3.2.3 Model calibration

Eqs. (3.18, 3.38 and 3.43) show that the fractions mS_{te}, mS_{xv} and mS_o depend on several parameters. Table 3.6 summarises the eight factors that influence the simplified model of the activated sludge system and attributes numerical values when this is possible.

Table 3.6 Factors that influence the simplified model and their numerical values

Parameter	Symbol	Typical value
Non biodegradable dissolved influent COD fraction	f_{ns}	Variable
Non biodegradable particulate influent COD fraction	f_{np}	Variable
Yield coefficient	Y	0.45 mg $COD.VSS^{-1}$
Fraction of decayed active sludge remaining as endogenous residue	f	0.2 mg $VSS.mg^{-1}$ VSS
COD/VSS ratio for organic sludge	f_{cv}	1.5 mg $COD.VSS^{-1}$
Decay constant for active sludge	b_h	$0.24 \cdot 1.04^{(T-20)}$ d^{-1}
Temperature	T	Variable
Sludge age	R_s	Variable

The sludge mass parameters (Y, f and f_{cv}) have constant values and the decay constant b_h is affected only by temperature. The values of these constants were determined by extensive experimental research, which is described in Chapter 8. As the sludge age is an operational variable that must be selected by the designer, this leaves only three unknown factors in Table 3.6: the temperature and the non-biodegradable COD fractions of dissolved (f_{ns}) and particulate (f_{np}) material.

In the case of sewage treatment, the temperature may be estimated taking into consideration the climate in the region where the activated sludge system is to be constructed, while for industrial waste waters it may be estimated from the temperature at which the effluent is produced.

The value of the non-biodegradable influent COD fractions can only be determined experimentally, requiring an activated sludge system to be operated under steady state conditions for various sludge ages. The determination of f_{ns} and f_{np} proceeds with the following steps:

(1) For at least one but preferably more values of the sludge age, the fractions mS_{te}, mS_{xv} and mS_o are determined experimentally when steady state conditions have been established;
(2) Check with Eq. (3.14) if the mass balance closes: i.e. if the sum of the three fractions deviates less than 10% from unity ($|B_o - 1| < 0.1$);
(3) With the aid of the measured values for mS_{te}, choose the value of f_{ns} that leads to the best correlation between experimental data and theoretical prediction, i.e. equate the value of f_{ns} to the average ratio of the effluent and influent;
(4) Having established the f_{ns} value and using experimental values for mS_{xv} and mS_o, select the f_{np} value that gives the closest correlation between the experimental results and the theoretical predictions for mS_{xv} and mS_o.

Naturally, the procedure presented above is only valid when the behaviour of the activated sludge system approaches ideality: i.e. when the concentration of suspended solids in the effluent is very low. An example of the determination of the f_{ns} and f_{np} values is presented in Fig. 3.4. The collected data refer to an experiment conducted with raw sewage from the city of Campina Grande by Dias et al (1981), which was discussed in Example 3.1. This data set was complemented by Van Haandel and Catunda (1985 and 1989). Table 3.2 deals specifically with the data presented by Dias et al (1981).

In this table it can be seen that the value of the recovery factor B_o deviates less than ten percent from the theoretical value of one, so that the data is considered acceptable. The experimental values of mS_{te}, mS_{xv} and mS_o were calculated using Eq. (3.14), as indicated in Table 3.3 while Eq. 3.15 was used to calculate the sludge age R_s. In Fig. 3.4 the measured values of mS_{te}, mS_{xv} and mS_o are shown as a function of the sludge age R_s. In so far as the non biodegradable and dissolved influent COD fraction is concerned, Fig. 3.4a shows that the ratio of effluent and influent soluble COD oscillates around 0.14 so that this value is accepted as the "best" value for f_{ns}.

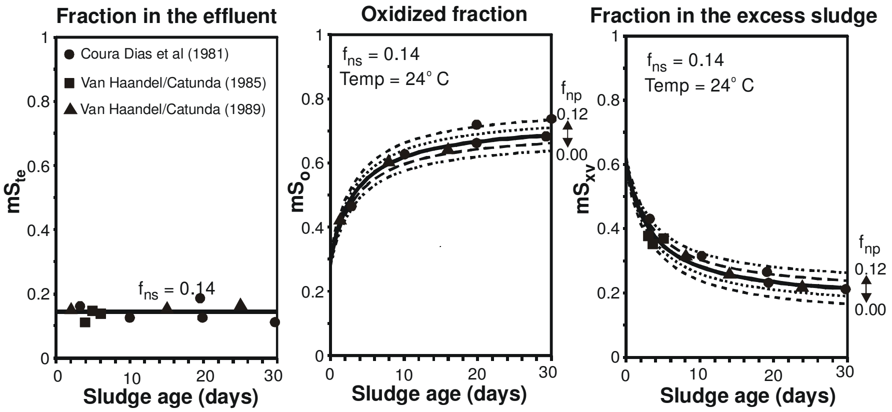

Figure 3.4 Experimental results of the COD fractions mS_{te}, mS_{xv} and mS_o compared to model calculated values for different f_{ns} and f_{np} values

Once the f_{ns} value has been established, the f_{np} value is determined as follows:

(1) With the aid of Eq. (3.38), calculate as a function of the sludge age theoretical values of mS_{xv} for different f_{np} values;
(2) Plot the theoretical mS_{xv} curves as a function of R_s for the chosen f_{np} values;
(3) Similarly, using Eq. (3.43), calculate and plot theoretical curves of mS_o as a function of R_s for the same series of f_{np} values;
(4) By comparing the theoretical curves of mS_{xv} and mS_o and the experimental results, the f_{np} value that gives the closest correlation between experimental and theoretical results is selected as the "best" value for the sewage under consideration.

In the case of Fig. 3.4, theoretical curves were generated for values of f_{np} ranging from 0.00 to 0.12. The figures 3.4 b and c show clearly that the value f_{np} = 0.06 results in the closest correlation between the theoretical and experimental values. In Fig. 3.4 there is a close correspondence between theory and practice over the entire sludge age range from 2 to 30 days.

In practice the sludge age will typically be longer than 2 days and shorter than 30 days, so that the simplified model for the activated sludge system can be used for most full scale plants, when temperature is not very much lower than the one prevailing during the investigation: $T = 24 \pm 2$ °C (at low temperatures combined with a short sludge age, the utilisation of organic material may be incomplete, see Section 3.4).

This conclusion is of great practical importance, because the parameters that the simplified model predicts are exactly those parameters that are of most interest in practice: (1) the COD fraction remaining in the effluent (or in other words, the COD removal efficiency), (2) the fraction of the influent COD discharged as excess sludge (or the sludge production), and (3) the fraction of the influent COD oxidised in the process (determining how much oxygenation capacity must be installed).

In practice it is often difficult or even impossible to carry out the experimental investigations required to determine the fractions f_{ns} and f_{np}. In such cases the only alternative may be to estimate the values of these fractions, based on the available information about the nature of the waste water and other parameters like the presence of pre-treatment systems and social-economic habits.

Pre-treatment systems like septic tanks tend to lead to a decrease of the biodegradable organic material (due to anaerobic digestion in the tank) and of the suspended solids concentration (due to settling). Hence pre-treated sewage tends to have a high f_{ns} value and a low f_{np} value. The use of garbage grinders and the habit of scouring of pots with sand are examples of social economic habits influencing the composition of sewage: the garbage grinders lead to the presence of a high concentration of particulates (both biodegradable and non biodegradable) and the use of sand tends to increase the mineral sludge fraction. In Fig. 3.5 the influence of f_{ns} on the activated sludge system is analysed. The values of mS_{te}, mS_{xv} and mS_o are plotted as function of the sludge age for $f_{np} = 0.1$ and different f_{ns} values.

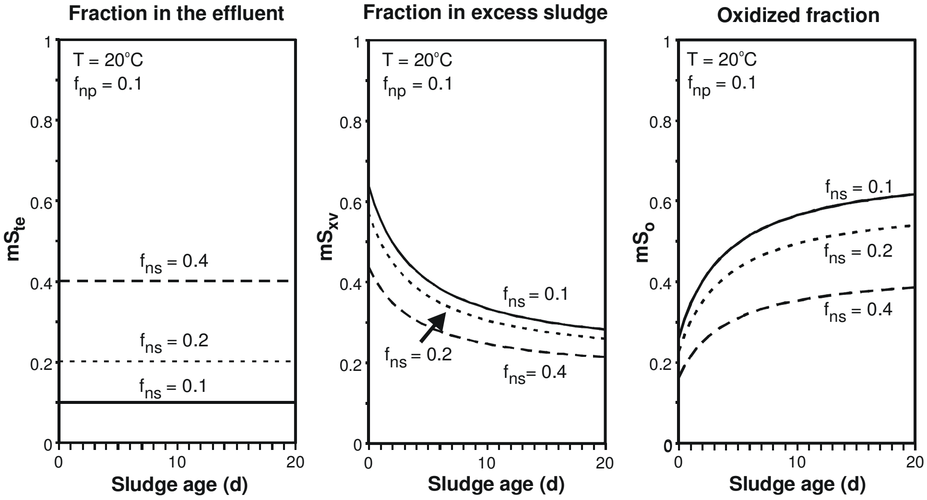

Figure 3.5 Evaluation of the influence of the f_{ns} fraction on the values of mS_{te}, mS_{xv} and mS_o

Municipal sewage usually has a f_{ns} value in the range of 0.1 (raw sewage) to 0.2 (pre-treated sewage). Larger values are encountered in some industrial wastes: for example black liquor from cellulose production contains a high concentration of non-biodegradable lignin. In Fig. 3.5 it can be observed that a 100 % increase from $f_{ns} = 0.1$ to $f_{ns} = 0.2$ has little influence on sludge production and a modest influence on oxygen consumption.

In Fig. 3.6 the influence of the value of f_{np} on activated sludge behaviour is evaluated. An f_{ns} value of 0.1 was adopted and the values of mS_{xv} and mS_o are shown as function of the sludge age for different f_{np} values: $f_{np} = 0.00$ (sewage after efficient primary sedimentation or dissolved industrial waste), $f_{np} = 0.06$ (raw municipal sewage) and $f_{np} = 0.25$. The latter value was found from the data presented by Sutton et al (1979) using sewage at Burlington-Canada. The high value possibly can be attributed to the North-American habit of using garbage grinders.

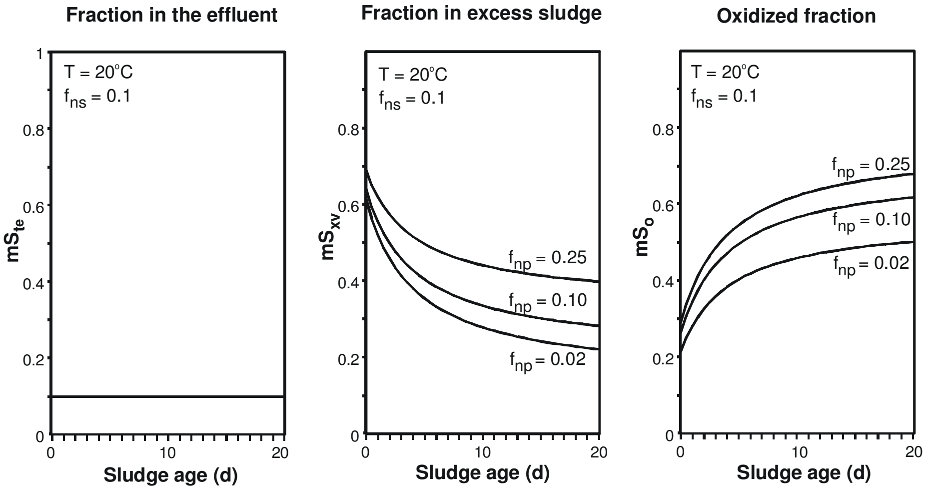

Figure 3.6 Evaluation of the influence of the f_{np} fraction on the values of mS_{te}, mS_{xv} and mS_o

It can be observed from Fig. 3.6 that variations of the f_{np} value lead to very significant changes in the basic behaviour of the activated sludge system, especially at long sludge ages. For example, an increase from f_{np} from 0.00 to 0.25 causes an increase of mS_{xv} from 0.20 to 0.40 when the sludge age is 20 days. At the same time the mS_o value decreases from 0.70 to 0.50 (Fig.3.6c).

When it is impossible to determine the values of f_{ns} and f_{np}, an estimate must be made. In the case of municipal sewage, the following approach may be used for design purposes: when the sludge production is estimated, a low f_{ns} value (for example 0.05) and a high f_{np} value (for example 0.15) are adopted. When oxygen consumption is estimated low values for both are adopted (for example $f_{ns} = f_{np} = 0.05$). Thus, the estimates for both sludge production and oxygen consumption are conservative and probably a little above the actual values, so that the sludge handling and aeration capacities will be adequate for the demand.