CONTENTS IN BRIEF

Chapter 1 - Introduction

This chapter provides a brief introduction into the field of biological wastewater treatment, including the concepts of primary-, secondary and tertiary treatment. Furthermore the scope of this text will be discussed.

Chapter 2 - Organic Material and Bacterial Metabolism

Several alternative parameters to indicate mass of organic material in wastewater are discussed and evaluated: biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC). It is demonstrated that COD is the most appropriate parameter for use in mass balance equations. The main metabolic processes that result in the removal of organic material are identified, under aerobic-, anoxic- and anaerobic conditions.

Chapter 3 - Organic Material Removal

The interaction between the activated sludge system and the organic material in the wastewater and its effects on effluent quality, oxygen demand and excess sludge production are evaluated. The importance of the sludge age, both as operational parameter and as the crucial design parameter is highlighted. Based on measurable system parameters, it will be demonstrated how to prepare a COD mass balance of an activated sludge system. A closing mass balance is a good indication of a system in steady state. An “ideal” steady-state activated sludge model for COD removal is developed that is used throughout this text as the basis for activated sludge system design and optimisation. The model has proven very valuable for the description and the prediction of the most important characteristics of the activated sludge process: excess sludge production, oxygen demand, effluent quality and the quantity and composition of the biomass that will develop. Model applications include the determination of the required biological reactor volume and the prediction of nutrient demand and -removal. The concepts of true- and apparent yield are discussed while the fallacies involved in using the F/M (food/mass) based method for the design of biological reactors are highlighted. Several methods for the control of the sludge age are presented and evaluated. Finally, several common configurations of the activated sludge system are discussed.

Chapter 4 - Aeration

The theoretical principles of the aeration process are presented, including the practical application of these methods to size of aeration equipment: both for surface aerators and for diffused aeration systems. Several practical examples demonstrate how to determine the values of main aeration parameters in full-scale activated sludge systems. This includes the use of the oxygen uptake rate (respirometrics).

Chapter 5 - Nitrogen Removal

The stoichiometrics and kinetics of nitrification and denitrification are presented, including the effect of these processes on alkalinity, pH and oxygen consumption. Similar to organic material, it will be demonstrated how to develop a mass balance for nitrogenous material in the activated sludge system. The steady state activated sludge model is extended to include nitrogen removal. In the first step a model for nitrification is presented, which can be used to determine (I) the minimum sludge age required for nitrification and (II) the minimum sludge age required to meet the specified ammonium effluent limit. Subsequently a model for denitrification is presented. Based on these models the nitrogen removal performance of an activated sludge system can be evaluated as a function of the sludge age and of the influent composition in terms of COD and nitrogen. An optimised design procedure is developed that can be used to define the optimal nitrogen removal configuration as a function of the required effluent nitrogen quality, the influent characteristics and the operational conditions. This includes the selection of the minimum sludge age required to meet the treatment objectives, the selection of the most appropriate configuration (BDP or pre-D configuration), the size of the anoxic zone(s) and the values of the various recirculation factors.

Chapter 6 - Innovative Systems for Nitrogen Removal

The most recent developments regarding sustainable nitrogen removal will be discussed. First the theoretical background of nitritation, anaerobic ammonium oxidation and bio-augmentation is presented, followed by a discussion on design aspects. Subsequently the performance of single and multiple reactor configurations for nitritation-Anammox processes are presented, including cases studies of existing full-scale installations.

Chapter 7 - Phosphorus Removal

The stoichiometrics and kinetics of the processes involved in biological- and chemical phosphorus removal are presented. The design and performance of various configurations for chemical phosphorus removal is discussed: pre-precipitation, simultaneous- and post-precipitation. As for biological phosphorus removal, the most popular configurations, i.e (modified) UCT and modified BDP will be discussed. A design model for bio-P removal is presented, which is incorporated into the steady-state activated sludge model to accommodate both biological- and chemical phosphorus removal.

Chapter 8 - Sludge Settling

The main methods to evaluate sludge settling are presented and evaluated. The solids flux theory is selected as the most appropriate theory to describe the settling process in activated sludge settlers. Using this theory and based on the mass balance over the final settler, an extensive mathematical description is given of the activated sludge settling process and of its implications for the design and optimisation of final settlers. Based on this model, for each given reactor sludge concentration an optimized final settler design can be obtained. Furthermore, an optimisation procedure is presented for the minimal total costs (or total volume) design of the aeration tank and the final settler, as a function of the influent composition, the settling characteristics of the sludge and the mixed liquor concentration. Finally, the static-point procedure is presented as a method to evaluate the performance of existing final settlers under conditions of varying load and flow.

Chapter 9 - Sludge Bulking and Scum Formation

This chapter presents an overview of the most recent theories on the mechanisms involved in the occurrence of sludge bulking and scum formation, while methods are presented to prevent or remediate these problems.

Chapter 10 - Membrane Bioreactors

The focus of this chapter is on Membrane Bioreactors (MBR). The theoretical principles of MBR treatment are explained and a design procedure for the main configurations is presented (submerged and cross-flow MBR), which includes sizing of the membrane units. The operational aspects of membrane bioreactors are discussed, such as membrane fouling processes and methods for membrane cleaning. Furthermore the effect of MBR treatment on activated sludge system performance is evaluated. The steady-state activated sludge model is adapted to reflect the changes introduced by MBR treatment. Recent design data of the main membrane suppliers is presented as well.

Chapter 11 - Moving Bed Biofilm Reactors

A completely new chapter which focuses on the MBBR technology. After an explanation of the treatment concept, several popular process configurations are discussed, including the Integrated Fixed film Activated Sludge (IFAS) system, which combines the advantages of MBBR with those of the conventional activated sludge process. Design guidelines and treatment performance are presented.

Chapter 12 - Sludge Treatment and Disposal

The chapter starts with the determination of the excess sludge quantity- and quality, as generated from primary settling and by activated sludge systems. This is followed by a section on the design of sludge thickeners, according to two methods: the solids flux theory and an alternative approach based on empirical guidelines. The kinetics, stoichiometrics and the operational parameters of both aerobic- and anaerobic sludge digestion are discussed: this includes digestion efficiency, release of nitrogen, stabilised excess sludge production, methane production and the potential for power generation. Furthermore a design procedure is developed for the optimized design of a system consisting of sludge thickeners and digesters: this includes the total required volume and the optimal process configuration. Finally, several alternatives for the final disposal of stabilised sludge are discussed. The focus is on the design and performance of sludge drying beds, as this is a cost-effective method to produce a very dry and high quality sludge in regions with a warm climate.

Chapter 13 - Anaerobic Pre-Treatment

The performance of several modern high rate anaerobic treatment systems is compared. The Upflow Anaerobic Sludge Blanket (UASB) reactor is currently considered as the most suitable system for the anaerobic treatment of municipal sewage. However, several design and operational issues that have a negative impact on performance will be discussed, such as design and engineering aspects and the presence of sulphate in the raw sewage. The loss of methane with the anaerobic effluent and the resulting impact on the carbon footprint of the sewage treatment plant are discussed, as well as the measures that can be taken to reduce both.

A design model for the anaerobic treatment process is presented, which includes the influence of the main operational and design parameters: sludge age, temperature and sewage composition (COD, SO_4). This model describes and predicts the most important characteristics for anaerobic treatment as function of the anaerobic sludge age: COD removal efficiency, methane production, effluent composition and excess sludge quantity and -composition. Combined anaerobic-aerobic treatment systems for secondary and tertiary treatment are discussed. The steady state model of the activated sludge system is integrated with the model for anaerobic pre-treatment. When the nitrogen removal model is included as well, it becomes possible to evaluate the maximum extent of denitrification that can be achieved. The interaction between anaerobic- and aerobic systems is highlighted. This includes for example the effect of the anaerobically produced sulphide on the performance of the aerobic post-treatment system. Furthermore the impact of the digestion of aerobic excess sludge in the UASB on treatment performance is evaluated, compared to the use of a dedicated heated digester. Some interesting new system configurations are presented, combining anaerobic pre-treatment with innovative nitrogen removal. Last but not least industrial anaerobic systems will be discussed. This includes granular high rate systems such as the Expanded Granular Sludge Bed reactor (EGSB) and the (granular) UASB.

Chapter 14 - Integrated Cost-Based Design and Operation

In the first section of this concluding integration chapter the basics of process design are discussed. This includes obtaining data on wastewater quantity and composition, kinetic- and stoichiometric data and costing data. In a series of examples it will be demonstrated how costing data can be used to compare alternative system designs with respect to total investment costs, operational costs and total annualized costs. Furthermore the optimised cost-based design procedure of the activated sludge system is demonstrated in extensive worked examples for several common secondary- and tertiary treatment configurations. This includes the implications on effluent quality, the size of the main treatment units and the treatment costs (investment- and operational costs). Several examples will address the optimisation and upgrading of existing wastewater treatment facilities. The chapter ends with a series of extensive design cases of advanced treatment configurations such as the MBR and different phosphorus removal configurations.

Appendices

The appendices cover those subjects that require more detail but would deviate too much from the main “storyline” in the book. The following subjects are discussed:

- Appendix A1 - Determination of the Oxygen Uptake Rate
- Appendix A2 - Calibration of the General Model
- Appendix A3 - The Non-Ideal Activated Sludge System
- Appendix A4 - Determination of Nitrification Kinetics
- Appendix A5 - Determination of Denitrification Kinetics
- Appendix A6 - Extensions to the Ideal Model
- Appendix A7 - Empiric Methods for Final Settler Sizing
- Appendix A8 - Denitrification in the Final Settler
- Appendix A9 - Aerobic Granular Sludge