The following example illustrates the basic sizing of a single-stage mixed sludge mesophilic anaerobic digester for a 37,800 m^3/d activated sludge municipal wastewater treatment plant.

Design parameters:

Primary sludge:

Solids (TS) produced : 5443 kg/d
TS concentration : 5%
Specific gravity : 1.02
Volatile solids (VS) % : 65%

Thickened waste activated sludge (WAS):

TS produced : 2722 kg/d
TS concentration : 4%
Specific gravity : 1.00
VS % : 75%

Calculations

1. Daily sludge volume:

$$\text{Sludge Volume} = \frac{\text{TS produced}}{\text{Specific gravity} * \text{Density of water} * \text{TS concentration}}$$

$$\text{Primary Sludge Volume} = \frac{5443\ \text{kg/d}}{1.02 * 1000\ \text{kg/m}^3 * 0.05} = 106.7\ \text{m}^3\text{/d}$$

$$\text{Thickened WAS Volume} = \frac{2722\ \text{kg/d}}{1.00 * 1000\ \text{kg/m}^3 * 0.04} = 68\ \text{m}^3\text{/d}$$

Total Sludge Volume = 106.7 + 68 = 174.7 m^3/d (≈175 m^3/d)

2. Digester Volume:

Assume → SRT = HRT = 15 d

Digester Volume = Q * HRT = 175 m^3/d * 15 d = 2625 m^3

3. Solids Loading Rate:

Total VS produced = (Primary sludge produced * VS %) + (WAS produced * VS %)
Total VS produced = (5443 kg/d * 0.65) + (2722 kg/d * 0.75) = 5579 kg/d

$$\text{VS Loading Rate} = \frac{\text{VS produced}}{\text{Digester Volume}} = \frac{5579\ \text{kg/d}}{2625\ \text{m}^3} = 2.12\ \text{kgVS/m}^3\text{.d}$$

4. Digester Sizing:

Assume → 2 cylinderical digesters with 15 m diameters

$$\text{Active Volume of each Digester} = \frac{2625\ \text{m}^3}{2} = 1312\ \text{m}^3$$

$$\text{Surface Area} = \frac{\pi * \text{D}^2}{4} = 176.7\ \text{m}^3 \approx 177\ \text{m}^2$$

$$\text{Active Depth} = \frac{\text{Volume}}{\text{Surface Area}} = \frac{1312\ \text{m}^3}{177\ \text{m}^2} = 7.4\ \text{m}$$

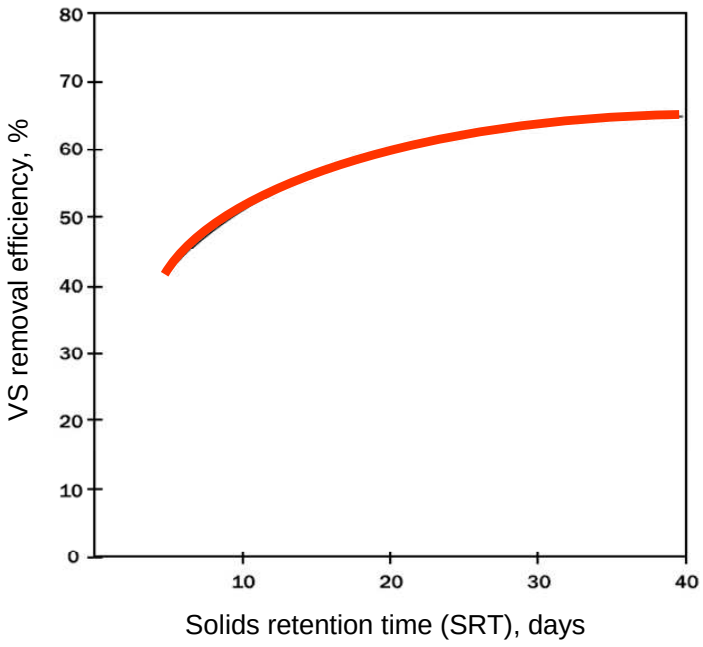
Additional depths for:

- Grit deposit (in addition to conical bottom) = 0.5 m
- Scum blanket = 0.5 m
- Space below cover = 1.0 m

Total additonal depth = 0.5 m + 0.5 m + 1 m = 2.0 m

Total Side-wall Depth = 7.4 + 2.0 = 9.4 m

5. VS Reduction and Biogas Production:



Assume → 55% VS removal at 15 days SRT under mesophilic conditions

VS removed = VS loading * VS removal efficiency = 5579 kg/d * 0.55 = 3068 kg/d

Assume → 1.0 m^3 biogas production/ kg VS removed

Total Biogas Produced = VS removed * 1 m^3/kg = 3068 m^3/d

Assume → 65% CH_4 in biogas

Total CH_4 produced = Total biogas produced * 0.65 = 1994 m^3/d

Assume → Lower heating values of CH_4 = 35,800 kJ/m^3 and 1 W = 1 J/s

Heat capacity of total CH_4 produced = 1994 m^3/d * 35800 kJ/m^3 = 82.6 kW

6. TS in Digested Sludge

Fixed Solids = Total Solids – Volatile Solids

Fixed solids = (Primary sludge + WAS) – Total VS

Fixed solids = (5443 kg/d + 2722 kg/d) – 5579 kg/d = 2586 kg/d

VS remained after digestion = Total VS – VS removed = 5579 kg/d – 3068 kg/d = 2511 kg/d

TS in Digested Sludge = Fixed solids + VS remained = 2586 + 2511 = 5097 kg/d

Assume → Specific gravity of digested sludge = 1.02

$$\text{TS}\,\% = \frac{\text{TS in Digested Sludge}}{1.02 * 1000\ \text{kg/m}^3 * \text{Sludge Volume}} = 0.285 = 2.85\%$$

7. Digester Heating

Assume → Temperature conditions:

Ambient air	= 5 °C
Earth around wall	= 7 °C
Earth below floor	= 12 °C
Raw sludge feed	= 15 °C
Digester contents	= 35 °C

Assume → Heat transfer coefficients, U:

Insulated wall exposed to air	= 0.70 W/m^2.°C
Wall exposed to dry earth	= 0.62 W/m^2.°C
Moist earth below floor	= 0.85 W/m^2.°C
Insulated cover (roof)	= 0.95 W/m^2.°C

$$\text{Volume of sludge fed to each digester} = \frac{175\ \text{m}^3/\text{d}}{2} = 87.5\ \text{m}^3/\text{d}$$

Compute heat required for each digester for raw sludge using equation

$$Q_1 = W_f . C_p . (T_1 - T_2)$$

Q_1 heat required, J/d
W_f feed sludge weight (density of sludge * volume), kg/d
C_p specific heat of sludge (assumed to be same as water), 4200 J/kg ·°C
T_2 design operating temperature of digester, °C
T_1 temperature of feed sludge, °C

Assume → Density of sludge = 1000 kg/m^3

Heat required for sludge (Q_1) = (1000 kg/m^3 * 87.5 m^3/d) * 4200 J/kg.^{o}C * (35-15) ^{o}C
= 73.5 *10^8 J/d

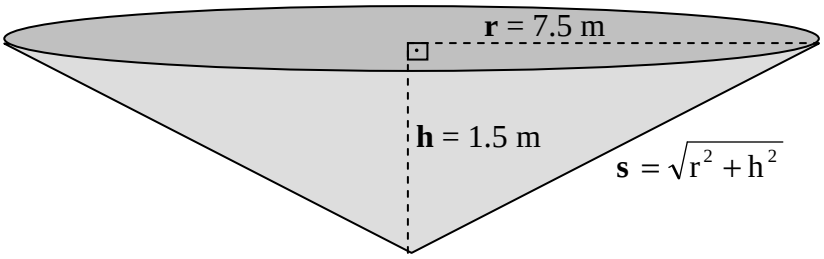
Wall area of each digester = Π * Diameter * Total depth = 443 m^2

Assume → ½ of the wall is below ground

$$\text{Areas exposed to dry earth or air} = \frac{443\ \text{m}^2}{2} = 221.5\ \text{m}^2$$

Center depth (h) of conical tank floor at a slope of 1:5 = 1.5 m

Floor area exposed to earth = Π * r * s = 180.3 m^2



Flat fixed cover (roof) area = Π * r^2 = 176.6 m^2

Compute the heat loss for each component using equation

$$Q_2 = U.A.(T_2 - T_3)$$

Q_2 heat loss, J/s
U heat transfer coefficient, J/m^2·s·°C
A surface area of digester through which heat losses occur, m^2
T_2 temperature of sludge in digester, °C
T_3 temperature outside the digester, °C

Wall above ground (exposed to air) = 0.70 W/m^2.°C * 221.5 m^2 * (35-5)^{o}C = 4652 W
Wall below ground (dry earth) = 0.62 W/m^2.°C * 221.5 m^2 * (35-7)^{o}C = 3845 W
Floor (exposed to moist earth) = 0.85 W/m^2.°C * 180.3 m^2 * (35-12)^{o}C = 3525 W
Cover (roof exposed to air) = 0.95 W/m^2.°C * 176.6 m^2 * (35-5)^{o}C = 5033 W

Total Heat Loss = 17055 W = 17055 J/s = $14.7*10^8$ J/d

Compute the required heat exchanger capacity for each digester:

Heat Capacity Required = Heat required for sludge + Heat lost in digester
= $(73.5 + 14.7)*10^8$ J/d
= $88.2*10^6$ J/d (single heat exchanger for raw+recirculating sludge)

If separate heat exchangers are used for heating raw sludge feed and the recirculating sludge, the heat exchanger capacities should be 3.38×10^7 J/h and 7.78×10^7 J/h, respectively.