WASTEWATER TREATMENT PLANT OPTIMIZATION USING A DYNAMIC MODEL APPROACH

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ABSTRACT

This paper reviews plant optimization and in particular the role a dynamic model can have in assessing plant capacity and performance. A dynamic model can be used to simulate a number of "what-if" scenarios, which may be difficult to evaluate at full-scale. A site specific well-calibrated model can be used as a "tool" in the optimization of facilities. This paper presents various examples which demonstrate some uses of a simulation model in plant optimization. A wastewater simulator can be used to assess capacity limitations, operational concerns and cost-benefits associated with various operating strategies.

KEY WORDS: Plant optimization, dynamic modeling, wastewater treatment.

INTRODUCTION

Optimizing the operation of existing facilities is becoming more important as effluent criteria become more stringent and available funds for upgrades/expansions become less available. Furthermore, operating costs are now raised as a major concern, especially energy costs. Getting more from existing facilities by either operational changes or minor upgrades is a mean to meet these restraints. Optimization involves reviewing plant operations, facilities and field testing to determine unit capacities and process bottlenecks. Field tests are available to diagnose unit processes, such as aeration efficiency tests (e.g. off-gas analysis) and clarifier flow profiling (i.e. dye testing). These tests can evaluate current operating limitations and lead to operational changes or facilities upgrade requirements.

Often recommended operational changes cannot be immediately verified at full-scale. A mathematical model of the plant can be used as a tool to provide a means to evaluate different operating strategies and upgrades.

BASIS OF MODELING

Models are representations of the knowledge we have about a system. If we can prepare models that are accurate representations of real systems, then we can use them to conduct experiments which otherwise could not be possible. For example, we can conduct stability and sensitivity analyses, test the limits of the model and 'run' the model under conditions that would be harmful or dangerous in the real system. Using quantitative and qualitative optimization techniques, we can determine the inputs required to achieve a desired output. In practical terms, this capability would allow us to build better tools for process design operation and control. Tools for model building, calibration and simulation facilitate these tasks and are changing the manner in which process and plant analysis is performed.

Modeling and simulation has been practiced by engineers and scientists in the environmental field for many years; however, the models are often steady-state rather than dynamic. With the advent or powerful, low-cost workstations, numerical solution of large-scale dynamic models has become practical. In wastewater engineering, there has been rapid progress in the development of models for the processes used in typical municipal or industrial plants. In 1986, the International Association on Water Quality (IAWQ) released a report outlining a general model for the activated sludge processes. This model is often referred to the ASM1 model. This was followed by a second publication in 1995, which included phosphorous removal. This second model is often referred to as ASM2. Sedimentation, biofilm, anaerobic and disinfection models have also seen gradual improvement. With these developments it has become possible to consider the preparation of models for entire treatment facilities from headwork to effluent disinfection.

GPS-X is a software developed in Canada which provides the platform and input/output capability to utilize these powerful models and the flexibility to compute numerical solutions. With the use of GPS-X, it is possible to considerably reduce the time required to build, calibrate and simulate treatment processes.

Dynamic modeling using a well-calibrated model can:

- Accurately size unit processes and select the best design alternatives.
- Save process design time.
- Validate and achieve confidence in design.
- Evaluate efficiently multiple optimization scenarios to minimize operational costs, such as energy costs, while meeting effluent quality requirements.
- Investigate process changes that are required to avoid/control nitrification or to achieve nutrient removal.
- Predict the effects of taking one unit processes off-line for maintenance.
- Assess impact of plant upsets and recovery time.
- Accurately evaluate process control improvements.
- Train operators by illustrating the effect of operating decisions on plant performance.
- Etc.

GPS-X is composed of program modules and wastewater process libraries. The program modules embrace the functionality of GPS-X, while the wastewater libraries are collections of process models that describe the relationship between the basic wastewater components. Given the number of modules and wastewater libraries available, the flexibility and power of GPS-X quickly becomes apparent. GPS-X has a number of features that makes it an ideal tool for modeling including:

Basic Simulator Features

- Steady state and dynamic simulation for entire treatment facilities from headwork to effluent disinfection.
- Completely interactive, allowing fast feedback and analysis of results, saves time compared to using "batch" (run and observe) simulators.
- Flexible data input and graphical output features (graphs, data files, DDE, etc.).
- Communicates with spreadsheet programs (e.g. Microsoft Excel).
- All forms are populated with default values from scientific literature (to be adjusted with site characteristics such as nature of pollutant loads and temperature).
- Reads and uses real plant data as simulation inputs or for comparison to simulation results.
- Automatic process consistency check and warnings.
- Capable of supporting different languages.

Advanced Simulator Features

- Customizable (user can change models and interface forms or can add new models).
- On-line automated real-time operation capability.
- Can be connected to SCADA systems.
- Automatic calibration, advanced sensor fault detection, process fault detection, automated forecasting available.
- Contains built-in routines for On-Off, P, PI, PID, and lead-lag feedforward control simulation.
- Built in PID controller tuning facility.
- Dynamically links to Matlab for design and simulation of advanced model.

Table 1 provides a summary of the wastewater model available in GPS-X.

Table 1: Summary of Wastewater Process Models Available in GPS-X

Type	Description
Biological Models	ASM1, ASM2, ASM2d, ASM3, Mantis (Temperature-dependent version of the ASM1), General (ASM1 extended to bio-P removal), VNP (Simplified bio-P model), Reduced (Simplified carbon-nitrogen model for control engineering applications), Filamentous Growth
Settling Models	Double exponential, flux-based
Influent Models	BOD-based (Input BOD, TSS, TKN and stoichiometry), ASM2 (Input COD, TSS, TKN and fractions of basic variables), States (input basic variables)
Fixed Film Models	ASM1, ASM2, Mantis (Temperature-dependent version of the ASM1)
Anaerobic Model	Andrews-Barnett basic two-stage anaerobic model. VSS destruction, VFA generation, CH and CO generation, pH, ammonium toxicity
Filtration	Model: Iwasaki-Horner suspended solids capture model
Miscellaneous	Empirical models for grit removal, dewatering, disinfection, filtration, and black box

CALIBRATION OF MODELS

For a model to accurately simulate the operation of a plant it needs to be developed to include the physical and process aspects of the full-scale plant. The model must include all physical processes and be operated in a similar fashion to the plant it is simulating. Most important is the calibration of the model. If operational data from a plant is being used for the calibration of the model, generally a period of equilibrium is used to establish the performance of the model and adjust the model parameters. Ideally a second period of different operations (e.g. lower water temperature) or dynamic data would be used to verify the model. The accuracy of the model predictions is entirely dependent on the degree of calibration conducted.

For a wastewater facility in southeastern Ontario, Canada, a period of intensive monitoring, which was 3 months in duration, was used to calibrate a model of the activated sludge plant. Table 2 shows the comparison of the actual period and steady-state modeling results. For the steady-state period, the model accurately characterized the performance of the plant and the biomass in the system. A stress test was also conducted to evaluate the performance of the secondary clarifiers under high solids loadings, and the testing resulted to a short period of washout from the final clarifier. This period was used to enhance the calibration of the model in terms of the final clarifier settling parameters, resulting in a model that better reflects the reality.

This example stresses the importance of model calibration, such that the model can be used to make accurate simulations of the plant so as to assess its capacity and operation under various operating modes.

Table 2: Comparison of Model and Actual Effluent Concentrations

Parameter	Effluent Concentration (mg/L)	
	Model	**Actual**
Chemical Oxygen Demand (COD)	47	47
Biochemical Oxygen demand (BOD_5)	3	3
Suspended Solids (SS)	13	8

MODELING CASE STUDIES

Modeling has been used in several treatment plants to evaluate future facilities upgrade and optimize operations. Table 3 summaries the application of modeling at various facilities in North America and Europe. For these various examples, there was a problem in terms of future need for capacity or improvements in effluent quality or excessive operating costs. Modeling was used in each project to evaluate operations and optimize each facility. Costs savings of 10 to 150 million dollars were realized from these projects because of unnecessary construction which would have been required based on traditional steady-state designs. Modeling operational performance have also shown considerable costs savings. Yearly operating savings from $20,000 to $120,000 per year were realized by using the dynamic model to evaluate current and proposed operations. Changes in operation not only demonstrated costs savings but ensured the process performance was not impacted by changes in operations.

Table 3: Summary of Modeling Projects and Implications

Plant/Location	Problem	Results	Savings ($)
Hamilton, Ontario, Canada	Requirement to nitrify	Modeling demonstrated ability to nitrify by reconfiguring existing aeration basins	$5 million saved in new tank construction
Toronto, Ontario, Canada	Requirement to nitrify	Optimization in conjunction with modeling showed most of the planned capital works could be eliminated through modest upgrades and improved plant control	$150 million saved of a proposed $220 million upgrade
Lethbridge, Alberta, Canada	New phosphorous removal requirement	Modeling used to develop new Bio-P process, which eliminated the need for new clarifier construction	Save $6 million
Burlington, Ontario, Canada	New effluent requirements	Value engineering project in conjunction with facility modeling optimized requirements to meet new effluent goals	$35 million saved on original proposed $60 million upgrade
Yorkshire Water, United Kingdom	Capacity limitations	New activated sludge process was not required to meet future needs based on dynamic modeling	$10 million saved in new construction
Wessex Water, United Kingdom	Operational costs	Aeration and chemical cost reductions obtained through optimized operations based on modeling	$210,000/year saved through operating cost reductions
SYVAB, Sweden	Operational costs	Lower RAS flow demonstrated by modeling results in operational savings	$21,500/year saved in energy costs

DISCUSSION

The example modeling application projects presented above show the power of utilizing a well-calibrated mathematical model for optimizing a wastewater treatment plant. The model can be used as a complement to standard wastewater treatment optimization tools. As a tool its usefulness is based on the degree to which the model can characterize the performance of the plant. Therefore, confidence in the model simulations increases with the degree of calibration conducted. Historical periods defining different operating conditions, intensive sampling and other optimization techniques assist in matching the performance of the model to the full-scale facility.

If design data is used to define the simulation, predictions of the performance of a facility based on typical kinetic and stoichiometric parameters can be made. These predictions can be useful in defining the operating procedures for a plant and expected concerns and bottlenecks. However, results of those simulations will require to be confirmed once the facility is operational. Considering that the use of modeling is increasing, experience gained at other facilities under similar operating conditions provides confidence in even these initial simulations, prior to plant's commissioning.

CONCLUSION

This paper reviews the part modeling can have in the optimization of a wastewater treatment plant. Many tools are available for providing information on the optimization of a facility, and process modeling is one of the most powerful if utilized properly. A well-calibrated model within an assessment study can be used to evaluate process capacities, operational changes and upgrades and/or process changes. Used in conjunction with other optimization techniques this tool can evaluate any number of "what-if" scenarios. Continual feedback between the model and reality can be used to confirm initial modeling results.

Process modeling can also be used to validate plant design of future facilities. As an example, GPS-X is currently used in the case of the Gabal El Asfar Stage 2 Phase 1 WWTP which is now under construction in Cairo, Egypt. Thanks to the use of GPS-X, it has been possible to assess the impact of the raw water characteristics on the occurrence of nitrification within this future 500 MLD activated sludge plant, which will be an expansion to the 1000 MLD existing Stage 1. With the use of the model, the efficiency of the proposed anoxic zones to achieve denitrification in the aeration tanks has been confirmed, so as to prevent potential problems of rising sludge in the final clarifier tanks.