Lecture 21 - Sludge

Types of sludge:

Primary sludge - organic solids, grit, inorganic fines
gray, greasy, odorous slurry
includes ~1% tank skimmings (scum)
solids conc. ~ 4-6%
VSS ~ 60 to 80%

Waste activated sludge (secondary sludge) - active microbial mass
dark brown suspension
inoffensive at first, can rapidly become odorous
solids conc ~ 0.5-1.5%
VSS ~ 70 to 80%

Trickling filter sludge (humus) - similar to waste activated sludge
solids conc ~ 4-5%
VSS ~ 45-70%

Anaerobically digested sludge - dark brown, thick slurry
smells like garden soil
VSS ~ 30-60% (VSS is consumed by digestion)
solids conc. ~ 3 to 12%

Aerobically digested sludge - dark brown
more difficult to process than anaerobically digested sludge due to flocculent nature
solids conc ~ 1-2%
VSS ~ 35 to 40%

Mechanically dewatered sludge - consistency of wet mud to chunky solid
solids conc 15 to 40%, resp.

Biosolids - processed solids suitable for beneficial use

Estimation of solids production

$$W_s = W_{sp} + W_{ss}$$

W_s = total dry solids [M/T]
W_{sp} = raw primary solids [M/T]
W_{ss} = raw secondary solids [M/T]

$$W_{sp} = f \cdot SS \cdot Q$$

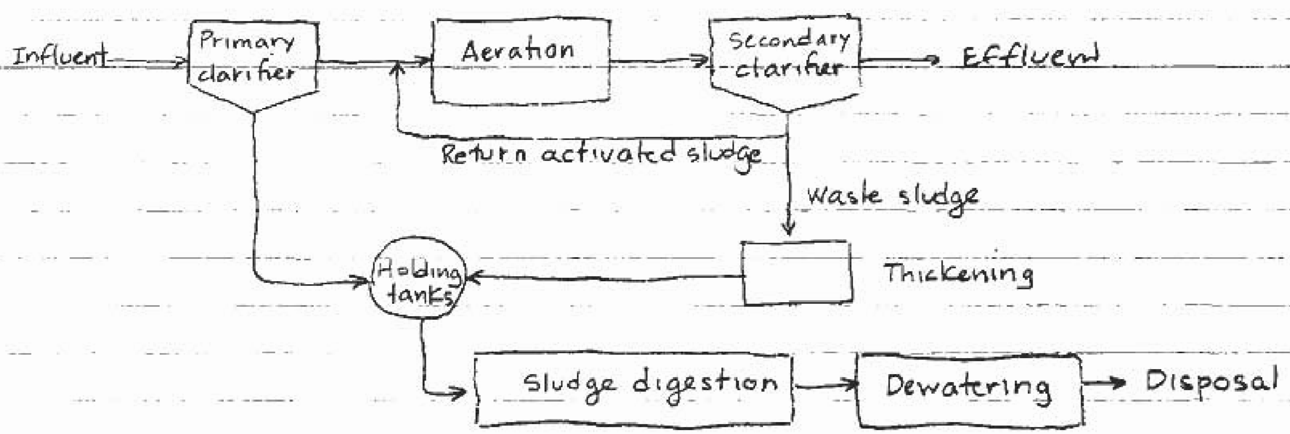
f = fraction of suspended solids removed in primary settling
$f \approx$ 0.4 to 0.6 – use 0.5 for domestic wastewater
SS = suspended solids conc. in wastewater $[M/L^3]$
Q = flow rate $[L^3/T]$

$$W_{ss} = K \cdot BOD \cdot Q$$

K = fraction of influent BOD that becomes excess biomass
$K \approx$ 0.3 to 0.5 (for F/M = 0.05 to 0.5 $\frac{kg\ BOD}{kg\ MLVSS \cdot d}$)

K is lower for extended aeration AST and RBC's

Sludge processing typically entails multiple steps:



Note: thickening may also occur after blending primary and secondary sludge

Theory of solids separation (applies to secondary clarifier and sludge gravity thickener)

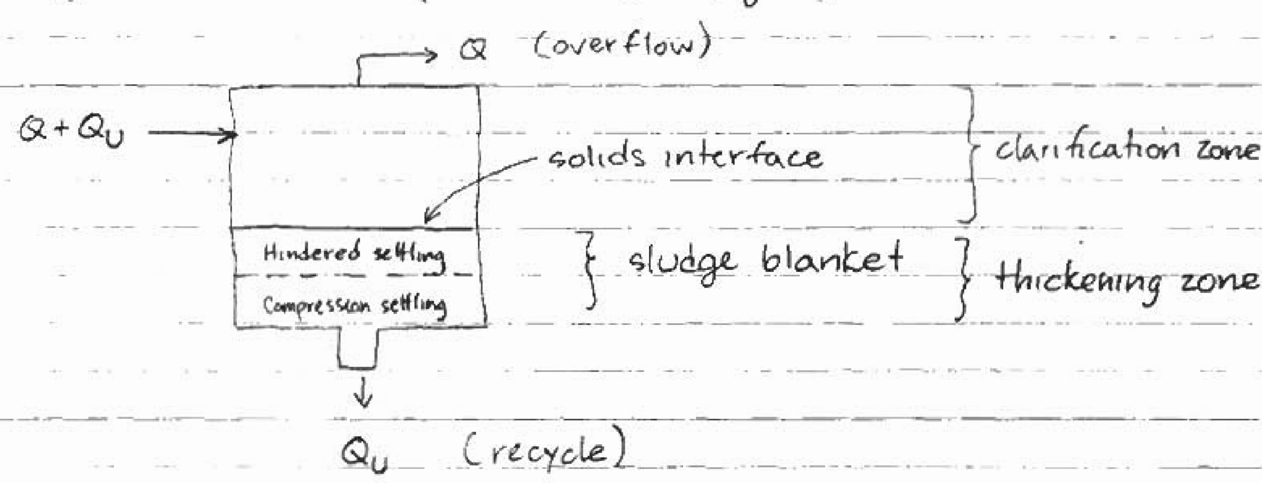
Biological solids are difficult to separate from wastewater for multiple reasons:

- Water is held in floc structure
- Water is adsorbed onto particles
- Water is contained within individual cells

Primary sludge has larger particles and is easier to separate

Biological sludge has fine colloidal particles, biological material that is mostly water, flocs with entrapped water – difficult to separate

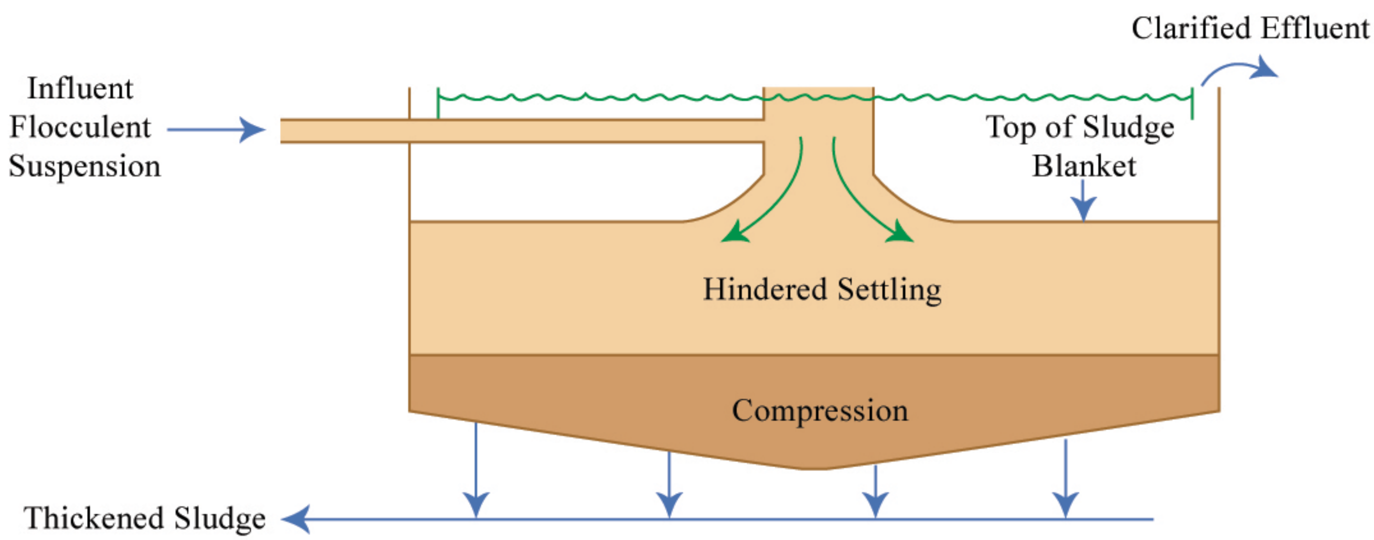
Settling basin at steady state (see page 4)



Basin is idealized as consisting of two zones

Clarification zone – individual particles settle from wastewater (Type 1 and Type 2 settling)

Thickening zone – Abrupt increase in solids concentration – zone and compression settling (Type 3 & 4)



A Schematic Diagram of Zone Settling in the Activated-Sludge Final Clarifier

Figure by MIT OCW.

Adpated from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005.

In clarification zone, solids are not in contact
In thickening zone, particles are in solid-solid contact, settling requires compression of solids and expeling entrapped water

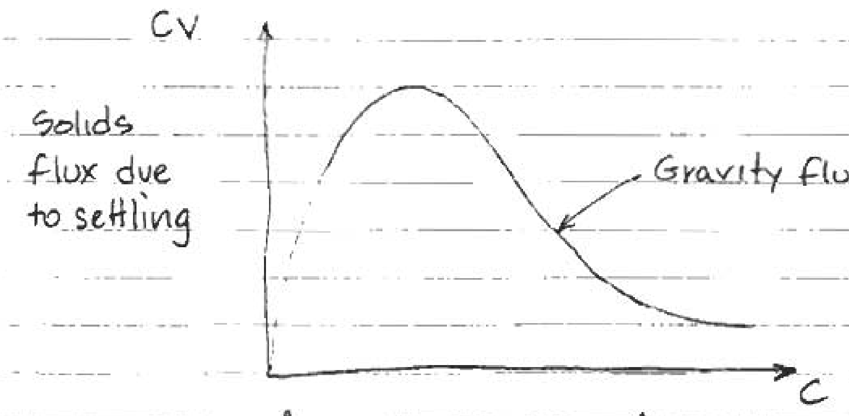
With zone settling, settling rate is presumed to be a function of concentration only

Settling rate is determined by placing a sludge of conc c in a graduated cylinder and timing the rate at which the liquids-solids interface falls

Results are plotted as curve of solids flux vs. solids conc:

$$\text{Solids flux} = Cv$$

C = solids conc.
v = velocity of interface velocity



At high C, settling is hindered and flux is small

Maximum where v is relatively unhindered (and thus high) and c is relatively high

At low C, v is small since it is due to movement of single particles $Cv \propto C$ since V does not change for low C

In addition to solids flux due to settling, there is also a flux due to sludge withdrawal at tank bottom

Sludge withdrawal leads to downward velocity

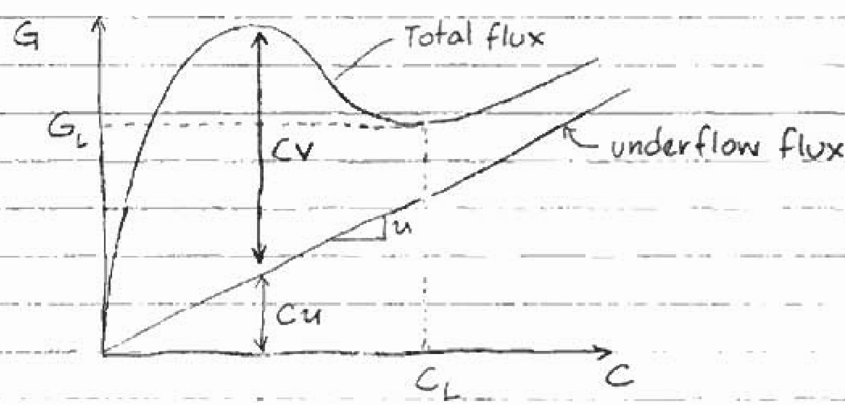
$$u = \frac{Q_u}{A}$$

A = tank surface area $[L^2]$
Q_u = sludge withdrawal ("underflow") $[L^3/T]$

u = downward velocity due to sludge withdrawal $[L/T]$

Total solids flux, G $[M/L^2T]$

$$G = Cv + Cu$$



Within thickener, C is actually changing from low C above sludge blanket to higher C within so there is a variation in G as well

C will thus vary along the total flux curve and G will be a minimum, G_L, when $C = C_L$

This is the limiting flux and is the maximum flux that can be maintained by clarifier

Figure 8-36 from M&E (pg 8) shows

Extend the horizontal line at G_L (SF_L in figure) to the underflow flux line to identify the corresponding value of C_u

At steady-state $(Q+Q_u)\,C_{in} = Q_u C_u = GA$ $\left[\frac{M}{T}\right]$

↑ solids flux $[M/L^2 \cdot T]$

A = area of tank

Define $Q_{in} = Q + Q_u$

assume tank is operating (properly) at G_L

then $A = \dfrac{Q_{in} C_{in}}{G_L}$ gives minimum surface area for tank

Note that Q_u is an operating parameter: to handle larger $Q_{in} C_{in}$ for given A, G_L can be raised by increasing u and lower part of solids flux curve (underflow) flux

What happens if $Q_{in} C_{in}$ exceeds G_L?

At some point down in tank C will have increased in value from C_{in} to C_L

Maximum flux through that level of the tank (assuming no change in Q_u) is G_L

Excess flux will build up, increasing C, and moving elevation of C_L upwards

Sludge blanket will thicken (and overtop tank if continued long enough)

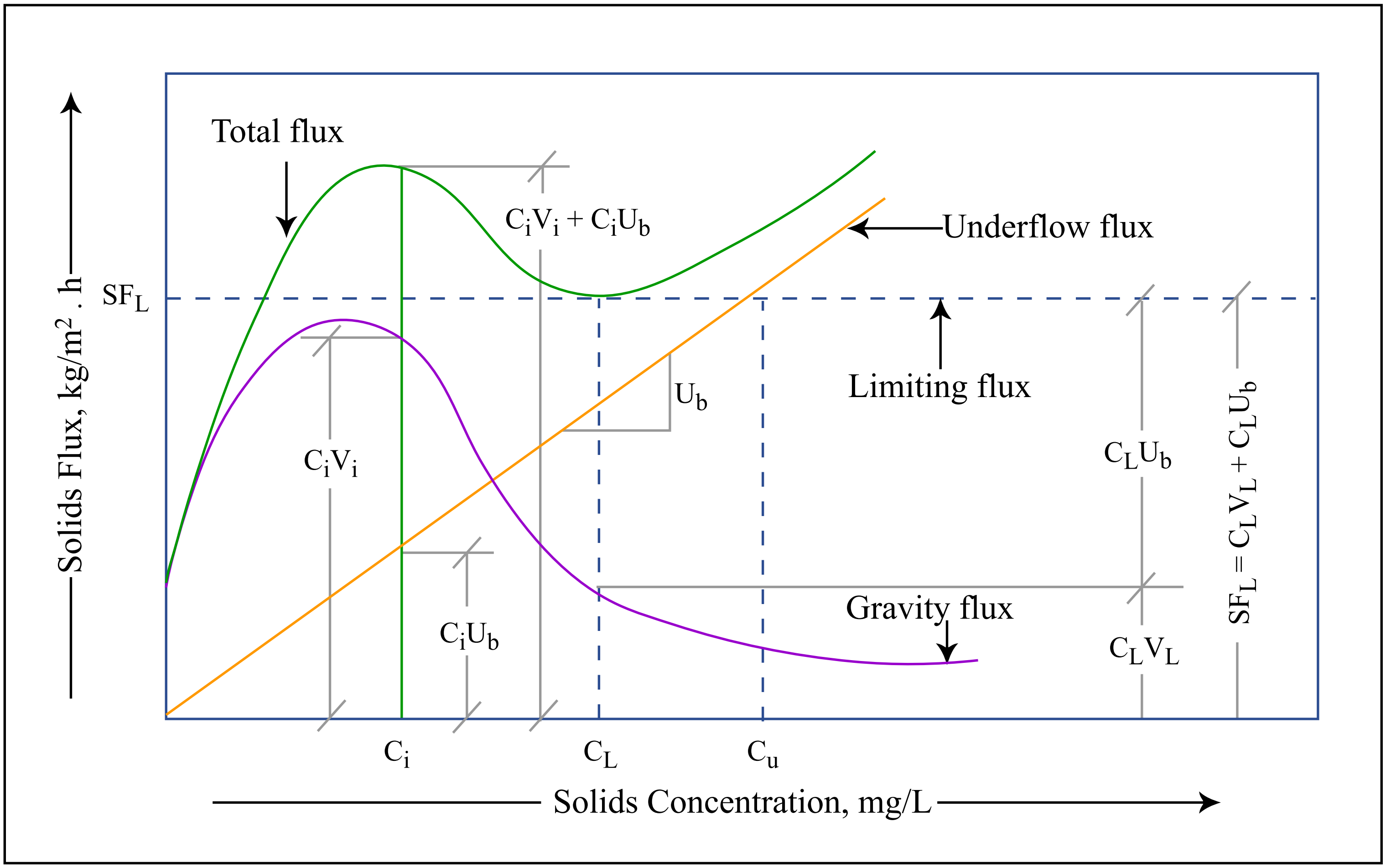


Figure by MIT OCW.

Adapted from: G. Tchobanoglous, F. L. Burton, and H. D. Stensel. *Wastewater Engineering: Treatment and Reuse*. 4th ed. Metcalf & Eddy Inc., New York, NY: McGraw-Hill, 2003, p. 823.

Sludge thickening

Gravity thickening – see Figure 21.1 from Reynolds and Richards on pg 10

Most common thickening method

Pickets rake sludge, breaking up sludge and releasing water

Primary sludge is thickened from about 4% to 8%
Activated sludge is thickened from about 1% to 3%
Primary-secondary mixture from about 4% to 6%

Thickened sludge is withdrawn at bottom, clarified supernatant withdrawn at top and returned to the primary clarifier

Operating criterion: solids applied per unit bottom area

Primary: 100–150 kg/m²·day
Primary plus AST: 40–80
AST: 20–40

Thickeners should recover 90–95% of solids

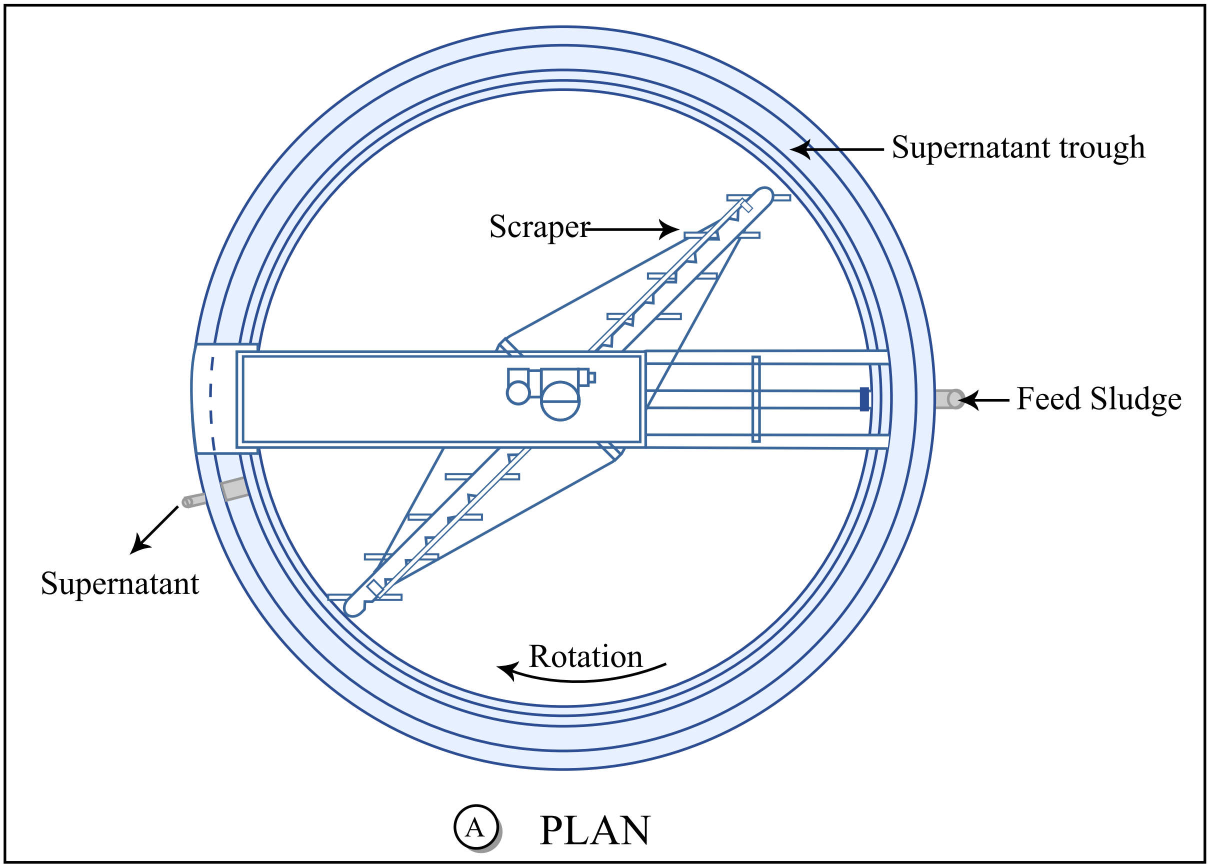
Bottom sludge blanket ≈ 1 m deep – ensures good sludge compaction (equals θ_c = 24 hrs)

Dissolved air flotation – see Fig 13.10 from V&H, pg. 11

Most applicable to solids near neutral buoyancy – e.g. activated sludge

Air is dissolved into wastewater (usually only a fraction of the flow) under high pressure

When wastewater enters the tank, air comes out of solution, often with particles acting as condensation nucleii



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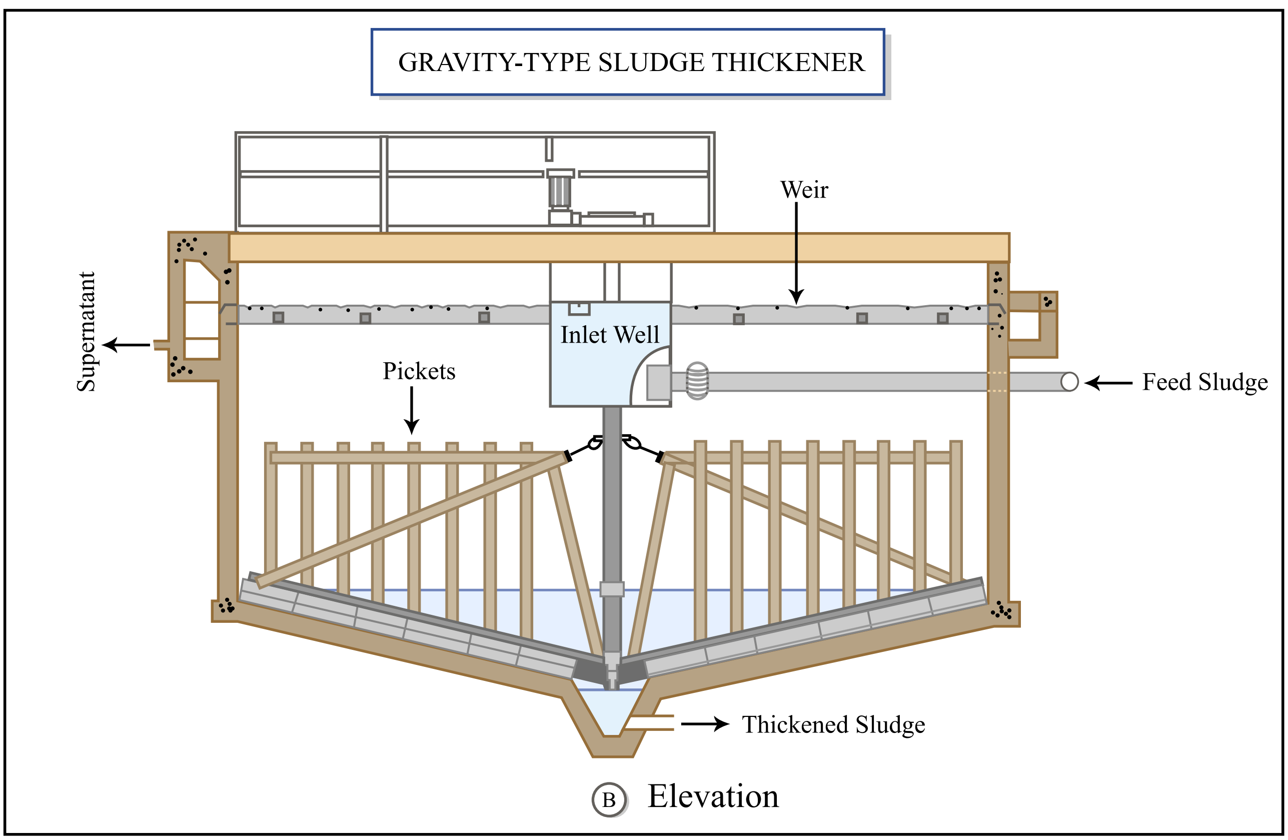

Figure by MIT OCW.

Adapted from: Reynolds, T. D., and P. A. Richards. *Unit Operations and Processes in Environmental Engineering*. 2nd ed. Boston, MA: PWS Publishing Company,1996, p. 631.

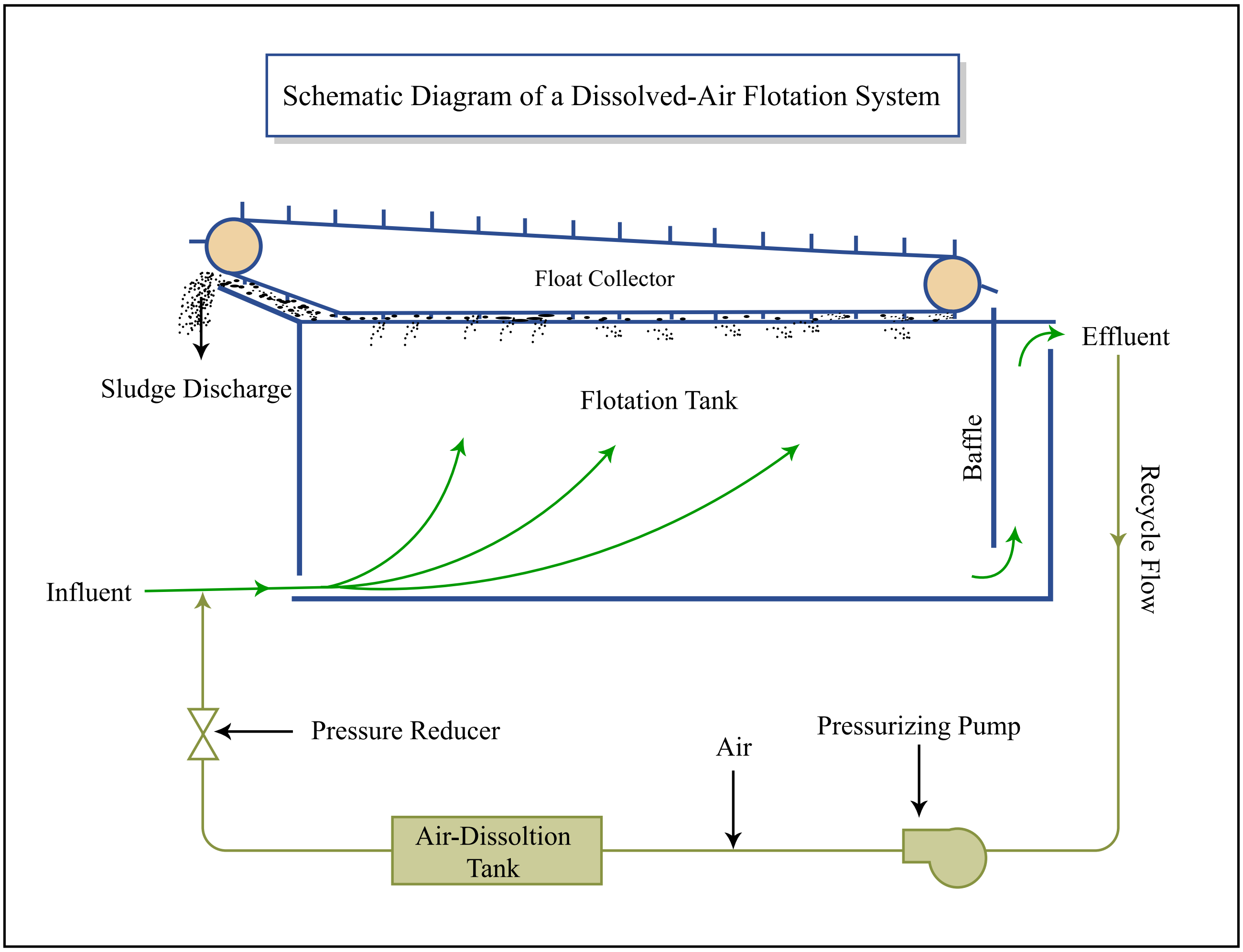

Figure by MIT OCW.

Adpated from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005, p. 678.

Air bubbles attached to solids float to surface, where solids are skimmed off into overflow weir

DAF is simply gravity settling in reverse - same mechanisms, theory apply

Thickened solids are 3 to 6% solids

Technology is not recommended for primary sludge or trickling filter humus - gravity thickening is much more effective

Typical loading 240 kg/m^2·day (lower area requirement than gravity thickeners) if polymers added as flotation aids

Solids removal = 90 to 98% with polymers

Centrifugal thickening (see M&E Fig 14-13, pg 13)

Sludge is centrifuged to concentrate solids (with polymers)

Thickened solids = 5 to 8%

High energy and maintenance costs, used only when space is limited

Gravity belt thickening (see pg 14)

Sludge is treated with polymer flocculants, then conveyed on continuous porous belt

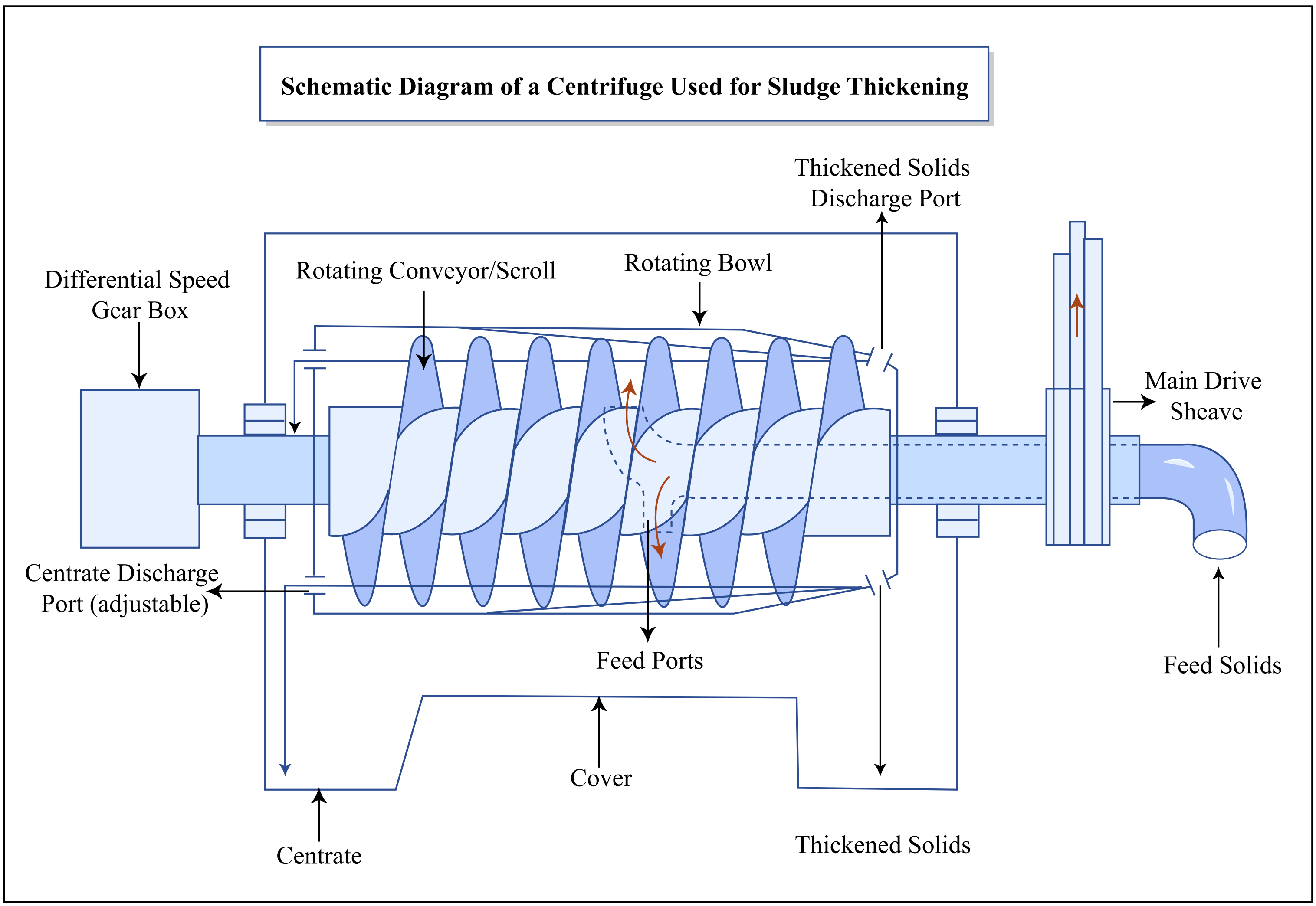

Figure by MIT OCW. Adapted from: G. Tchobanoglous, F. L. Burton, and H. D. Stensel. *Wastewater Engineering: Treatment and Reuse*. 4th ed. Metcalf & Eddy Inc., New York, NY: McGraw-Hill, 2003, p. 1469.

Gravabelt

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Gravity belt thickening (con't)

Key aspect is addition of polymer in flocculation well
(See Fig 14.8 from Water Environment Federation, 2003, Wastewater Treatment Plant Design, pg 16)

Cationic polymers promote flocculation of solids, freeing of water, which drains through porous belt

Vanes and guides distribute sludge across the belt at the start and then "plows" turn it and redistribute it along the way

Finally, solids collect some at the end of belt and roll backward, increasing retention time and mixing, releasing additional water

Solids sticking to the belt are scrapped off and the belt spray washed on the underside

Wash water is collected and returned back to treatment

Typical performance

	Solids Conc. (%) Start	Final
Primary sludge -	2 - 5	8 - 12
Secondary	0.4 - 1.5	4 - 6
50-50 Primary - Second.	1 - 2.5	6 - 8

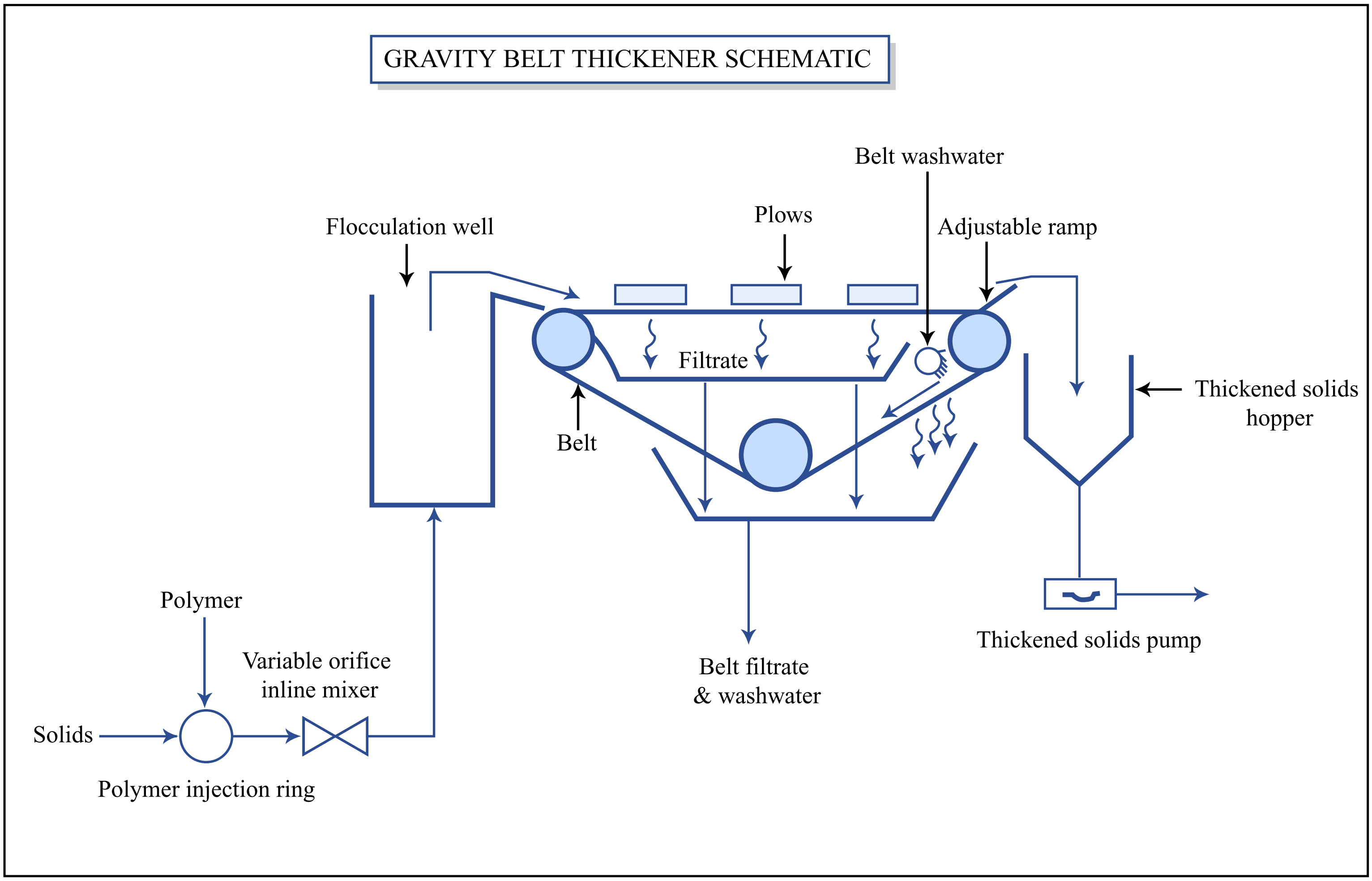

Figure by MIT OCW.

Adapted from: WEF. "Wastewater Treatment Plant Design. Water Environment Federation." Alexandria, Virginia, 2003.