ENVE 302
Environmental Engineering Unit Processes

CHAPTER: 14

SLUDGE TREATMENT

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SLUDGE TREATMENT

The constituents removed in wastewater treatment plants:

- screenings
- grit, scum
- solids — primary sludge
- biosolids — WAS

Screening: all types of organic and inorganic materials large enough to be removed on bar racks

Grit: heavier inorganic solids

Scum/grease: consists of the floatable materials skimmed from the surface of primary and secondary settling tanks and from grit chambers

See **Table 14.8 (M& E, 4th Ed. p. 1457) :** expected solids concentrations from various treatment operations and processes

SLUDGE TREATMENT

Primary sludge : sludge from primary settling tank
usually gray and slimy
has an extremely offensive odor
5-9 % (typical 6%)

Sludge from Chemical Precip. with metal salts : usually dark in color
lime sludge is grayish-brown
the odor of chemical sludge may be objectionable but it is not as objectionable as the odor of primary sludge

Activated Sludge: has a brown flocculant appearance
if the color is dark, the sludge may be approaching a septic condition
WAS with primary settling = 0.5-1.5 %
WAS without primary settling = 0.8-2.5 %

See **Table 14.8 (M& E, 4th Ed. p. 1457) :** expected solids concentrations from various treatment operations and processes

REUSE AND DISPOSAL OF SOLIDS

- regulations
- organic content
- nutrients
- pathogens
- metals
- toxic organics

The fertilizer value of the sludge is based primarily on the content of :
- nitrogen - phosphorus - potassium

In most land application systems, biosolids provide sufficient nutrients for plant growth

QUALITY OF BIOSOLIDS according to 40 CFR Part 503 REGULATIONS

Class A Biosolids:

- must meet specific criteria to ensure they are safe to be used by the general public courses
- fecal coliform < 1000 MPN/g total dry solids

  or

  salmonella sp . < 3 MPN /g total dry solids

Class B Biosolids:

- have lesser treatment requirements than Class A
- are used for application to agricultural land or disposed of in a landfill
- Bulk biosolids applied to lawn or home gardens must meet the Class A criteria for pathogen reduction

LEVELS OF TREATMENT REQUIRED TO MEET PATHOGEN REQUIREMENT (EPA)

PFRP

(Processes to Further Reduce Pathogens)

reduce pathogen below detectable level

composting

heat drying

heat treatment

thermophilic anaerobic digestion

β and γ radiation

pasteurization

PSRP

(Processes to Significantly Reduce Pathogens)

reduce but not eliminate pathogens

PSRPs treated biosolids still have the potential to transmit disease

aerobic digestion

air drying

anaerobic digestion

composting

lime stabilization

SLUDGE PROCESSING

A) Preliminary Operations

Grinding: large and stringy material contained in the sludge is cut and shredded into small particles

Screening: coarse solids are removed

Degritting: grit removal

Blending: mixing of sludge (primary-WAS) to produce a uniform mixture to downstream operations

Storage: allow solids to accumulate during periods when subsequent facilities are not operating
e.g, night shifts, weekends

SLUDGE PROCESSING

B) Thickening Operations

to increase the solid content of the sludge by removing a portion of liquid fraction

Benefits for subsequent treatment processes:

1. capacity of tanks and equipment decreases
2. quantity of chemicals required for sludge conditioning decreases
3. amount of heat required by digesters decreases
4. for large treatment plants where sludge must be transported a significant distance , a reduction in sludge volume may result in reduction of pipe size and pumping cost

Gravity Thickening (about 4 %)
Centrifuge (4-6 %)
Rotary drum thickener (3-6 %)

Dissolved Air Floatation (3.5-5 %)
Belt thickener (3-6 %)

SLUDGE PROCESSING

C)Stabilization Operations

to reduce pathogens

to eliminate offensive odor

to eliminate the potential for putrefaction

Survival of pathogens,release of odor,putrefaction occur when the microorganisms are allowed to flourish in the organic fraction of the sludge

to eliminate these nuisance conditions ;

biological reduction of volataile content (Digestion, composting)
or
the addition of chemicals to the solids and biosolids to render them unsuitable for the survival of microorganisms
(alkaline stabilization)

SLUDGE PROCESSING

D)Sludge Conditioning

to improve the dewaterability characteristics of sludge

chemical conditioning

results in coagulation of the solids and released of the absorbed water

is used in advance of mechanical dewatering (centrifugation, belt filter)

polymers
iron salts
lime

SLUDGE PROCESSING

E)Sludge Dewatering

used to reduce the moisture content of sludge for the following reasons:

The cost of trucking sludge to ultimate disposal site become substantially lower when the volume is reduced by dewatering

Dewatered sludge are generally easier to handle than thickened or liquid sludge

belt filter press
filter press
centrifugation
sludge drying beds

SLUDGE PROCESSING

F)Heat Treatment

application of heat to evaporate water and to reduce the moisture content of sludge below that achivable by conventional dewatering methods

reduced product transportation cost

further pathogen reduction

improved storage capability

marketability

GRAVITY THICKENER

•accomplished in a tank similar in design to a conventional sedimentation

•circular tank is used

•dilute sludge is fed to a center feed well
allowed to settle and compact
thickened sludge is withdrawn from the conical tank bottom

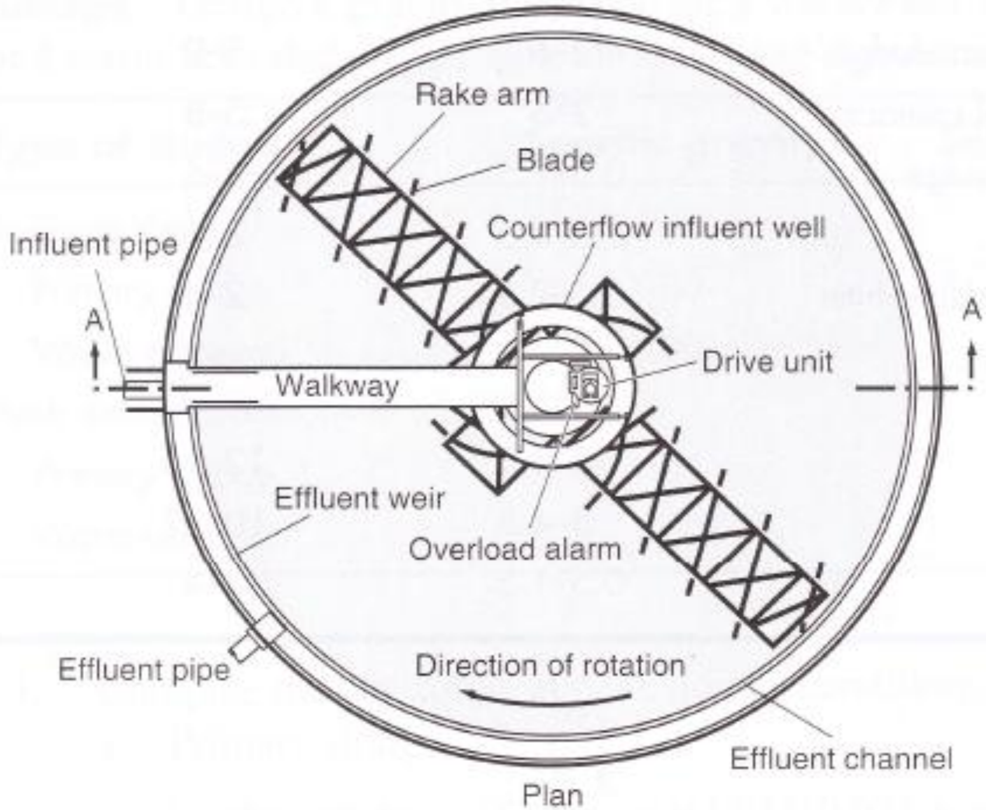
•vertical pickets on scraper cause a horizontal agitation which helps to release water trapped in the flocculant structure of sludge
vertical pickets stir the sludge gently
opening up channels for water to escape promote densification

•supernatant is returned to the primary sedimentation tank (if any)
or
returned to the inlet of biological systems

GRAVITY THICKENER

Figure 14-11

Schematic diagram of a gravity thickener: (*a*) plan and (*b*) section.



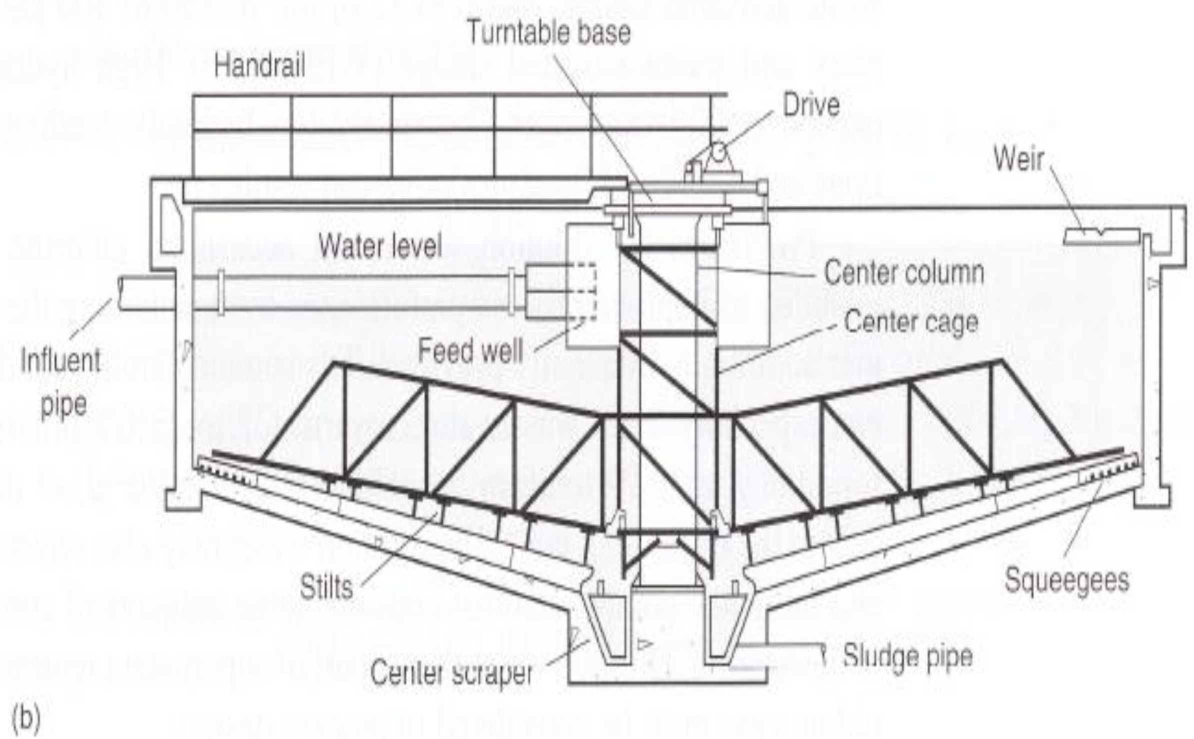
(a)

Ref: Metcalf & Eddy

GRAVITY THICKENER

Figure 14-11

Schematic diagram of a gravity thickener: (*a*) plan and (*b*) section.



GRAVITY THICKENER

Table 14–19
Typical concentrations of unthickened and thickened sludges and solids loadings for gravity thickeners[a]

Type of sludge or biosolids	Solids concentration, %: Unthickened	Solids concentration, %: Thickened	Solids loading: lb/ft²·d	Solids loading: kg/m²·d
Separate:				
Primary sludge	2–6	5–10	20–30	100–150
Trickling-filter humus sludge	1–4	3–6	8–10	40–50
Rotating biological contactor	1–3.5	2–5	7–10	35–50
Air-activated sludge	0.5–1.5	2–3	4–8	20–40
High-purity oxygen-activated sludge	0.5–1.5	2–3	4–8	20–40
Extended aeration-activated sludge	0.2–1.0	2–3	5–8	25–40
Anaerobically digested primary sludge from primary digester	8	12	25	120
Combined:				
Primary and trickling-filter humus sludge	2–6	5–9	12–20	60–100
Primary and rotating biological contactor	2–6	5–8	10–18	50–90
Primary and waste-activated sludge	0.5–1.5	4–6	5–14	25–70
	2.5–4.0	4–7	8–16	40–80
Waste-activated sludge and trickling-filter humus sludge	0.5–2.5	2–4	4–8	20–40
Chemical (tertiary) sludge:				
High lime	3–4.5	12–15	24–61	120–300
Low lime	3–4.5	10–12	10–30	50–150
Iron	0.5–1.5	3–4	2–10	10–50

[a] Adapted from WEF (1996).

DISSOLVED AIR FLOATATION (DAF) THICKENING

•Air is introduced into the solution that is being held at an elevated pressure

•When the solution is depressurized, the dissolved air is released as finely divided bubbles carrying the sludge to the top where it is removed

•Important Design Criteria:

Air/Solids ratio

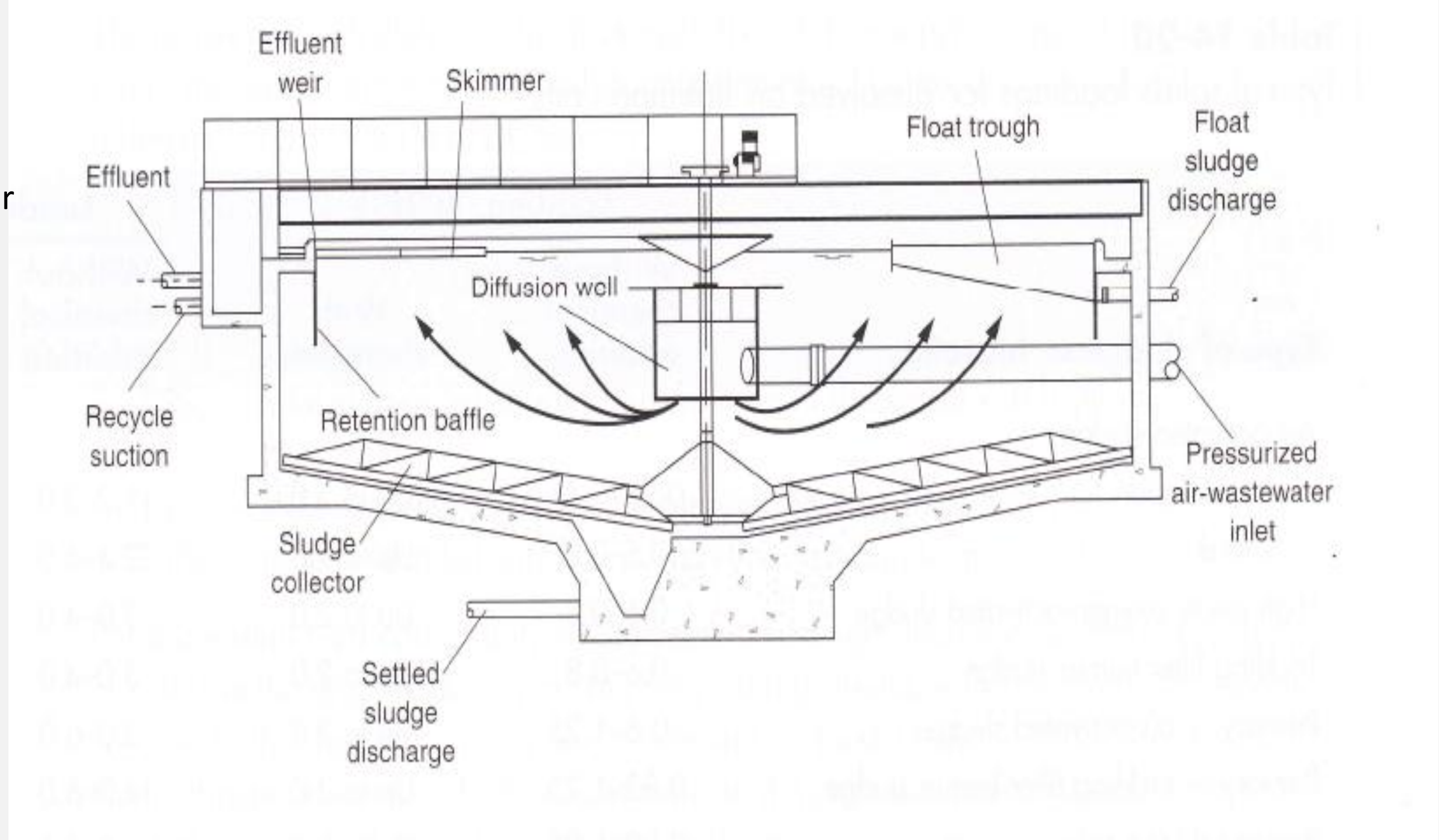
SVI

solids loading rate

DISSOLVED AIR FLOATATION (DAF) THICKENING

Figure 14 – 12

Typical dissolved air flotation unit used for thickening waste-activated sludge.



DISSOLVED AIR FLOATATION (DAF) THICKENING

Table 14-20
Typical solids loadings for dissolved air flotation units[a,b]

Type of sludge or biosolids	Loading, lb/ft²·h		Loading, kg/m²·h	
	Without chemical addition	With chemicals	Without chemical addition	With chemicals
Air-activated sludge:				
Mixed liquor	0.25–0.6	Up to 2.0	1.2–3.0	Up to 10
Settled	0.5–0.8	Up to 2.0	2.4–4.0	Up to 10
High-purity oxygen-activated sludge	0.6–0.8	Up to 2.0	3.0–4.0	Up to 10
Trickling-filter humus sludge	0.6–0.8	Up to 2.0	3.0–4.0	Up to 10
Primary + air-activated sludge	0.6–1.25	Up to 2.0	3.0–6.0	Up to 10
Primary + trickling-filter humus sludge	0.83–1.25	Up to 2.0	4.0–6.0	Up to 10
Primary sludge only	0.83–1.25	Up to 2.5	4.0–6.0	Up to 12.5

[a]Adapted, in part, from U.S. EPA (1979) and WEF (1998).
[b]Loading rates necessary to produce a minimum 4 percent solids concentration in the float.

CENTRIFUGAL THICKENING

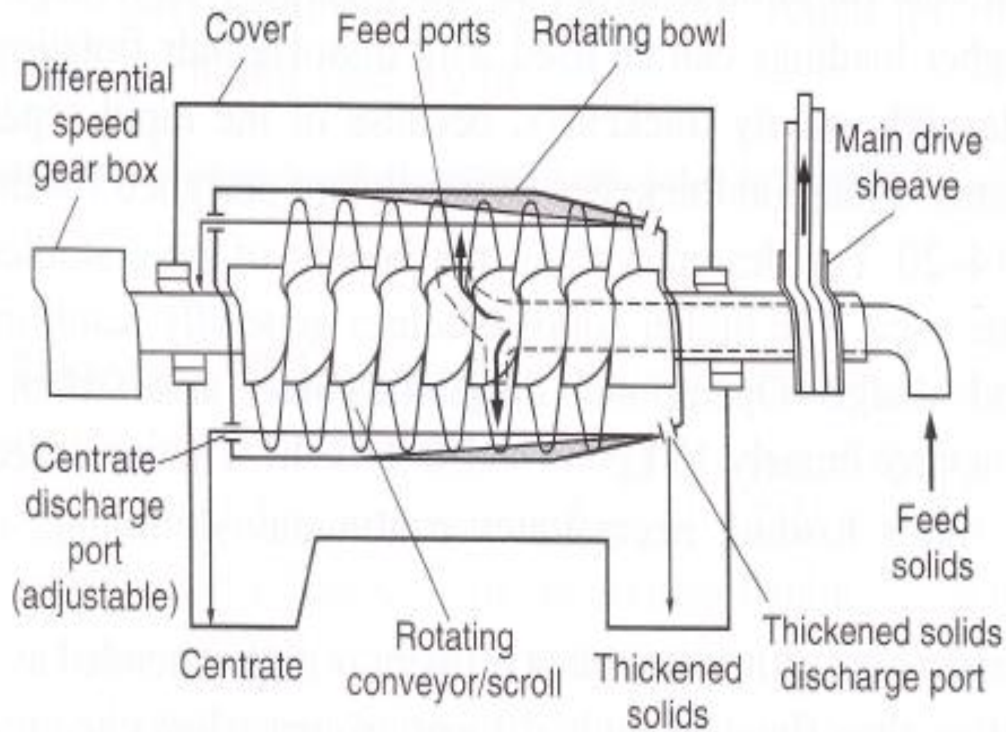
- settling of sludge particles under the influence of centrifugal forces
- basic type → solid-bowl
- sludge is introduced into the unit continuously and the solids concentrate on periphery
- high maintenance and power cost
- attractive where space is limited
- polymer addition→ to improve performance

Ref: Metcalf & Eddy

CENTRIFUGAL THICKENING

Figure 14-13

Schematic diagram of a centrifuge used for sludge thickening.



GRAVITY BELT THICKENING
(Gravity Drainage Decks , GDD)

•the equipment consists of a gravity belt that moves over rollers driven by a variable-speed drive unit

•The sludge is conditioned by polymer and fed into a feed- distribution box at one end, where the sludge is distributed evenly across the width of the moving belt

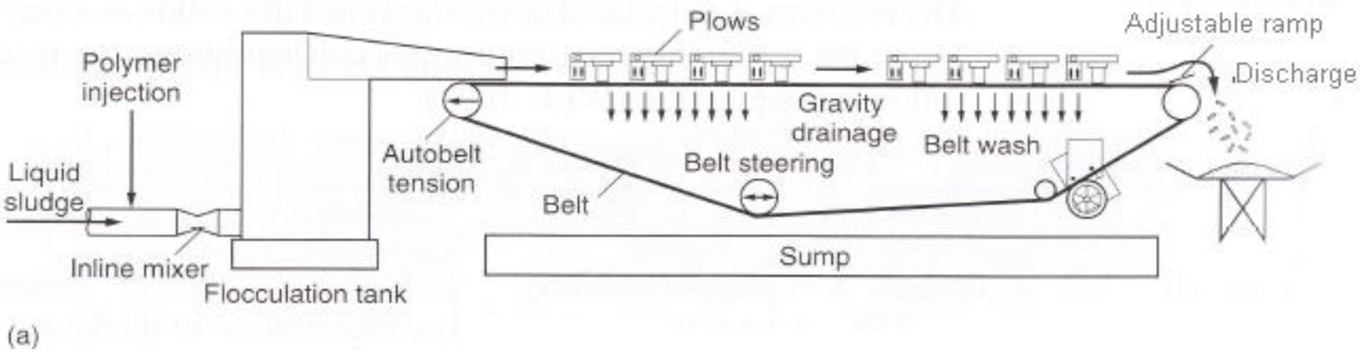
•The water drains through the belt as the concentrating sludge is carried toward the discharge end

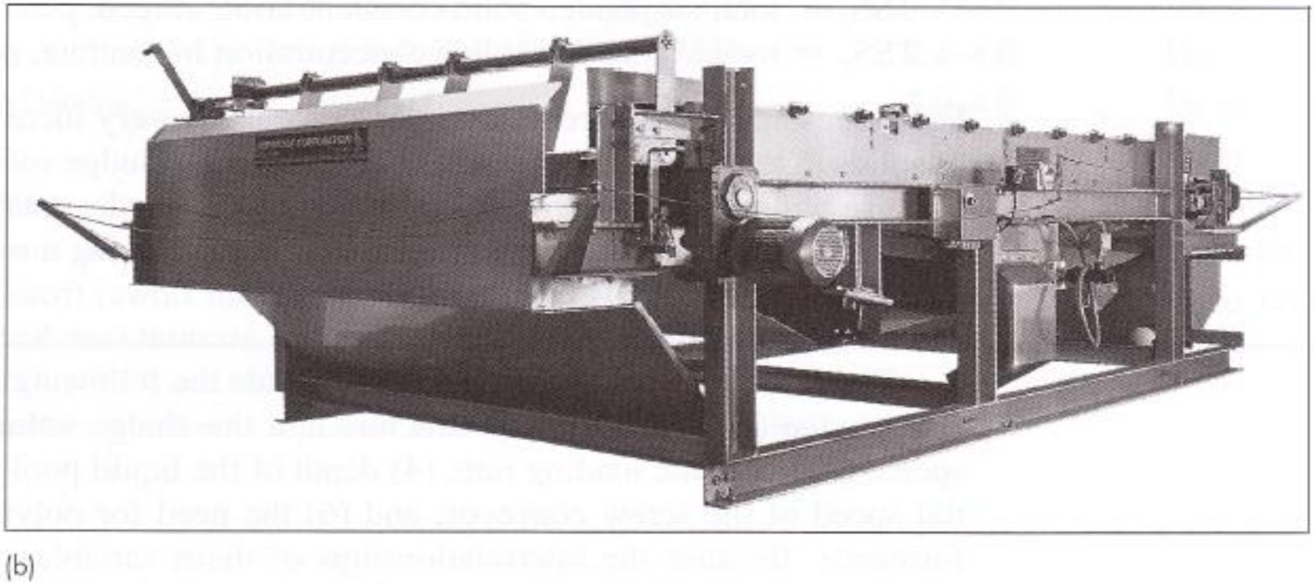
•After the thickened sludge is removed, the belt travels through a wash cycle

GRAVITY BELT THICKENING (Gravity Drainage Decks , GDD)

Figure 14–14

Gravity-belt thickener: (*a*) schematic diagram, and (*b*) pictorial view showing the inlet to the thickener on the top left-hand side. The sludge moves along the belt to the far end while water drains through the porous belt. *(Courtesy Ashbrook Corporation.)*





GRAVITY BELT THICKENING (Gravity Drainage Decks , GDD)

Table 14-21
Typical hydraulic loading rates for gravity belt thickeners[a,b]

Belt size (effective dewatering width), m	Hydraulic loading range gal/min	Hydraulic loading range L/s
1.0	100–250	6.7–16
1.5	150–375	9.5–24
2.0	200–500	12.7–32
3.0	300–750	18–47

[a] Assumes 0.5 to 1.0 percent feed solids for municipal sludges. Variations in sludge density, belt porosity, polymer reaction rate, and belt speed will act to increase or decrease the rates of flow for any given size belt.
[b] Adapted from WEF (1998).

ROTARY DRUM THICKENING

•consist of a conditioning system (polymer feed system) and rotating cylindrical screens

•polymer is mixed with dilute sludge

•the conditioned sludge is then passed to a rotating-screen drum which separate the flocculated solids from the water

Ref: Metcalf & Eddy

ROTARY DRUM THICKENING

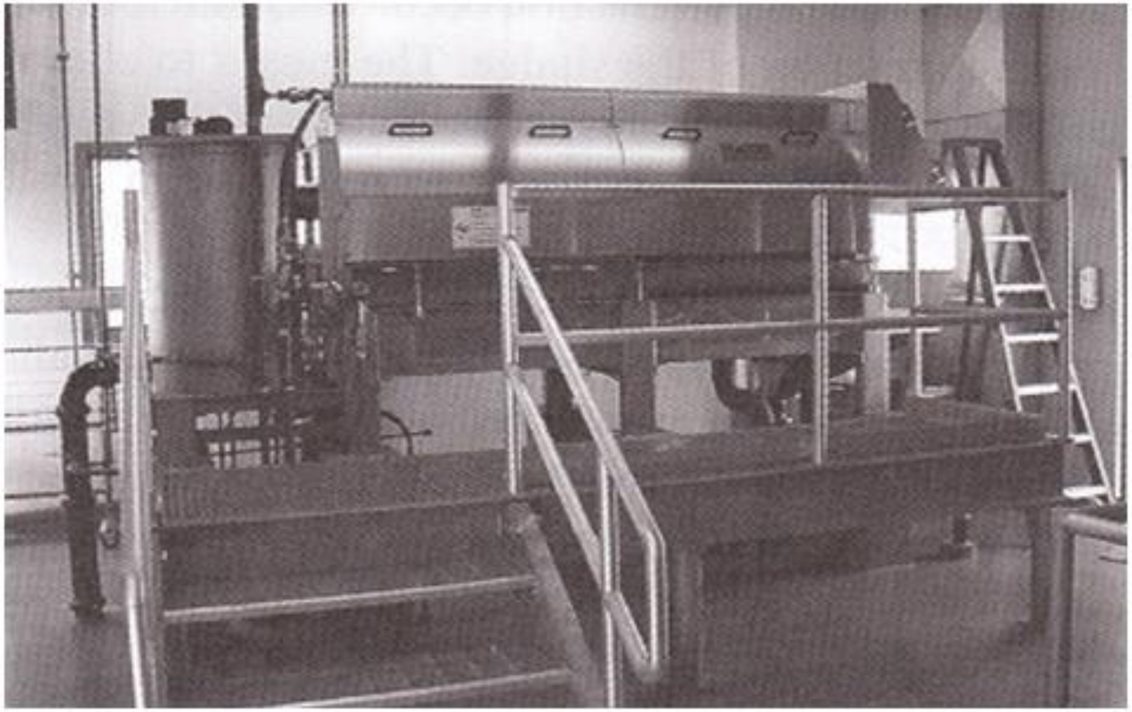


Figure 14–15

Rotary-drum thickener. *(Courtesy Parkson Corporation.)*

ROTARY DRUM THICKENING

Table 14–22
Typical performance ranges for rotary-drum thickeners[a]

Type of solids or biosolids	Feed, % TS	Water removed, %	Thickened solids, %	Solids recovery, %
Primary	3.0–6.0	40–75	7–9	93–98
Waste activated	0.5–1.0	70–90	4–9	93–99
Primary + waste activated	2.0–4.0	50	5–9	93–98
Aerobically digested	0.8–2.0	70–80	4–6	90–98
Anaerobically digested	2.5–5.0	50	5–9	90–98

[a] WEF (1996).

SLUDGE STABILIZATION

A. ALKALINE STABILIZATION

• use of alkaline material to render the sludge unsuitable for the survival of microorganisms

• lime stabilization→ most commonly used

• lime is added to untreated sludge in sufficient quantity to raise the pH to 12 or higher

The high pH creates an environment that halts the microbial reactions (does not destroy organics)

US EPA criterion: maintain pH above 12 for about 2 hr to ensure pathogen destruction

SLUDGE STABILIZATION

<u>REMARK:</u>

Biological activity produces compounds , such as CO_2,organic acids that react with lime.

If biological activity in the sludge is not sufficiently be inhibited, these compounds will be produced, reducing the pH and resulting inadequate stabilization

Therefore, excess lime (1.5 x amount needed to maintain the initial pH of 12) is necessary

2 methods of alkaline stabilization:

addition of lime to sludge prior to dewatering (lime pretreatment)
addition of lime to sludge after dewatering (lime post treatment)

<u>Lime pretreatment:</u>
-scaling problems in dewatering
-seldom used with centrifuges and belt filters

SLUDGE STABILIZATION

Table 14–23
Description of stabilization processes

Process	Description	Comments
Alkaline stabilization	Addition of an alkaline material, usually lime, to maintain a high pH level to effect the destruction of pathogenic organisms	An advantage of alkaline stabilization is that a rich soil-like product results with substantially reduced pathogens. A disadvantage is that the product mass is increased by the addition of the alkaline material. Some alkaline stabilization processes are capable of producing a Class A sludge
Anaerobic digestion	The biological conversion of organic matter by fermentation in a heated reactor to produce methane gas and carbon dioxide. Fermentation occurs in the absence of oxygen	Methane gas can be used beneficially for the generation of heat or electricity. The resulting biosolids may be suitable for land application. The process requires skilled operation as it may be susceptible to upsets and recovery is slow
Aerobic digestion	The biological conversion of organic matter in the presence of air (or oxygen), usually in an open-top tank	Process is much simpler to operate than an anaerobic digester, but no usable gas is produced. The process is energy-intensive because of the power requirements necessary for mixing and oxygen transfer
Autothermal thermophilic digestion	Process is similar to aerobic digestion except higher amounts of oxygen are added to accelerate the conversion of organic matter. Process operates at temperatures of 40 to 80°C, autothermally in an insulated tank	Process is capable of producing a Class A sludge. Skilled operators are required and the process is a high-energy user (to produce air or oxygen)
Composting	The biological conversion of solid organic matter in an enclosed reactor or in windrows or piles	A variety of solids or biosolids can be composted. Composting requires the addition of a bulking agent to provide an environment suitable for biological activity. Volume of compost produced is usually greater than the volume of wastewater solids being composted. Class A or Class B sludge can be produced. Odor control is very important, as process is odorous

SLUDGE STABILIZATION

Table 14–24
Relative degree of attenuation achieved with various sludge stabilization processes[a]

Process	Degree of attenuation: Pathogens	Putrefaction	Odor potential
Alkaline stabilization	Good	Fair	Fair
Anaerobic digestion	Fair	Good	Good
Aerobic digestion	Fair	Good	Good
Autothermal thermophilic digestion (ATAD)	Excellent	Good	Good
Composting	Fair	Good	Poor to fair
Composting (thermophilic)	Excellent	Good	Poor to fair

[a] Adapted, in part, from WEF (1998).

Table 14–25
Typical lime dosages for pretreatment sludge stabilization[a]

Type of sludge	Solids concentration, %: Range	Average	Lime dosage[b]: lb $Ca(OH)_2$/ton dry solids: Range	Average	g $Ca(OH)_2$/kg dry solids: Range	Average
Primary	3–6	4.3	120–340	240	60–170	120
Waste activated	1–1.5	1.3	420–860	600	210–430	300
Anaerobically digested mixed	6–7	5.5	280–500	380	140–250	190
Septage	1–4.5	2.7	180–1020	400	90–510	200

[a] Adapted from WEF (1995a).
[b] Amount of $Ca(OH)_2$ required to maintain a pH of 12 for 30 min.

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

•among the oldest process used for stabilization of solids ad biodsolids

•involves the decomposition of organic matter and inorganic matter (principally sulfate) in the absence of oxygen

•methane gas produced
produced methane gas meet the portion of the energy needed for plant operation
energy conservation and recovery

•Reactions occur in anaerobic digestion:
hydrolysis→ fermentation→ acidogenesis→ methanogenesis

Important factors:

•SRT, Temperature, Alkalinity, pH , presence of inhibitory compounds, bioavalibility of nutrients and trace metals

•single-stage or two-stage

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

Single - Stage

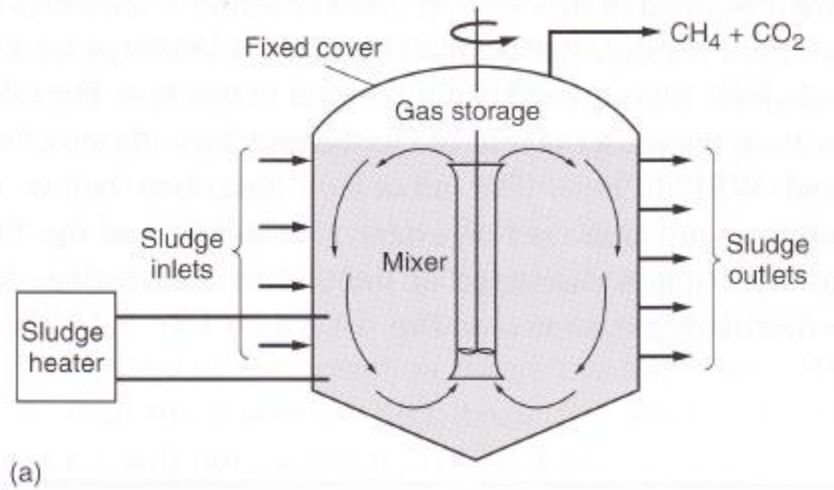


Figure 14-20
Schematic diagram of typical anaerobic digesters: (*a*) single-stage high-rate, and (*b*) two-stage.

Sludge mixing
- Gas recirculing
- Pumping
- mixer

No supernatant seperation

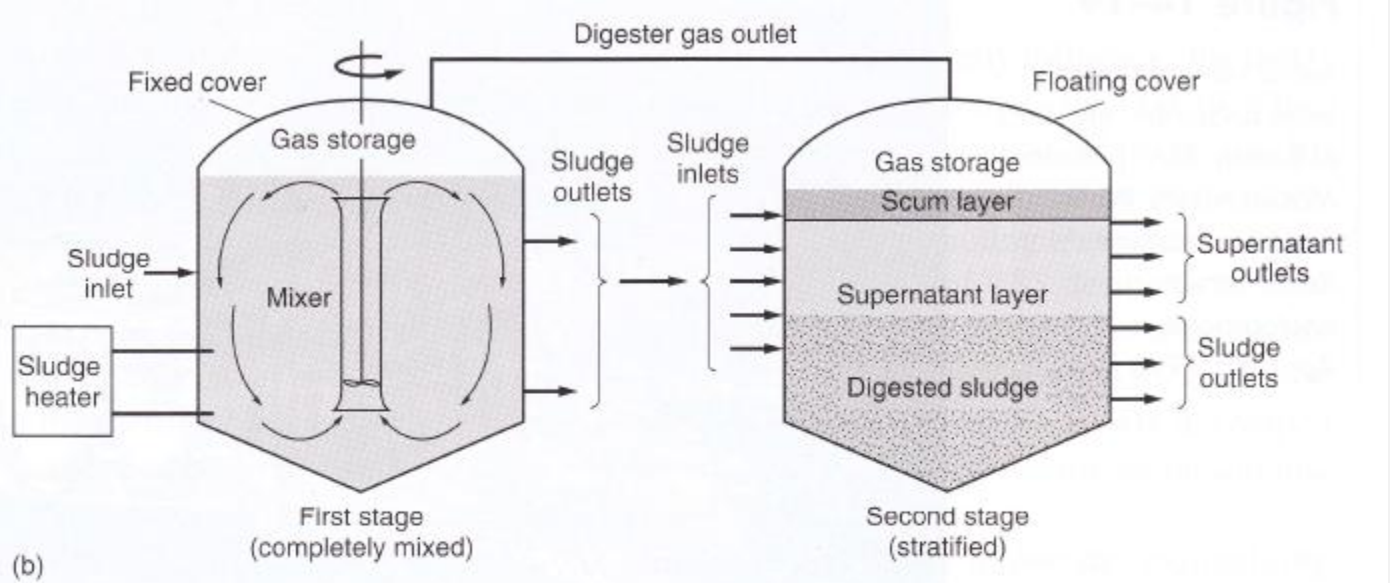
Total solis reduction 45 - 50%

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

Two - Stage

Figure 14.20
(continued)



used for digestion heated and equipped with mixing facility

unheated used principally for storage

- Seldom used in modern digester design
- Anaerobically digested solids may not settle well. Therefore; Supernatant withdrawn from 2nd tank may contain high concentration of suspended solids

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

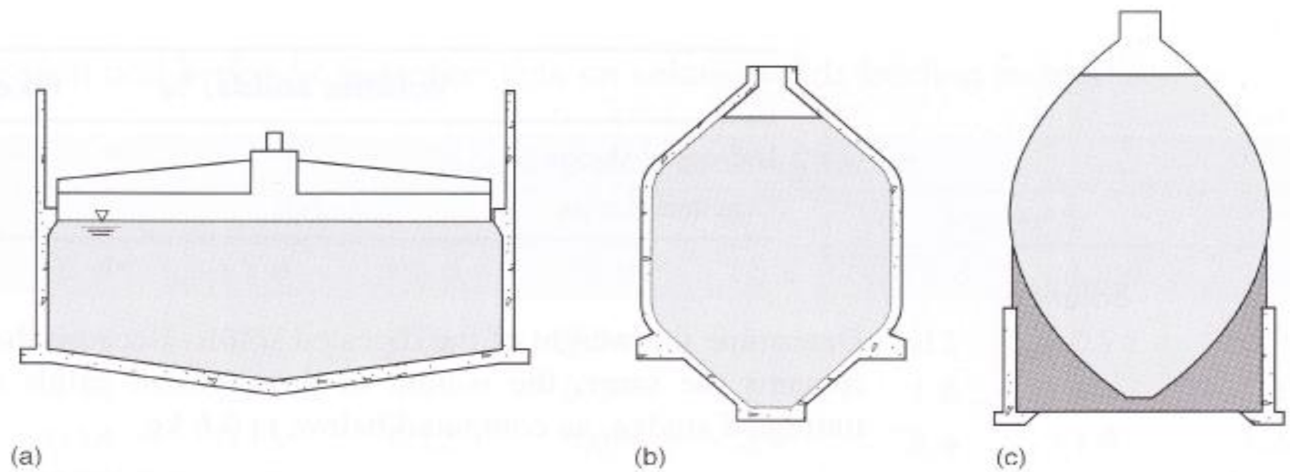
Table 14 – 26
Suggested solids retention times for use in the design of complete-mix anaerobic digesters[a]

Operating temperature, °C	SRT (minimum)	SRT_{des}
18	11	28
24	8	20
30	6	14
35	4	10
40	4	10

[a]McCarty (1964) and (1968).
Note: 1.8 (°C) + 32 = °F.

Figure 14–21

Typical shapes of anaerobic digesters: (*a*) cylindrical with reinforced concrete construction, (*b*) conventional German design with reinforced concrete construction, and (*c*) egg-shaped with steel shell.



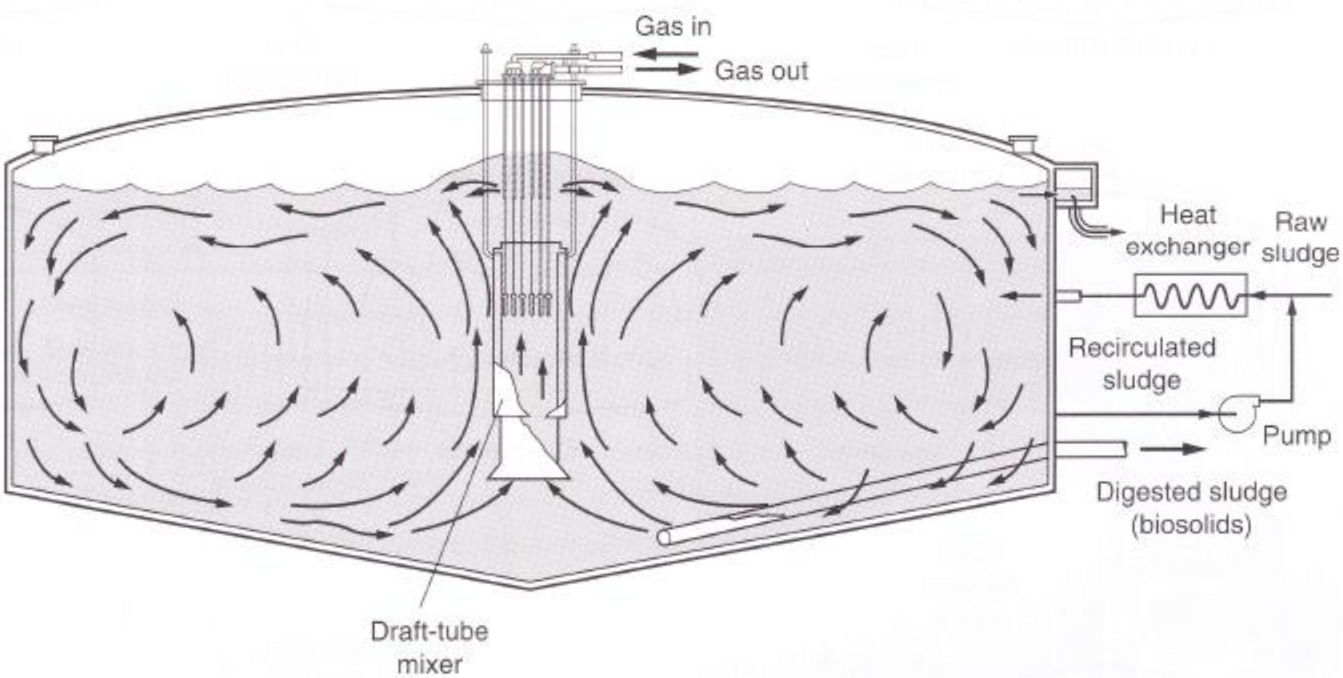
SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

CYLINDIRICAL

Figure 14–22

Typical cross section through a high-rate, gas-mixed cylindrical digester.



Floor; usually conical

Alternative; waffle bottom (fig. 14.23)

to minimize grit accumulation

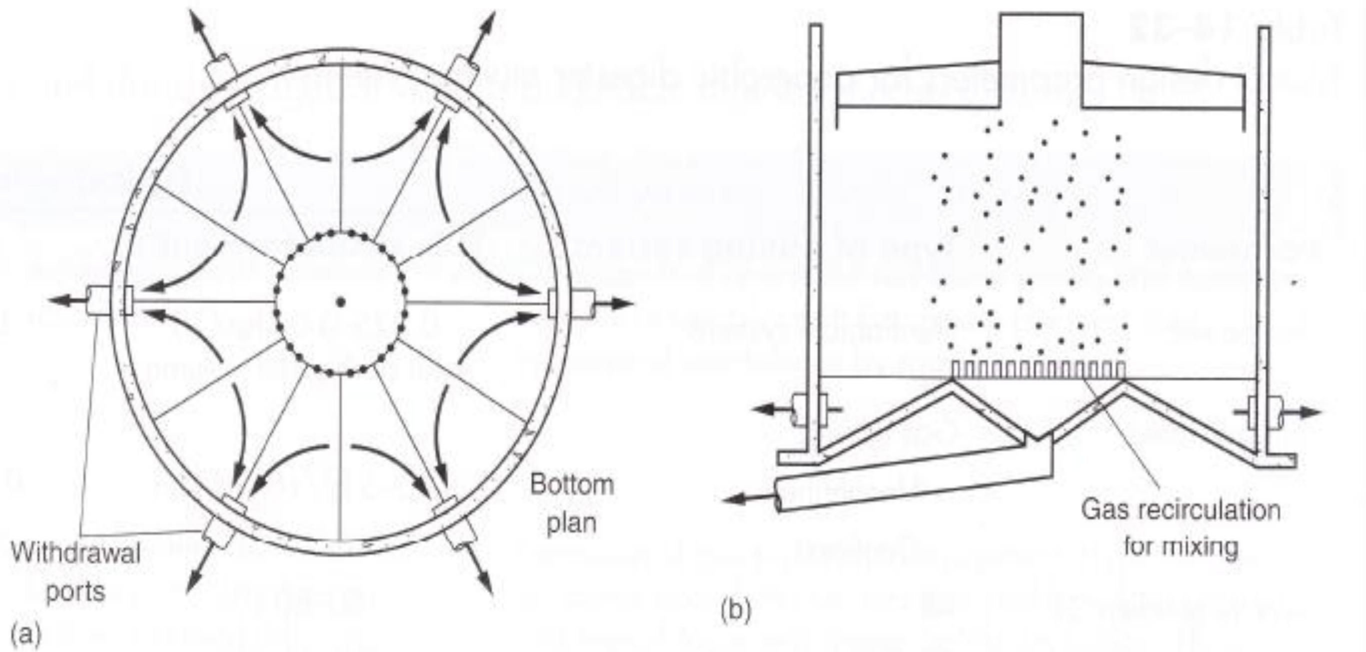
to reduce the need for frequent digester cleaning

SLUDGE STABILIZATION

B. **ANAEROBIC DIGESTION**

Figure 14–23

Typical waffle-bottom anaerobic digester: (*a*) plan view, (*b*) section.



Ref: Metcalf & Eddy

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

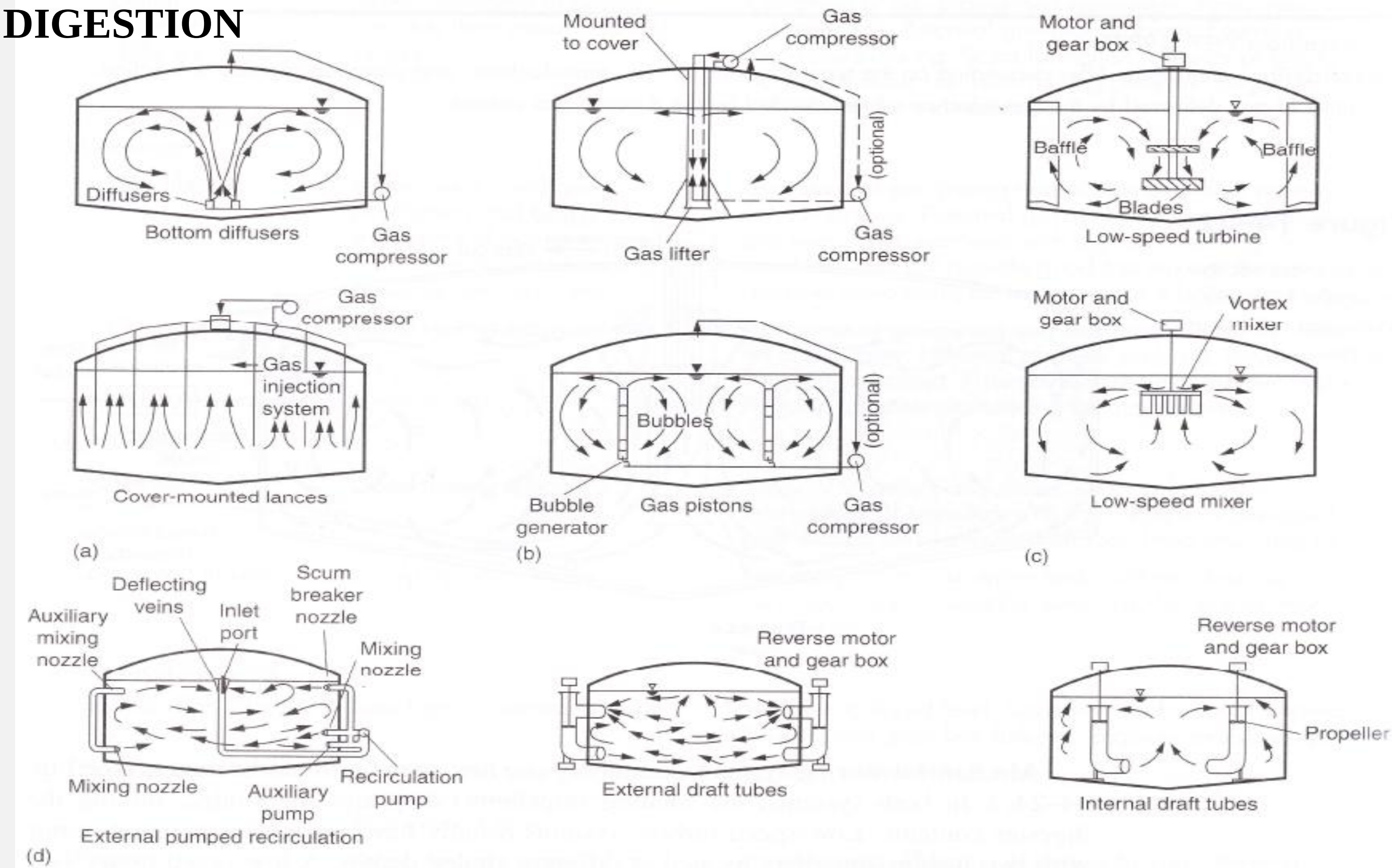


Figure 14–24

Devices used for mixing contents of anaerobic high-rate digesters: (*a*) unconfined gas-injection systems, (*b*) confined gas-injection systems, (*c*) mechanical stirring systems, (*d*) mechanical pumping systems. *(Metcalf & Eddy, 1984a.)*

Ref: Metcalf & Eddy

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

EGG - SHAPED DIGESTER

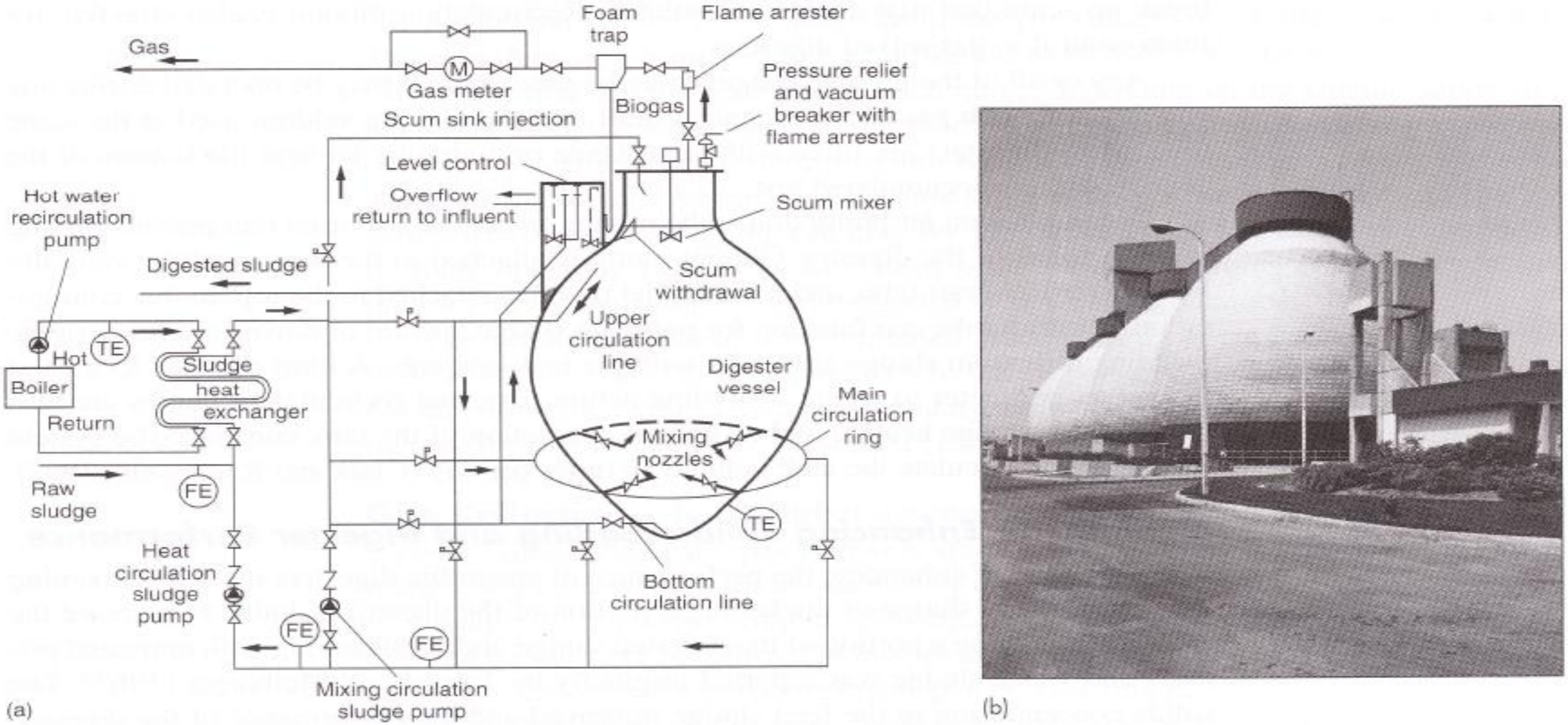


Figure 14–25

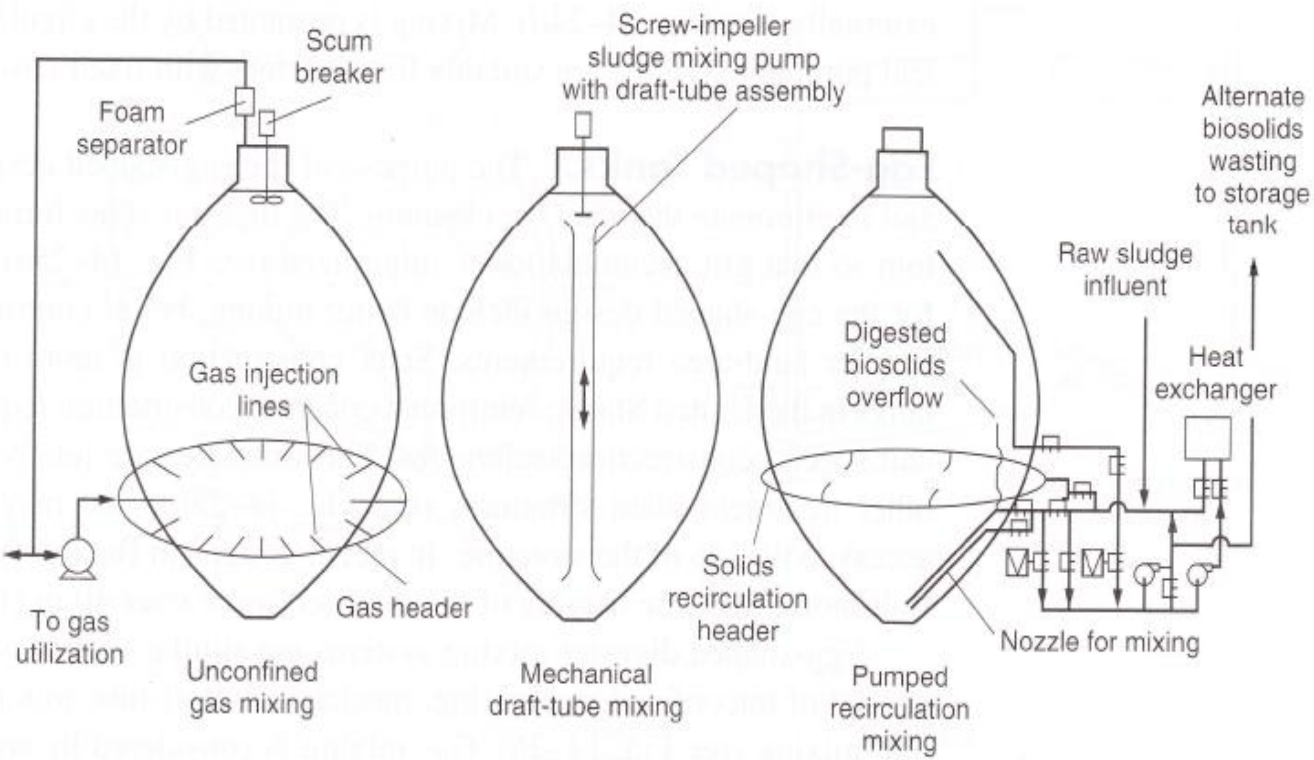
Egg-shaped anaerobic digester: (*a*) schematic diagram from Walker Process catalog, (*b*) pictorial view.

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION
EGG - SHAPED DIGESTER

Figure 14-26

Mixing systems for egg-shaped anaerobic digesters. *(From Stukenberg et al., 1992.)*



- To enhance mixing
- To eliminate the need for cleaning
- Steel construction is more common

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

Gas Production:

V_{CH4} (m^3/d)= 0.4 (for 35^0C)[(S_0-S) Q (10^3 g/kg)$^{-1}$-1.42 P_x]

For a complete mix high rate digester without recycle

Px= [YQ(S_0-S) (10^3 g/kg)$^{-1}$]/ [1+$k_d\theta_c$]

Estimation of gas production:

Typically 0.75 – 1.12 m^3/kg VS destroyed

Gas from anaerobic digesters contains about→ 65-70 % CH_4 by volume

25-30 % CO_2

small amounts of N_2,H_2, H_2S

water vapor

Gas and air must not be allowed to mix. Otherwise, an explosive mixture may result

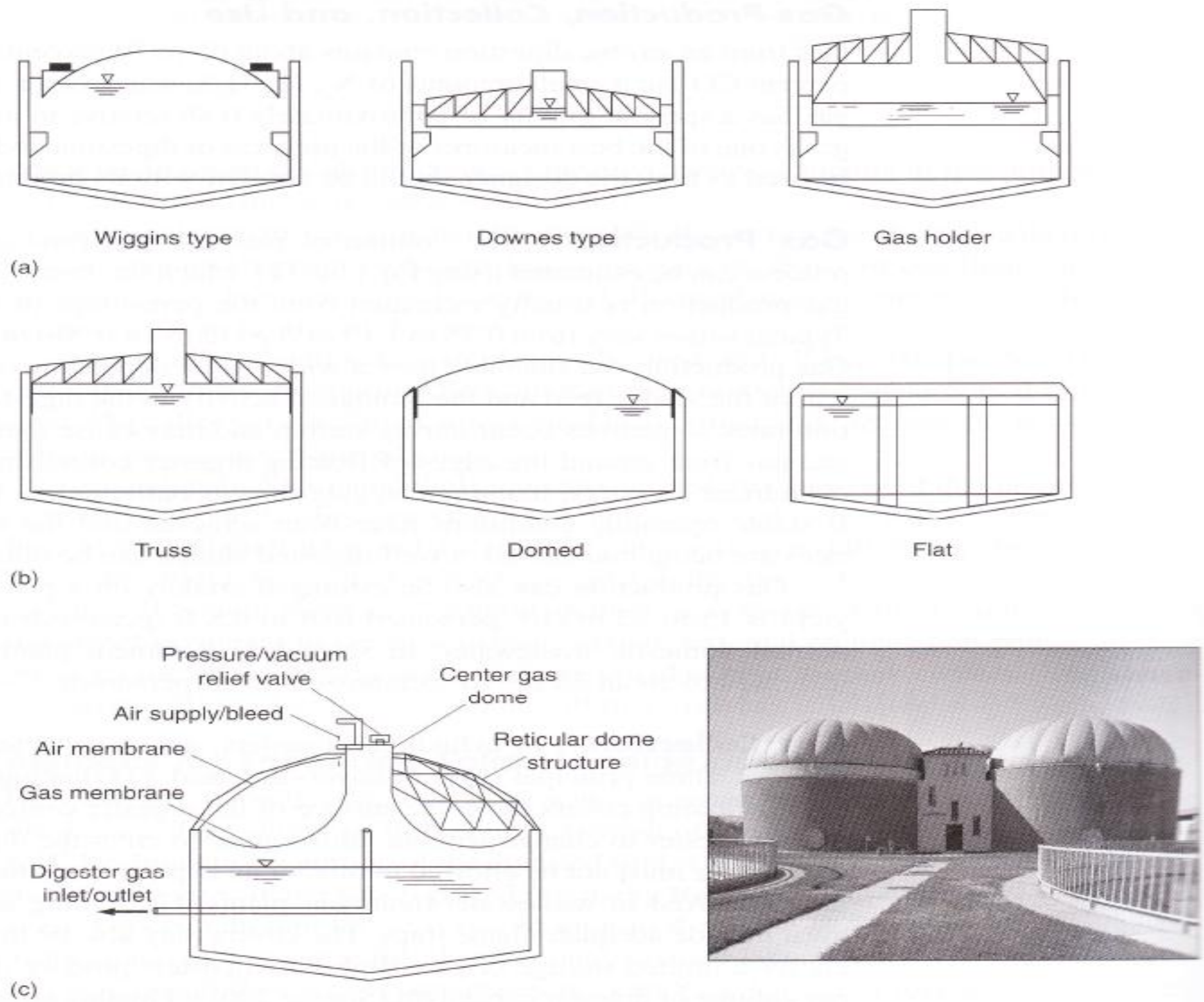
CH_4 heating value = 35800 kJ/m^3

SLUDGE STABILIZATION

B. ANAEROBIC DIGESTION

Figure 14–27

Types of anaerobic digester covers: (*a*) floating, (*b*) fixed, and (*c*) schematic and view of membrane gas cover.



SLUDGE STABILIZATION

C. AEROBIC DIGESTION

•similar to activated sludge process

•as the supply of available substrate (food) is depleted, the microorganisms begin to consume their own protoplasm .

•when energy is obtained from cell tissue, the microorganisms are said to be in the endogenous phase

Only 75-80 % of the cell tissue can be oxidized

Remaining 20-25 % is composed of inert components that are not biodegradable

Nonbiodegradable VSS will remain in final product from aerobic digestion

SLUDGE DEWATERING

A. Belt Filter Press

In most types of belt filter press,

•conditioned sludge is first introduced on a gravity drainage section where it is allowed to thicken

•In this section majority of the free water is removed from the sludge by gravity

•Following to gravity drainage, pressure is applied in a low pressure section, where sludge is squeezed between opposing porous cloth belts

•Low pressure section is followed by a high pressure section where the sludge is subjected to shearing forces as the belts pass through a series of rollers

SLUDGE DEWATERING

A. Belt Filter Press

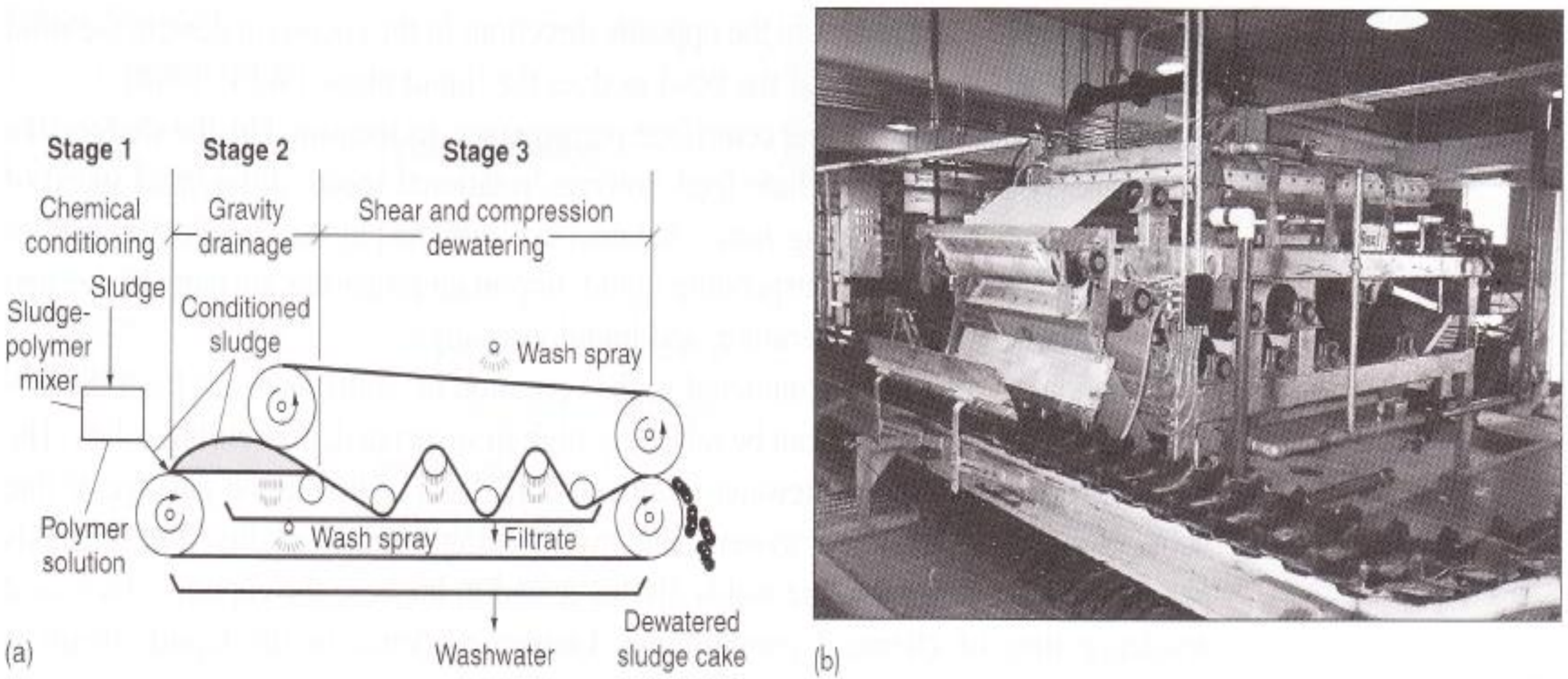


Figure 14-41

Belt-press dewatering: (*a*) three basic stages of belt-press dewatering, (*b*) pictorial view of a typical installation.

SLUDGE DEWATERING

B. Filter Press

- dewatering is achieved by forcing the water from the sludge under high pressure
- High concentrations of cake solids can be achieved
- high chemical cost, limitations for filter cloth life

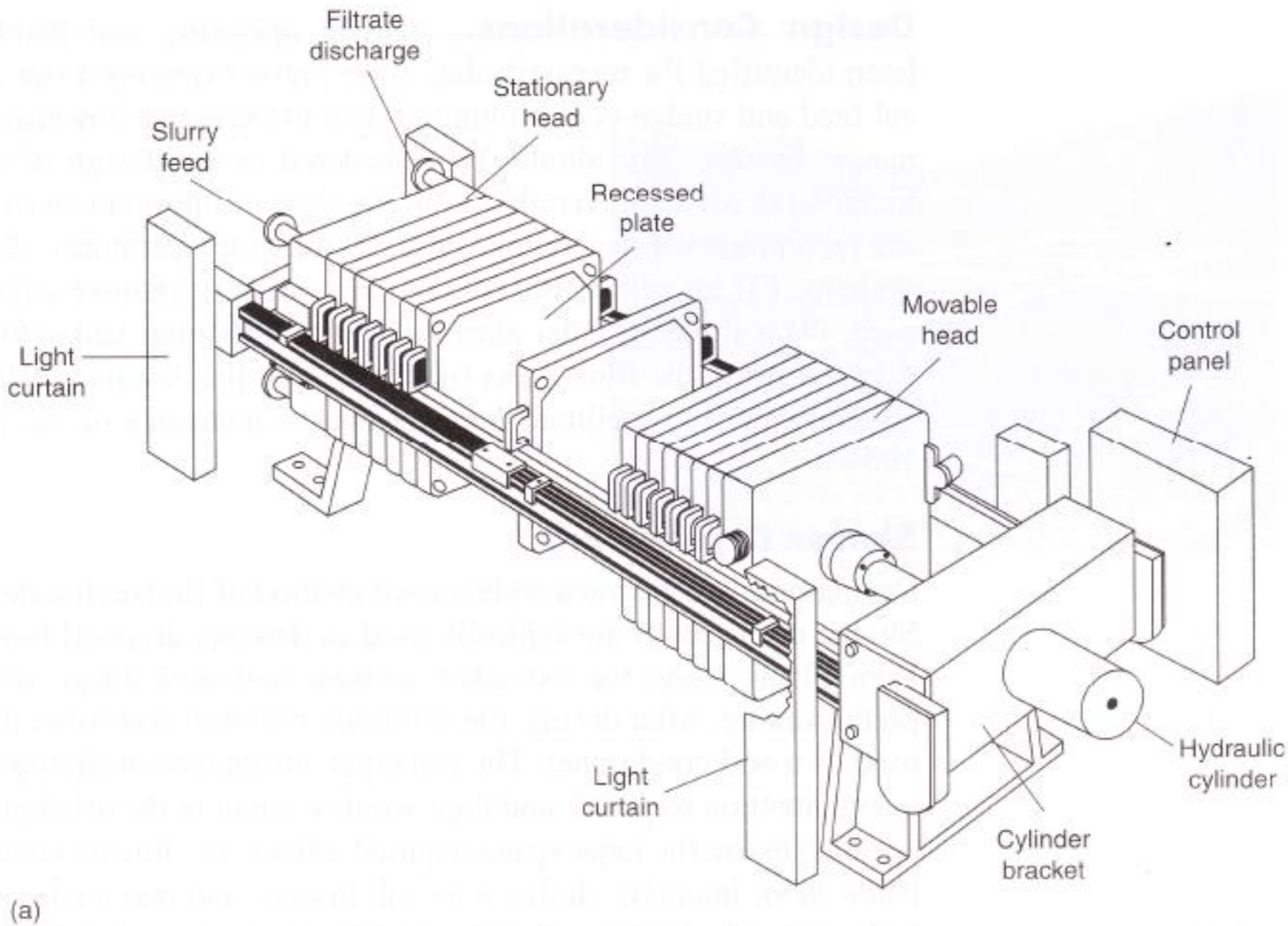
Ref: Metcalf & Eddy

SLUDGE DEWATERING

B. Filter Press

Figure 14–43

Typical fixed-volume, recessed-plate filter press used for dewatering sludge: (*a*) schematic, (*b*) pictorial view of a typical installation.



SLUDGE DEWATERING

C. Centrifugal Dewatering

same principle with centrifugal thickening

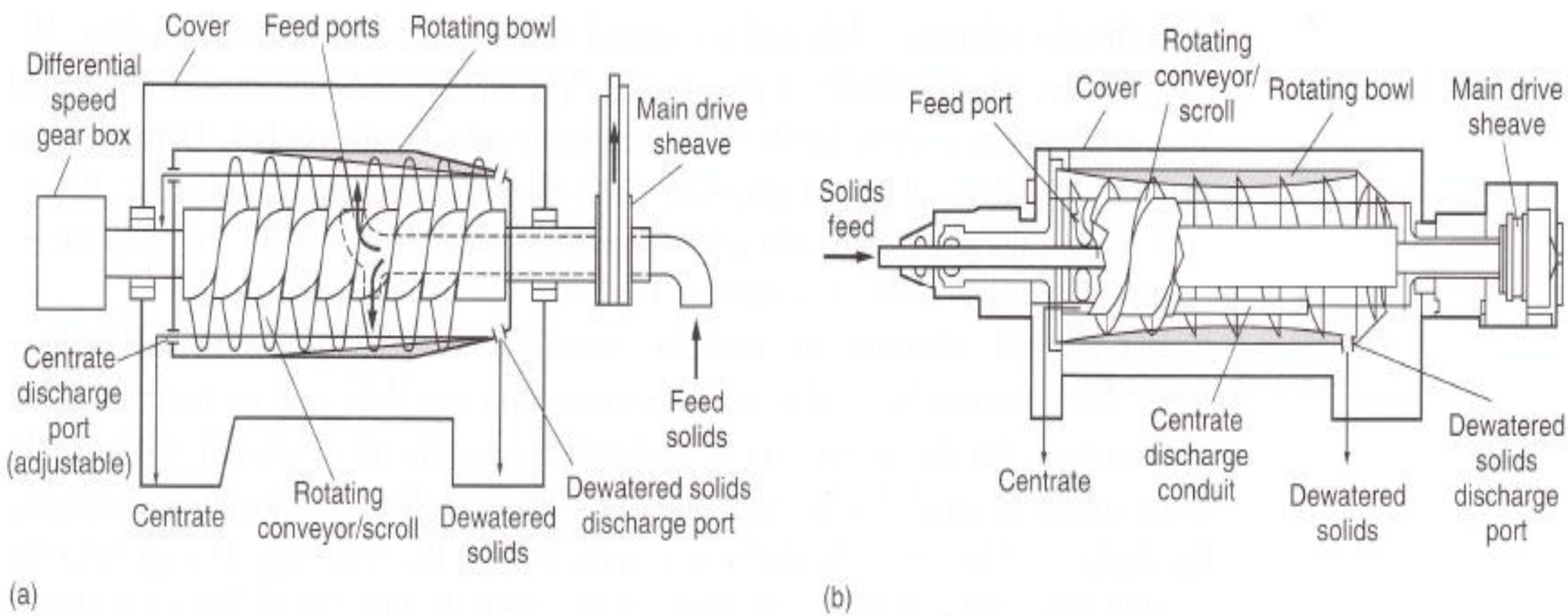


Figure 14-40

Schematic diagrams of two solid-bowl centrifuge configurations for dewatering sludge: (*a*) countercurrent and (*b*) cocurrent.

SLUDGE DEWATERING

D. Sludge Drying Beds

sludge is placed on the bed in a 200 to 300 mm layer and allowed to dry

sludge dewaters by drainage through the sludge mass and evaporation from the surface exposed to atmosphere

major advantage→ low cost

major disadvantage→ large space requirement, effects of climatic changes on drying characteristics , insects, potential odor