IWA TG on Benchmarking of Control Strategies for WWTPs

The Quest for Objective Control Performance Evaluation

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Outline

- Motive
- Background
- Benchmark systems
- Recent developments
- Software platforms
- Outcome from Task Group

IWA Task Group members

- Dr Ulf Jeppsson, Lund Univ., Sweden (chair)
- Prof. P. Vanrolleghem, Univ. Laval, Canada (vice-chair)
- Dr John Copp, Primodal Inc., Canada
- Dr Marie-Noëlle Pons, CNRS-ENSIC-INPL, France
- Prof. Jean-Philippe Steyer, INRA, France
- Dr Christian Rosen, VA-Ingenjörerna, Sweden
- Dr Jens Alex, IFAK, Germany
- Dr Krist Gernaey, Tech. Univ. of Denmark

+ 10-20 associated senior researchers world-wide

Fundamental concept

Model simulations represent a relevant way to evaluate performance of control strategies for WWTPs

- Low cost
- Safe
- Fast
- Include process, actuator and sensor problems
- Effects of varying influent characteristics

and much more …

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Motive

A large number of proposed control strategies for WWTPs have been described. The available information is normally too limited to allow for detailed validation by other groups. Instead these strategies remain paper products. How can we promote the validation process, and thereby be able to compare the potential benefits of proposed strategies for a general WWTP and enhance their practical use?

Answer: the Benchmark Simulation Protocol!

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Benchmark simulation protocol?

- General WWTP layout
- Mathematical process models
- Influent wastewater characteristics
- Sensor and actuator models
  - Allow for users to provide control strategies
- Simulation procedures
- Criteria and tools for performance evaluation

- Provide software
- Promote plant-wide/integrated control and flexible solutions

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Background

- Initial work started in 1997 within EU COST Actions 682&624 and IWA TG on Respirometry
- Basically the same research team today
- Task Group approved by IWA in October 2005
- Supported by IWA ICA and SAIA specialist groups

- Benchmark models used by >50 groups world-wide
- 100-200 papers at int. conferences and journals and several PhD theses

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Benchmark systems

- No specific national or regional preferences
- Based on 'accepted' models, e.g. ASM1, ADM1, 10-layer 1-D settler model
- Fully dynamic including noise
- Allow for high flexibility of control
- Reasonable input and plant behaviour – focus is on *relative comparison of control strategies*
- Evaluation periods – one week or one year

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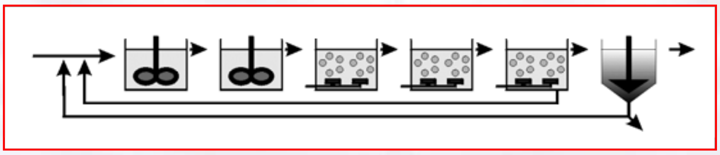
Benchmark Simulation Model no1 (BSM1)

- Models, benchmarking procedure and evaluation criteria
- Five-reactor AS plant with secondary clarification
- Sensor classes and noise defined, ideal actuators
- Three weather scenarios (dry, storm, rain)
- Performance during one week evaluated



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BSM1 Long-Term (BSM1_LT)

The original BSM1 configuration extended with:

- One-year dynamics for evaluation period
- Influent wastewater generation model
- Time (temperature) varying parameters
- Sensor and actuator failures and disturbances
- Process faults and disturbances
- Additional actuators with long-term effects
- Focus on process monitoring
- Different evaluation criteria

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Benchmark Simulation Model no 2 (BSM2)

- BSM1 and BSM1_LT allow only for local control (monitoring) of an AS system
- Need for plant-wide ("within-fence") evaluation
- Importance of the sludge train
- Allow for supervisory long-term strategies
- Include full plant process interactions
- Avoid sub-optimisation
- Seasonal and holiday effects (also in BSM1_LT)
- Generalization of influent generation (also in BSM1_LT)

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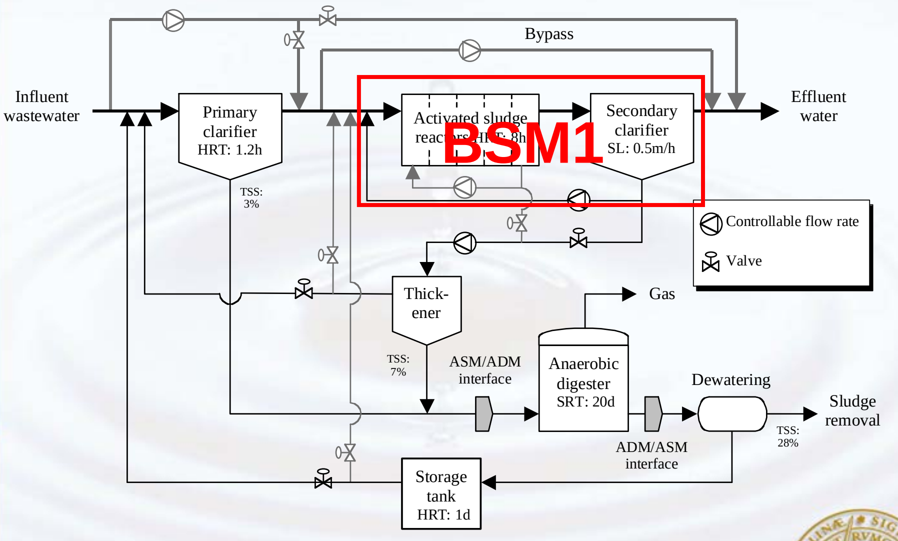

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Benchmark Simulation Model no 2 (BSM2)

- One year dynamics for evaluation period
- ASM/ADM/ASM interfaces developed
- More than 60 control handles available
- Full temperature dependency
- All realistic sensors possible, defined by classes:
  - Noise level, drift, time response and delay, calibration and maintenance requirements, lower & upper limits, measuring interval (*Wat. Sci. Tech.*, Rieger *et al.*, 2003)
- Allows for measurements from 'lab analyses'
- Considerable efforts to enhance simulation speed

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Evaluation criteria

- Effluent quality index (BOD, COD, TSS, TKN, NO_3)
- Operational cost index based on:
  - Aeration energy
  - Pumping energy
  - Sludge production for disposal
  - External carbon
  - Mixing energy
  - Methane production (BSM2 only)
  - Heating energy (BSM2 only)
- Effluent limit violations, 95-percentiles and more
- Specific controller criteria (e.g. wear-and-tear)
- Possibly also a risk index (e.g. foaming, bulking, rising sludge) by Girona University, Spain

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Influent wastewater generation

Dynamic model-based approach (*Wat. Sci. Tech.*, Gernaey *et al.,* 2005; 2006):

- Dry weather with diurnal, weekend, seasonal and holiday effects (household and industrial)
- Rain and storm water generation including first-flush effects in sewers
- More sewer network effects
- Simple drainage, soil and infiltration models
- Batch-type solid waste input (e.g. septic waste)
- Used for BSM2 (and BSM1_LT) but also stand-alone model for other applications

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Anaerobic digester

- IWA Anaerobic Digestion Model no 1 (ADM1) with several modifications (*Wat. Sci. Tech.*, Rosen *et al.* 2006)
- Biological transformations, liquid-gas interactions, gas production
- Currently mostly used ADM1 version
- Slow and fast dynamics – stiff system
- Stiff solvers not good for noise and discrete events
- Complex model –> slow simulation
- Includes algebraic solver for pH and S_{h2} – speed enhancements of factor 100

Model interfaces

- Necessary for combining ASM1 and ADM1
- 13 vs 24 state variables
- COD fractions vs protein, lipids, carbohydrates
- Rudimentary proposal in ADM1 STR
- AD disintegration process part of interface
- General solution for both primary and secondary sludge
- Always maintain mass balances
- *Wat. Res.*, Nopens *et al.*, submitted

Software platforms

Development in parallel on:

- MATLAB®/SIMULINK®
- WEST™
- SIMBA™
- GPS-X™
- Standalone FORTRAN

Possibly: standalone C, SciLab, STOAT, JASS, BioWin

Extensively verified on all platforms by independent implementations

Outcome from Task Group

- Protocol for objective benchmarking of control and process monitoring strategies
- Enhance use of integrated control at WWTPs
- Available “free” software for several platforms
- Workshops (IWA2006, Watermatex2007, IWA2008)
- IWA Scientific and Technical Report (end of 2008)

Future perspectives

- BSM1_LT + BSM2 + more = BSM3
- Plant-wide monitoring and control
- Allow for ASM1, ASM2d, ASM3, ASM4
- Reactive settlers, changing sludge characteristics, etc.
- Extend ADM1 with phosphorus, sulphur
- Special phenomena, e.g. bulking sludge, filamentous organisms, coagulants, polymers, toxicity
- Full pH dependency in all processes
- Xenobiotics?

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Thank You for Your Attention!

Questions and comments?