IWA TG on Benchmarking of Control Strategies for WWTPs

The Beginning: BSM1

6 May 2007
Washington DC, USA

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SIMULATION BENCHMARK #1

- WHAT IS IT ...
- WHY DO WE NEED IT ...
- BRIEF HISTORY & BACKGROUND ...
- BENCHMARK DESCRIPTION ...

SIMULATION BENCHMARK

- WHAT IS IT?:
  - DEFINITION OF A SIMULATION PROTOCOL FOR EVALUATING ACTIVATED SLUDGE CONTROL STRATEGIES
    - plant layout (configuration)
    - simulation models (biological and settling)
    - model parameter values
    - influent loads and disturbances
    - test procedures
    - evaluation criteria

SIMULATION BENCHMARK

- WHY?:
  - STANDARDISE THE EVALUATION PROCEDURE
    - experimental evaluation prohibitively expensive
    - innumerable perturbations in possible configurations and simulation results (i.e. model parameters, influent waste ….)
    - unbiased comparison of reported simulation results impossible

BENCHMARK HISTORY

- ORIGINALLY CONCEIVED OF BY 1ST IAWQ TASK GROUP ON RESPIROMETRY
  - aim: standardise method for the evaluation of activated sludge respirometry-based control strategies through simulation

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- FORMULATION OF THE BENCHMARK ADOPTED BY 'COST'
  - aim: a 'general' standardised method for the evaluation of activated sludge control strategies
  - EU publication

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BENCHMARK HISTORY

- EXTENSION BY 2ND TASK GROUP ON RESPIROMETRY
  - aim: to remain as consistent as possible with the generalised benchmark
  - IWA Scientific and Technical Report

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- EXTENSION BY NEW TASK GROUP ON BENCHMARKING
  - aim: to extend BSM system to whole plant modelling
  - BSM1_LT, BSM2, BSM3…

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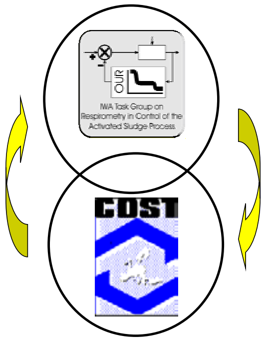
NEW STR - 2008



IWA Task Group on Respirometry in Control of the Activated Sludge Process

(5 common participants)

European Co-operation in the Field of Scientific and Technical Research (COST)

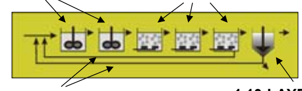
'COST-624' DEFINITION

PRE-DENITRIFICATION PLANT LAYOUT

- 5 TANKS-IN-SERIES & 1 SETTLER, WITH DEFINED VOLUMES

2 UNAERATED TANKS

3 AERATED TANKS WITH DEFINED AERATION



2 INTERNAL RECYCLE STREAMS

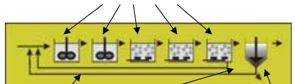
1 10-LAYER SETTLER

'COST-624' DEFINITION

DEFINED BIOLOGICAL AND SETTLING MODELS

- INTERNATIONALLY ACCEPTED ACTIVATED SLUDGE MODELS

BIOLOGICAL:
IAWQ's ACTIVATED SLUDGE MODEL #1 (ASM#1)



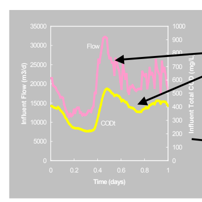
NO BIOLOGICAL REACTIONS IN THE SETTLER OR RECYCLES

SETTLING:
TAKACS DOUBLE EXPONENTIAL SETTLING VELOCITY MODEL

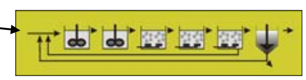
DYNAMIC DISTURBANCES

DEFINED INFLUENT WASTEWATER

- 3 different 14-DAY influent files
- representations of 3 potential weather disturbances

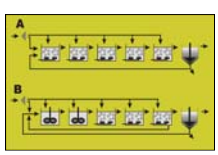


CHARACTERISTICS:
DIURNAL VARIATIONS IN FLOW AND CONSTITUENT CONCENTRATIONS



RESPIROMETRY EXTENSION

- **SAME 5 TANKS-IN-SERIES DESIGN**
- **PROCESS EXPANSION**
  - completely aerobic C-only
  - completely aerobic nitrifying
- **STEP-FEED CAPABILITY**
- **EFFLUENT QUALITY VARIANCE ADDED TO PERFORMANCE INDEX**



PERFORMANCE ASSESSMENT

- **PLANT PERFORMANCE ASSESSMENT**
  - effluent quality
  - effluent violations
  - sludge production & disposal
  - pumping & aeration energy
- **CONTROLLER ASSESSMENT**
  - error calculations (setpoint tracking)
  - variance in manipulated variables

SIMULATION DEFINITION

DEFINED STEP-WISE TESTING PROCEDURE:

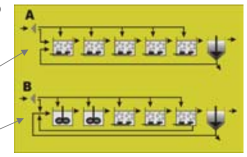
1. SIMULATION SET-UP IN SIMULATOR OF CHOICE (benchmark definition is platform independent)
2. STEADY STATE SIMULATIONS (without any active controllers)
3. DYNAMIC SIMULATIONS (using dynamic influent files)
4. DEFINED CONTROL STRATEGY IMPLEMENTATION (NO3 and DO)
5. EVALUATION OF USER-DEFINED STRATEGY

NOTE: simulation output is compared to verified data at each step (excluding the last) to ensure simulator tuned correctly.

BENCHMARK SET-UP

STEP 1:

- CHOOSE APPROPRIATE PLANT LAYOUT BASED ON CHARACTERISTICS OF CONTROL STRATEGY TO BE EVALUATED



CARBON REMOVAL OR NITRIFYING LAYOUT

DENITRIFYING LAYOUT

BENCHMARK SET-UP

STEP 2:

- CONFIGURE LAYOUT ACCORDING TO DESCRIBED FEATURES

	Carbon Removal	Nitrification	Denitrification	Units
Influent flow rate	18446	18446	18446	m3 day-1
Recycle flow rate	9223	18446	18446	m3 day-1
Internal recycle flow rate	0	0	55338	m3 day-1
Wastage flow rate	385	385	385	m3 day-1
Volume - Tank 1	600	1200	1000	m3
Volume - Tank 2	600	1200	1000	m3
Volume - Tank 3	600	1200	1333	m3
Volume - Tank 4	600	1200	1333	m3
Volume - Tank 5	600	1200	1333	m3
Depth - Settler	3	4	4	m
Area - Settler	1000	1500	1500	m2
Volume - Settler	3000	6000	6000	m3

BENCHMARK SET-UP

STEP 3:

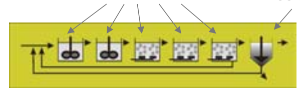
- ASSIGN THE APPROPRIATE MODEL TO EACH UNIT PROCESS
- INPUT THE DEFINED PARAMETER VALUES

DEFINED STOICHIOMETRIC & KINETIC PARAMETERS

DEFINED SETTLING PARAMETERS
(no biological reactions)

ASM#1

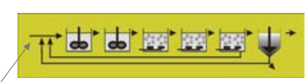
TAKACS SETTLING MODEL



BENCHMARK SIMULATIONS

STEP 4:

- STEADY STATE
(100 DAYS or STEADY STATE)



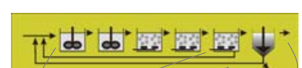
Component	Dry Weather	Units
S_S	69.50	g COD m^{-3}
$X_{B,H}$	28.17	g COD m^{-3}
X_S	202.32	g COD m^{-3}
X_I	51.20	g COD m^{-3}
S_{NH}	31.56	g N m^{-3}
S_I	30.00	g COD m^{-3}
S_{ND}	6.95	g N m^{-3}
X_{ND}	10.59	g N m^{-3}
Q	18446	m^3 day^{-1}

CONSTANT FLOW-WEIGHTED AVERAGE INFLUENT
(from dry weather file)

BENCHMARK SIMULATIONS

STEP 5:

- OUTPUT COMPARISON
(simulator tuning)



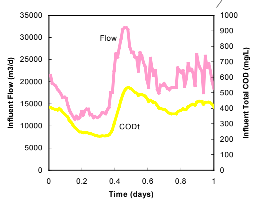
COMPARISON WITH VERIFIED OUTPUT
(data verified using 6 different simulators and one user defined FORTRAN coded implementation)

Component	Tank 1	Tank 5	Settler Underflow	Settler Discharge	Units
VSS	2959.7	2945.9	5760.5	11.252	g m^{-3}
TSS	3285.2	3269.8	6393.9	12.497	g m^{-3}
S_I	30	30	30	30	g COD m^{-3}
S_S	2.8082	0.88949	0.88949	0.88949	g COD m^{-3}
X_I	1149.2	1149.2	2247.1	4.3895	g COD m^{-3}
X_S	82.135	49.306	96.415	0.18834	g COD m^{-3}
$X_{B,H}$	2551.8	2559.4	5004.7	9.7761	g COD m^{-3}
$X_{B,A}$	148.39	149.8	292.92	0.5722	g COD m^{-3}
X_P	448.86	452.22	884.29	1.7274	g COD m^{-3}
S_O	0.00430	0.49093	0.49093	0.49093	g COD m^{-3}
S_{NO}	5.3699	10.415	10.415	10.415	g N m^{-3}
S_{NH}	7.9179	1.7333	1.7333	1.7333	g N m^{-3}
S_{ND}	1.2166	0.6883	0.6883	0.6883	g N m^{-3}
X_{ND}	5.2849	3.5272	6.8973	0.01347	g N m^{-3}
OUR	1.4928	31.869			g m^{-3} hr^{-1}

BENCHMARK SIMULATIONS

STEP 6:

- DYNAMIC INFLUENT
  (28 DAYS, DATA ANALYSIS ON LAST 7 DAYS OF OUTPUT)



DYNAMIC INFLUENT FILES
(dry weather, rain weather & storm weather files)

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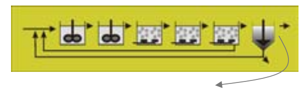
Watermatex2007 Workshop, 6 May 2007, Washington DC, USA

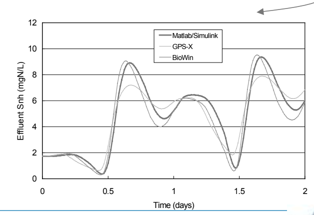
BENCHMARK SIMULATIONS

STEP 7a:

- OUTPUT COMPARISON
  (qualitative)



SIMULATOR SPECIFIC OPTIONS PREVENT EXACT DUPLICATION OF DYNAMIC RESULTS



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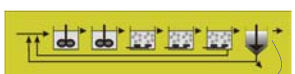
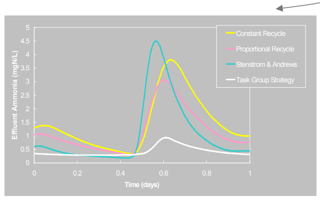
BENCHMARK SIMULATIONS

STEP 7a:

- OUTPUT COMPARISON
  (qualitative)



QUALITATIVE COMPARISON OF DIFFERENT STRATEGIES



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BENCHMARK SIMULATIONS

STEP 7b:

- OUTPUT COMPARISON
  (performance index)

USE OF THE PERFORMANCE INDEX ALLOWS FOR A MORE QUANTITATIVE COMPARISON

Process Summary

IQ index =	1.482E+07	kg/d
EQ index =	2.899E+06	kg/d
Avg Sludge Production (disposal) =	2438.7	kg SS/d
Avg Sludge Production (effluent) =	234.8	kg SS/d
Avg Sludge Production (total) =	2673.5	kg SS/d
Aeration Energy =	6476.1	kWh/d
Pumping Energy =	2966.8	kWh/d
Total N (constraint limit) =	18	g N/m3
% of time plant in violation (Ntot) =	0.89	%
# of violations (Ntot) =	1	

Composite Summary

	mean	std dev	
Effluent avg. TSS conc. =	13.0	5.4	g SS/m3
Effluent avg. TKN conc. =	6.8	3.2	g N/m3
Effluent avg. N conc. =	15.7	4.8	g N/m3
Effluent avg.total COD conc. =	48.3	16.0	g COD/m3
Effluent avg. BOD5 conc. =	2.8	1.1	g/m3

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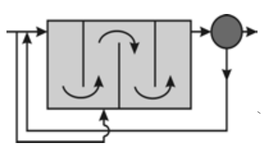
STRATEGY EXAMPLE

- **STENSTROM AND ANDREWS (1979)**

AIM: TO DECREASE THE INFLUENCE OF A DYNAMIC INFLUENT ON EFFLUENT QUALITY

APPROACH: CONTROL REACTOR SOUR

METHOD: Q_{RAS} MANIPULATION



` Part 1

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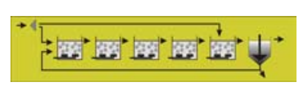
STRATEGY EXAMPLE

- **TASK GROUP STRATEGY**

AIM: TO DECREASE THE VARIABILITY IN EFFLUENT QUALITY

APPROACH: CONTROL OUR IN 5^{TH} TANK

METHOD: STEP-FEED MANIPULATION



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PROBLEM DEFINITION

- TWO STRATEGIES
- SIMILAR, BUT DIFFERENT PROCESS AIMS
- DIFFERENT LAYOUTS
- DIFFERENT CONTROL OBJECTIVES
- DIFFERENT MANIPULATED VARIABLES

How is an unbiased comparison made?

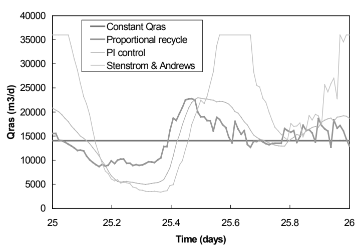
BENCHMARK RESULTS

- SIMILARLY APPLIED ANALYSES ALLOW A MULTI-CRITERIA COMPARISON TO BE MADE
- FURTHER ANALYSES CAN BE BASED ON LOCATION SPECIFIC CRITERIA AND TERM WEIGHTING (i.e. SLUDGE PRODUCTION MORE IMPORTANT THAN PUMPING COSTS…)

	constant Qras	proportional Qras	S-A Part I	Task Group Strategy	
EQ index =	5239	5186	5195	4950	t/d
Avg Sludge Production (total) =	2628	2638	2598	2664	kg SS/d
Aeration Energy =	14247	14247	14247	12175	kWh/d
Pumping Energy =	577	577	1014	813	kWh/d
Effluent avg. Sno conc. =	34.6	34.6	34.6	34.0	g N/m3
Effluent avg. Snh conc. =	1.4	1.2	1.1	0.5	g N/m3
Effluent avg. TSS conc. =	12.1	12.2	13.1	13.0	g SS/m3
Effluent avg. TKN conc. =	3.3	3.0	3.1	2.4	g N/m3
Effluent avg. N conc. =	37.8	37.6	37.6	36.3	g N/m3
Effluent avg. total COD conc. =	47.0	47.1	48.3	48.1	g COD/m3
Effluent avg. BOD5 conc. =	2.5	2.5	2.7	2.7	g/m3

BENCHMARK RESULTS

- VARIATIONS IN THE MANIPULATED VARIABLE
  → ARE THE VARIATIONS PRACTICAL



FEATURES RECAP

- **DEFINED CONFIGURATIONS**
  - C-only, Nitrifying, Denitrifying (IWA)
  - Denitrifying (COST)
- **FIXED PROCESS MODELS & PARAMETERS**
  - ASM#1, Takacs
- **DEFINED DYNAMIC DISTURBANCES**
- **DEFINED SIMULATION PROCEDURES**
- **DEFINED PERFORMANCE ASSESSMENT**

CONCLUSION

- **BENCHMARKING IS:**
  - a valuable tool for the comparison of multi-facetted simulation problems
  - the first step in evaluating the potential impact of particular control strategies
  - a multi-criteria decision making problem