IWA TG on Benchmarking of Control Strategies for WWTPs

BSM2 Plant-Wide Wastewater Treatment Plant Modelling

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Outline

- Background
- The BSM2 system
- Sensors and actuators
- Recent developments (influent, AD, interfaces)
- Evaluation criteria
- Software platforms
- Possible future development

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

IWA BSM 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

Background BSM

- Promote control strategy development and evaluation
- Based on 'accepted' models, e.g. ASM1, ADM1, 10-layer 1-D settler model
- No specific national or regional preferences
- Fully dynamic including noise
- Allow for high flexibility of control
- Reasonable input and plant behaviour – focus is on *relative comparison of control strategies*
- Availability on many platforms

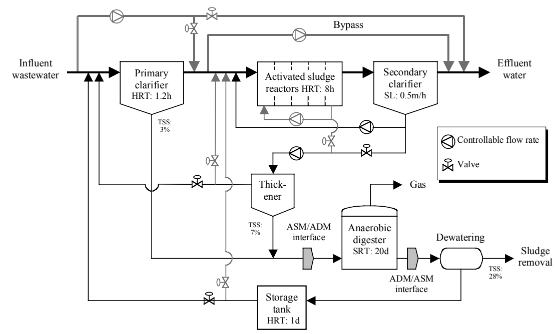
BSM1 Long-Term (BSM1_LT)

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

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 (load and temperature) and holiday effects

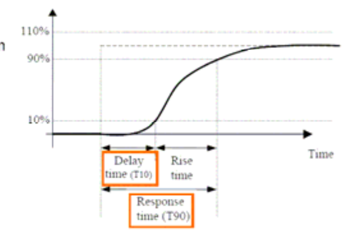


BSM2

- One year dynamics for evaluation period
- Influent wastewater generation model
- ASM/ADM/ASM interfaces developed
- About 60 control handles available
- All realistic sensors possible, defined by classes
- Allows for measurements from 'lab analyses'
- Considerable efforts to enhance simulation speed (specifically for AD)

Sensors

According to ISO 2003 norm



Measuring range

Noise : random noise, standard deviation = 1, x noise level (2.5% of range)

Sensor classes

Sensor classes	Response time (T90) [min]	Measuring interval (T0) [min]	Examples
Class A	1	0	Ion sensitive, optical without filtration
Class B_0	10	0	Gas sensitive + fast filtration
Class B_1	10	5	Photometric + fast filtration
Class C_0	20	0	Gas-sensitive + slow filtration
Class C_1	20	5	Photometric + slow filtration or sedimentation
Class D	30	30	Photometric or titrimetric for total components

Recommended sensor parameters

Measured variable	Class	Measurement Range	Measurement noise (δ)
Flow rate (m^3/d) high range	A	0-100 000 m^3/d	2500
Water level (m)	A	0-5 m	0.125
Temperature (°C)	A	5-25 °C	0.5
pH	A	5-9	0.1
S_O (mg O_2/l)	A	0-10	0.25
Sludge blanket level (m)	A	0-5	0.125
S_{NO} (mg N/l)	B0	0-20	0.5
S_{NH} (mg N/l) low range	B0	0-20	0.5
S_{NH} (mg N/l) high range	B0	0-50	1.25
S_{ALK} (mol HCO_3/m^3)	B0	0-20	0.5
Mixed-liquor suspended solids (mg/l)	A	0-10 000	250
Effluent total suspended solids (mg/l)	A	0-200	5
Total COD (mg COD/l)	D	0-1 000	25
OUR (mg/(l·d))	D	0-2 000	50

Actuators – control handles

- Basically all flow rates
- Basically all flow patterns
- External carbon addition
- Reject water storage capacity
- Aeration
- Anoxic/aerobic volumes
- Bypassing of primary, AS and/or complete WWTP

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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
- Special inputs (toxicity, inhibition etc.)
- Used for BSM2 (and BSM1_LT) but also useful as stand-alone model for other applications

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Basic influent model principles

- Model building in Matlab/Simulink (general; modularity)
- Model simplicity
  - e.g limited number of model parameters
- Model transparency
  - e.g. parameters with physical meaning when possible
- Model flexibility
  - e.g. the model user can replace one or more model blocks with his/her own model code or specific data (e.g. rainfall time series data)

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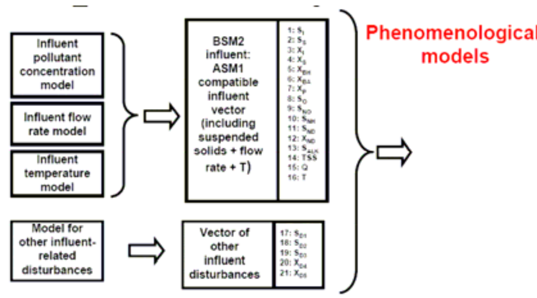
BSM2 influent generation



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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

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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
- Charge balance calculated and maintained
- *Wat. Res.*, Nopens *et al.*, submitted

Model interfaces

- S1: COD-demand → S_S, X_S, X_{BH}, X_{BA}
- S2: S_{ND}, S_S → S_{aa}, S_{su}
- S3: X_{ND}, X_S → X_{pr}, X_{ch}, X_{li}
- S4: X_{BH}, X_{BA} → X_{pr}, X_{ch}, X_{li}
- S5: S_{alk} → S_{IC}
  S_{NH} → S_{IN}
- S6: S_I → S_I
  X_I, X_P, X_{BH}, X_{BA} → X_I

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
  - Heating energy
- 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)

Changes to BSM2 (Girona 2007-04-23)

1. Increased volume of activated sludge reactors
2. Reduced influent ammonia load
3. Demand effluent limits always fulfilled (15 min basis)
4. Separation of nitrate and ammonia in terms of effluent quality index weights

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)

Possible future extensions

- 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?

Thank You for Your Attention!

Questions and comments?