8.3.3 Influence of operational parameters

Among the various operational parameters that influence the anaerobic digestion process, the most important ones are the temperature in the digester, pH value and stability, the presence of nutrients in the digester, and finally the presence- and concentration of toxic materials in the digester.

(a) Temperature

In Fig. 8.14 the experimental values of the anaerobic digestion rate determined by several researchers are shown plotted as a function of the temperature in the range of 0 to 45°C. The rate increases until a maximum is reached at 35 to 37°C. An increase of temperature beyond 37°C leads to a decrease in the rate, but when the temperature is maintained above 42°C, the digestion rate increases again and reaches an absolute maximum at 53 to 55°C (not shown in Fig. 8.14). Thus a mesophilic digestion range to 42°C and a thermophilic range above this value can be distinguished.

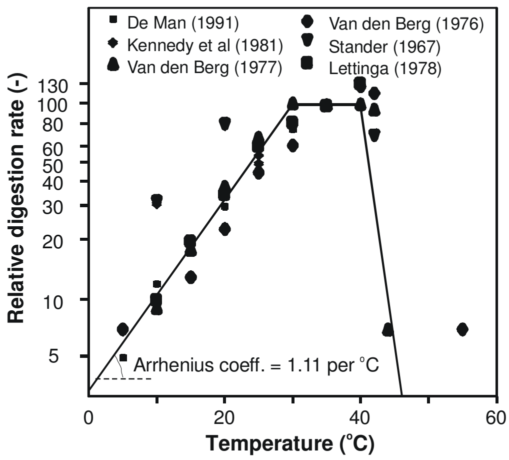

Figure 8.14
Digestion rate as a function of the temperature by different authors

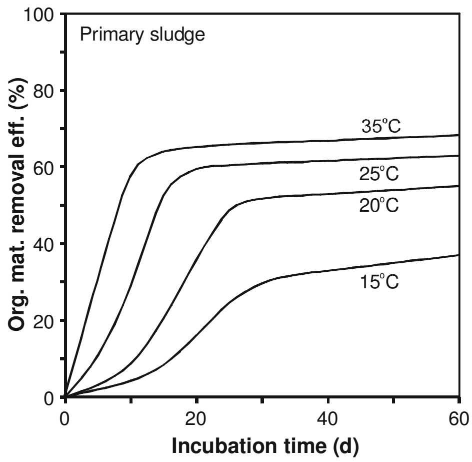

Figure 8.15
Solids conversion efficiency as a function of retention time at different temperatures, O'Rourke (1969)

Although the maximum rate of thermophilic digestion is superior to the maximum for thermophilic digestion, up to the present no full-scale thermophilic sludge digesters have been built. Apparently the operational difficulties and costs involved in order to maintain the temperature at 53 to 55°C are not compensated by its advantages. In the future, this situation may change because thermophilic digestion has another important advantage: it is very efficient in the reduction of pathogens and produces a stabilised sludge with a good hygienic quality.

Temperature does not only influence the rate but also the extent of anaerobic digestion. The classical work by O'Rourke (1968) showed the influence of temperature on the decrease of the volatile solids concentration of primary sludge in an anaerobic digester. In Fig. 8.15 the converted fraction of volatile solids of primary sludge in a high rate digester is shown plotted as a function of the retention time for different temperatures. It can be noted that the extent of anaerobic digestion tends to increase with temperature until the optimal temperature range of 35 to 37°C is reached.

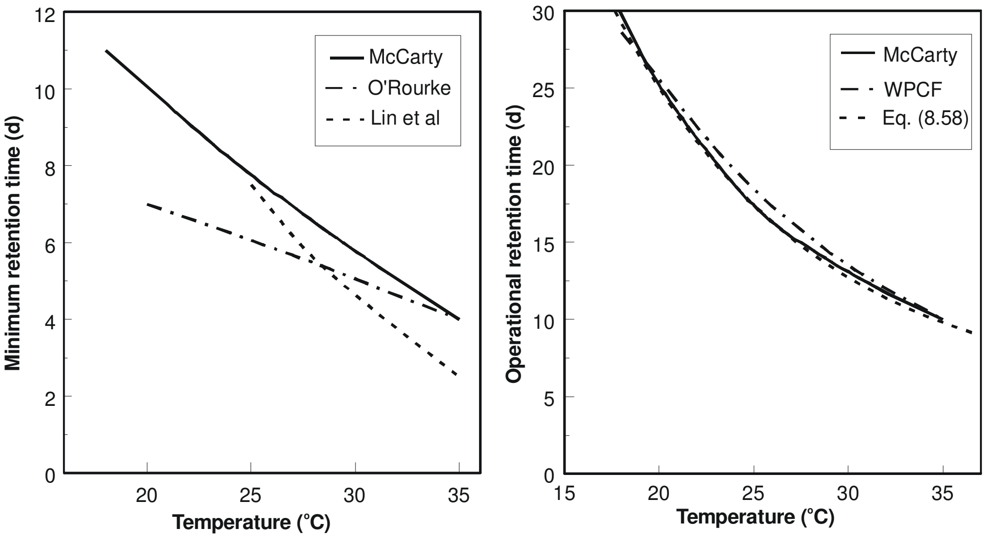

Figure 8.16 Minimum retention time (left) and practical values for full-scale design (right) as function of the operating temperature

Fig. 8.15 reveals another important point: the time required to obtain the maximum conversion efficiency increases when the temperature decreases. On the basis of O'Rourkes data presented in Fig. 8.15, a diagram may be constructed, linking the minimum retention time for maximum solids conversion to the digestion temperature.

Fig. 8.16a shows the relationship for the data by O'Rourke as well as other research workers (McCarty, 1964 and Lin et al, 1987). McCarty suggested adopting a safety factor of 2.5 for the retention time in full-scale units. In Fig. 8.16b the values suggested by McCarty (1964) and the WPCF (1979) for the retention time in full-scale high rate digesters are shown plotted as a function of the digestion temperature. Taking into consideration the experimental data and design criteria presented above, the following empiric expression is suggested for the retention time in a high rate anaerobic digester:

$$R_{di} = 20 \cdot 1.1^{(20-T)} + 5 \quad (15°C < T < 35°C) \tag{8.58}$$

Where:

R_{di} = retention time in the high rate digester (d)
T = temperature (°C) in the mesophilic range

The empiric relations of McCarty are valid for both primary and secondary sludge. Eq. (8.58) is also indicated in Fig. 8.16b.

(b) pH value

Maintaining the pH up or near the neutral value of 7 is a prerequisite for stable operation of the anaerobic digester. Methanogenesis occurs at a very low rate when the pH is outside the narrow pH range from about 6.5 to 7.5. It has been demonstrated in Section 8.3.1 that alkalinity is produced during anaerobic digestion and that bicarbonate is formed from the generated carbon dioxide. Therefore, the carbonic system is always the predominant buffer system in anaerobic digesters and its presence automatically ensures a pH in the appropriate range.

However, if for some reason acid fermentation develops more rapidly than methanogenic fermentation, the accumulation of acetic acid (acting as a strong acid in the neutral pH range) will reduce the alkalinity and as a consequence, the pH in the mixed liquor may drop to values as low as 4.5 to 5.0. Once a low pH value has been established, the methanogenesis rate will remain very low and the reactor can only return to its normal performance by introducing external alkalinity.

(c) Presence of nutrients

The presence of macronutrients in excess sludge is normally guaranteed automatically in the case of secondary sludge or a mixture of primary and secondary sludge. The biological material to be digested has a high fraction of nitrogen and phosphorus (10 and 2.5 percent respectively) and a large part of it is mineralised during the anaerobic digestion process and will be available for the anaerobic bacteria in the form of ammonium and phosphate. However, Speece (1985) showed that the availability of micronutrients (especially iron) may be problematic and that sometimes the performance of digesters can be improved considerably when the appropriate salt is added.

(d) Presence of toxic materials

The methanogenic bacteria are very sensitive to the presence of toxic materials. In the case of sewage treatment, the presence of toxic materials is unlikely in primary sludge and almost impossible in secondary sludge. In the case of industrial wastes, the presence of toxins is a real danger especially in the primary sludge. The toxic components can be divided into three classes according to their nature:

- Toxicity related to pH;
- Immediate toxicity even at low concentrations;
- Gradually increasing toxicity with increasing concentration of the material.

The toxicity of some weak acids and bases is related to pH, which determines the degree of dissociation. The components most likely to be found in sludge digesters are:

- Sulphides originating from the mineralisation of sulphur containing proteins and from the reduction of sulphate in the anaerobic digester, a process that develops parallel to anaerobic digestion. Normally the sulphide concentration will remain below 50 to 100 $mg.l^{-1}$ and in that case it will not inhibit methanogenic activity seriously. Possible temporary problems may be overcome by the addition of ferrous salt, resulting in precipitation of FeS;
- Volatile fatty acids, which only have a significant concentration if there is a predominance of acid fermentation due to equilibrium disruption of the anaerobic digestion processes. The ionised form is not toxic. The toxicity of the unionised acids is due to their diffusion through the cell membrane and subsequent dissociation in the bacterial cell. The unionised acids may be converted into ions by adding alkalinity to increase pH;
- Ammonium. Only the unionised form is toxic, but the anaerobic populations can adapt to very high concentrations. Ammonia mainly originates from the mineralisation of proteinic material and amounts to about 10% of the mass of digested secondary sludge. It is always possible to adapt the anaerobic sludge to the ammonia concentrations normally found in excess sludge digesters.

The components that have an immediate toxic effect are industrial products like biocides and chlorinated organics. These products may be introduced in the digester together with primary sludge. A distinction can be made between material with an irreversible action (toxic materials) and those that only have an effect as long as they are present in the reactor (inhibitory materials). It is possible that after the removal of an inhibitory material, the sludge requires a long time to recover its original activity. A special case is the presence of dissolved oxygen, which is toxic for the methanogens. Normally the introduced dissolved oxygen concentration is low and will be removed rapidly by facultative acidifying bacteria present in the digester.

Heavy metals such as Hg, Cd, Zn, Cr, Ni etc. form another special group. Their ions are very toxic for methanogens, but in the anaerobic digester their effect is often neutralised by sulphide that forms insoluble salts with these metal ions. In the class of concentration depending toxic materials, calcium and sodium may be important, especially if these are added to the reactor together with alkalinity (e.g. in the form of lime or caustic soda). Methanogenic bacteria can adapt very well to high concentrations of alkali and earth alkali metal ions, provided the increase of the concentration is gradual.