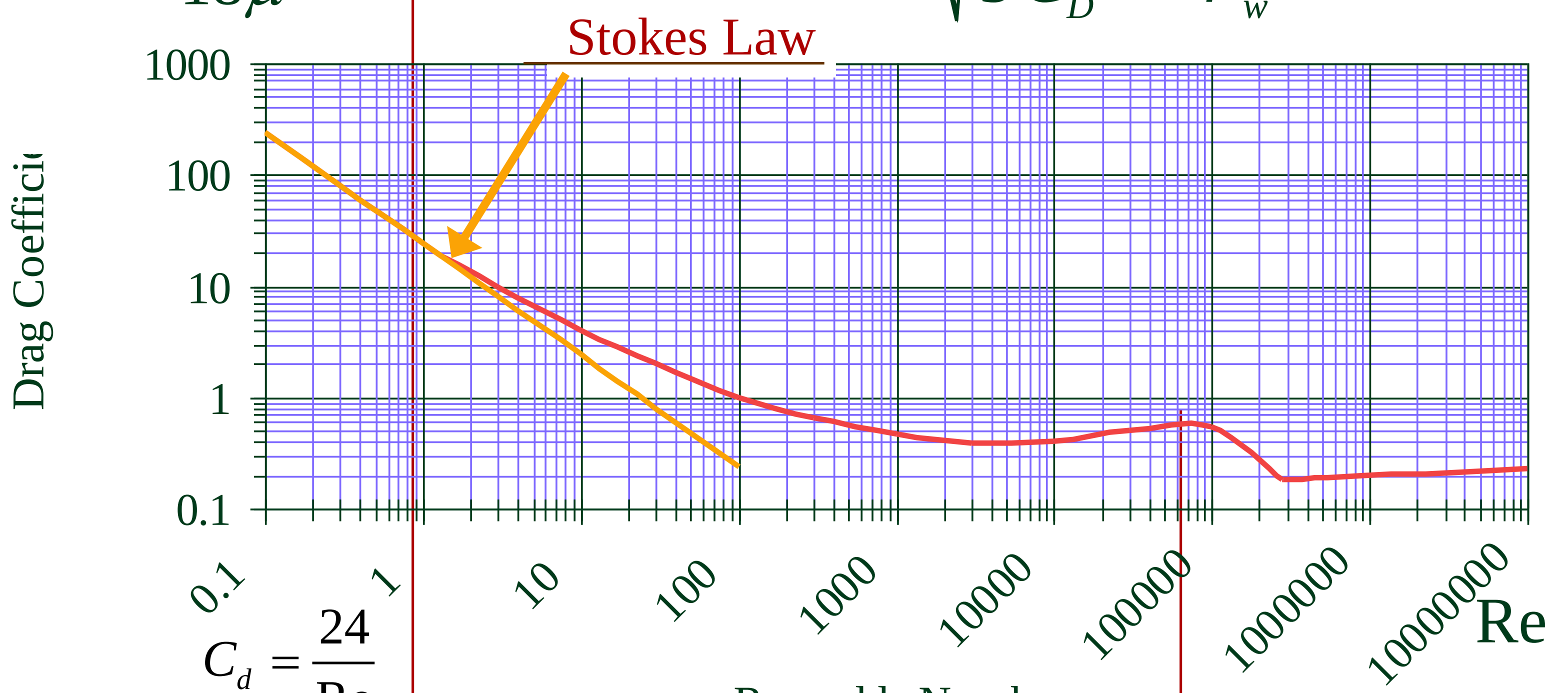
V_t = particle terminal velocity

$$V_t = \sqrt{\frac{4}{3}\frac{gd}{C_D}\frac{(\rho_p - \rho_w)}{\rho_w}}$$

Drag Coefficient on a Sphere

$$V_t = \frac{d^2 g(\rho_p - \rho_w)}{18\mu}$$

$$V_t = \sqrt{\frac{4}{3}\frac{gd}{C_D}\frac{(r_p - r_w)}{r_w}}$$



$$C_d = \frac{24}{\text{Re}}$$

$$\text{Re} = \frac{V_t d\rho}{\mu}$$

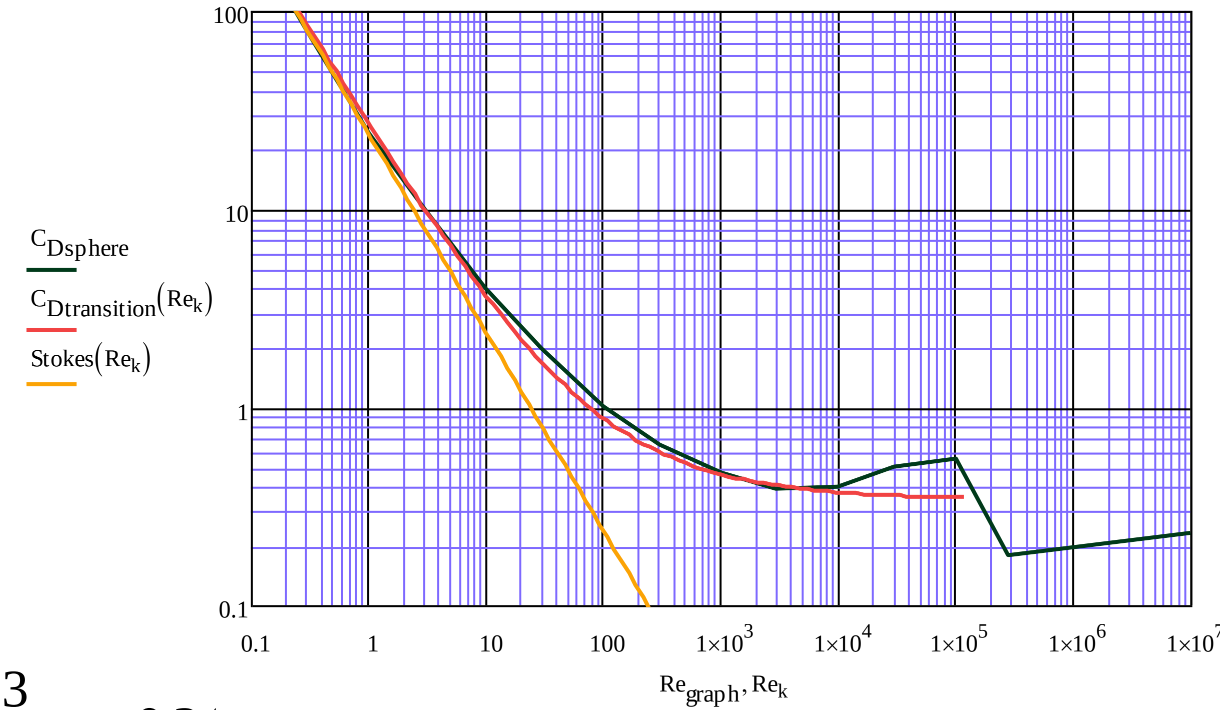
laminar

turbulent

turbulent boundary

Floc Drag

Flocs created in the water treatment process can have Re exceeding 1 and thus their terminal velocity must be modeled using



$$C_{.Dtransition}(Re) := \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$$

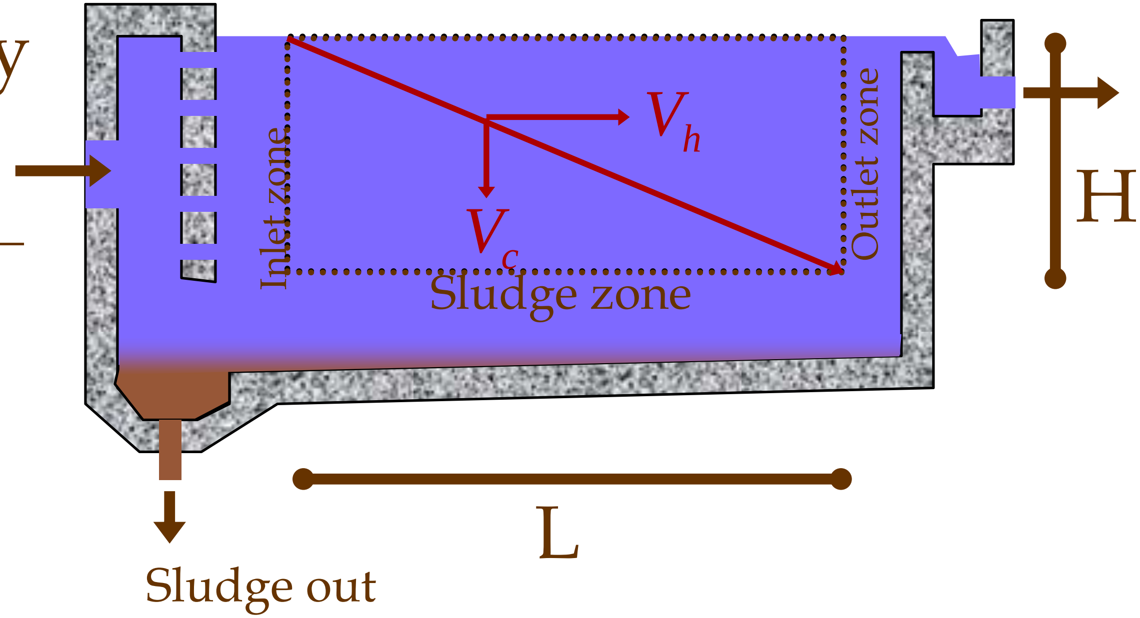
Sedimentation Basin: Critical Path

- Horizontal velocity

$$V_h = \frac{Q}{A}$$

$Q \rightarrow$ flow rate

$A \rightarrow$ WH



- Vertical velocity

V_c = particle velocity that just barely gets captured

What is V_c for this sedimentation tank? $V_c = \frac{H}{\theta}$

Sedimentation Basin: Importance of Tank Surface Area

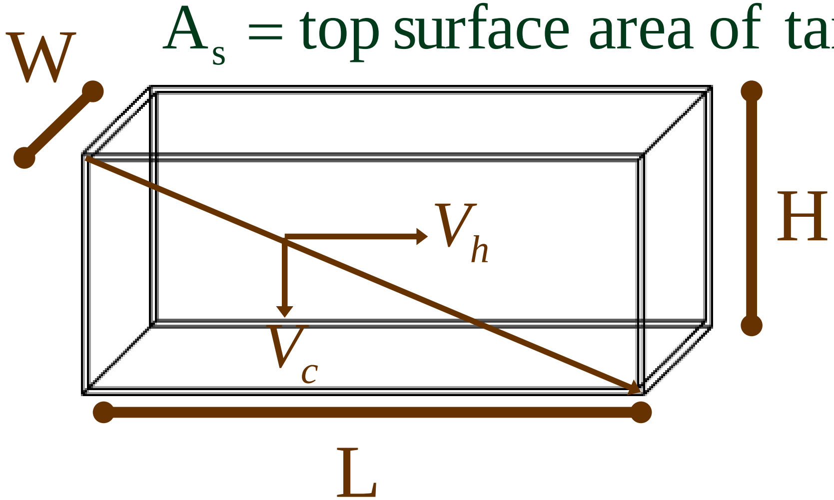
$$\theta = \frac{\forall}{Q}$$ Time in tank

θ = residence time

$\forall = WHL$ = volume of tank

A_s = top surface area of tank

$$V_c = \frac{H}{\theta} = \frac{HQ}{\forall} = \frac{Q}{LW} = \frac{Q}{A_s}$$



V_c is a property of the sedimentation tank!

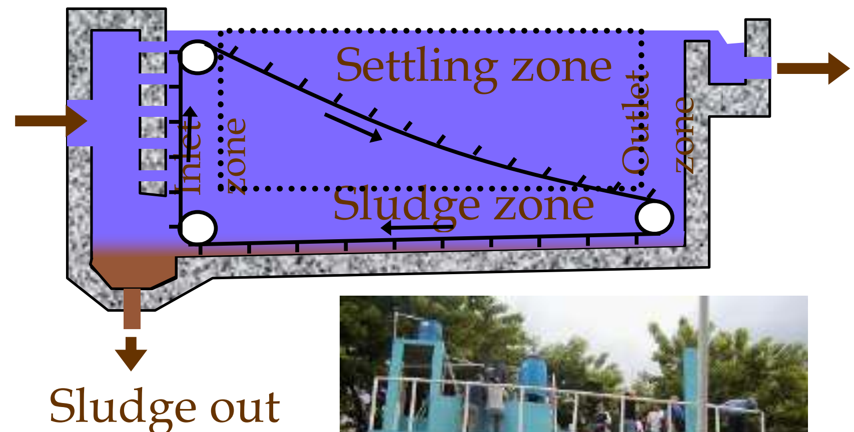
Want a small V_c, large A_s, small H, large θ.

Suppose water were flowing up through a sedimentation tank. What would be the velocity of a particle that is just barely removed?

$$V_c = \frac{Q}{A_s}$$

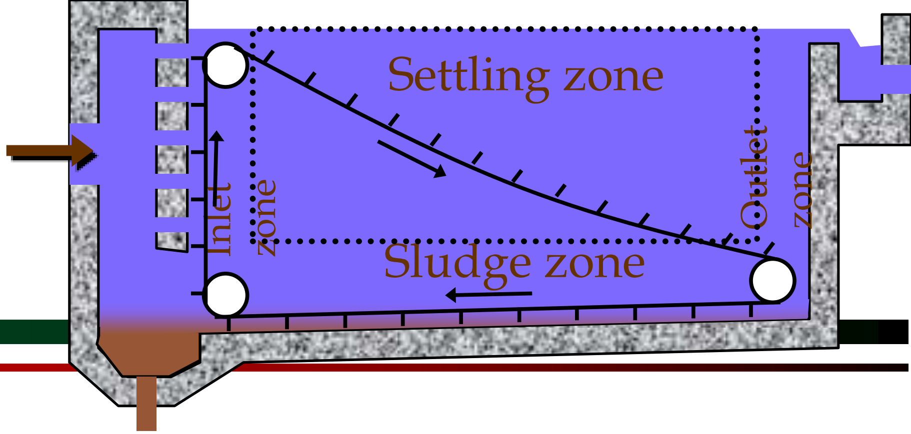
Conventional Sedimentation Basin

- long rectangular basins
- 4-6 hour retention time
- 3-4 m deep
- max of 12 m wide
- max of 48 m long
- What is V_c for conventional design?



$$V_c = \frac{\quad}{\quad} = \frac{\quad}{\quad}\frac{\quad}{\quad} = 18\, m/day$$

Design Criteria for Horizontal Flow Sedimentation Tanks



- Minimal turbulence (inlet baffles)
- Uniform velocity (small dimensions normal to velocity)
- No scour of settled particles
- Slow moving particle collection system
- Q/A_s must be small (to capture small particles)
- V_c of 20 to 60 m/day*
- Residence time of 1.5 to 3 hours*

* Schulz and Okun

And don't break flocs at inlet!

Sedimentation Tank particle capture

- What is the size of the smallest floc that can be reliably captured by a tank with critical velocity of 60 m/day?
- We need a measure of real water treatment floc terminal velocities
- Research…

Physical Characteristics of Floc: The Floc Density Function

- Tambo, N. and Y. Watanabe (1979). "Physical characteristics of flocs--I. The floc density function and aluminum floc." Water Research **13**(5): 409-419.
- Measured floc density based on sedimentation velocity (Our real interest!)
- Flocs were prepared from kaolin clay and alum at neutral pH
- Floc diameters were measured by projected area

Floc Density Function: Dimensional Analysis!

- Floc density is a function of
  floc size
- Make the density dimensionless $\dfrac{\rho_{floc} - \rho_w}{\rho_w}$
- Make the floc size dimensionless $\dfrac{d_{floc}}{d_{clay}}$
- Write the functional relationship

$$\left(\frac{\rho_{floc} - \rho_w}{\rho_w}\right) = f\left(\frac{d_{floc}}{d_{clay}}\right)$$

- After looking at the data conclude that a power law relationship is appropriate

$$\left(\frac{\rho_{floc} - \rho_w}{\rho_w}\right) = a\left(\frac{d_{floc}}{d_{clay}}\right)^{n_d}$$

Model Results

$$\left(\frac{\rho_{floc}-\rho_w}{\rho_w}\right)=a\left(\frac{d_{floc}}{d_{clay}}\right)^{n_d}$$

- For clay assume d_{clay} was 3.5 μm (based on Tambo and Watanabe)
- a is 10 and n_d is -1.25 (obtained by fitting the dimensionless model to their data)
- The coefficient of variation for predicted dimensionless density is
  - 0.2 for d_{floc}/d_{clay} of 30 and
  - 0.7 for d_{floc}/d_{clay} of 1500
- The model is valid for _clay/alum_ flocs in the size range 0.1 mm to 3 mm

Additional Model Limitation

- This model is simplistic and doesn't include
  - Density of clay
  - Ratio of alum concentration to clay concentration
  - Method of floc formation
- Data doesn't justify a more sophisticated model
- Are big flocs formed from a few medium sized flocs or directly from many clay particles?
  - Flocs that are formed from smaller flocs may tend to be less dense than flocs that are formed from accumulation of (alum coated) clay particles

Model Results → Terminal Velocity

$$V_t = \sqrt{\frac{4}{3}\underbrace{\frac{gd}{C_D}}\underbrace{\frac{\left(\rho_{floc}-\rho_w\right)}{\rho_w}}}$$

$$\left(\frac{\rho_{floc}-\rho_w}{\rho_w}\right) = a\left(\frac{d_{floc}}{d_{clay}}\right)^{n_d}$$

$$C_d = \left(\frac{24}{\mathrm{Re}} + \frac{3}{\sqrt{\mathrm{Re}}} + 0.34\right)\Theta$$

$$\mathrm{Re} = \frac{V_t d_{floc}}{\nu}$$

Θ = shape factor (1 for spheres)

Requires iterative solution for velocity

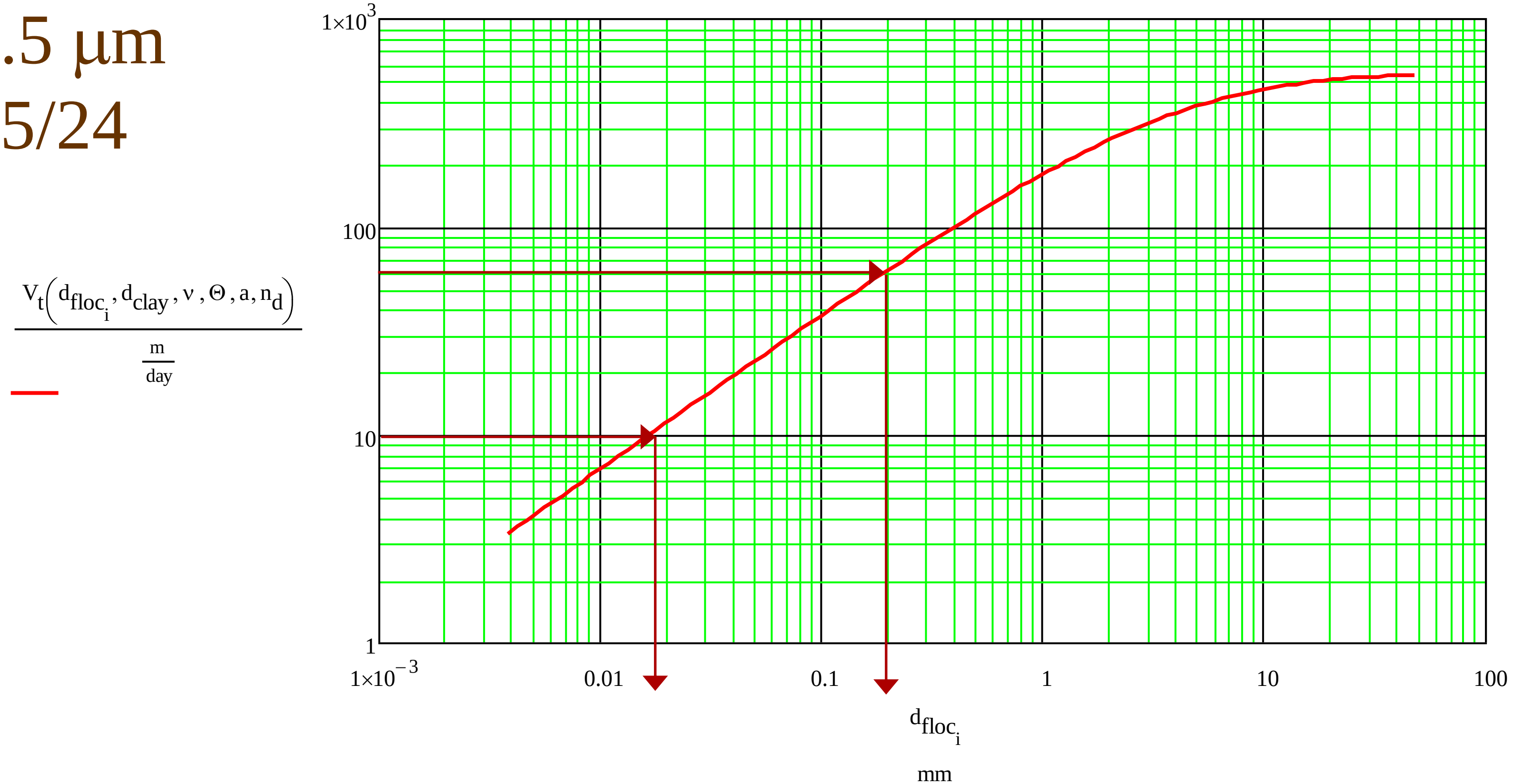
Floc Sedimentation Velocity

a: 10

n_d: -1.25

d_{clay}: 3.5 μm

Θ: 45/24

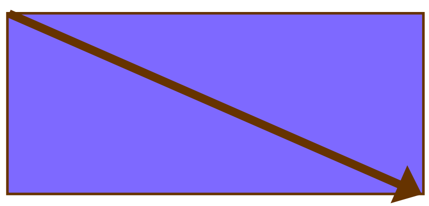


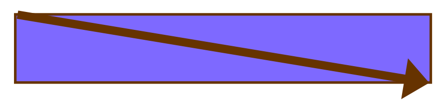
Floc density summary

- Given a critical velocity for a sedimentation tank (V_c) we can estimate the smallest particles that we will be able to capture
- This is turn connects back to flocculator design
- We need flocculators that can reliably produce large flocs so the sedimentation tank can remove them

Flocculation/Sedimentation: Deep vs. Shallow

- Compare the expected performance of shallow and deep horizontal flow sedimentation tanks assuming they have the same critical velocity (same Q and same surface area)





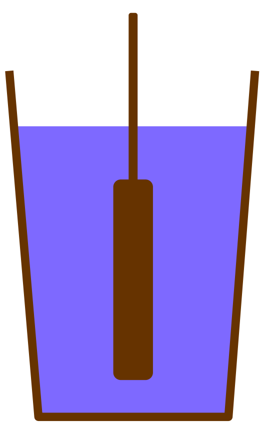
More opportunities to collide with other particles by differential sedimentation or Brownian motion

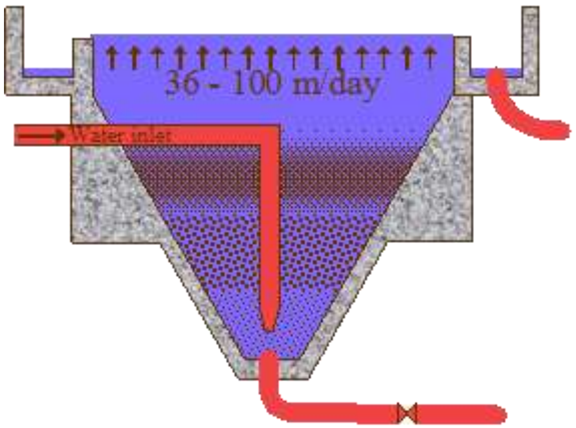
Expect the deeper tank to perform better!

But the deep tank is expensive to make and hard to get uniform flow!

Flocculation/Sedimentation: Batch vs. Upflow

- Compare the expected performance of a batch (bucket) and an upflow clarifier assuming they have the same critical velocity
- How could you improve the performance of the batch flocculation/sedimentation tank?

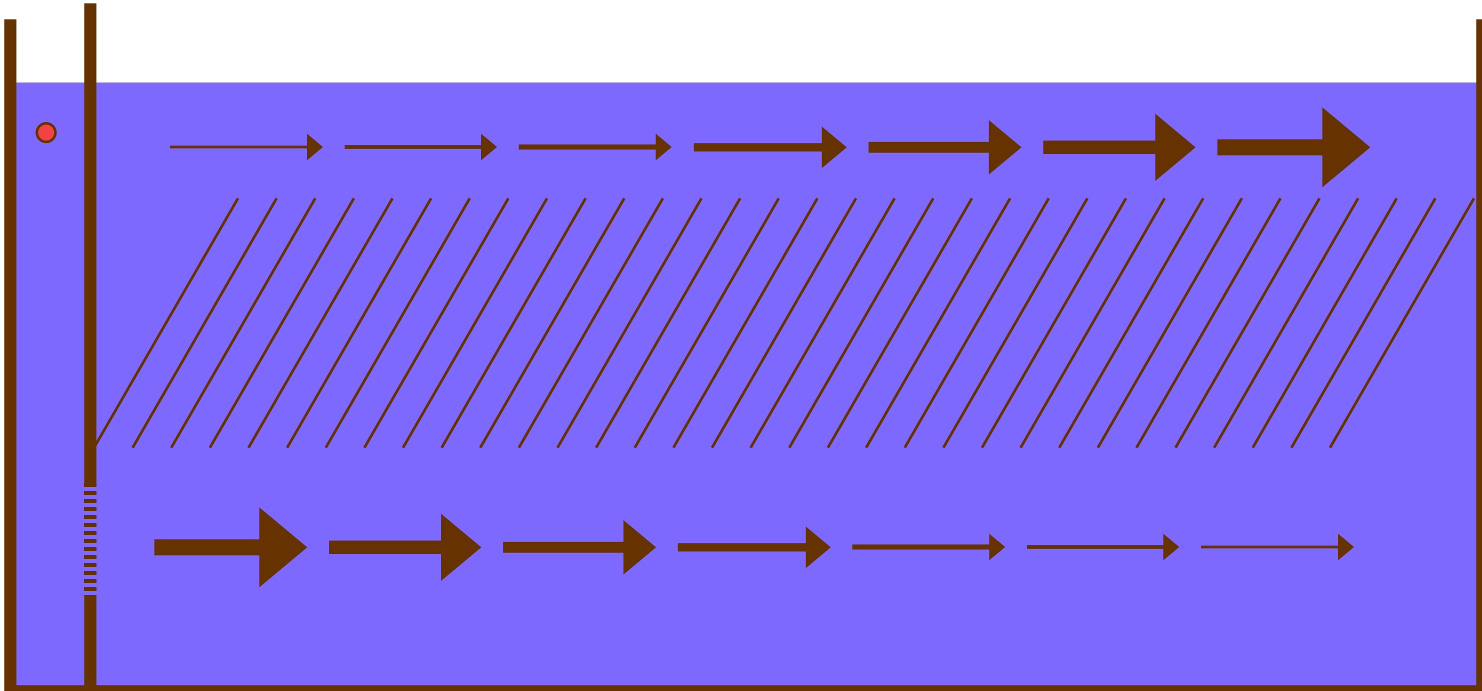




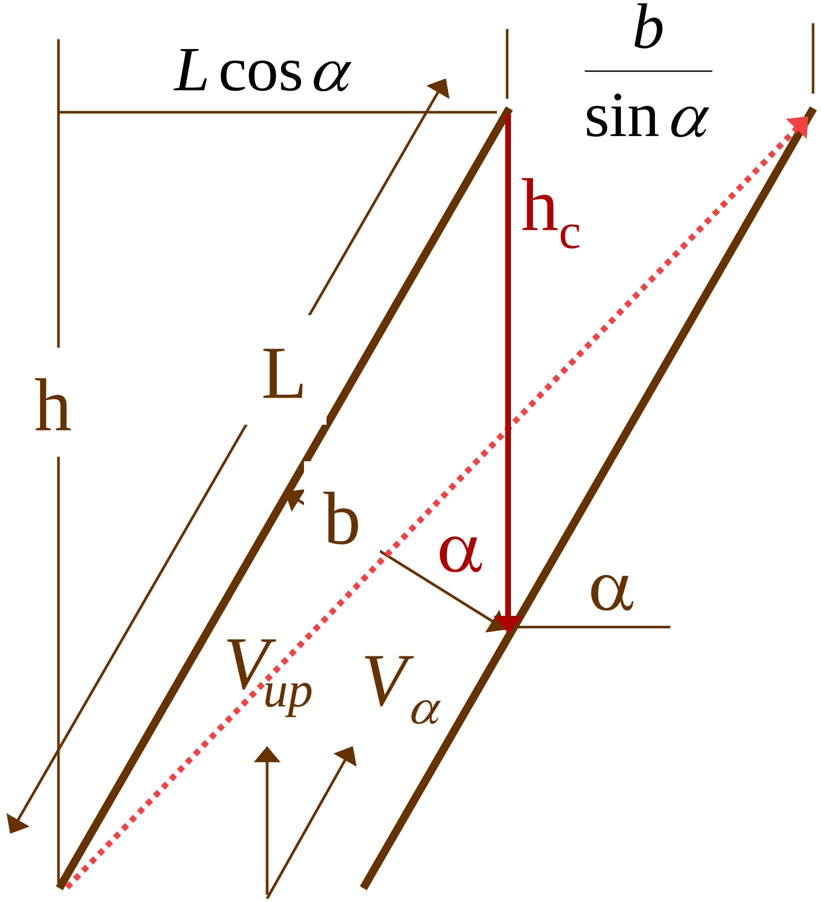
Lamella

- Sedimentation tanks are commonly divided into layers of shallow tanks (lamella)
- The flow rate can be increased while still obtaining excellent particle removal

Lamella decrease distance particle has to fall in order to be removed



Defining critical velocity for plate and tube settlers



Path for critical particle?

How far must particle settle to reach lower plate?

$$\cos\alpha = \frac{b}{h_c} \qquad h_c = \frac{b}{\cos\alpha}$$

What is total vertical distance that particle will travel?

$$h = L\sin\alpha$$

What is net vertical velocity?

$$V_{net} = V_{up} - V_c$$

Compare times

Time to travel distance h_c = Time to travel distance h

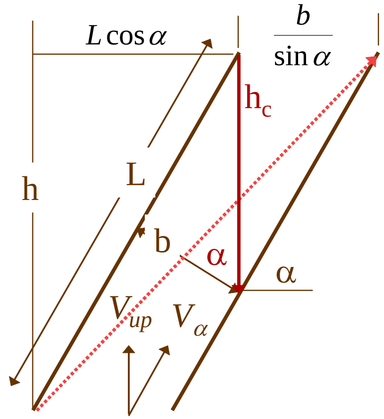
$$\frac{h_c}{V_c} = \frac{h}{V_{up} - V_c}$$

$$\frac{b}{V_c \cos\alpha} = \frac{L\sin\alpha}{V_{up} - V_c}$$

$$bV_{up} - bV_c = L\sin\alpha V_c \cos\alpha$$

$$bV_{up} = (L\sin\alpha\cos\alpha + b)V_c$$

$$V_c = \frac{bV_{up}}{L\sin\alpha\cos\alpha + b}$$



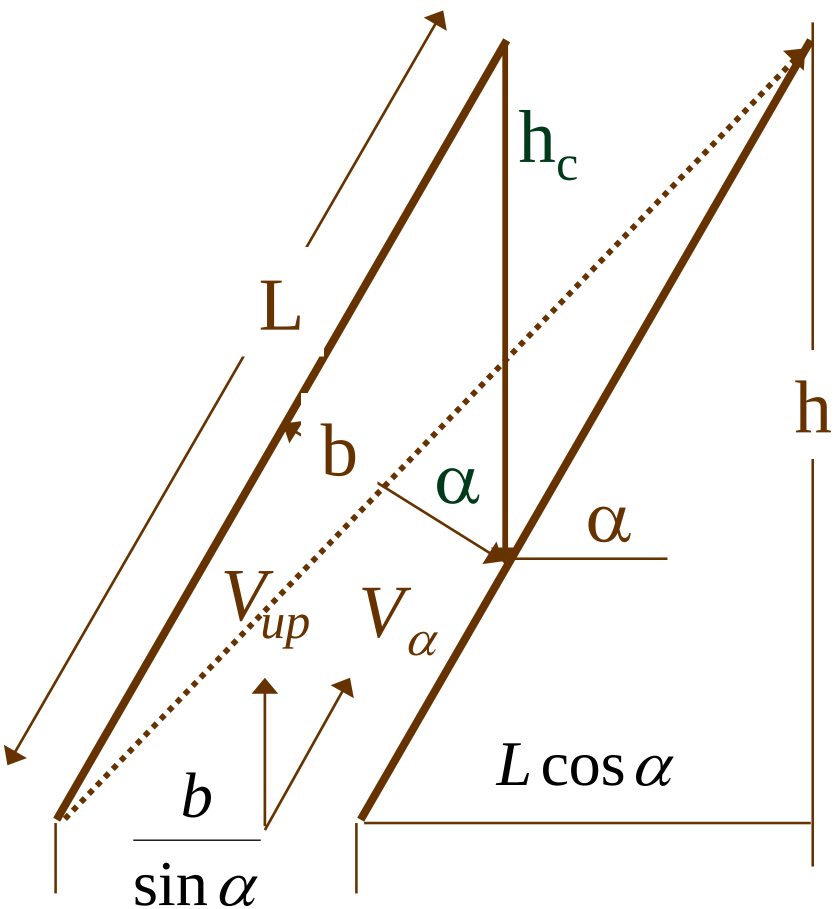
$$h_c = \frac{b}{\cos\alpha}$$

$$h = L\sin\alpha$$

$$\frac{V_{up}}{V_c} = 1 + \frac{L}{b}\cos\alpha\sin\alpha$$

Comparison with Q/A_s

A_s is horizontal area over which particles can settle



$$Q = V_\alpha b w$$

$$\frac{V_{up}}{V_\alpha} = \sin\alpha \qquad Q = \frac{V_{up} b w}{\sin\alpha}$$

$$A = \left(L\cos\alpha + \frac{b}{\sin\alpha} \right) w$$

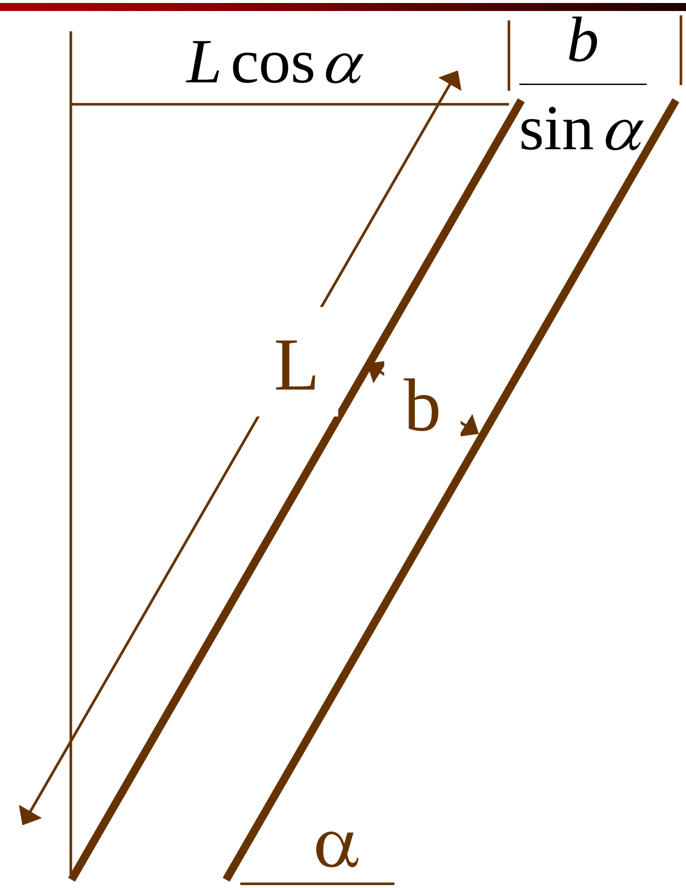
$$V_c = \frac{Q}{A} = \frac{V_{up} b w}{\sin\alpha} \frac{1}{\left(L\cos\alpha + \frac{b}{\sin\alpha} \right) w}$$

$$V_c = \frac{V_{up} b}{L\cos\alpha\sin\alpha + b}$$

Same answer!

Performance ratio (conventional to plate/tube settlers)

- Compare the area on which a particle can be removed
- Use a single lamella to simplify the comparison



Conventional capture area

$$A_{conventional} = w\frac{b}{\sin\alpha}$$

Plate/tube capture area

$$A_{tube} = w\frac{b}{\sin\alpha} + wL\cos\alpha$$

$$A_{ratio} = 1 + \frac{L}{b}\cos\alpha\sin\alpha$$

Critical Velocity Debate?

$$V_c = \frac{V_\alpha}{\frac{L}{b}\cos\alpha + \sin\alpha}$$

Schulz and Okun

Water Quality and Treatment (1999)

$$\frac{V_{up}}{V_c} = 1 + \frac{L}{b}\frac{\cos\alpha}{\sin\alpha}$$

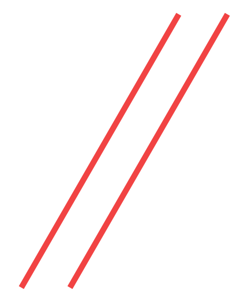
WQ&T shows this geometry

But has this equation

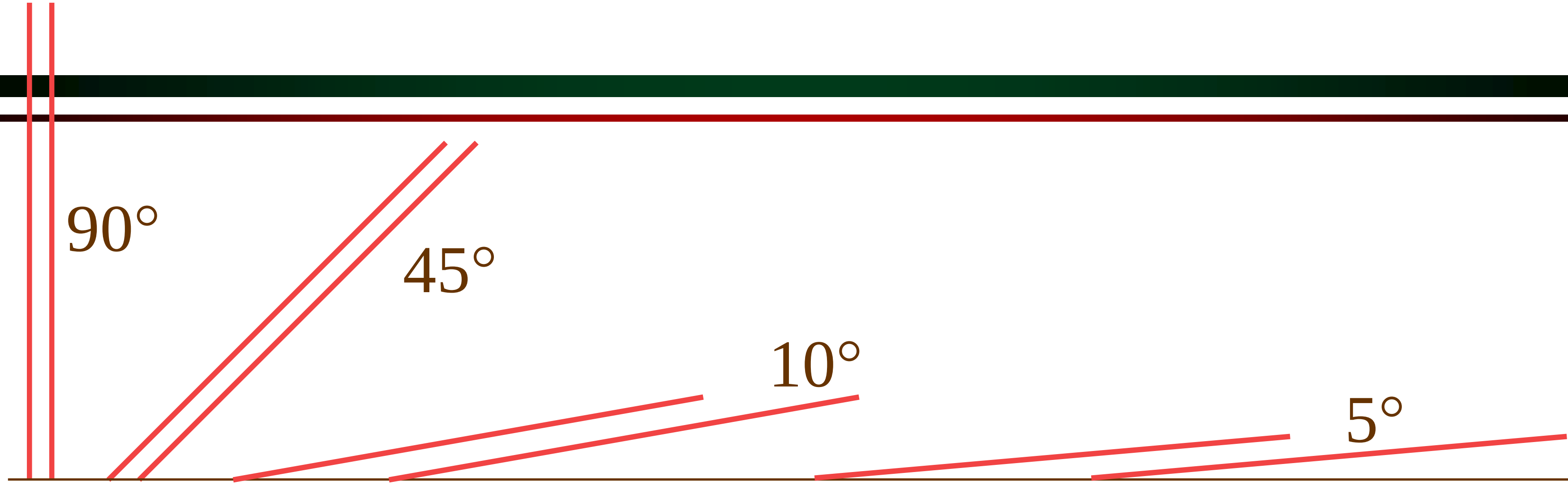
$$\frac{V_{up}}{V_c} = 1 + \frac{L}{b}\cos\alpha\sin\alpha$$

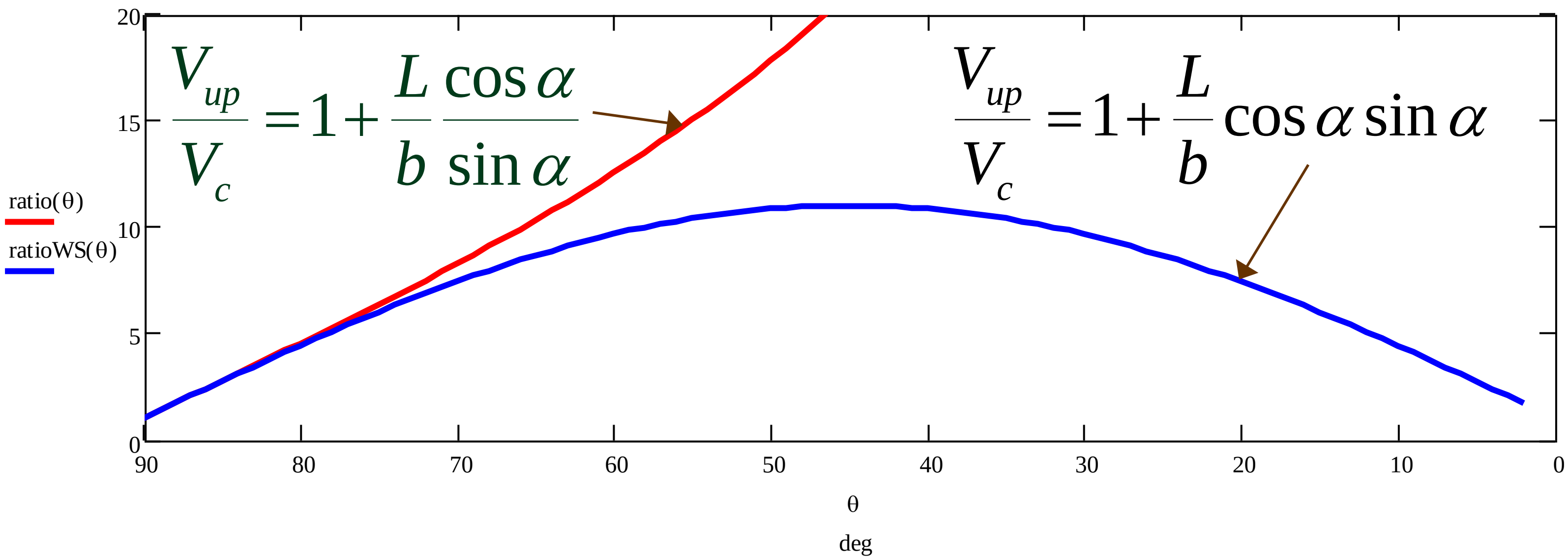
Weber-Shirk

Assume that the geometry is



Check the extremes!





Critical Velocity Guidelines

- Based on tube settlers
  - 10 – 30 m/day http://www.brentwoodprocess.com/tubesystems_main.html
- Based on Horizontal flow tanks
  - 20 to 60 m/day Schulz and Okun
- Unclear why horizontal flow tanks have a higher rating than tube settlers
- Could be slow adoption of tube settler potential
- Could be upflow velocity that prevents particle sedimentation in the zone below the plate settlers

Problems with Big Tanks

$$R_h = \frac{A}{P}$$

- To approximate plug flow and to avoid short circuiting through a tank the hydraulic radius should be much smaller than the length of the tank
- Long pipes work well!
- V_c performance of large scale sedimentation tanks is expected to be 3 times less than obtained in laboratory sedimentation tanks*
- Plate and tube settlers should have much better flow characteristics than big open horizontal flow sedimentation tanks

Goal of laminar flow to avoid floc resuspension

Is Re a design constraint?

$$\frac{V_{up}}{V_\alpha} = \sin\alpha$$

$$\frac{V_{up}}{V_c} = 1 + \frac{L}{b}\cos\alpha\sin\alpha$$

$$\mathrm{Re} = \frac{V_\alpha 4R_h}{\nu}$$

$$R_h = \frac{Area}{Wet\ Perimeter}$$

$$V_c = 30\ m/day$$

$$L = 1\ m$$

$$b = 5\ cm$$

$$\alpha = 60^\circ$$

$$\mathrm{Re} = \frac{V_\alpha 2b}{\nu}$$

$$R_h = \frac{b * w}{2w} = \frac{b}{2}$$

$$V_\alpha = V_c\left(\frac{1}{\sin\alpha} + \frac{L}{b}\cos\alpha\right)$$

$$\mathrm{Re} = \frac{2bV_c\left(\frac{1}{\sin\alpha} + \frac{L}{b}\cos\alpha\right)}{\nu} = 390$$

Re is laminar for typical designs, not a design constraint

Mysterious Recommendations

- Re must be less than 280 (Arboleda, 1983 as referenced in Schulz and Okun)
- The entrance region should be discounted due to “possible turbulence” (Yao, 1973 as referenced in Schulz and Okun)

$$\frac{L}{b}_{useful} = \frac{L}{b} - 0.13\,\mathrm{Re}$$

But this isn’t about turbulence (see next slide)!!!

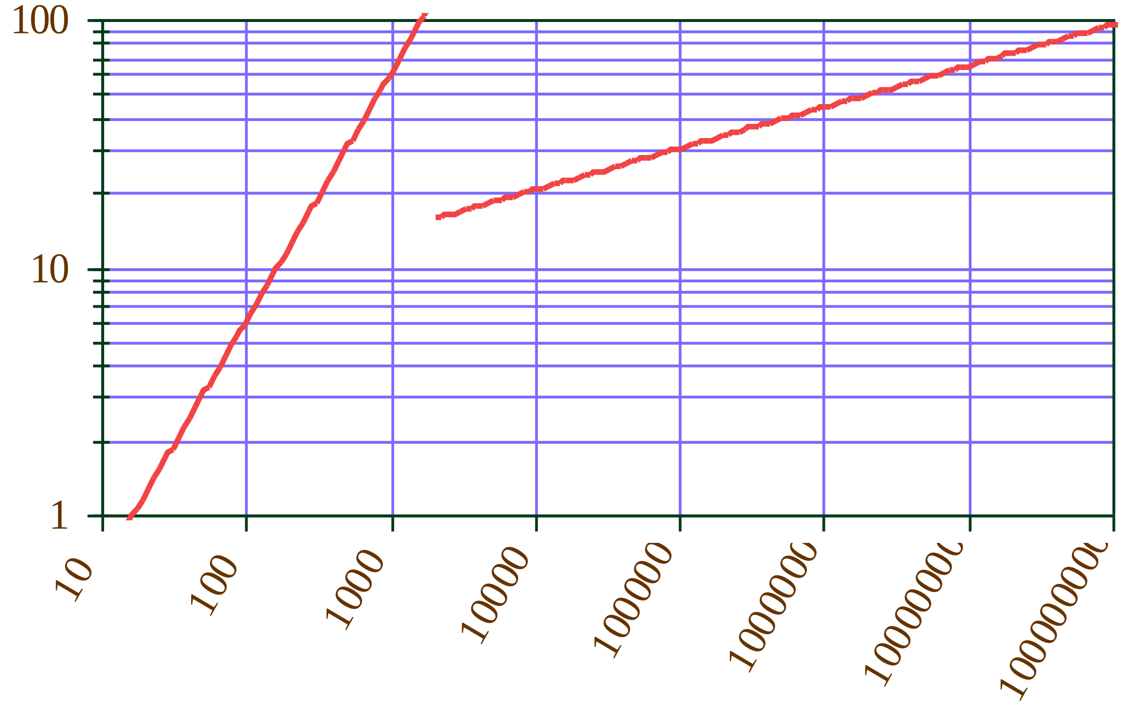
At a Re of 280 we discard 36 and a typical L/b is 20 so this doesn’t make sense

Entrance Region Length

$$\frac{l_e}{D} = f\left(\text{Re}\right) \longrightarrow \frac{l_e}{D} = 0.06\,\text{Re}$$

$$\frac{l_e}{D} = 4.4\left(\text{Re}\right)^{1/6}$$

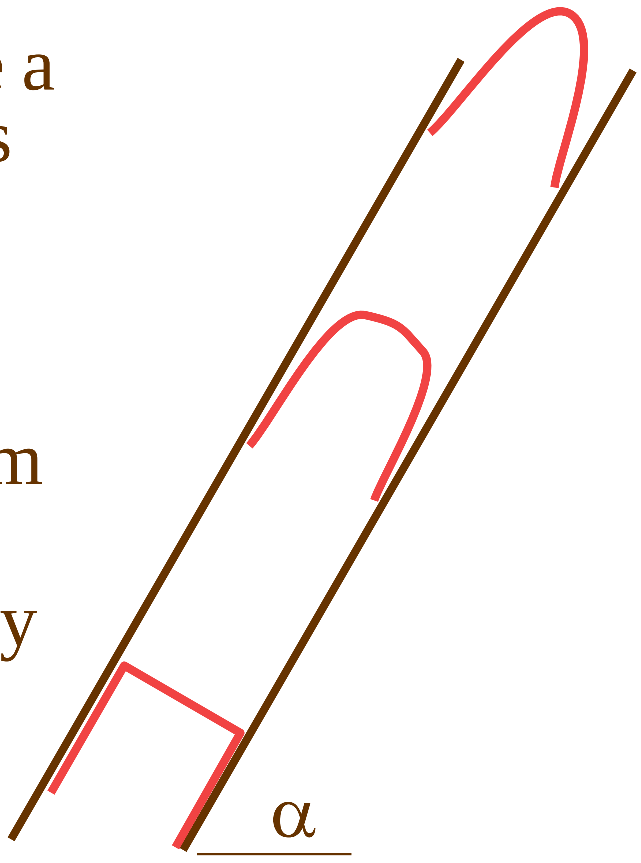
Distance for velocity profile to develop



$$\frac{l_e}{b} = 0.12\,\text{Re}$$

Entrance region

- The distance required to produce a velocity profile that then remains unchanged
- Laminar flow velocity profile is parabolic
- Velocity profile begins as uniform flow
- Tube and plate settlers are usually not long enough to get to the parabolic velocity profile



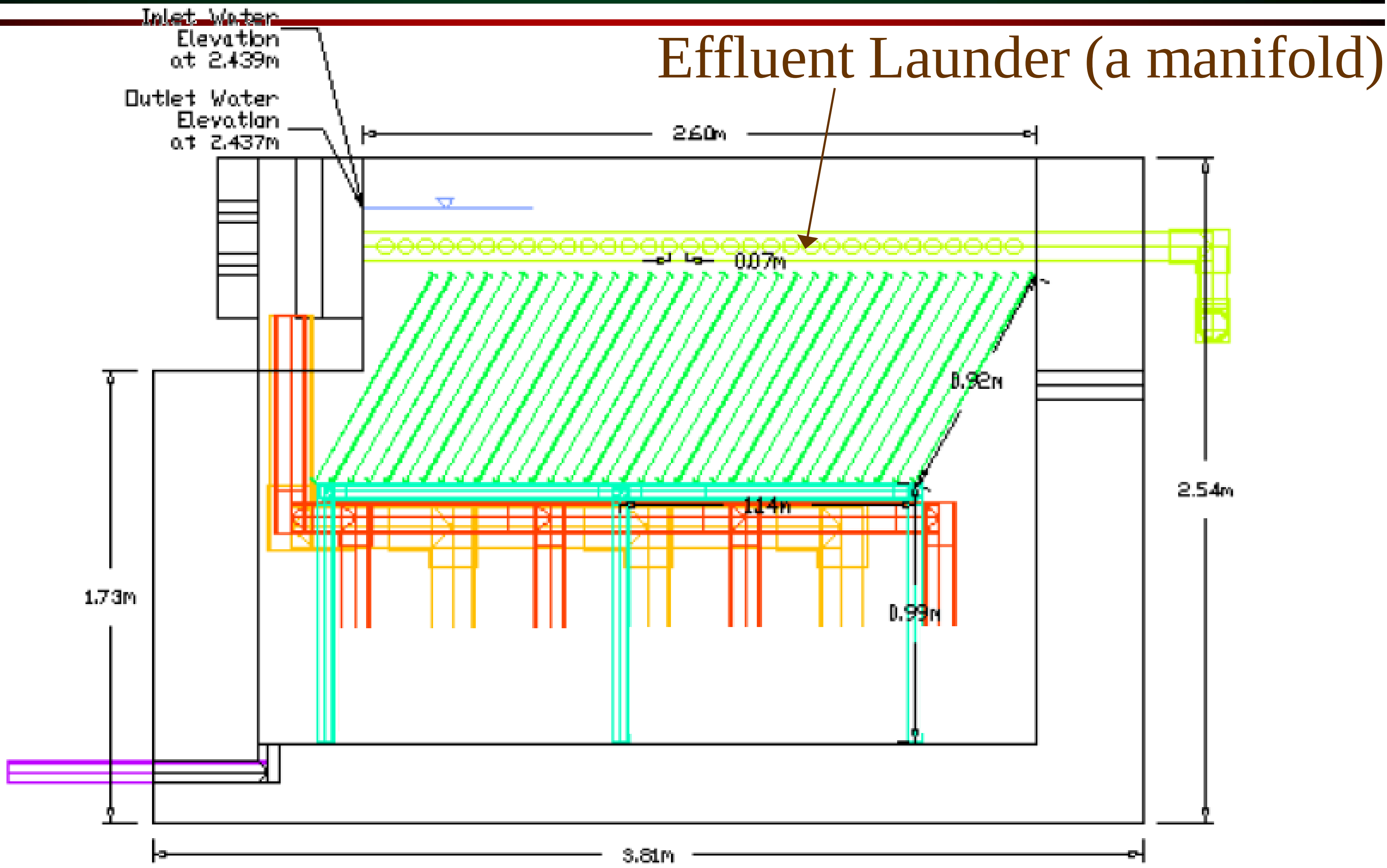
Lamella Design Strategy

- Angle is approximately 60° to get solids to slide down the incline
- Lamella spacing of 5 cm (b)
- L varies between 0.6 and 1.2 m
- V_c of 10-30 m/day
- Find V_{up} through active area of tank
- Find active area of sed tank
- Add area of tank required for angled plates: add L*cos(α) to tank length

$$V_{up} = V_c\left(1 + \frac{L}{b}\cos\alpha\sin\alpha\right)$$

$$A_{active} = \frac{Q_{tank}}{V_{up}}$$

Sedimentation tank cross section



Design starting with Vup

- The value of the vertical velocity is important in determining the effectiveness of sludge blankets and thus it may be advantageous to begin with a specified Vup and a specified Vc and then solve for L/b

Equations relating Velocities and geometry

$$\frac{V_{up_{active}}}{V_c} = 1 + \frac{L_{lamella}}{b} \cos\alpha \sin\alpha$$

Lamella gain

$$\frac{V_{up_{active}}}{V_{up}} = \frac{L_{total}}{L_{active}}$$

Continuity (Lengths are sed tank lengths)

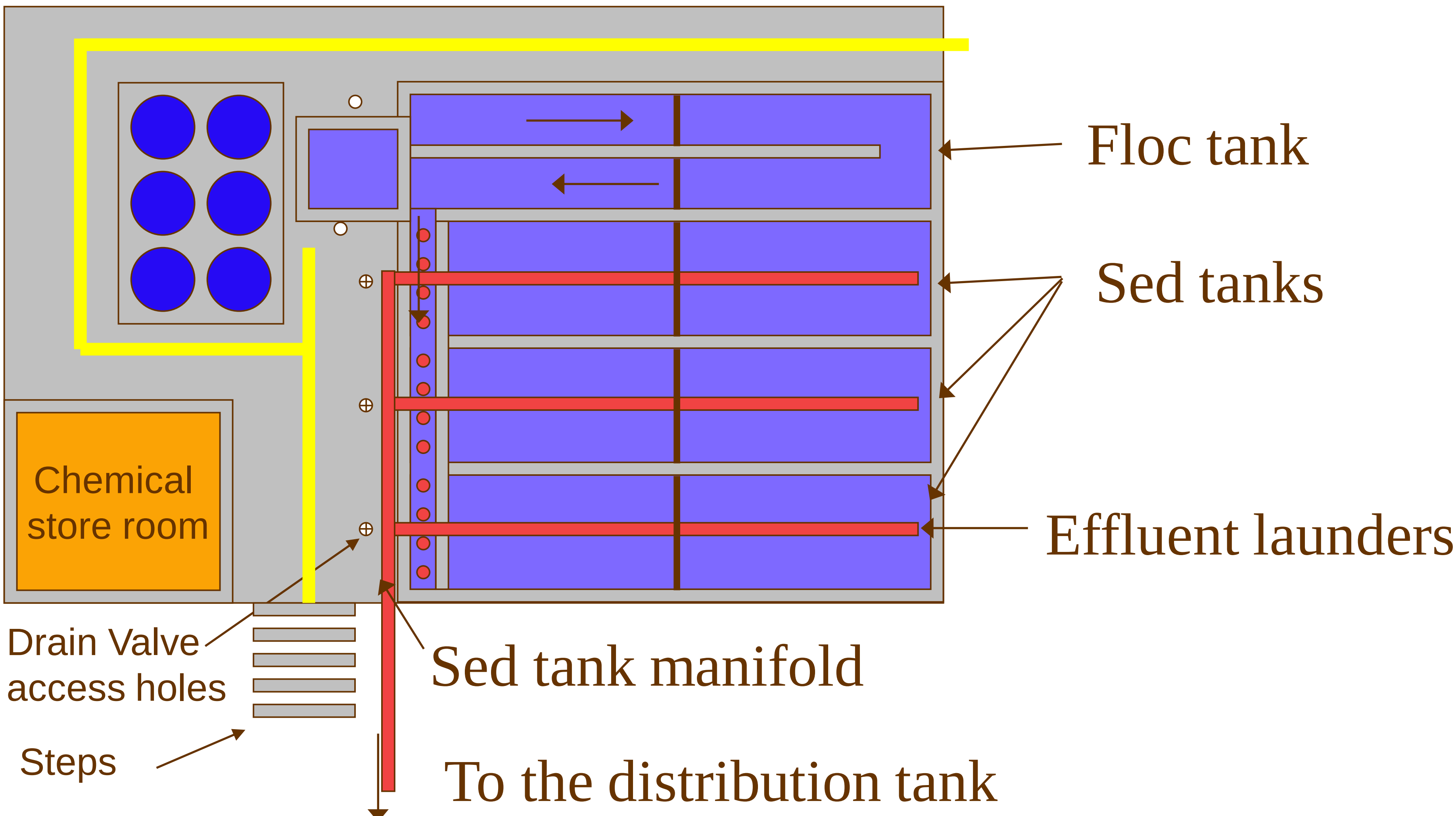
$$L_{active} = L_{total} - L_{lamella} \cos\alpha$$

Designing a plate settler

- w_{plate}
- b_{plate}
- L_{plate}
- Q_{plant}
- N_{tanks}
- α

- Vertical space in the sedimentation tank divided between
  - sludge storage and collection
  - flow distribution
  - Plates
  - flow collection

AguaClara Plant Layout (draft)

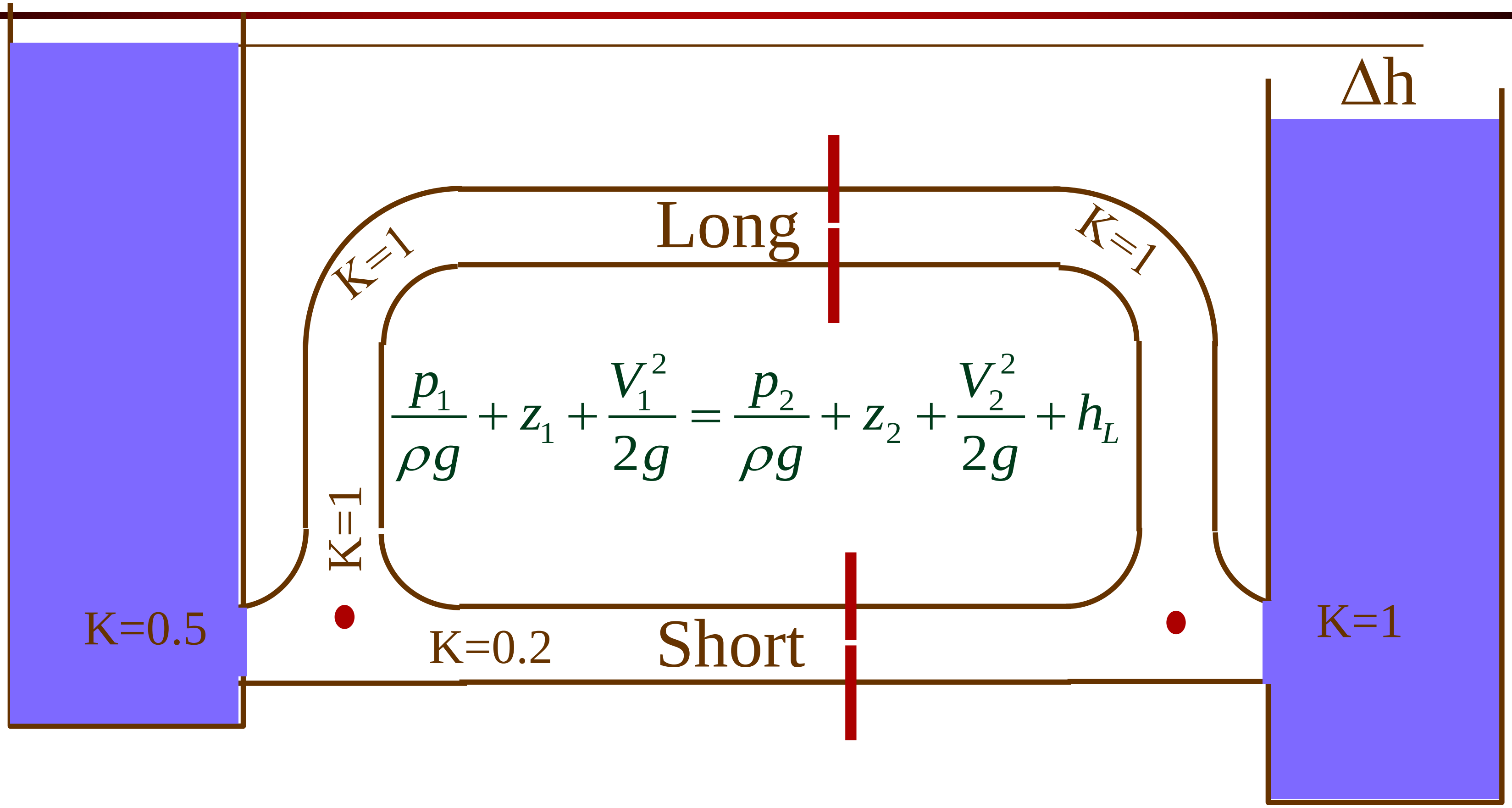


Distributing flow between tanks

- Which sedimentation tank will have the highest flow rate?
- Where is the greatest head loss in the flow through a sedimentation tank?

  Where is the highest velocity?
- Either precisely balance the amount of head loss through each tank
- Or add an identical flow restriction in each flow path

Will the flow be the same?

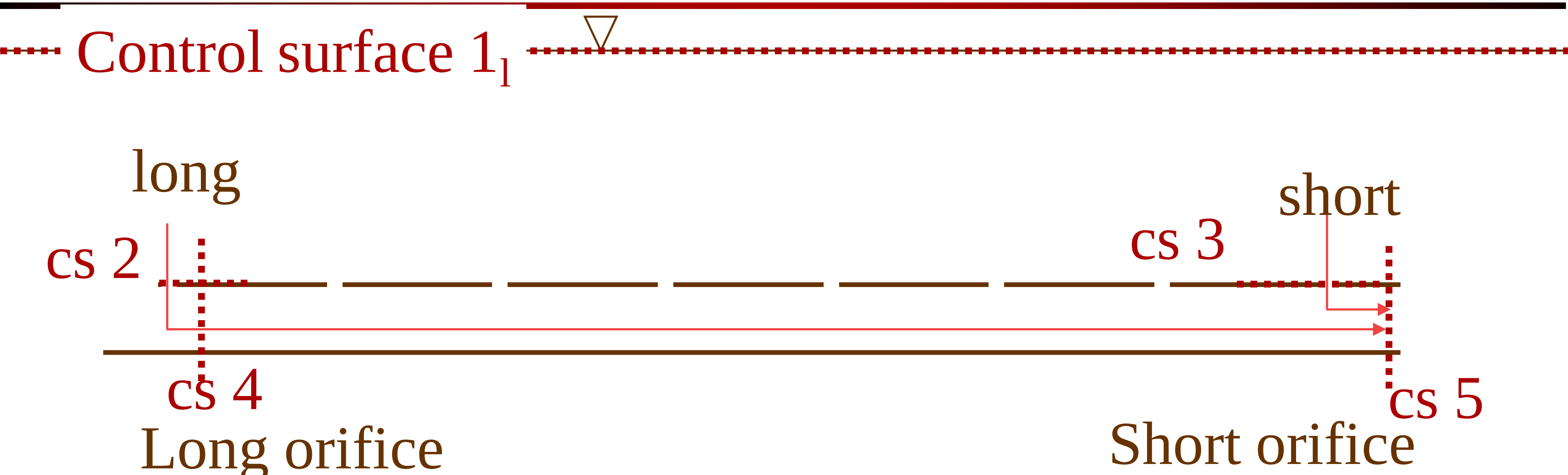


$$\frac{p_1}{\rho g} + z_1 + \frac{V_1^2}{2g} = \frac{p_2}{\rho g} + z_2 + \frac{V_2^2}{2g} + h_L$$

Head loss for long route = head loss for short route if KE is ignored

Q for long route< Q for short route

Conservative estimate of effects of manifold velocity



$$H_1 = H_2 + \frac{V_{port}^2}{2g} + h_{L_{longport}} \qquad H_2 = H_3 + \frac{V_{\max manifold}^2}{2g} + h_{L_{manifold}} \qquad H_1 = H_3 + \frac{V_{port}^2}{2g} + h_{L_{shortport}}$$

$$H_2 + \frac{V_{port}^2}{2g} + h_{L_{longport}} = H_3 + \frac{V_{port}^2}{2g} + h_{L_{shortport}}$$

$$\frac{V_{\max manifold}^2}{2g} + h_{L_{manifold}} + h_{L_{longport}} = h_{L_{shortport}}$$

This neglects velocity head differences

Modeling the flow

$$h_{L_{long}} = h_{L_{short}}$$

Since each point can have only one pressure

$$Q_{.pipeminor}(D, h_{.e}, K) := A_{.circle}(D)\cdot\sqrt{\frac{2\cdot g\cdot h_{.e}}{K}}$$

$$\frac{Q_{long}}{Q_{short}} = Q_{ratio} = \frac{\cancel{A_{long}}\sqrt{\frac{\cancel{2gh}_{elong}}{\sum K_{long}}}}{\cancel{A_{short}}\sqrt{\frac{\cancel{2gh}_{eshort}}{\sum K_{short}}}}$$

$$Q_{ratio} = \sqrt{\frac{\sum K_{short}}{\sum K_{long}}} = \sqrt{\frac{0.2}{3}} = 0.26$$

We are assuming that minor losses dominate. It would be easy to add a major loss term (*f*L/d). The dependence of the friction factor on Q would require iteration.

Design a robust system that gets the same flow through both pipes

$$Q_{ratio} = \sqrt{\frac{\sum K_{short} + K_{control}}{\sum K_{long} + K_{control}}}$$

Add an identical minor head loss to both paths

$$K_{control} = \frac{\left[Q_{ratio}{}^{2} \sum K_{long} \right] - \sum K_{short}}{1 - Q_{ratio}{}^{2}}$$

Solve for the control loss coefficient

$$K_{control} = \frac{\left[(0.95)^{2} \sum 3 \right] - \sum 0.2}{1 - (0.95)^{2}} = 25.7$$

Design the orifice…

Piezometric head decrease in a manifold assuming equal port flows

Head loss Kinetic energy

$$\Delta H = -\sum_{i=1}^{n} \frac{8\left(iQ_{\text{port}}\right)^2 C_{p_{port}}}{g\pi^2 d^4} - \frac{8\left(nQ_{\text{port}}\right)^2}{g\pi^2 d^4}$$

Piezometric head decrease in a manifold with n ports
d is the manifold diameter

$$\Delta H = -\frac{8Q_{\text{port}}^2}{g\pi^2 d^4}\left(C_{p_{port}} \sum_{i=1}^{n} i^2 + n^2\right)$$

$C_{p_{port}}$ represents the head loss coefficient **<u>in the manifold</u>** at **each** port or along the manifold as fL/d

$$\sum_{i=1}^{n} i^2 = \frac{n}{6}\left(2n^2 + 3n + 1\right)$$

$$\Delta H = -\frac{8Q_{\text{port}}^2}{g\pi^2 d^4}\left(C_{p_{port}} \frac{n}{6}\left(2n^2 + 3n + 1\right) + n^2\right)$$

Note that we aren't using the total flow in the manifold, we are using Q_{port}

Convert from port to total manifold flow and pressure coefficient

$$\Delta H = -\frac{8Q_{\text{port}}^2}{g\pi^2 d^4}\left(C_{p_{port}}\frac{n}{6}\left(2n^2+3n+1\right)+n^2\right)$$

$$Q_{total} = nQ_{port} \qquad \sum C_p = nC_{p_{port}}$$

$$\Delta H = -\frac{8Q_{\text{total}}^2}{g\pi^2 d^4}\left(\sum C_p\left(\frac{1}{3}+\frac{1}{2n}+\frac{1}{6n^2}\right)+1\right)$$

Loss coefficient

Velocity head

$$\sum C_p = f\frac{L_{manifold}}{d_{manifold}}+\sum K$$

Note approximation with f

These are losses in the manifold

Calculate additional head loss required to get uniform flow

Long path

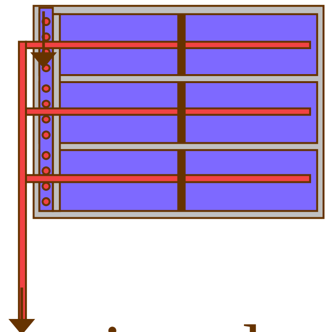
$$\sum K_{long} = \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right) + 1$$

Short path

$$\sum K_{short} \cong 0$$

Note that this K_{long} gives the correct head loss when using $Q_{maxmanifold}$

$$K_{control} = \frac{\left[Q_{ratio}{}^2 \sum K_{long} \right] - \sum K_{short}}{1 - Q_{ratio}{}^2}$$



$$K_{control} = \frac{1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)}{\frac{1}{Q_{ratio}{}^2} - 1}$$

$K_{control}$ is the minor loss coefficient we need somewhere **<u>in</u>** the ports connecting to the manifold

Total Loss Coefficient

$$\sum K_{long} = 1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)$$

We are calculating the total loss coefficient so we can get a relationship between the total available piezometric head and the diameter of the manifold

$$K_{control} = \frac{Q_{ratio}{}^2 \sum K_{long}}{1 - Q_{ratio}{}^2}$$

$$K_{total} = \sum K_{long} + K_{control} = \frac{\sum K_{long}}{1 - Q_{ratio}{}^2}$$

Including KE (more conservative)

$$K_{total} = \sum K_{long} - 1 + K_{control} = \frac{\sum K_{long} + 1 - Q_{ratio}{}^2}{1 - Q_{ratio}{}^2} = \frac{\sum K_{long}}{1 - Q_{ratio}{}^2} - 1$$

Excluding KE

Calculate the manifold diameter given a total manifold head loss

K_{total} is defined based on the total flow through the manifold and includes KE .

$$K_{total} = \frac{\sum K_{long}}{1 - Q_{ratio}^{\ 2}}$$

$$\sum K_{long} = 1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)$$

$$h_l = \frac{8 Q_{manifold}^{\ 2}}{g \pi^2} \frac{K_{total}}{d_{manifold}^{\ 4}}$$

Minor loss equation

$$d_{manifold} = \left(\frac{8 Q_{manifold}^{\ 2}}{g \pi^2} \frac{K_{total}}{h_l} \right)^{\frac{1}{4}}$$

Solve the minor loss equation for D

We could use a total head loss of perhaps 5 to 20 cm to determine the diameter of the manifold. After selecting a manifold diameter (a real pipe size) find the required control head loss and the orifice size.

Full Equation for Manifold Diameter

$$K_{total} = \frac{\sum K_{long}}{1 - Q_{ratio}^{\ 2}}$$

$$d_{manifold} = \left(\frac{8 Q_{manifold}^{\ 2}}{g h_l \pi^2} K_{total} \right)^{\frac{1}{4}}$$

$$\sum K_{long} = 1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)$$

$$d_{manifold} = \left(\frac{8 Q_{manifold}^{\ 2}}{g h_l \pi^2} \frac{1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)}{1 - Q_{ratio}^{\ 2}} \right)^{\frac{1}{4}}$$

$\sum C_p$ is loss coefficient for entire length of manifold

Manifold design equation with major losses

$$d_{manifold} = \left(\frac{8Q_{manifold}^{\;2}}{g h_l \pi^2} \frac{1 + \left(f \frac{L_{manifold}}{d_{manifold}} + \sum K \right)\left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)}{1 - Q_{ratio}^{\;2}} \right)^{\frac{1}{4}}$$

Iteration is required!

n is number of ports

f is friction factor (okay to use f based on Q_{total})

Q_{ratio} is acceptable ratio of min port flow over max port flow

h_l is total head loss through the ports **and** through the manifold

$Q_{manifold}$ is the total flow through the manifold from the n ports

$\sum K$ is the sum of the minor loss coefficients for the manifold (zero for a straight pipe)

Head loss in a Manifold

$$h_{l_{manifold}} = \underbrace{\frac{8Q_{total}^{\;2}}{d_{manifold}^{\;\;4} g\pi^2}\Bigg[\left(\frac{fL_{manifold}}{d_{manifold}} + \sum K\right)}_{h_l}\left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2}\right)\Bigg]$$

$$h_{l_{manifold}} = h_l\left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2}\right)$$

The head loss in a manifold pipe can be obtained by calculating the head loss with the maximum Q through the pipe and then multiplying by a factor that is dependent on the number of ports.

Now find the effluent launder orifice area

Use the orifice equation to figure out what the area of the flow must be to get the required control head loss. This will be the total area of the orifices into the effluent launder for one tank.

$$Q = K_{or} A \sqrt{2gh_{control}}$$

$$K_{control} = \frac{1 + \sum C_p \left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2} \right)}{\frac{1}{Q_{ratio}{}^2} - 1}$$

$$A = \frac{Q}{K_{or} \sqrt{2gh_{control}}}$$

Orifice flow (correction!)

$$Q = K_{or} A \sqrt{2g\Delta h}$$

$$\Delta h = \frac{1}{K_{or}^2} \frac{Q_{or}^{\ 2}}{2gA_{or}^2}$$

$$h_e = K \frac{Q_{manifold}^{\ 2}}{2gA_{manifold}^2}$$

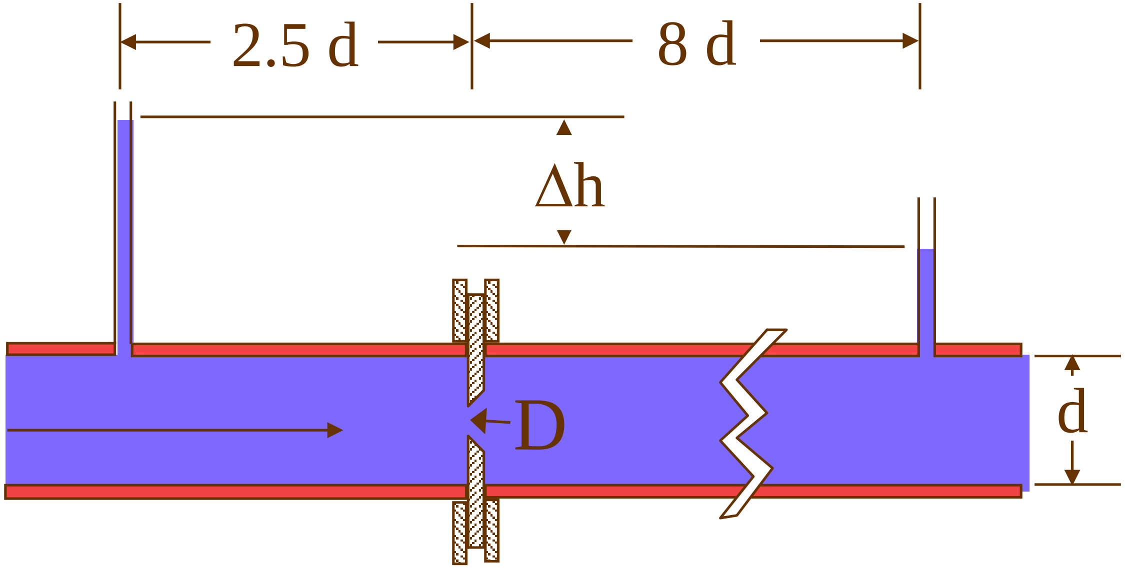
$$K = \frac{1}{K_{or}^2} \frac{d_{manifold}^4 Q_{or}^{\ 2}}{d_{or}^4 Q_{manifold}^{\ 2}}$$

$$Q_{or} n_{or} = Q_{manifold}$$

$$K = \frac{1}{K_{or}^2} \frac{d_{manifold}^4}{d_{or}^4 n_{or}^{\ 2}}$$

Solve for h and substitute area of a circle to obtain same form as minor loss equation

$K_{or} = 0.63$



Calculating the orifice diameter based on uniform flow between orifices

$$\sum C_p = f\,\frac{L_{manifold}}{d_{manifold}} + \sum K$$

$$K_{control} = \frac{1 + \sum C_p\left(\frac{1}{3} + \frac{1}{2n} + \frac{1}{6n^2}\right)}{\frac{1}{Q_{ratio}{}^2} - 1}$$

$$d_{or} = d_{manifold}\left(\frac{1}{K_{or}^2 n_{or}{}^2 K_{control}}\right)^{\frac{1}{4}}$$

$$K_{control} = \frac{1}{K_{or}^2}\,\frac{d_{manifold}^4}{d_{or}^4 n_{or}{}^2}$$

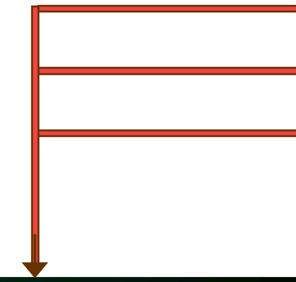
How small must the orifice be? Case of 1 orifice

$$K = \frac{d_{pipe}^4}{K_{or}^2 d_{or}^4} \qquad d_{or} = d_{pipe}\left(\frac{1}{KK_{or}^2}\right)^{\frac{1}{4}}$$

For this case $d_{orifice}$ must be approximately $0.56 d_{pipe}$.

- We learned that we can obtain equal similar parallel flow by ensuring that the head loss is similar all paths.
- We can compensate for small differences in the paths by adding head loss that is large compared with the small differences.

Effluent Launders: Manifold Manifolds



- Two Goals
  - Extract water uniformly from the top of the sed tank so the flow between all of the plates is the same
  - Create head loss that is much greater than any of the potential differences in head loss through the sedimentation tanks to guarantee that the flow through the sedimentation tanks is distributed equally
- A pipe with orifices
- Recommended orifice velocity is 0.46 to 0.76 m/s (Water Treatment Plant Design 4th edition page 7.28)
  - The corresponding head loss is 3 to 8 cm through the orifices
  - but it isn't necessarily this simple!

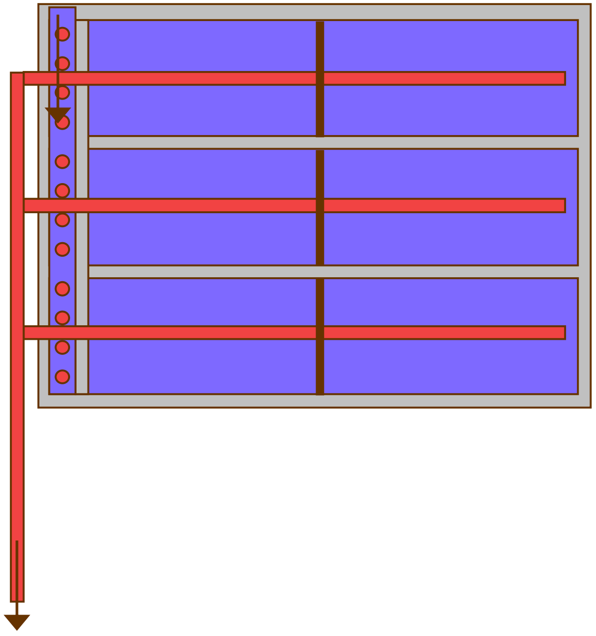
We need to get a low enough head loss in the rest of the system

Effluent Launders and Manifold

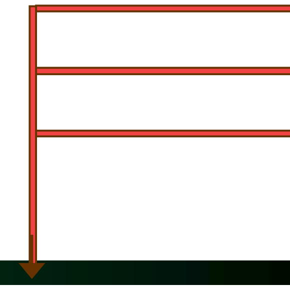
- We need to determine
  - the required diameter of the effluent launder pipe
  - The number and the size of the orifices that control the flow of water into the effluent launder
  - The diameter of the manifold
- The head loss through the orifices will be designed to be large relative to the differences in head loss for the various paths through the plant
- We need an estimate of the head loss through the plant by the different paths
- Eventually take into account what happens when one sedimentation tank is taken off line.

Head Loss in a sed tank?

- Head loss through sed tank inlet pipes and plate settlers is miniscule
- The major difference in head loss between sed tanks is due to the different path lengths in the manifold that collects the water from the sed tanks.
- We want equally divided flow two places
  - Sed tanks
  - Plate settlers (orifices into launders)



Manifold head loss: Sed tanks equal!



- We will assume minor losses dominate to develop the equations. If major losses are important they can be added or modeled as a minor loss.
- The head loss coefficient from flowing straight through a PVC Tee is approximately 0.2
- We make the assumption that the flow into each port is the same
- Eventually we will figure out the design criteria to get identical port flow

Minor losses vs. Major losses

- Compare by taking a ratio

$$h_e = K\frac{V^2}{2g}$$

$$\frac{h_e}{h_f} = \frac{D}{L}\frac{\sum K}{f}$$

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

$$\frac{L}{D} = \frac{h_f}{h_e}\frac{\sum K}{f}$$

$$\frac{L}{D} = 1\frac{\sum 1}{0.02}$$

Thus in a 10 cm diameter pipe, an elbow with a K of 1 gives as much head loss as 5 m of pipe

Now design the Effluent Launder

- The effluent launder might be a smaller diameter pipe than the sed tank manifold (especially if there are many sedimentation tanks)
- The orifice ports will be distributed along both sides of the launder

Now design the Effluent Launder

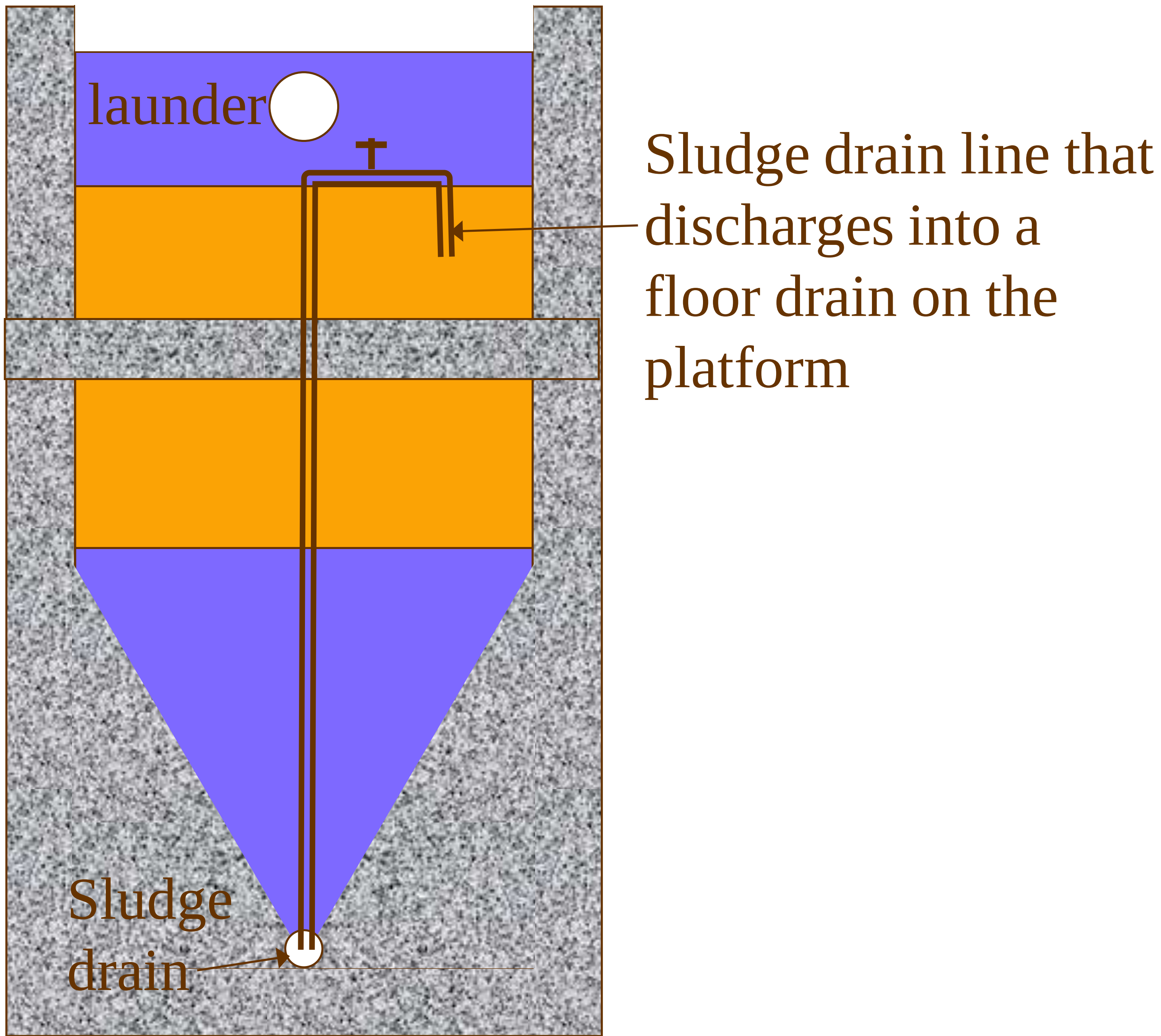
- Port spacing should be less than the vertical distance between the ports and the top of the plate settlers (I'm not sure about this constraint, but this should help minimize the chance that the port will cause a local high flow through the plate settlers closest to the port)
- The depth of water above the plate settlers should be
  - 0.6 to 1 m with launders spaced at 1.5 m (Water Treatment Plant Design 4th edition page 7.24)
  - This design guideline forces us to use a very deep tank. Deep tanks are expensive and so we need to figure out what the real constraint is.
  - It is possible that the constraint is the ratio of water depth to launder spacing.

Effluent Launder

- The solution technique is similar to the manifold design
- We know the control head loss – the head loss through the ports will ensure that the flow through each port is almost the same
- We need to find the difference in the head loss between the extreme paths
- Then solve for the diameter of the effluent launder

Sedimentation Tank Appurtenances

- Distributing the flow between parallel tanks
- Effluent Launders
- Sludge removal (manifold design similar to effluent launders)
- Isolating a tank for fill and drain: using only a single drain valve per tank
  - Filling the tank with clean water
  - Not disturbing the water levels in the rest of the plant
- Entrance manifolds: designed to not break up flocs


launder
Sludge drain line that discharges into a floor drain on the platform
Sludge drain