Example 8.3

An activated sludge system treats industrial effluents and produces 40 ton TSS.d^{-1} of sludge (f_v = 0.75) with an active fraction f_{av} of 0.6. The temperature is 30°C and the sludge exhibits good settling characteristics: k = 0.25 l.g^{-1} and v_0 = 12 m.h^{-1}. The system consists of three aerobic digesters of 5000 m^3 each and two thickeners with a diameter of 18 m. Determine the optimal configuration to carry out sludge stabilisation. Calculate the required aeration power (assume that nitrification does not develop).

Solution:

In Fig. 8.11 several possible configurations for the sludge stabilisation are shown:

(a) Two parallel systems of thickener and digester;
(b) Two thickeners in parallel followed by two digesters in series;
(c) Two systems in series, each consisting of a thickener + digester;
(d) Thickener and two digesters plus a second thickener in series.

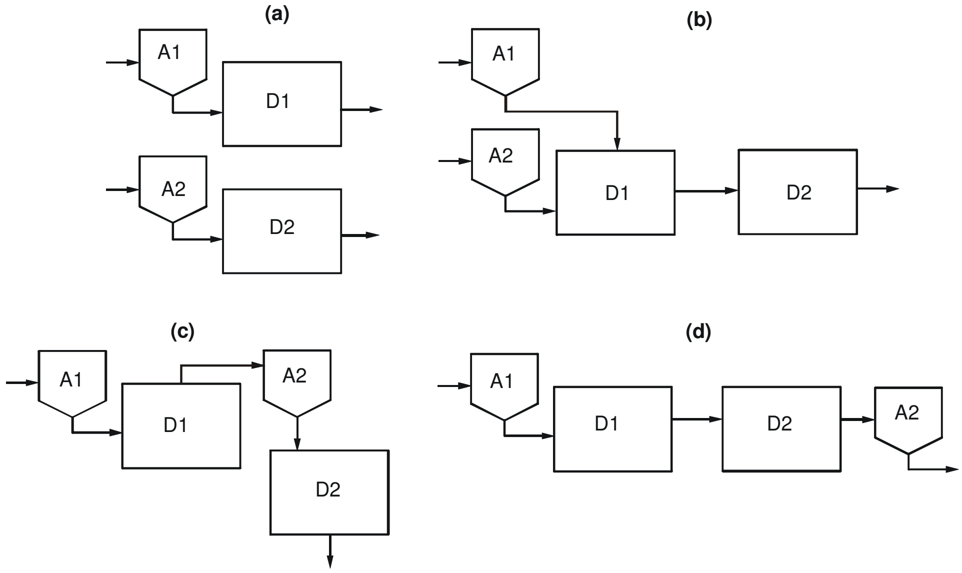

Figure 8.11 Schematic representation of different configurations for thickening and digestion of the sludge in Example 8.3

If all the sludge (40 ton.d^{-1}) is discharged into a single thickener with a diameter of 18 m (the thickener area is 314 m^2), the applied solids load is 40,000/314 = 123 kg.m^{-2}.d^{-1} or 5.1 kg.m^{-2}.h^{-1}. By equating this value to the limiting flux (i.e. with a s_f of 1), the concentration of the thickened sludge can be calculated:

F_l = $F_{sol} = X_r \cdot (k \cdot X_l - 1) \cdot \exp(-k \cdot X_l)$ = 5.1 g TSS.l^{-1}

For a single thickener, the trial and error solution is 28 g TSS.l^{-1}. In case of having two parallel thickeners, the applied solids load to each is 2.55 g TSS.l^{-1} and the thickened sludge concentration increases to 32 g TSS.l^{-1}.

As the applied sludge mass is 40 $ton.d^{-1}$, the flow of thickened sludge is 40,000/28 = 1428 $m^3.d^{-1}$ for a single thickener and 40,000/32 = 1250 $m^3.d^{-1}$ for two thickeners in parallel. Since the digesters have a volume of 5000 m^3, the retention time per digester would be 3.5 and 4 days respectively.

In the case of configuration (a) of Fig. 8.11, the thickened sludge concentration is 32 g $TSS.l^{-1}$ and the flow of thickened sludge is divided over the two digesters so that each receives 625 $m^3.d^{-1}$. Hence the retention time is R_d = 5000/625 = 8 days and the active fraction in the digested sludge is given by Eq. (8.39):

$$1/f_{ae} + f - 1 = (1/f_{ai} + f - 1)\cdot(1 + b_h\cdot R_d)$$
$$= (1/0.6 + 0.2 - 1)\cdot(1 + 0.36\cdot 8) = 3.36 \text{ and } f_{ae} = 0.24$$

The digested active sludge concentration is:

$$X_{ad} = X_{ai}\cdot(1/f_{ai} - 1/f_{ae})/(1 - f - 1/f_{ae})$$
$$= 0.60\cdot 0.75\cdot 28\cdot(1/0.6 - 1/0.24)/(1 - 0.2 - 1/0.24) = 9.4 \text{ g VSS.l}^{-1}$$

Hence the decrease of the volatile sludge concentration is:

$$X_{vd} = (1 - f)\cdot X_{ad} = 0.8\cdot 9.4 = 7.5 \text{ g VSS.l}^{-1}$$

It is concluded that the excess volatile sludge mass decreases by 100·7.5/28 = 27%. In the case of configuration (b) of Fig. 8.11, the concentration of active sludge is again 32 g $TSS.l^{-1}$ and the retention time is $R_{d1} = R_{d2}$ = 4 days. Hence:

$$1/f_{ae} + f - 1 = (1/f_{ai} + f - 1)\cdot(1 + b_h\cdot R_{d1})^2 = (1/0.6 - 0.8)\cdot(1 + 0.36\cdot 4)^2 = 5.2 \text{ and } f_{ae} = 0.17$$

The concentrations of digested active sludge and the decrease of volatile sludge in this configuration are X_{ad} = 12.2 g $VSS.l^{-1}$ and X_{vd} = 9.8 g $VSS.l^{-1}$ respectively. The decrease of volatile sludge in this configuration represents 100·9.8/32 = 30 % of the excess volatile sludge mass. In configuration (c) of Fig. 8.11, in the first thickener the flux is 5.1 $kg.m^2.d^{-1}$ and the concentration of thickened sludge is 28 g $TSS.l^{-1}$ with R_{d1} = 3.5 d. Thus the fraction of active sludge leaving the first digester is:

$$1/f_{ae1} + f - 1 = (1/f_{ai} + f - 1)\cdot(1 + b_h\cdot R_{d1}) = 1.96 \text{ and } f_{ae1} = 0.36$$

The concentration of digested active sludge is calculated from Eq. (8.50):

$$X_{ad1} = X_{ai}\cdot(1/f_{ai} - 1/f_{ae1})/(1 - f - 1/f_{ae1})$$
$$= 0.60\cdot 0.75\cdot 28\cdot(1/0.6 - 1/0.36)/(1 - 0.2 - 1/0.36) = 7.0 \text{ g VSS.l}^{-1}$$

Thus the decrease of the sludge concentration in the first digester is (Eq. (8.51)):

$$X_{vd1} = (1 - f)\cdot X_{ad1} = 0.8\cdot 7.0 = 5.6 \text{ g VSS.l}^{-1}.$$

The concentration of the sludge leaving the first digester is 28 - 5.6 = 22.4 g $TSS.l^{-1}$, resulting in a flux of 1428·22.4/324 = 99 $kg.m^{-2}.d^{-1}$ or 4.1 $kg.m^{-2}.h^{-1}$ in the second thickener. If it is assumed that the settleability does not change, the thickened sludge concentration in the second thickener can be calculated as 29 g $TSS.l^{-1}$, so that the flow of sludge is then decreased from 1428 to 1428·22.4/29 = 1100 $m^3.d^{-1}$, and the retention time in the second digester becomes R_{d2} = 5000/1100 = 4.5 days. Hence the final active fraction will be:

$$1/f_{ae2} + f - 1 = (1/f_{ae1} + f - 1)\cdot(1 + b_h\cdot R_{d2}) = 5.20 \text{ and } f_{ae2} = 0.17$$

The digested active sludge concentration and the decrease of volatile sludge are calculated as X_{ad} = 10.5 and X_{vd} = 8.4 $g.l^{-1}$ respectively, i.e. a fraction of 100·8.4/28 = 30% of the volatile sludge is mineralised.

In configuration (d) the situation in the first thickener is the same as in configuration (c). In the series of two digesters the final active sludge fraction is calculated as:

$$1/f_{ae} + f - 1 = (1/f_{ai} + f - 1)\cdot(1 + b_h \cdot R_{d1})^2$$
$$= (1/0.6 - 0.8)\cdot(1 + 0.36\cdot 3.5)^2 = 4.42 \text{ and } f_{ae} = 0.19$$

The digested active sludge concentration is now calculated as:

$$X_{ad} = X_{ai}\cdot(1/f_{ai} - 1/f_{ae})/(1 - f - 1/f_{ae})$$
$$= 0.60\cdot 0.75\cdot 28\cdot(1/0.6 - 1/0.19)/(1 - 0.2 - 1/0.19) = 10.0 \text{ g VSS.l}^{-1}$$

Hence :

$$X_{vd} = 0.8\cdot 10.0 = 8.0 \text{ g VSS.l}^{-1}$$

The solids flux to the second thickener will be 1428·(28 - 8)/324 = 88 $kg.m^{-2}.d^{-1}$ or 3.7 $kg.m^{-2}.h^{-1}$. For this value, the concentration of thickened sludge is calculated as 29.8 g $TSS.l^{-1}$: i.e. the flow of thickened digested sludge will be 20/29.8·1428 = 960 $m^3.d^{-1}$ (it is assumed that the digestion does not effect the settleability of the sludge).

Table 8.4 Summary of the performance of the different thickening and stabilisation configurations of Example 8.3

Parameter	UoM	Configuration (Fig. 8.11)			
		(a)	(b)	(c)	(d)
Residual active sludge fraction	-	0.24	0.19	0.17	0.19
Mass flow of stabilised sludge	ton $TSS.d^{-1}$	30.6	28.6	28.0	28.6
Volumetric flow of stable sludge	$m^3.d^{-1}$	1428	1250	1100	960
Fraction mineralised volatile sludge	%	23	29	30	29

In Table 8.4 the results of the calculations are summarised. It can be concluded that option (a) is the most unattractive alternative: the stabilised sludge still has a fraction of 24 percent of active sludge, which is more than the 20 percent generally adopted as an acceptable upper limit, and the flow of stabilised sludge is also larger than in the other options: 1428 $m^3.d^{-1}$. The other three options are more or less equivalent in terms of the residual active fraction. However, the digested sludge flow (and hence disposal costs) of option (d) is the smallest and for that reason might be adopted in practice.