

Example 4.1

As an example of the application of mass balance concept for nitrogen removal, the experimental data obtained during the operation of a nitrogen removal pilot plant are discussed (Ekama et al, 1976). The process was composed of five reactors each with volume 5 m^3 and a settler. The first reactor (receiving all the influent) was kept anoxic, whereas the other four were aerated. The average temperature was 21.6°C . Fig. 4.2 shows the flow scheme of the process.

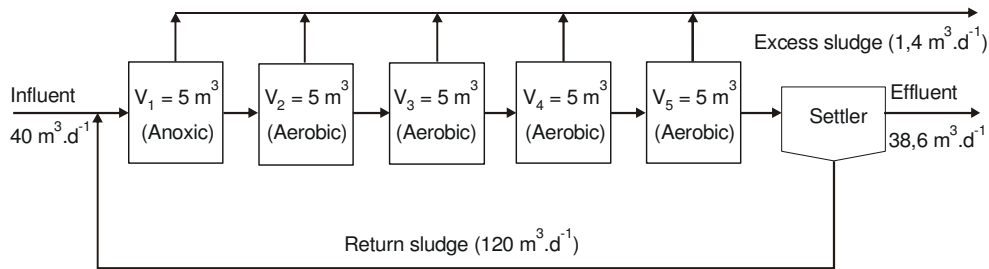


Figure 4.2 Flow scheme of the pilot process from Example 4.1

Table 4.1 shows the average values of the experimental determinations that were carried out over a period of 18 days, after a steady state had been established. Fig. 4.1 and Table 4.1 contain all the information necessary to perform the mass balance calculations as shown below.

Table 4.1 Average values of the process parameters during the pilot experiment of Example 4.1

Parameter		Influent	Reactor					Effluent
			1	2	3	4	5	
COD	mg.l^{-1}	477	25	19	18	18	18	18
TKN	mg N.l^{-1}	45.1	9.2	4.8	3.3	2.6	2.0	1.9
NH_4^+	mg N.l^{-1}	32.8	9.4	3.4	0.6	0.3	0.2	0.0
NO_3^-	mg N.l^{-1}	<0.3	1.2	5.8	9.2	9.7	9.8	8.7
VSS	mg VSS.l^{-1}		25	2447	2466	2406	2477	2469 ⁽¹⁾
OUR	$\text{mg O}_2.\text{l}^{-1}.\text{h}^{-1}$		50	59.3	36.5	23.4	19.3	

Note: (1) Average of the five reactors.

Solution:

The following calculation procedure is out to determine the nitrogen recovery factor B_n :

(1) Calculate MN_{ti} (Eq. (4.3))

$$N_{ti} = Q_i \cdot (N_{oi} + N_{ai} + N_{ni}) = 40 \cdot (45.1 + 0.3) = 1816 \text{ g N.d}^{-1}$$

(2) Calculate MN_i

(a) Calculate the sludge age (Eq. (3.15))

$$R_s = V_r/q = 25/1.4 = 18 \text{ days}$$

(b) Calculate MN_i (Eq. (4.5)):

$$MN_i = f_n \cdot V_r \cdot X_v / R_s = 0.1 \cdot 25 \cdot 2469 / 18 = 343 \text{ g N.d}^{-1}$$

(3) Calculate MN_{te}

$$MN_{te} = Q_i \cdot (N_{oe} + N_{ae} + N_{ne}) = 40 \cdot (1.9 + 8.7) = 424 \text{ g N.d}^{-1}$$

(4) Calculate MN_d

The data indicates that denitrification took place in the first reactor and in the settler (in these two the nitrate concentration decreased). The nitrate concentration entering into the first reactor N_{n0} is calculated as the weighted average of the concentrations in the influent- and recycle flows. Assuming the nitrate concentration in the return sludge flow is equal to the effluent nitrate concentration, one has:

$$N_{n0} = (Q_i \cdot N_{ni} + Q_r \cdot N_{ne}) / (Q_i + Q_r) = (40 \cdot 0.3 + 120 \cdot 8.7) / (40 + 120) = 6.6 \text{ mg N.l}^{-1}$$

As the nitrate concentration in the flow leaving the first reactor was 1.2 mg N.l^{-1} (Table 4.1), the decrease equals $\Delta N_{n1} = 6.6 - 1.2 = 5.4 \text{ mg N.l}^{-1}$. Hence the flux of removed nitrogen in the first reactor was:

$$MN_{d1} = (Q_i + Q_r) \cdot \Delta N_{n1} = (40 + 120) \cdot 5.4 = 864 \text{ g N.d}^{-1}$$

Similarly the flux of nitrogen removed in the settler is calculated as:

$$MN_{dd} = (Q_i + Q_r) \cdot \Delta N_{nd} = (40 + 120) \cdot (9.8 - 8.7) = 176 \text{ g N.d}^{-1}$$

Where:

$$MN_{dd} = \text{denitrified nitrogen in the settler (g N.d}^{-1}\text{)}$$

$$\Delta N_{nd} = \text{decrease of the nitrate concentration in the settler (mg N.l}^{-1}\text{)}$$

Now the total flux of nitrogen removed by denitrification can be calculated as:

$$MN_d = MN_{d1} + MN_{dd} = 864 + 176 = 1040 \text{ g N.l}^{-1}$$

Having calculated all the relevant flows, the nitrogen recovery factor can now be determined with the aid of Eq. (4.1):

$$B_n = (MN_i + MN_{te} + MN_d) / MN_{ni} = (343 + 424 + 1040) / 1816 = 1807 / 1816 = 0.995$$

In the example there is a difference of only 0.5% between the experimentally determined values of the nitrogen fluxes entering and leaving the pilot plant. This shows that the experimental procedures to obtain the data have been correct and for this reason the data is attributed a high degree of reliability. It is interesting to note that once one has established that the nitrogen mass balance closes, it is also possible to determine the recovery factor for the organic material. To do this, first the three fractions mS_e , mS_{xv} and mS_o must be calculated.

In the case of the above example one has:

$$mS_e = S_e/S_{ti} = 18/477 = 0.038$$

$$mS_{xv} = f_{cv} \cdot mEv = f_{cv} \cdot X_v \cdot R_H / (R_S \cdot S_{ti}) = 1.5 \cdot 2469 \cdot 0.625 / (18 \cdot 477) = 0.270$$

The value of mS_o is calculated as the sum of the oxygen consumption for organic matter and the equivalent oxygen recovered in the denitrification process:

$$mS_o = MS_o/MS_{ti} = (MO_c + MO_{eq})/MS_{ti}$$

In the above expression, the oxygen consumption for the oxidation of organic matter is the difference between the total consumption and the consumption for nitrification. The total consumption in the four aerobic reactors (with a total volume of 20 m³) is:

$$\begin{aligned} MO_t &= V_1 \cdot (OUR_{t2} + OUR_{t3} + OUR_{t4} + OUR_{t5}) \\ &= 5 \cdot (59.3 + 36.5 + 23.4 + 19.3) \cdot 24 = 16,620 \text{ g O}_2 \cdot \text{d}^{-1} \end{aligned}$$

In order to calculate the oxygen consumption for nitrification, first the flux of nitrified ammonium is determined as the difference between the TKN flux in the influent and the fluxes leaving the system in the effluent or the excess sludge. Knowing there is an oxygen consumption of 4.57 mg O₂ per mg N nitrified, one has in the case of the example:

$$\begin{aligned} MO_n &= 4.57 \cdot (MN_{ti} - MN_{ni} - MN_l - MN_{oe} - MN_{ae}) \\ &= 4.57 \cdot (1,816 - 40 \cdot 0.3 - 343 - 40 \cdot 1.9) = 6329 \text{ g O}_2 \cdot \text{d}^{-1} \end{aligned}$$

Hence the oxygen consumption for oxidation of organic matter is:

$$MO_c = MO_t - MO_n = 16,620 - 6329 = 10,291 \text{ g O}_2 \cdot \text{d}^{-1}$$

The equivalent oxygen recovered in the denitrification process is easily determined as:

$$MO_{eq} = 2.86 \cdot MN_d = 2.86 \cdot 1040 = 2974 \text{ g O}_2 \cdot \text{d}^{-1}$$

Now, the fraction of influent COD that is oxidised in the activated sludge is determined as:

$$mS_o = (MO_c + MO_{eq})/MS_{ti} = (10,291 + 2974)/(40 \cdot 477) = 13,210/19,080 = 0.695$$

Finally, the recovery factor for organic matter can be calculated as:

$$B_o = mS_e + mS_{xv} + mS_o = 0.038 + 0.270 + 0.695 = 1.003$$

It can be concluded that the mass balance for organic material also closes: the experimentally determined recovery factor of 1.003 is practically equal to the theoretical value of 1.000. In practice it should be expected that the recovery factors B_o and B_n deviate more from the theoretical value than in the above example. The main reason is that most activated sludge processes are not completely in steady state conditions.