

10.1.1 The basis of design

In the design of waste water treatment plants, often neither quantity nor characteristics of the waste water to be treated are known and have to be estimated, for instance based on the size of the population and its expected growth, the fraction of the population served by a sewer system and the expected development of organic- and hydraulic contributions per capita. For any rational design approach, it will be necessary to attribute values to all of these parameters. In practice, there will be sometimes no alternative than to refer to “expert judgment” or “common sense” in order to come up with any numbers at all. In addition to quantitative data concerning the amount and concentration of the waste water, it will be necessary to obtain data about the values of the kinetic parameters of the processes in the future treatment system and of the settleability constants. Finally the relevant costing data have to be obtained, which will ultimately define the investment and operational costs.

10.1.1.1 Waste water characteristics

A prerequisite for any rational process design is the availability of information about the quality and quantity of the waste water to be treated. However, in many cases at the start of the design phase the waste water to be treated does not even exist yet. In that case it will be necessary to refer to similar projects or to design literature to obtain the required data. In the case of the activated sludge system the most important parameters are:

- (1) Influent flow rate;
- (2) Concentration and composition of the organic material in the influent;
- (3) Concentration of the inorganic suspended solids in the influent;
- (4) Temperature profile;
- (5) Value and stability of pH;
- (6) Nutrient concentration;
- (7) Especially in the case of industrial waste waters: the presence of toxic components.

(1) Influent flow rate

In the case of domestic sewage, the flow rate depends on five main factors:

- Size of the contributing population;
- Per capita water use;
- Type of sewer system: combined or separate;
- Contribution of industries;
- Quality of the sewer network and the amount of infiltration water;

Each of these factors tends to change in time: the population will increase or decrease and the per capita water consumption increases when the economical conditions get better. The industrial contribution might increase together with the level of industrial production, but this might be partly offset by more efficient use of water in the production process (e.g. the use of water in the paper industry has been reduced by a factor of 10 in the last fifty years). Furthermore it might be advantageous (or obligatory) for companies to treat their effluent. When the quality of the sewer system deteriorates, the infiltration rate of ground water into the sewer system will increase.

Apart from determining the average expected flow it is also necessary to consider daily and seasonal variations. This is particularly important for the determination of the OUR and its variation in time in the aeration tanks: the installed oxygen transfer capacity should be sufficient to meet the oxygen demand of the process under maximum loading conditions. When the daily variation in OUR is substantial, it will be necessary to install some form of process control on the aerators in order to maintain a stable and adequate dissolved oxygen concentration in the reactor without having excessive aeration during periods of low load.

An alternative is the construction of a buffer tank to equalise variations in concentration and flow. Especially for industrial waste waters, where large fluctuations in flow, temperature and/or pH occur, construction of a buffer tank may be required anyway to ensure operational stability. The average flow rate and its variation are also of major importance for the design of units in which size is primarily determined by hydraulic considerations, such as primary- and final settlers. The influence on the thickener and digester will be limited, as the design of these units is based on the organic load.

(2) Concentration and composition of the organic material in the influent

Together with the influent flow rate, the concentration and composition of the organic material in the influent are the most important parameters in the design of an activated sludge system, as together they determine the organic load to be removed. The organic loading determines the production of excess sludge and the oxygen consumption for carbonaceous material removal. These variables also depend on the sludge age, the main operational parameter to be optimised.

As discussed above, both concentration- and flow rate of municipal sewage (and of most of the industrial waste waters) tend to fluctuate in time. In many cases there is a distinct daily pattern as well. The amplitude of the variation depends on local topographic conditions and the residence time of sewage in the sewer system. In larger sewer systems there tends to be some equalisation. It is important to note that the organic load to the activated sludge system is defined as the average of the product of the variable flows and the associated concentrations and is **not** equal to the average flow multiplied by the average concentration. For domestic sewage, the concentration also in general tends to be at its maximum value at the hours of peak hydraulic flow rate. Therefore the organic load to the activated sludge system is significantly larger than the product of average flow and concentration. It is concluded that it is very important to acquire information about the expected daily profile of both influent flow and -concentration.

Finally, the composition of the organic material, i.e. the value of the three important fractions f_{ns} , f_{np} and f_{sb} is also very important, as it will directly affect effluent quality, excess sludge production and oxygen consumption. If the values of these fractions cannot be determined experimentally then either default values from the literature or measured values from similar projects should be used.

(3) Concentration of inorganic suspended solids in the influent

The concentration of inorganic suspended solids is important, not only because it affects the concentration and production of excess sludge but also because it tends to influence the settling characteristics of the sludge.

(4) Temperature profile

The temperature is very important as it has a large influence on the values of the kinetic parameters in the activated sludge system. Determining the minimum expected operational temperature is critical: if the system will function satisfactory at its lowest expected temperature then performance at higher temperature will not be a problem. The nitrification process is highly affected by a decrease in temperature. Apart from the direct influence on nitrifier growth rate, seasonal dynamics play a role as well: at the beginning of the cold season nitrification capacity is not yet negatively affected as the fraction of nitrifiers in the sludge is still large. However, in time the nitrifier fraction will decrease and so will the nitrification capacity. At the beginning of spring a similar (but reverse) effect will occur: although the temperature increases the nitrification capacity will tend to lag behind, as it will take longer before the nitrifier fraction in the sludge will be restored.

Apart from the obvious absolute lower limit of zero degrees Celsius, activated sludge systems are also limited with respect to the allowable upper temperature limit. Especially when nitrification is involved, the temperature in the reactor should not exceed a value of 35 to 40°C. The highest average temperature to be expected for municipal sewage is about 30°C in the range of the equator decreasing to about 20°C at the tropics of cancer (23.5°N latitude) and capricorn (23.5°S latitude).

In regions with a moderate and cold climate the average temperature tends to be much more dependent on the change of seasons. Large seasonal temperature fluctuations can cause problems as processes might develop at higher temperatures that do not occur at lower temperature, for instance nitrification. If the system has not been designed for nitrification, serious problems may develop in the hot season. In the case of hot industrial waste waters it may be required to install heat exchangers in order to avoid the temperature rising above 35 to 40°C. The large treatment plant operated by CETREL at Camaçari successfully treats petrochemical waste water at a temperature range varying between 35 and 39 °C in the aeration tanks, producing an effluent with very low concentrations of biodegradable organic material and ammonium.

Large short-time temperature variations should also be avoided, as these will have an adverse effect on biomass activity. When these kinds of temperature variations occur, the use of an influent buffer tank might be advantageous. Finally, the installed aeration capacity is also affected by temperature. The reactor temperature influences the equilibrium dissolved oxygen concentration, while the ambient temperature influences the size of the air flow to be compressed (for diffused aeration systems only). At higher temperatures the difference between the equilibrium oxygen concentration and the oxygen setpoint, the driving force for oxygen transfer to the mixed liquor, will be smaller. At the same time, a high ambient temperature will increase the required compression power of the blower.

(5) Value and stability of pH

The value and stability of pH is mainly determined by the amount of alkalinity present in the influent and the amount of alkalinity produced or consumed in the activated sludge system. If the alkalinity in the reactor is not maintained at a minimum value of 35 ppm CaCO₃, external alkalinity should be added to prevent operational instability, as the pH might at least occasionally be reduced to values much below the optimum of 7.0 to 7.5.

(6) Nutrient concentration

A certain minimum concentration of nutrients (mainly nitrogen and phosphorus) is necessary to cover the requirements for the production of excess sludge. If nutrients are not available in sufficient quantity, the bacteria will still grow but the settleability of the sludge will decrease. In case of industrial waste waters, the nutrient concentration in the influent might not be enough to meet the demand, making nutrient addition necessary. For domestic waste water and some industrial waste waters, the nutrient concentration will be much higher than the requirements for excess sludge production and in these cases the system should be designed for nutrient removal.

(7) Toxic components

Industrial waste waters (or domestic sewage with industrial contributions) might contain toxic components, either having an impact on kinetic parameters such as growth and decay rates or on sludge properties such as sedimentability. Depending on the nature of the material the effect may be either acute or chronic. In the former case there is a temporary presence of toxic material. The toxic material may be removed in the treatment system by metabolism or desorption. Examples are volatile organic compounds (VOCs) such as light aromatics and chlorinated organics in oil refinery or petrochemical wastes. In the case of chronic toxicity, the toxic material tends to be retained in the treatment system and accumulates in the sludge, e.g. heavy metals. It is important to distinguish inhibitory compounds, which will only have an effect while they are present, from real toxic materials that will have an irreversible effect, even after having been eliminated.

10.1.1.2 Kinetic parameters and settleability of the sludge

In addition to the qualitative and quantitative characteristics of the waste water to be treated, it will be necessary to determine the value of kinetic parameters, as these are important in determining both the performance of the system and the dimensions of the main treatment units. The parameters that determine the minimum sludge age for nitrification and the denitrification rate are especially important. If biomass is already available (for instance in projects for expansion of treatment capacity), the settleability should be established. This can be done either by means of an experimental procedure allowing direct determination of the Vesilind constants or through determination of a parameter that allows estimation of these constants. Often the value of these constants fluctuates in time: in this case the most unfavourable values should be adopted. When no activated sludge is available, literature values or measured values from similar waste water treatment plants can be used. It is recommended to be somewhat conservative in the design, as underperformance of the final settler may otherwise cause sludge loss with the effluent.