Popular Summary

Water supply is one of society's most important commodities. Water use gives rise to wastewater and for health and environmental protection purposes, treatment of wastewater was one of the great challenges of the past century. The sanitary revolution was voted the greatest medical advance since 1840 by the readers of the distinguished British Medical Journal. Still, wastewater treatment continuously evolve as the awareness of emerging environmental problems grows. The knowledge about the influence of human activities on climate change has widened the scope for treatment plants beyond only effluent water quality and cost. Today greenhouse gas emissions, energy efficiency and resource recovery also need to be considered when evaluating operational strategies.

In the present research, the use of mathematical models has shown the importance of considering the highly dynamic effects of wastewater treatment processes, and at the same time including the up- and down-stream impacts – from resource use and discharge of residues and wastes – that the treatment plant operations give rise to. Simulation of, for example, enhanced primary treatment with chemical precipitants or advanced measures for meeting stricter effluent constraints, show that reduced eutrophication can be achieved along with reduced emissions of greenhouse gases. However, the increased resource consumption, primarily of chemicals, leads to a manyfold increase in depletion of both elemental and fossil resources.

Mathematical modelling and simulation of wastewater treatment processes has a long history and is common practice in the industry in many parts of the world. For this project, a plant-wide modelling platform, The Benchmark Simulation Model no. 2, was adopted and further developed for multi-objective performance assessment. To be able to capture the additional criteria, energy efficiency and greenhouse gases, the model was developed and extended in the following three areas:

Energy for aeration As oxygen supply to the biological unit processes is the most energy intense process of any advanced treatment plant, a detailed dynamic aeration model was implemented in the Benchmark model. The aeration model was tested in three case studies and shown to be adequate for its purpose, robust and easy to adapt to real plants.

Anaerobic co-digestion Energy recovery from the influent organic material via anaerobic digestion is common practise. In anaerobic digestion, organic material in sewage sludge or other materials are degraded, leading to less sludge, and converted to energy-rich biomethane. At many plants redundant digester volumes allow this energy production to be increased by adding external organic substrates (so called co-digestion). The digester model was modified to allow for dynamic simulation of co-digestion and a procedure to characterise the substrates was proposed. A simulation study showed that modelling is beneficial to assess both digester stability and secondary effects on the water treatment from co-digestion.

Greenhouse gas emissions Repeated measurements on greenhouse gas emissions from wastewater treatment plants have shown a large span of total emissions. The current state of knowledge explains that production and emission of the potent greenhouse gas nitrous oxide (N_2O) in biological treatment processes is highly dynamic and varies greatly with the operational conditions. Therefore, the operational strategy and ambient conditions have a great impact on the total emissions. The model library of the Benchmark model was extended with a biological model that covers the most important production pathways for nitrous oxide. Furthermore, fugitive emissions of carbon dioxide, methane and nitrous oxide from other treatment processes, primarily the sludge treatment, were included. Multiple case studies calibrating the model to experimental data showed the highly dynamic behaviour of the emissions, demonstrating that dynamic models are critical to evaluate greenhouse gas emissions at wastewater treatment plants. However, calibration efforts also indicate that the available models are not yet capturing all the existing processes in the biological reactors and further research is likely required.

All these modifications were included in the Benchmark Simulation Model no. 2 and tested in a full scale case study of a real plant in Sweden. The model outputs were then connected to a life cycle analysis model to capture the off-site up- and down-stream effects of the operations. The use of external goods, such as electrical power and chemicals, leads to resource depletion. Furthermore, discharges of residues (effluent water and sludge) have an impact on the environment downstream. By evaluating the entire wastewater treatment plant considering all these objectives – water quality, energy efficiency, greenhouse gas emission and operational cost – for both on-site effects and off-site environmental impact, the trade-offs between the objectives and different impact categories can be revealed. The presented modelling tool is capable of capturing these trade-offs and the results are essential for decision support when deciding on modifications of operational strategies at wastewater treatment plants.