# Maximising the benefits of activated sludge modelling

● Modelling activated sludge processes has moved from fairly simple prediction to the complex requirements for improved modelling of key aspects in the process.

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**Activated sludge (AS) has been around for 100 years now, but the dynamic modelling of this process has been undertaken for only the last four decades, starting probably with the pioneering work of John Andrews (1974). The recent WWTmod2014 event (see box) and a brainstorm among the authors – as seasoned AS modellers – in Wendake, Québec, Canada, resulted in the development of some key points of direction with regards to the short-term needs in AS modelling. These range from further model development over development of modelling tools as well as the way modelling projects are (or should be) better conducted.**

### The resource recovery paradigm

The rapid paradigm shift from being a wastewater treatment industry to becoming a water resource recovery industry has clear implications for AS modelling too. To date, the major objectives for modelling have been related to predicting effluent quality, energy consumption (though less refined), sludge production and more recently greenhouse gas emissions (for instance, $N_2O$ and $CH_4$).

In addition to clean water for reuse, the resources that can potentially be recovered from wastewater are energy (biogas production through anaerobic digestion (AD)), nutrients (such as struvite and ammonium sulphate as fertiliser) and other products such as plastics (PHA (polyhydroxyalkanoates) production through reformed AD). For this reason, the objective of generating maximum product quantity of a guaranteed quality has been added to the list of objectives. Some technologies have already been put into practice, whereas others are still under development. The focus of wastewater treatment modellers has rarely been on product creation, however, so efforts will have to shift to developing new or extending existing models for these particular processes.

A unit process that has not received sufficient attention in the last four decades in terms of modelling is the primary settler, as well as primary treatment in general. The models that are used are mostly based on equations that mimic measured removal efficiencies measured instead of really modelling the underlying mechanisms, sometimes including a flow-dependency to describe reduced efficiency during diurnal flow rate changes or wet weather flow. The practice of chemically enhanced primary treatment (CEPT), where coagulent and / or polymer are added to primary influent, and the impacts of recycle stream solids, which affect wastewater composition and setting, are examples of factors that affect model predictions. Prediction uncertainties are thus significant. There are some other models, but these have not really been adopted by the profession.

Primary settling is a key process when it comes to describing the organic content of the sludge and the amount produced. Studies investigating how to maximise biogas production or product quantity from the sludge train will depend greatly on good primary settler models. Recently, work has been initiated on the settling characteristics of different influent fractions and these seem to be quite similar at three wastewater treatment plants tested in different continents (Bachis et al, 2014).

Improved primary settler modelling has been achieved thanks to the use of particle settling velocity distributions. Such models also allow the description and optimisation of chemically-enhanced primary treatment, which results in increased settling velocities, although it is important to note that different mechanisms are at play when adding ferric salts or polymers.

Other recent work has investigated the shift in wastewater composition (the chemical oxygen demand (COD) and nitrogen fractions) before and after the primary settler and indicates that shifts do occur at the level of the primary clarifier (Bachis et al, 2014). More understanding is crucial, as this again impacts not only the downstream processes in the water line, but also the digestion process of the sludge-laden underflow. In order to connect all this with the behaviour of the plant-wide system, including resource recovery, an integrated modelling approach is needed to account for the multitude of interactions in the system. Significant modelling efforts will have to be made in the near future to establish this.

In the above work, wastewater characterisation plays a major role both in terms of quality (accurate composition) as well as quantity (measurement frequency). This makes it a tedious and expensive task. Because of this,

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## WWTmod2014

The 4th IWA / WEF Wastewater Treatment Modelling seminar (WWTmod2014) took place 30 March to 2 April in Spa, Belgium. WWTmod seminars provide a platform to discuss any relevant aspect of wastewater treatment modelling, the main objective being to build consensus.

The seminar was the first of two specialist events organised by the IWA Specialist Group on Modelling and Integrated Assessment (MIA), the other being Watermatex, which will take place next year in Gold Coast, Australia, 14 to 17 June. For the last six years, WWTmod has been the point of reference for a balanced blend of wastewater treatment process modelling professionals coming from academia, industry, utilities, consultancies, software companies and other relevant industry groups.

With this edition, WWTmod2014 was hosted in Europe for the first time and brought together 137 leading wastewater modelling experts from all continents. Also remarkable is the fact that almost half of those were young water professionals, that is, the next generation of modellers, who were actively involved in the preparation of the seminar and very visible throughout.

automation (for example, online sensors) and cost-effective measurement options need to be explored. It is also recommended that the number of days devoted to modelling (including influent characterisation) in a design project should be increased as the marginal gain can be substantial.

Obviously, all of this needs to be properly linked to certain modelling objectives. Post-project audits of commissioned plants can shed more light on the quality of designs and how the use of modelling can be further improved (Benedetti et al, 2013). The problem is that post-project audits rarely happen. Hence, there is no solid base to see which part of the modelling exercise contains the most uncertainty. Audits can highlight those steps in the modelling process that deserve more attention in the future. This includes a better definition of model validation, as well as its evaluation. Models become more complex and might do a good job for one component, but may perform worse for another. A more standardised way of approaching the imbalances in submodel detail and quality within the overall model is required. The end result is that better modelling could be undertaken, leading to savings and better working plants (usually less overdesigned). The continued use of simulators after the design phase by plant engineering and operations groups is one way to gain the information of a post-project audit, whilst also developing a useful tool.

### Balancing model complexity

Over the last few decades, the biokinetic submodel has received the most attention in wastewater treatment plant modelling. This led to the Activated Sludge Model (ASM) family of models and finally to whole-plant models developed by simulator designers. Whereas the ASM1 model was the outcome of a thorough consensus-building process across the industry, this was much less the case for ASM2d and 3. The latter models contain a lot of detail and contain far too many parameters, hampering their calibration.

However, even ASM1 suffers with respect to the parameter values used. Process rates in ASM-based models usually contain a product of switching functions – factors for providing a smooth transition from an active to a non-active state. But are these factors really independent, thereby creating a multiplicative effect? Furthermore, as ASM-based models are developed to include new conditions, new switching functions are added to existing process rate expressions and the impacts of new switching functions on previously calibrated coefficients is not fully explored. During model analysis, it is also not always easy to see which of these terms is actually rate limiting. Visualisation tools to further analyse this are available (for instance, Amerlinck et al, 2014) but have yet to be implemented in software platforms.

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Furthermore, maximum growth rates and parameters relating to microbial affinity to substrates are often adapted without proper justification during model calibration. It seems that these 'lumped' kinetic terms can be used improperly to cure all remaining deviations of the model predictions from the measurements. This leads to mere fitting exercises, significantly reducing the predictive power of the model.

The fundamental underlying reason for this is the fact that wastewater treatment plant sub-models have become imbalanced, that is, some processes are described in a lot of detail whereas others remain too simplistic. This leads to the use of degrees of freedom in the more complex sub-models to compensate for defects in the simplified sub-models.

Models for primary settling, mixing and aeration are good examples of these simplified sub-models. It should be realised that the models used here stem from the early days of wastewater treatment plant modelling and have not been reconsidered since. Nowadays, new tools are available, such as Computational Fluid Dynamics (CFD), and methods for characterising settling that can help us better understand how these processes work.

CFD can be coupled with biokinetics and settling functions. The knowledge gained can subsequently be used to improve and better balance the currently used wastewater treatment plant models. Note that balancing does not necessarily mean that the complexity of the simple models has to be increased. However, it might turn out that by properly modelling the above processes, fewer model additions have to be made to the biokinetic models. A further added value of CFD is that it can help in reactor design.

Developing CFD models for some specific cases (for instance, rectangular tanks, circular tanks, the type and location of mixers and aerators, inlets, outlets and so on) could help to improve the system design without the need for a separate CFD model for each project, but rather reusing the gained expertise. Currently, a working group under the IWA's Modelling and Integrated Assessment (MIA) Specialist Group is leading this development.

Model balancing is also something to keep in mind when developing models to better describe technologies or sub-processes for resource recovery. Models for these unit processes can be developed in isolation to engineer a quality product through thorough process knowledge (in other engineering fields this is called 'Quality by Design' or QbD). However, these models need to be embedded in integrated models of the entire treatment plant, to better capture the overall picture and investigate how good a solution is in accounting for different performance criteria.

The objective of the model to be developed should therefore always be clearly defined up front, as stipulated by the Good Modelling Practice guidelines (Rieger et al, 2012). Different objectives usually need different models, in terms of complexity. However, the overall balance of an integrated model is an often-overlooked issue that deserves much more attention than it is currently receiving.

Methods for checking model (im)balances using uncertainty analysis should be developed in the near future to address this in a systematic and objective way.

### Wastewater source separation and the move to decentralisation

Decisions on source separation and decentralisation of treatment have a large impact on overall wastewater system behaviour and have already led to a lot of debate. However, this should be viewed within the bigger picture, keeping in mind that waste-water treatment plants are reforming into resource recovery plants. Verifying economic viability and optimisation of such systems will also require dedicated models, as the human brain is simply not capable of accounting for all of the constraints involved, let alone the dynamics of such systems. In order to achieve this, the above evolutions of model developments should take place over the next couple of years, ensuring that new developments and insights are taken into account when developing the models.

### Using models and innovative evaluation tools

The application of wastewater treatment models has moved from research tools helping to increase the understanding of these complex systems to standard engineering tools. This change in use requires a shift of effort from model building to:

- Developing tools to help prepare simulation data (defining data requirements, checking quality of data, generate missing data, and so on)
- Facilitating running simulations (such as scenario management and probabilistic methods)
- Analysing results (databases to store measurements and simulation results, evaluation tools, optimisers, improved plotting tools, mass balance, and so on)
- Providing reporting and export features for project documentation, review and transparency

Modern simulators will easily create gigabytes of data, and this can overwhelm users. Special tools are required to firstly deal with the sheer volume of data created, then encapsulate knowledge to help users analyse all of the data generated by the simulator, and lastly, to evaluate the results based on multiple criteria. More attention should be given to how the human brain processes information. Based on this, new tools should be developed to improve the conversion of data into information, leading to a better basis for decision making.

### Integrated tools

Whereas the focus in engineering practice during the last few decades has been on developing simulators to run process models, new developments focus on integrating different tools into platforms to design, optimise and operate more areas of the urban water cycle. One direction of development is integrated modelling, which includes water resource recovery facilities (formerly wastewater treatment plants), the sewer system and the receiving water body. Another emphasis has been on including other connected fields such as pipe design and equipment selection into the same platform. Control system design has been a major driver for the simulator and model developments, but the classic focus has been on high-level process control, neglecting low-level controls and automation.

A major problem of the transition from designing control strategies to the final implementation has been the disconnect between the different tools used (software) and the experts involved. Typically, design and implementation is a one-way street with no feedback between process, control, instrumentation and automation groups. Modern platforms should integrate the main tools to create a seamless workflow, and provide a common language for all experts. In this way, all stakeholders can test the full system and check if all of their requirements are still fulfilled.

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### Incorporating uncertainty analysis

In recent years the use of models as aids in the design and operation of treatment plants has been increasing steadily. In design, mathematical models implemented in simulation software are the first and often the only design method engineers employ. They are used instead of, or in combination with, conventional heuristic guidelines (with safety factors). In operations, mathematical models are used more and more for optimisation.

In contrast to design guidelines, where uncertainty and variability are accounted for through the use of safety and peaking factors, process models do not incorporate risk evaluation procedures. Therefore, when using simulators to predict energy requirements, resource recovery potential and effluent quality for a plant with a 30-year design horizon, it is unclear how uncertainties linked to climate change, for example, will translate to appropriate design flexibility to meet all the criteria outlined above (Belia and Johnson, 2013).

There is a need for scientific methods that assess the probability of compliance, quantify key sources of uncertainty and evaluate how risk, benefits and costs are distributed among stakeholders such as consultants, contractors, operators and owners. The Design and Operational Uncertainty Task Group (DOUT) (Belia et al, 2015) in conjunction with several other efforts under the DOUT umbrella (Vanrolleghem et al, 2010) is working on methods that incorporate explicit uncertainty evaluations in its simulation-assisted design or operation projects. ●

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