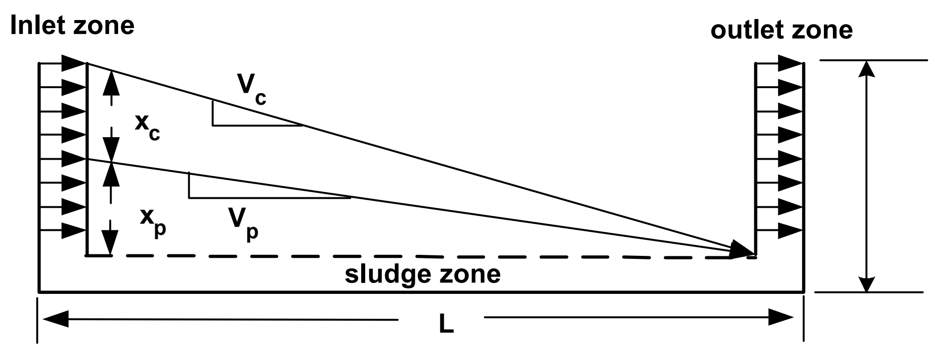
6-12 M&E, 2nd Edition or 6-16 M&E, 3rd edition

The rate of flow through an ideal (TYPE I) clarifier is 8000 m^3 / day, the detention time is 1 - hour, the depth is 3 m and the length to width ratio for the basin is 3 to 1. If a full length, moveable, horizontal tray is set 1 m below the surface of the water, determine the percentage removal of particles having a settling velocity of 1 m/hour. Could the removal efficiency of the clarifier be improved by raising or lowering the tray within the basin? If so where should the tray be located to maximize removal efficiency ? Plot removal effeciency of the basin as a function of the depth of the tray. What would be the effect of moving the tray if the particle settling velocity were 0.3 m / hr.?

Assume that any particle reaching the bottom of the clarifier OR the tray (think of it as a false bottom) is removed

An idealized diagram of the clarifier is provided below



Assumptions:

1. Flow enters tank all along the left side from top to bottom

2. Particle sizes uniformly distributed in flow

V_c = velocity of largest particle 100% removed in tank

V_p = velocity of arbitrary particle removed in tank

Note that the particle trajectories, bottom and left side of the tank form similar triangles

From the drawing we see that any perticle with a settling velocity v_p entering BELOW x_p will be 100% removed.

Based on similar triangles we see that the percentage of particles of an arbitrary size (less that the smallest particle 100% removed) that will be rmoved is given by:

$$\frac{x_p}{x_c} = \frac{V_p}{V_c}$$

$$x_p = \frac{V_p}{V_c} \cdot x_c$$ but x_C equals 1 for the critical particle

While the problem above is somewhat simplified and theoretical, this concept has been applied in the development of what are known as tray or tube settlers, used to retrofit existing clarifiers to improve their removal efficiency. A disadvantage of this system is that it is difficult to remove the settled material.

A general description of the problem solution: The basic concepts of type I clarification regarding removal efficiency apply here but they have to be applied above and below the tray separately. In addition the removal efficiencies obtained above and below the tray have to be corrected for the VOLUME of tank affected.

The critical particle is defined as the one which if entering from the top reaches the bottom just before it is to be lost. The velocity of the critical particle in this basin is:

$$Q := 8000 \cdot \frac{m^3}{day} \qquad \theta := 1 \cdot hr \qquad depth := 3 \cdot m$$

velocity of the critical sized particle to be reomoved: $V_c = \frac{Q}{A_{bottom}} = \frac{depth}{detention\_time}$

$$Volume := Q \cdot \theta \qquad Volume = 333.333\, m^3$$

$$depth \cdot width \cdot 3 \cdot width = Q \cdot \theta$$ volume of the tank in terms of the depth and width

$$width := \begin{bmatrix} \frac{1}{(3 \cdot \sqrt{depth})} \cdot \sqrt{3} \cdot \sqrt{Q} \cdot \sqrt{\theta} \\ \frac{-1}{(3 \cdot \sqrt{depth})} \cdot \sqrt{3} \cdot \sqrt{Q} \cdot \sqrt{\theta} \end{bmatrix}$$ choose correct solution

$$width := \frac{1}{\left(3 \cdot \sqrt{depth}\right)} \cdot \sqrt{3} \cdot \sqrt{Q} \cdot \sqrt{q}$$

$$width = 6.086\, m$$

$A_{bottom} := width^2 \cdot 3$ 3 to 1 L:W ratio

$$A_{bottom} = 111.111\, m^2$$

$V_c := \frac{Q}{A_{bottom}}$ $V_c = 3\frac{m}{hr}$

Because the tank is 3 m deep and has a detention time of 1 hour all particles with a velocity of 3 m/hr or greater will be 100% removed.

Using similar triangles, the percentage of particles with a settling velocity $V_p < V_c$ which will be removed is:

$$X_r = \frac{V_p}{V_c}$$

The effect of installing a tray is decrease the settling distance without increasing the horizontal velocity, thus a greater amount of bottom area is now available for particle settling. The equation above holds for the region above the tray as well as the region below the tray. Note also that this arrangement does not affect the hydraulic detention time.

Carry out the analysis for a critical sized particle with 1 m/hr velocity. Vary the distance from the water surface to the tray from .1 m to 2.99 m:

$$d_a := .1 \cdot m, .12 \cdot m .. 2.99 \cdot m$$

$$depth := 3 \cdot m$$

Critical particle settling velocity $V_p := 1 \cdot \frac{m}{sec}$. Critcal size implies we want to remove as close to 100% of particles that size or bigger as possible.

ABOVE THE TRAY

Let d_a be the depth the tray is below the surface. If a particle with velocity V_p settles a depth > d_a within the detention time of the tank, $\frac{V_p}{d_a} \geq 1$ then all particles entering above the tray will be removed. If $\frac{V_p}{d_a} \leq 1$ then weather or not a particle entering above the tray is removed depends on where along the tank depth (above the tray) it enters. The fraction removed is $\frac{V_p}{d_a}$ up to a maximum of 100% or 1.0 .

$$\text{percent\_removal}_{above}(d_a, V_p) := \text{if}\left(\frac{V_p}{d_a} \geq 1, 1, \frac{V_p}{d_a}\right)$$

<u>In words</u> : If $\frac{V_p}{d_a} \geq 1$ then all particles with velocity V_p will be removed. If $\frac{V_p}{d_a} \leq 1$ then the fraction of particles with velocity V_p that are removed is $\frac{V_p}{d_a}$

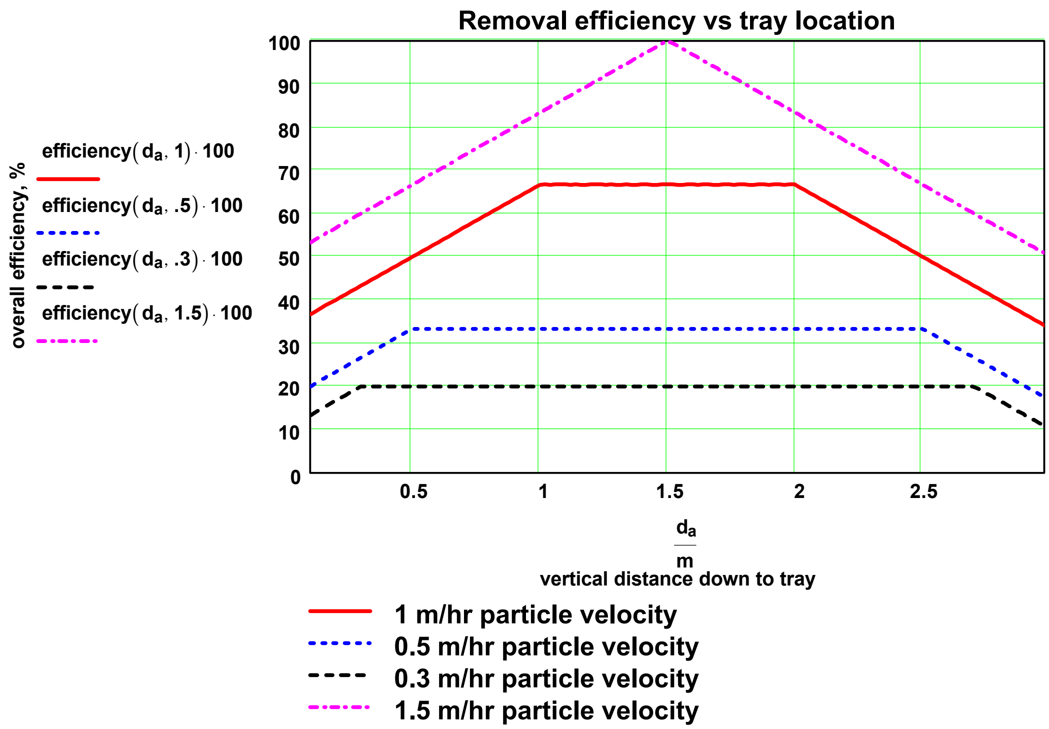
<u>BELOW THE TRAY</u>: NOTE : (depth - d_a) is the distance from the tray to the bottom of the clarifier a particle entering immediately below the tray must settle.

$$\text{percent\_removal}_{below}(d_a, V_p) := \text{if}\left[\left(\frac{V_p}{\text{depth} - d_a} \geq 1\right), 1, \frac{V_p}{\text{depth} - d_a}\right]$$

In words : If $\frac{V_p}{\text{depth} - d_a} \geq 1$ then all particles with velocity V_p will be removed. If $\frac{V_p}{\text{depth} - d_a} \leq 1$ then the fraction of particles with velocity V_p that are removed is $\frac{V_p}{\text{depth} - d_a}$

Total reactor efficiency is the <u>volume weighted average</u> of the removal efficiency above and below the tray. That is, if the tray is located very near the top of the tank the removal efficiency above the tray may be 100% but the fraction of total tank volume affected is quite small. Thus, for a unit width of tank we can write

$$\text{efficiency}(d_a, V_p) := \text{percent\_removal}_{above}(d_a, V_p)\cdot\frac{d_a}{\text{depth}} \; ... \\ + \text{percent\_removal}_{below}(d_a, V_p)\cdot\frac{\text{depth} - d_a}{\text{depth}}$$



<u>Results :</u> The maximum removal drops as the particle velocity gets lower, regardless of try location. For the 1 m/hr particle the optimal tray location is from 1 to 2 meters below the surface. Without the tray the removal efficiency is around 35%. Maximum removal with the tray is just below 70%

What could be done to increase the removal of smaller particles?

Examine the removal efficiency above and below the tray seperately

$$\text{efficiency}_{above}(d_a, V_p) := \text{percent\_removal}_{above}(d_a, V_p)$$

$$\text{efficiency}_{below}(d_a, V_p) := \text{percent\_removal}_{below}(d_a, V_p)$$

Plot the simple efficiency of the tray and the region below the tray - do not use weighted average