

Chapter 10

INTEGRATED COST-BASED DESIGN AND OPERATION

In the preceding chapters a general model of the activated sludge system has been presented that can be used for optimisation of design and operation of waste water treatment plants. In this chapter some practical applications will be presented.

The design of activated sludge systems has been the subject of a large amount of research attention. Several software design applications have been developed, most of which have been based on the activated sludge models number 1 to 3 developed by a task group of the IWA (Henze et al; 1986, 1994 and 1998). These models are for a large part based on the research results obtained at the University of Cape Town (UCT) in South Africa (Water Research Commission, 1984). These results also form the basis of the general and ideal steady state design models presented in in this book.

However, the format of the IWA models is not particularly suitable for application as a design tool. The main objective of these dynamic models was to increase the understanding of activated sludge systems, for instance by allowing system behaviour to be simulated. For this purpose, a large number of variables and parameters have been included. These are indispensable when studying system reactions to disturbances or to process control measures, but can be considered as unnecessary ballast from a design viewpoint. In fact the IWA models are of such a complexity that an analytical optimised design solution is not possible.

An example is for instance the dissolved oxygen concentration, which is included in the IWA model as one of the twenty or more state variables. Each of these state variables has a separate mass balance. Furthermore, dissolved oxygen is also included in almost all reaction rate equations, in the form of a Monod type switching function. This function can be either of the type $DO/(K + DO)$ or $(K + DO)/DO$ and thus “switches” a particular process on or off, depending on the dissolved oxygen concentration. This is a crucial feature when simulating the behaviour of activated sludge systems.

However, it is not required for system design, where sufficient availability of oxygen in the aerobic reactors and the absence of oxygen in anoxic- and anaerobic reactors is presupposed. Proper aeration control, including sufficient aeration capacity and suitable process controls, is there to ensure that oxygen will be present at the right time, -location and -quantity. From a design perspective it will not make a significant difference whether the actual oxygen concentration will be 1.9 or 2.3 mg O₂·l⁻¹.

A second example is alkalinity, also included as a state variable and present in a number of switching functions (e.g. in the growth rate of nitrifiers). For activated sludge system design, it is only important to know whether sufficient alkalinity is available in the influent, given the requirements of future system design and operation. If not, then provisions will be made for pH control.

Another issue is that most design models and -books only take into consideration the processes that develop in the biological reactor, such as metabolisation of organic material, nitrogen removal and biological excess phosphorus removal. The design of auxiliary units such as final settler, thickeners and digesters is either excluded or handled as a separate, stand-alone unit.

In this chapter, based on the theory presented in the previous sections, an integrated design approach is presented that also includes the other main treatment units of the activated sludge system: final settler, sludge thickener, sludge digester, and optionally pre-treatment units such as the primary settler and the UASB reactor. In various detailed examples, the use of this design approach will be demonstrated in a step-by-step determination of the optimal configuration of the activated sludge system.

During design optimisation, the waste water treatment plant presumably has not been constructed and the different parts of the systems can be optimised based on information or presuppositions about the composition and characteristics of the influent and the kinetic constants. However, the presented theory can also be applied to the operation of existing systems, to ensure the desired effluent criteria are met at minimum costs and under conditions of good operational stability. In many cases, existing activated sludge systems are considerably over designed when compared to the actual average applied flow and load. This is mainly caused by (1) the necessity to take into account peak organic and hydraulic loads, and (2) a conservative design including safety margins, as there is uncertainty both with regard to expected loadings and to equipment performance. Some practical examples dealing with this subject will be discussed later in this chapter.

An important aspect in the design of waste water treatment systems is the dynamic nature of the quality and quantity of the incoming waste water flow. In many cases the waste water flow increases in time, because the number of contributors and/or the fraction of the population served by a sewer system will increase. However, in a number of developed countries the total sewage flow is decreasing due to (1) stabilisation of the population, (2) the tendency to construct separate sewer systems for rainfall and municipal sewage in new residential areas, (3) the reduction of water consumption by the industry, and (4) the construction of waste water treatment plants by industry. However, whenever an increase is expected, a staged approach might be advantageous. This could be in the form of a modular approach with several parallel identical treatment "trains", constructed when additional treatment capacity is required and/or when funding becomes available. Another possibility is the construction in parts, first preliminary treatment followed at a later stage by secondary treatment, which will then deliver the desired effluent quality. The staged approach has the advantages that the initial investment is reduced and that possible shortcomings in system design or equipment performance can be corrected in the subsequent modules.