## 10.3 OPERATIONAL OPTIMISATION PROCEDURE

The previous examples in this chapter all refer to the design of an activated sludge system based on an expected or experimentally determined waste water flow or composition. Once the treatment system has been designed, actual quantity and quality of the waste water will probably differ from those expected, as well as the values of the operational parameters. In this case the theory presented in this book can be used for another type of optimisation: for a given configuration determine the optimal operational conditions, characterised by production of the specified effluent quality at minimal costs.

**Example 10.11**

After construction of the Bardenpho activated sludge system designed in Example 10.5, it is determined that flow and composition of the waste water differ from the design values. I.e. the actual values are $Q_i$ = 10,000 $m^3.d^{-1}$, $S_{ti}$ = 975 $mg.l^{-1}$, $N_{ti}$ = 40 $mg.l^{-1}$ and an average temperature in wintertime of 24°C. Define the optimal operational conditions required to produce an effluent without nitrate and with maximum 2 mg ammonium in the effluent and estimate the costs of treatment. Assume that the anoxic volumes cannot be increased or reduced.

**Solution:**

The effects on the activated sludge system of the changes in actual loading and temperature compared to the design values will be the following:

- The minimum sludge age required for full denitrification will be smaller than the one calculated in Example 10.5 (12 days) because (1) the ratio $N_{ti}/S_{ti}$ has decreased and (2) the temperature is higher, increasing the values of the kinetic parameters;
- However, a new limiting factor in this example will be the ammonium concentration, as it depends on the applied aerobic sludge age and it is not possible to increase the aerobic fraction in the system as the anoxic volumes are fixed;
- The increase in organic load and the reduction in sludge age will increase the solids load to the digester, although this is partly compensated by the increase in digestion efficiency at higher temperature;
- The hydraulic loading rate of the final settler will be lower as a result of the decrease in influent flow. However, depending on the actual sludge concentration the solids loading rate might increase.

Taking the above constraints into consideration a solution will have to be determined. As it is not possible to adapt the size of the anoxic zones in the existing activated sludge system (i.e. $f_x$ = 0.38), it can be calculated with Eq. 4.37 that in order to comply with the limit of $N_{ae}$ < 2 mg $N.l^{-1}$ it will not be possible to lower the minimum sludge age to a lower value than 8.25 days. At this sludge age denitrification will be complete. However, it can be demonstrated that the digester will be slightly overloaded. For the temperature of 24°C the required sludge retention time in the digester is equal to:

$$R_{di} = 20 \cdot 1.1^{(T-20)} + 5 = 18.7 \text{ days.}$$

As the volume of the aerobic reactor does not change, the value of q will be equal to 8234/8.25 = 998 $m^3.d$. $MX_t$ is equal to 24,838 kg $TSS.m^{-3}$.

For an excess sludge production of $ME_t = MX_t/R_s$ = 24,838/8.24 = 3011 kg TSS.d$^{-1}$ and an available thickener surface $A_{th} = V_{th}/(H_{th}.Sf_{th})$ = 530/(3·1.5) = 118 m$^2$, the applied solids flux is:

$F_{sol}$ = $ME_t/A_{th}$ = 3011/118 = 25.6 kg TSS.m$^{-2}$.d$^{-1}$

Furthermore it is know that the solids flux is minimum for the limiting flux. Therefore:

$F_l = F_{sol} = 25.6 = X_{thr} \cdot v_0 \cdot (k \cdot X_{thl} - 1) \cdot \exp(-k \cdot X_{thl})$

This can be solved iteratively for $X_{thr}$ = 15.7 kg TSS.m$^{-3}$. The thickened excess flow $q_{th}$ = 3011/15.7 = 192 m$^3$.d$^{-1}$, resulting in a sludge retention time in the digester of $R_{di} = V_{di}/q_{th}$ = 3370/192 = 17.6 d, which is indeed slightly smaller than the required digestion time of 18.7 days. A solution complying with all boundary restrictions can be found for $R_s$ = 9.75 days.

$N_{ae}$ = 1.6 mg N.l$^{-1}$

$D_{C1} + D_{C3}$ = 57.5 mg N.l$^{-1}$

$R_{di}$ = 18.8 days

The combined denitrification capacity is much larger than the nitrification capacity $N_c$ of 26.7 mg N.l$^{-1}$, so denitrification is complete (it can be verified that $D_c > N_{av}$ for both anoxic zones). To evaluate the performance of the final settler, the applied solids loading rate must be compared with the solids flux that can be transported into the settler for all values of X between $X_t$ = 3.4 and $X_r$ = (s+1)/s·3.4 = 6.8 g TSS.l$^{-1}$. The solids loading rate is calculated as $(s+1) \cdot X_t \cdot Q_i/(A_d/S_f)$ = 143 kg TSS.m$^{-2}$.d$^{-1}$. The solids flux due to abstraction of return sludge is $s \cdot Q_i \cdot X/(A_d/S_f)$ and the flux due to settling is $X \cdot v_0 \cdot \exp(-k \cdot X)$. The combined solids flux has a lowest value of 149 kg TSS.m$^{-2}$.d$^{-1}$ for X = 6 g TSS.l$^{-1}$ and thus no problems with solids-liquid separation are to be expected in the settler.

**Table 10.34 Main operational parameters and cost of the optimised system under estimated and actual conditions**

| Parameter | UoM | Original design | Actual situation |
|---|---|---|---|
| Influent parameters: | | | |
| - $Q_i$ | m$^3$.d$^{-1}$ | 12,000 | 10,000 |
| - $S_{ti}$ / $N_{ti}$ / $P_{ti}$ | mg.l$^{-1}$ | 650 / 50 / 15 | 975 / 40 / 10 |
| - T (min) | $^o$C | 20 | 24 |
| Operational $R_s$ | days | 12 | 9.75 |
| Sludge production: | | | |
| - total | kg TSS.d$^{-1}$ | 1.8 | 2.2 |
| - volatile | kg VSS.d$^{-1}$ | 1.1 | 1.4 |
| Energy: | | | |
| - demand / pot. generation | kW | 188 / 37 | 213 / 50 |
| Costs: | | | |
| - financial | US$.year$^{-1}$ | 890,000 | 890,000 |
| - operation | US$.year$^{-1}$ | 1,020,000 | 1,080,000 |
| - total | US$.year$^{-1}$ | 1,910,000 | 1,970,000 |

In Table 10.34 the main operational values and the costs of the original design are compared with the actual situation. The data show that using the theory presented in this book, it is possible to accommodate the 25% increase in daily organic load (from 7800 kg COD to 9750 kg COD per day) without additional investments and for a limited increase in operational costs.