Aalto University
School of Engineering

Physical & chemical treatment processes of water and waste

Lecture 5 Gravity separation – sedimentation, flotation, thickening, dewatering

WAT - E2120

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Lecture content

- **Gravity separation**
  - Settling
  - Lamella settlers
  - Flotation
  - Thickening
- **Dewatering**

- **Theories and practice**

Vocabulary:

Phase separation

Gravity seperation

Settler = Sedimentation basin (solids settle)

Clarifier = solids up or down

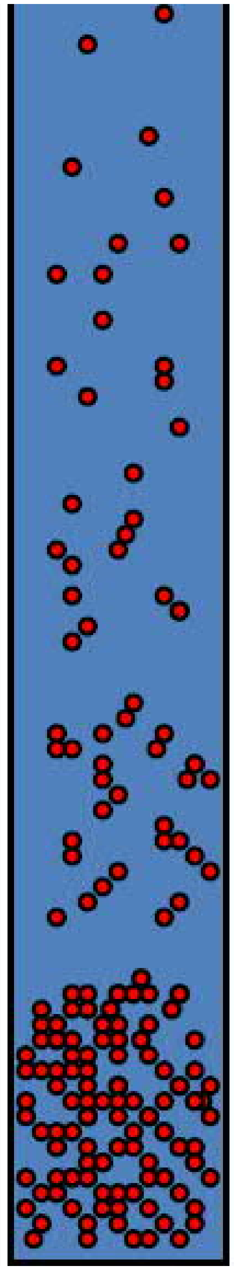
Settling Classes or Types

Discrete
Settling of dilute suspensions, little or no tendency to flocculate

Flocculent
Settling of dilute suspensions with flocculation taking place during the settling

Hindered (Zone settling)
Particles settle as a mass; inter-particle forces hold them in fixed position, settlement in a zone

Compressive
Settlement provided by the compacting mass resulting from particles that are in contact



Adapted from Prof. Pagilla Illinois Institute of technology

Gravity separation Phenomena

Phenomena	Description	Application
Discrete particle settling	Low solids concentration Individual settling	Grit removal
Flocculent settling	Quite dilute suspension, some coalescing	Settling basins
Hindered or zone settling	Intermediate concentration Neighbouring particles hinder	Settling basins
Compression settling	Compression by the weight of particles	Wastewater settling
Ballasted flocculent settling	Inert ballasting agent or chemical to improve settling	Polymers, microsand,
Accelerated gravity settling	Settling in an acceleration field	Grit and sand removal
Flotation	Particles rise up due to air or gas bubbles	Removal of grease and oil, other light particles

Particle settling - theory

The particle is influenced by gravitational force, buoyancy and frictional force depending on fluid density, viscosity and particle diameter

Stokes' law

$$V_s = \frac{g(\rho_p - \rho)D_p^2}{18\mu}$$

V_s = settling velocity

g = gravitational constant

D_p = particle diameter

μ = water viscosity

ρ = density of particle/water

Valid in laminar settling (Re < 1)

Reynolds number

$$N_R = \frac{\phi v_s d_p \rho_w}{\mu}$$

Laminar $N_R < 1$

Transitional $N_R = 1 – 2000$

Turbulent $N_R > 2000$

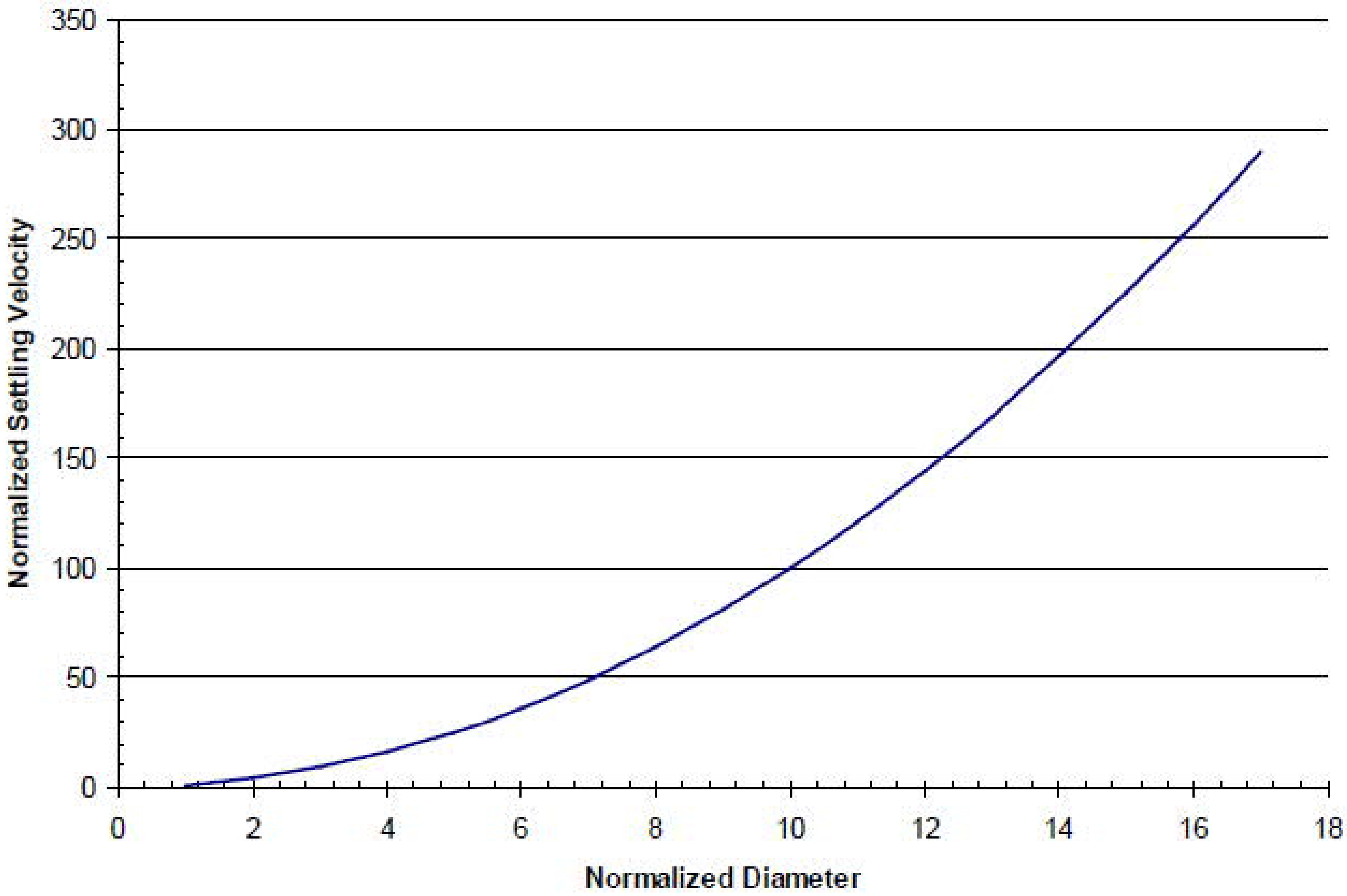
$\rho_{p/w}$ = density of particle/water

d = diameter of particle

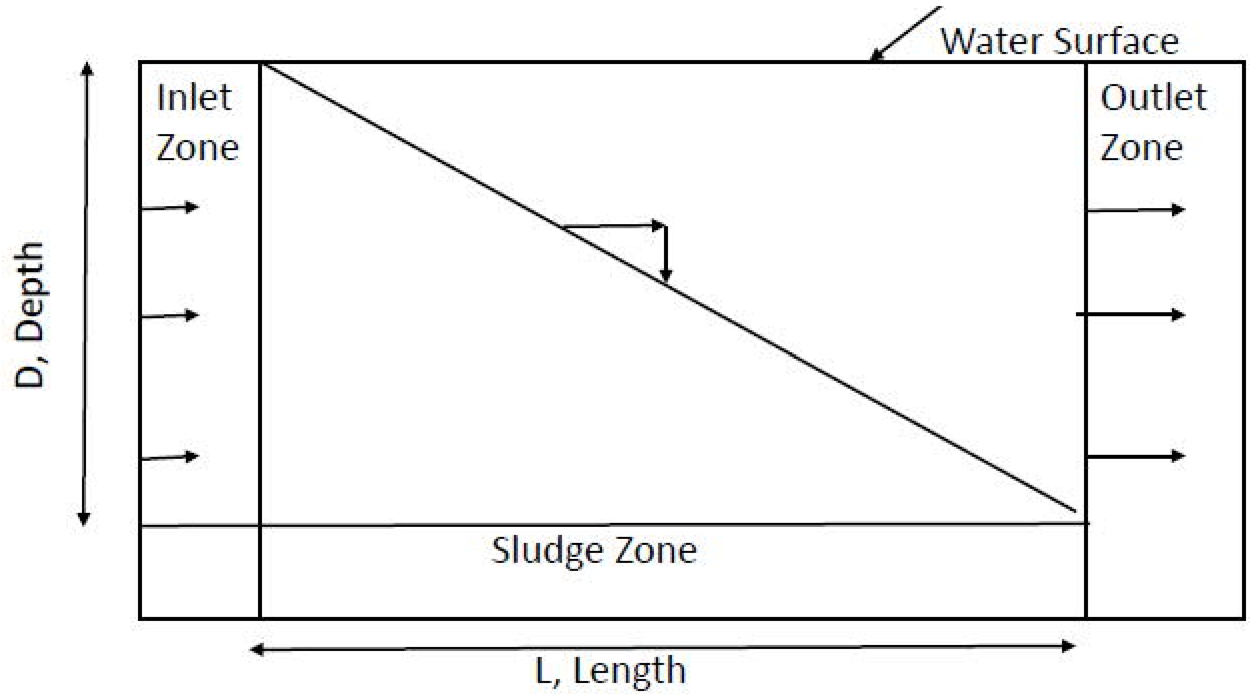
μ = dynamic viscosity

Φ= shape factor

Clarifier theory



Particle settling theory



Particles that settle faster than the hydraulic retention time of the basin are removed.

Removal of particles in discrete settling

In a settling basin all the particles that have a terminal velocity equal or greater than v_0 are removed.

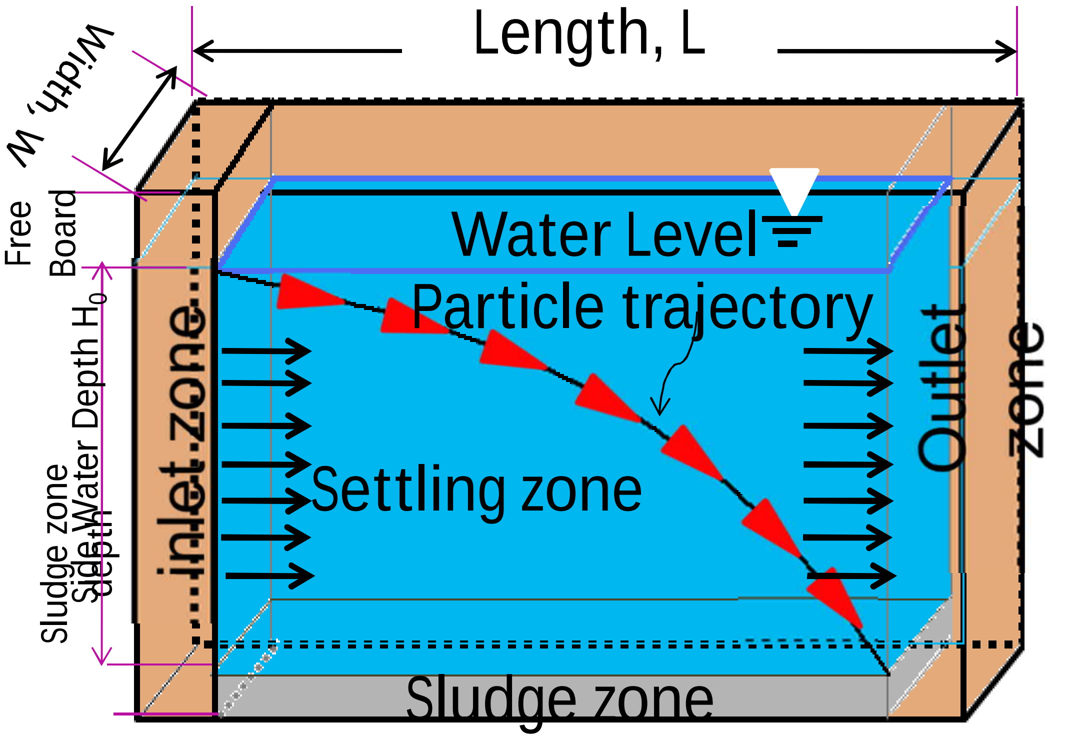
$$v_0 = h / t = Q / A$$

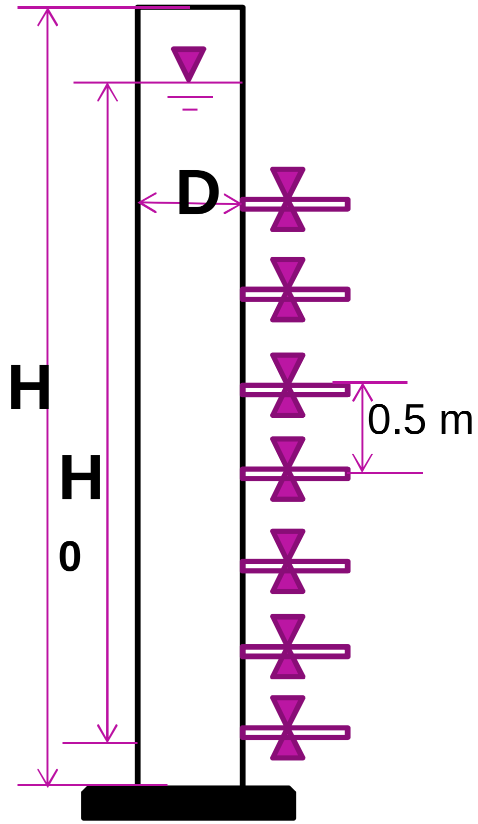
Where: $t = V/Q$

A = surface area of the basin

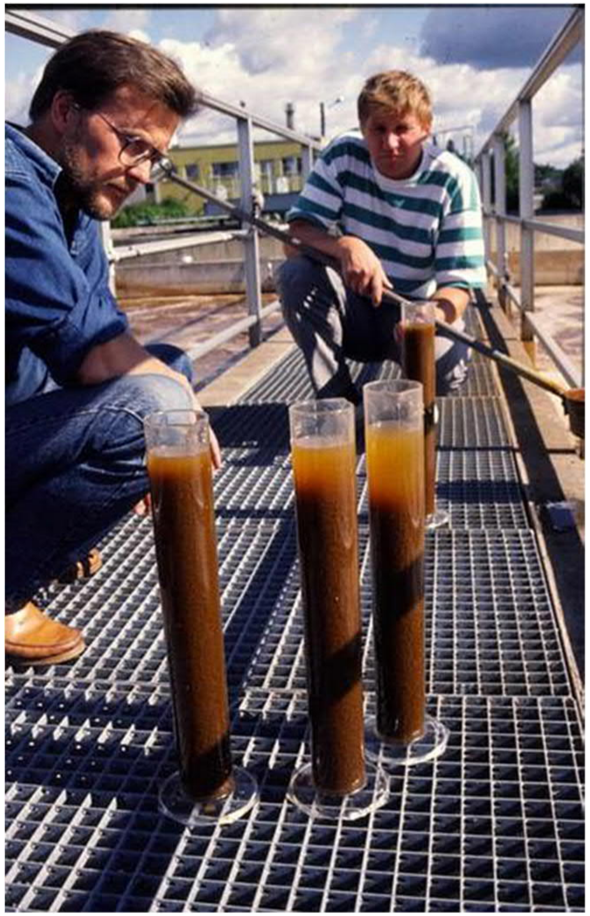
Flocculent and zone settling

In flocculent and zone settling the effects on settling velocity are determined by settling tests





How to measure settleability in biological sludges?



Sludge settleability (ml/1000 ml): measured in 1000 ml column during ½ h

Sludge volume index SVI (ml/g)

Settleability is divided by MLSS (g/l)

DSVI (ml/g) diluted SVI (dilution to obtain less than 250 ml settleability)

Good settling sludge:

- SVI < 100 ml/g

Bad settling sludge:

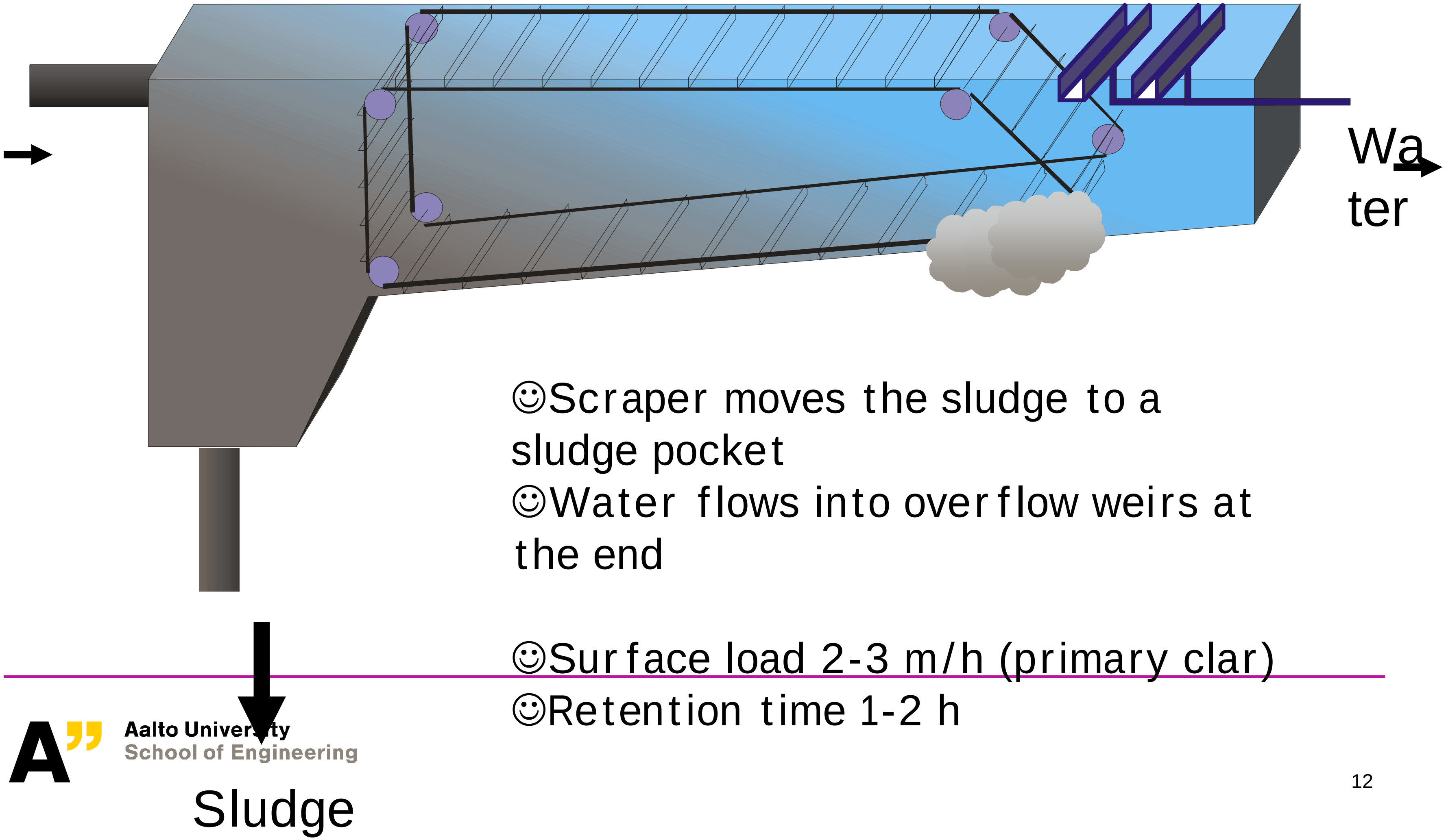
- SVI > 250 ml/g

Applications for gravity settling

- Flocculation can be enhanced by chemicals
  - Used widely in drinking water treatment to separate the flocs and in wastewater treatment to settle and thicken the sludge
  - Low energy demand, quite high space requirement
- Horizontal (rectangular or circular) or vertical

Clarifier

Horizontal



☺Scraper moves the sludge to a sludge pocket
☺Water flows into overflow weirs at the end

☺Surface load 2-3 m/h (primary clar)
☺Retention time 1-2 h

Clarifier

- Circular => Sludge removed from the middle
- Water enters in the middle

Simple Solids/Liquid Separators

- Percent solids removal
  - Primary ≈ 65%
  - Final ≈ 99.8 %
  - Membrane ≈ 100%
  - Thickener ≈ 85 – 95 %
  - Centrifuge solids capture ≈ 90%
- Calculated on mass flow basis
- Difference provides effluent solids

Settler design – engineering approach

Design parameters used in practice:

- the surface overflow rate (hydraulic loading);

- the solids loading rate (sludge mass loading);

- the volumetric loading rate (sludge volume loading);

- the weir loading rate (hydraulic loading of the overflow weir).

Hydraulic loading rate $v = Q_e/A$ $(m^3 \cdot m^{-2} \cdot h^{-1})$

Solids loading rate is the hydraulic loading rate multiplied by the incoming solids concentration $N_A = vX_a$ $(kg \cdot m^{-2} \cdot h^{-1})$ NOTE: should be <6

Volumetric loading rate is the solids loading rate multiplied by the sludge volume index SVI. If the units of SVI are in l/g, then the units of the volumetric loading are l/m² h.

NOTE: should be <1.5

DEMO 1

Design a secondary clarifier for a wastewater treatment with the design flow rate of 1577 m^3/h using surface loading rate of 0,8 m/h. Verify the design with solids loading and volumetric loading.

MLSS is 3 g/l and SVI in worst case 250 ml/g. Use a max flow coefficient of 1.43.

Surface loading rate 0,8 m/h → Clarifier area = 1971 m^2 (→ 2000 m^2)

Solids loading = 1,43 x 1577 m^3/h x 3 g/l / 2000 m^2 = 3,38 $kgSS/m^2/d$ OK

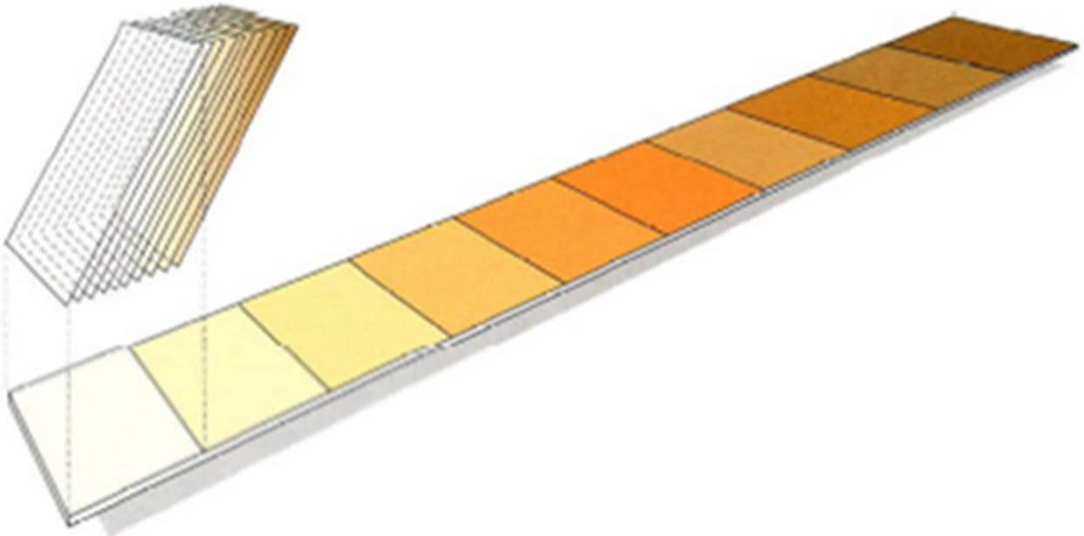
Volumetric loading rate (SVI 250)

= 0,85 $m^3/m^2/d$ OK

Note: 1,43 for max flow

Lamella settler theory

- Inclined plates are added in the clarifier basin
- Distance between the plates usually 5 – 10 cm
- Reduces the vertical distance a floc must settle before agglomerating to form larger particles

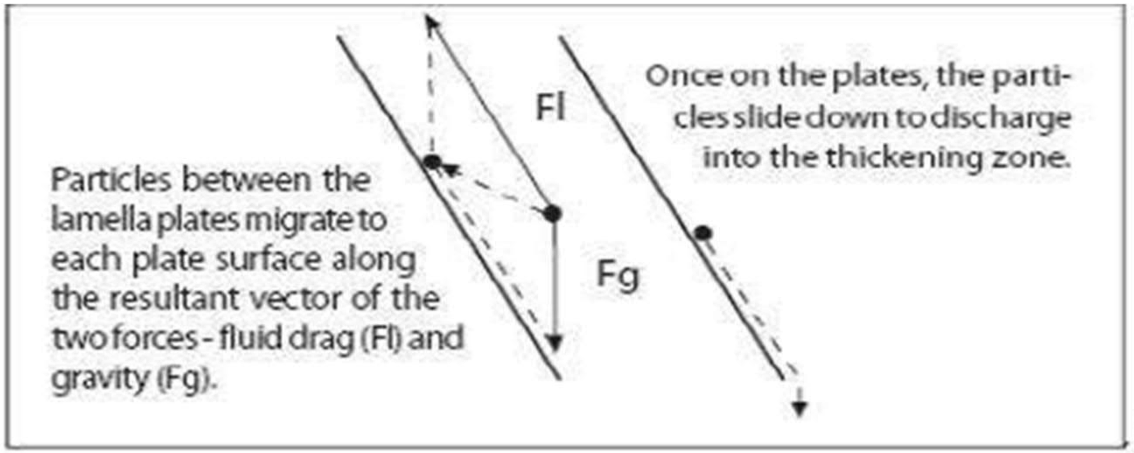


Lamella settling

In countercurrent setting time to settle is determined:

$$t = \frac{w}{v\ cos\theta}$$

w = distance between plates
Θ = angle of plates from horizontal
V = settling velocity



Lamella or tube settlers

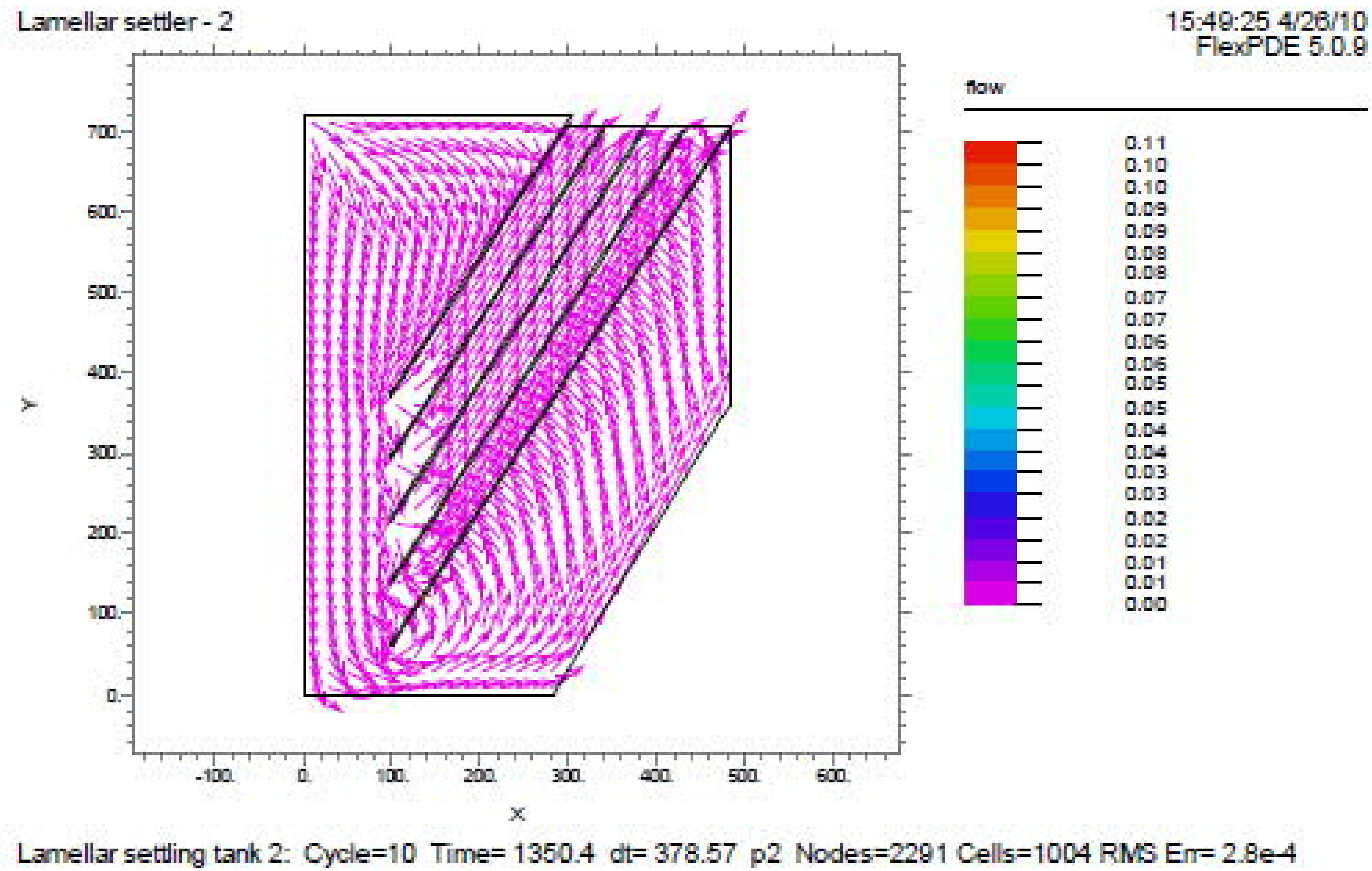
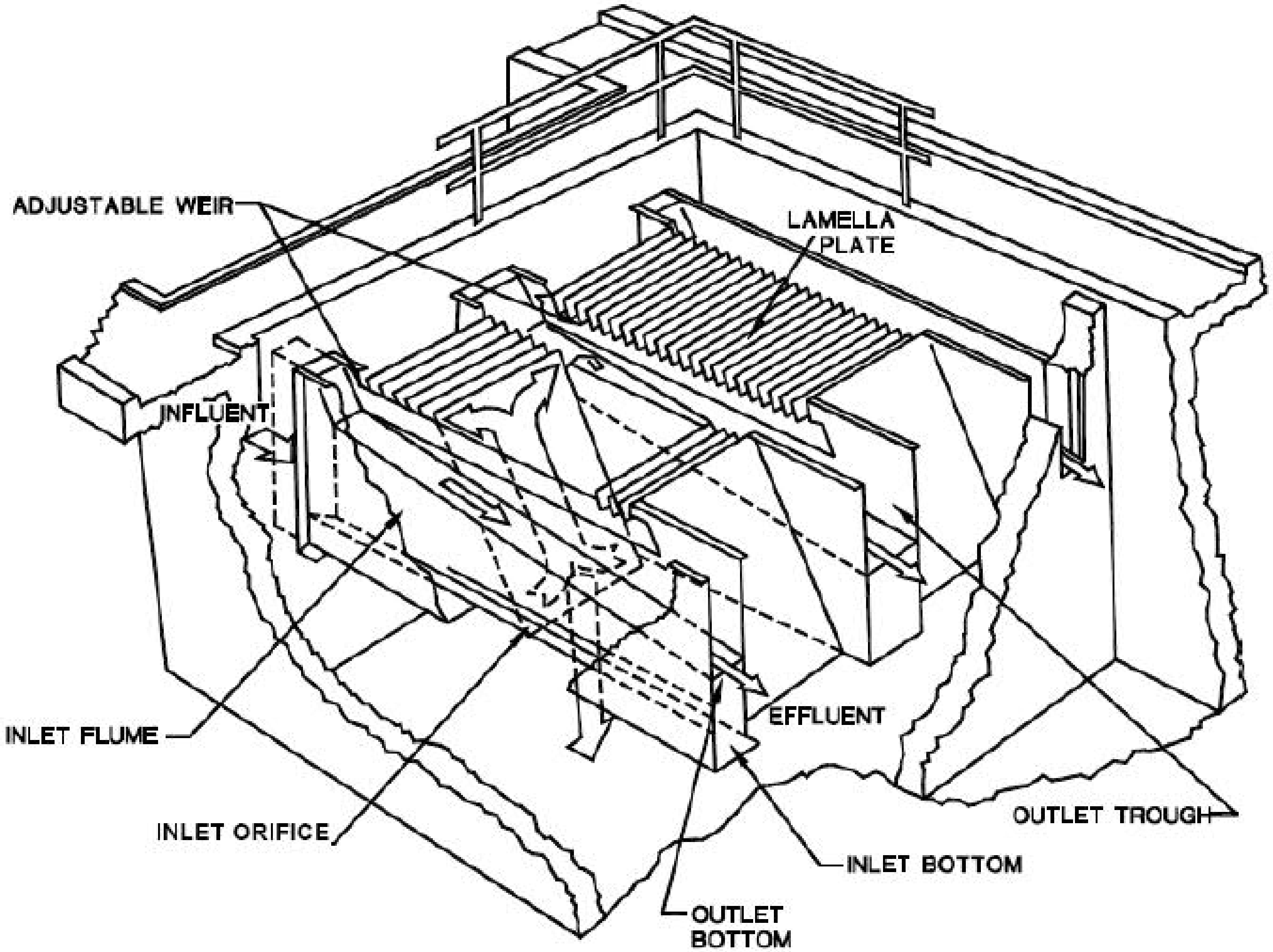


Fig. 3. Results for the second computational domain.

Robescu et al. 2010

Lamella settler

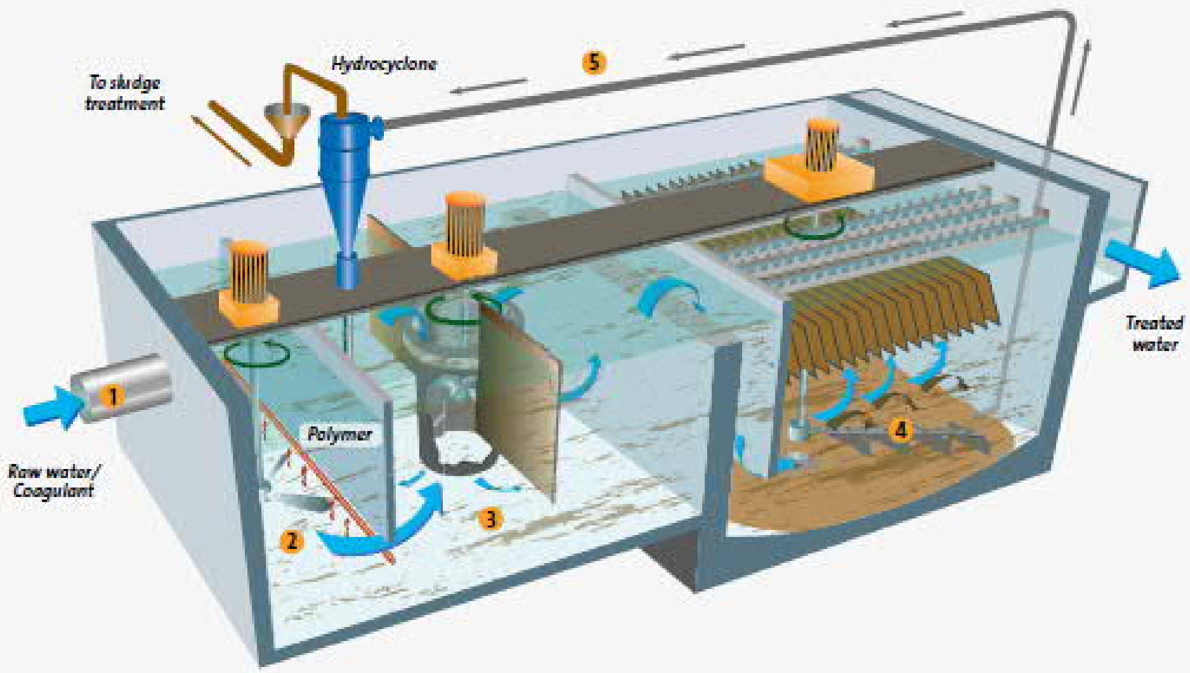


Source: AWWA and ASCE, 1998.

Ballasted settling

- Heavy particles are added to inhance flocculation and setting

E.g. Actiflo® Densadeg®



1 **Chemicals:** a coagulant, such as an iron or aluminium salt, is added to the raw water.

2 **Coagulation:** hydroxide flocs are formed during the coagulation phase.

3 **Turbomix™ flocculation:** the flocs formed during the coagulation phase are ballasted with microsand with the help of polymer.

4 **Clarification:** the ballasted flocs settle quickly thanks to the specific weight of the microsand.

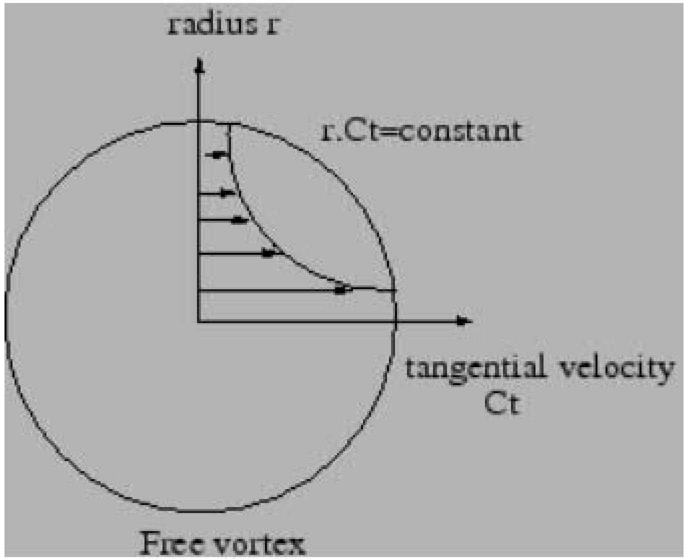
5 **Recirculation:** the sludge and microsand slurry is pumped to a hydrocyclone where the sludge is separated from the microsand via centrifugal force. The clean microsand is recycled back to the flocculation tank while the sludge is continuously discharged.

Gravity separation in accelerated flow field

Rotating flow creates a free vortex

In free vortex the tangential velocity times radius is a constant

Velocity's in the middle are higher resulting in separation of particles



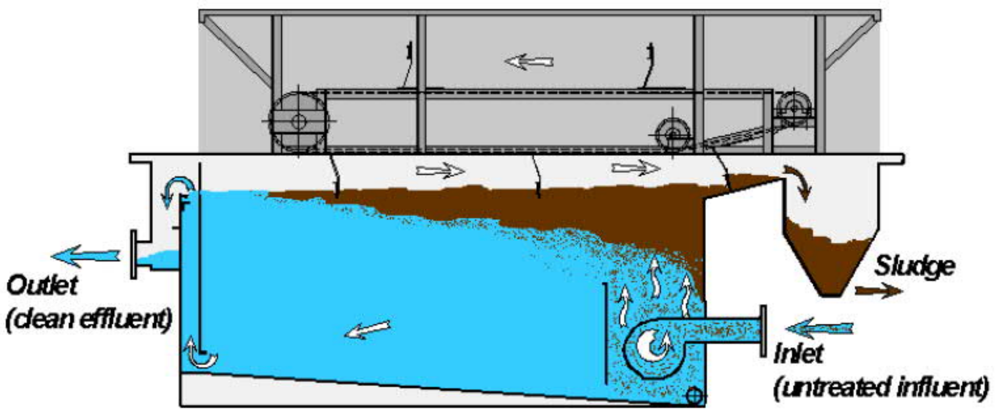
Flotation

- Separation is obtained by introducing fine gas bubbles into the liquid
- The bubbles attach to the particulate matter
- The buoyant force of the combined particle causes the particle to rise to the surface
- Surface is skimmed to remove the particles
- Usually dissolved-air flotation DAF, also dispersed-air flotation

Working principle of flotation

- A part of the effluent into which air is dissolved under pressure is recycled in the process.
- When this recycle flow enters the process, pressure drops and air forms micro-bubbles in the wastewater
- These bubbles attach or form within solids or flocs causing them to float
- Solids are removed with a skimmer from the surface

Demands energy, but saves space



Flotaatio (DAF)

Flotation calculation

- The performance of a DAF systems depends on the ratio of air to mass of solids (A/S)
- $\frac{A}{S} = \frac{1,3 s_a (fP - 1)}{S_a}$

s_a is air solubility ml/l

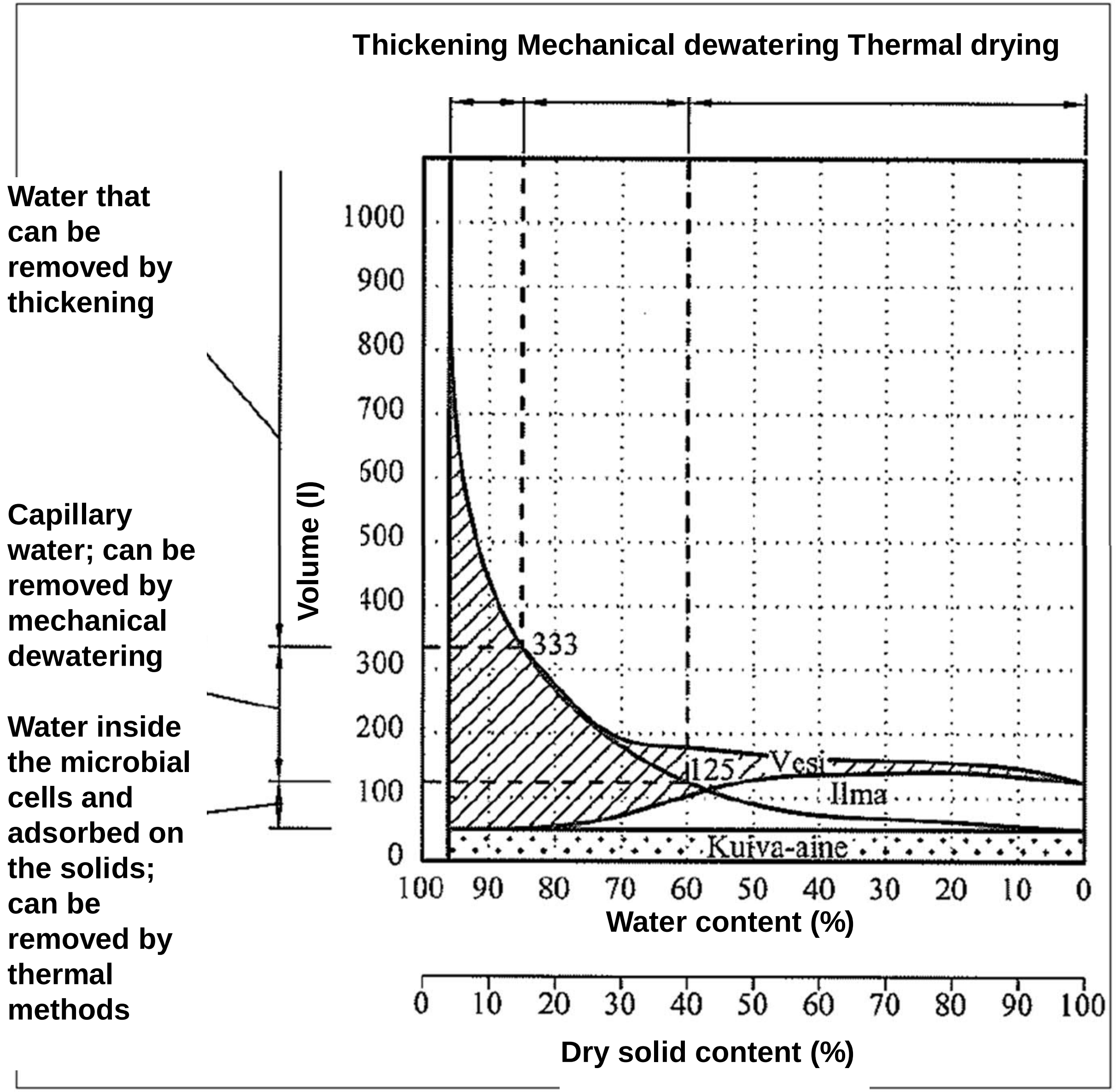
f is fraction of air dissolved at pressure P

P is pressure (atm)

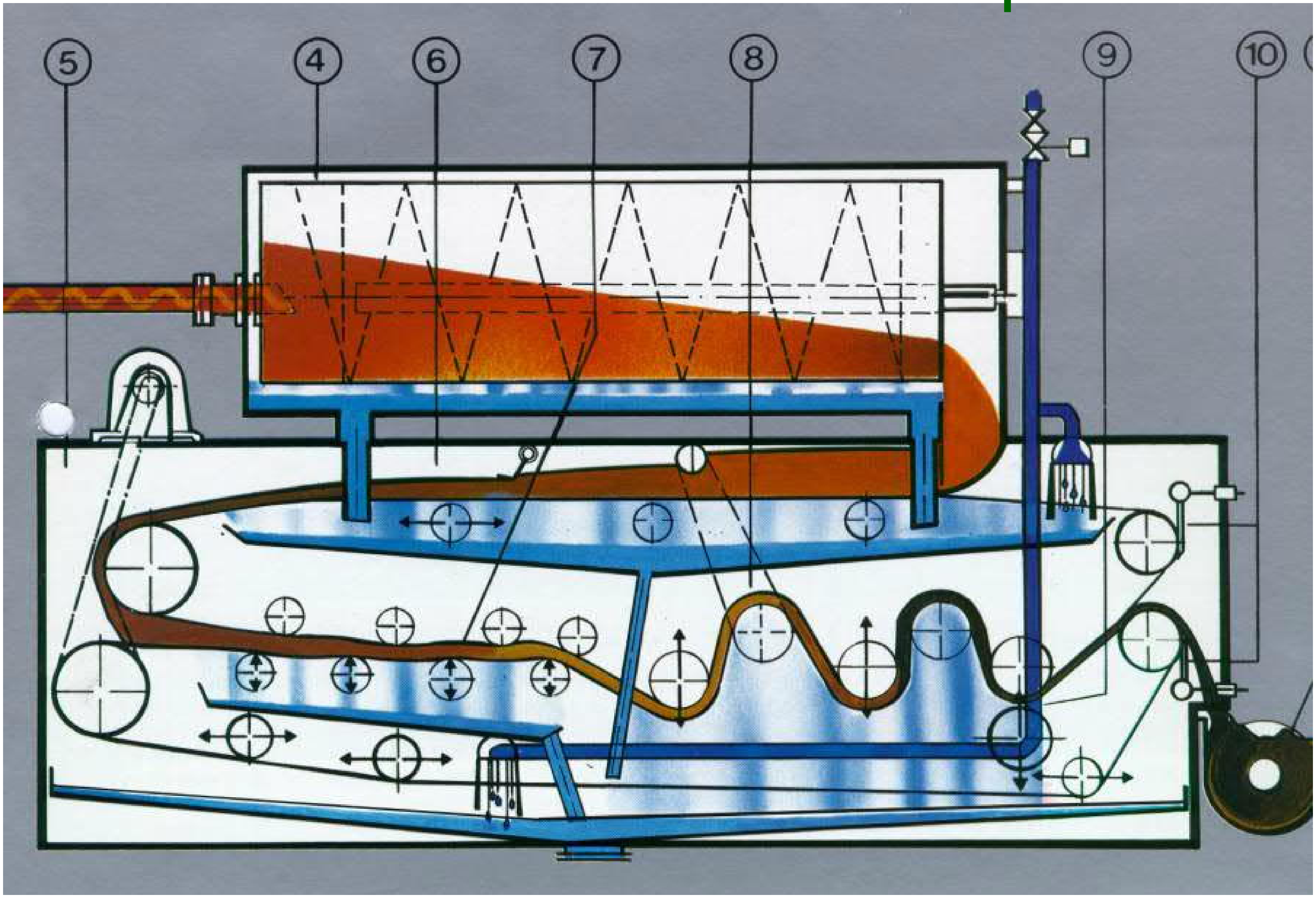
S_a is influent suspended solids (mg/l)

Dewatering

- Separation of water from solids
- Usually with biological sludge
- up to 20 – 40 %

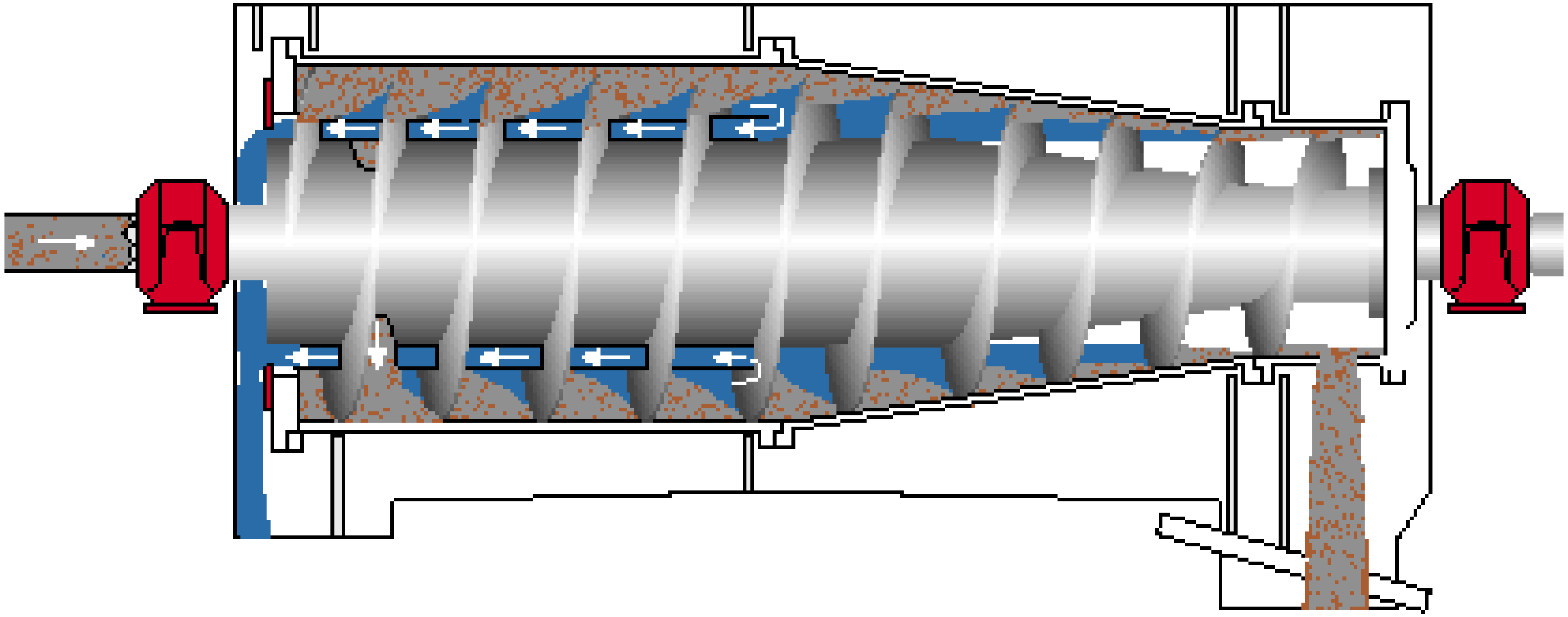


Belt press



Belt press

Centrifuge



Centrifuge